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Hydrochemical Evaluation and Utilization of Groundwater in Khanaqin Area, Diyala Governorate - East of Iraq

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Abstract

The groundwater evaluation has been carried out in Khanaqin area in Diyala governorate to the east of Iraq. The analyzed hydrochemical parameters such as pH, electrical conductivity, total dissolved solids as well as cations and anions are used to describe groundwater quality and its suitability for different purposes. The study area covers (1920) km^2. According to hydrogeological investigation (43) water points were inventoried and water levels in wells were measured. (34) Wells were sampled during 2013-2014 during water surplus and water deficit periods. The studied area is divided groundwater aquifers into two main units, the unconfined and confined aquifers. The values of pH, electrical conductivity (EC) and total dissolved solids (TDS) are in the range of (7.1-7.6) and (283-3070) µS/cm, (200-2370) mg/l respectively. Salinity distribution map within area showed maximum values are in southeastern part of the basin in water deficit period, while a north-west south-east pattern of highly salinity values was indicated during water surplus period. Groundwater origins and types were continental and (NaCl) as major type followed by ($NaSO_4$) as second type of groundwater in the area of study.

Keywords: Groundwater hydrochemistry, Khanaqin Area , East of Iraq

التغاير الهيدروكيميائي واستخدامات المياه الجوفية في جزء من حوض ديالى – شرق العراق

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الخلاصة

تم تقييم نوعية المياه الجوفية في جزء من حوض ديالى في شرق العراق لتحديد خصائصها الهيدروكيمائية حيث استخدمت المعاملات الفيزو– كيميائية المتمثلة بالاس الهيدروجيني والتوصيلية الكهربائية ومجموع الاملاح الذائبة الكلية بالاضافة الى الايونات الموجبة والايونات السالبة لتوصيف نوعية المياه الجوفية وملاءمتها للأغراض المختلفة. يبلغ مساحة الحوض (1920كم^2) وبينت التحريات الهيدروجيولوجية المنفذة بان مكامن المياه الجوفية مقسمة الى وحدتين رئيسيتين هما طبقات المياه الجوفية الحرة والمحصورة على التوالي . تراوحت القيم الدنيا والقصوى لحامضية المياه الجوفية والتوصيلة الكهربائية بالاضافة الى مجموع الاملاح الذائبة الكلية من (7.1) إلى (7.6) و (283) إلى (3070) ميكروموز / سم و(200) إلى (2370) ملغ / لتر على التوالي خلال فترتي النقصان والزيادة المائية فيما بينت خارطة توزيع الملوحة في الحوض بان اقصى تراكيز للملوحة سجلت في المنطقة الجنوبية الشرقية من الحوض خلال فترة النقصان المائي بينما امتد نطاق من ارتفاع تركيز الملوحة من الجنوب الشرقي باتجاه الشمال الغربي خلال فترة الزيادة المائية . المياه الجوفية عموما كانت من أصل قاري وبنوعية كلوريد الصوديوم (NaCl) بالدرجة الاولى تتبعها نوعية كبريتات الصوديوم (Na_2SO_4) .

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Introduction

Groundwater is one of the important components in development of any area. The use of water increased due to increasing in human population and activities [1]. Groundwater becomes a primary and an important resource in many areas of the world, so it is important to study its quality and quantity to identify its suitability for drinking, irrigation, industrial and other usages [2].

Determination of physical and chemical parameters of water is essential for assessing its suitability for various purposes. Generally, the quality of groundwater depends on the composition of recharge water, the interaction between the water and the soil, the soil-gas interaction, the rock with which it comes into contact in the unsaturated zone, the residence time, and reactions that take place within the aquifer [3].

The geochemistry of groundwater data gives crucial evidence to the geologic history of rocks and indications of groundwater recharge, movement, and storage [4, 5].

The continuing of groundwater extraction from the aquifers for different purposes is contributing to groundwater depletion in many parts of world, thus understanding of groundwater chemistry contribute in determining its usefulness for domestic and agricultural purposes [6].

Several studies have been done to evaluate the accessibility of groundwater in Diyala governorate for domestic and agricultural uses such as Jalut, et al., 2015 [7] who studied hydrochemical analysis of groundwater resources in Kanan region located north east of Baqubba the capital of Diyala governorate were most of the groundwater pumping wells are not suitable for drinking purposes due to very high concentration of TDS, SO4, Mg, Ca and Na values. Al-Sudani, 2017 [8] studied the hydraulic parameters of groundwater aquifers in Khanaqin basin in order to calculate hydraulic parameters of the most important product groundwater aquifers. Al-Sudani, 2018 [9] also studied the morphometric properties and water balance using thornthwaite method in Khanaqin Basin, East of Iraq where the studied area characterized by is elongated low relief, gentle ground slopes and far from being circular with moderate peak flows of fifth stream order, while The ratio of water surplus calculated from annual rainfall was (13.15%) and the actual evapotranspiration and soil moisture was (86.82%) according to average annual rainfall during (1990-2013). Finally Al-Sudani et al., 2018 [10] studied the groundwater system of Khanaqin Basin in Diyala Governorate – East of Iraq where hydrogeological investigation of the basin divided groundwater aquifers into two main units, the unconfined and confined aquifers. The studied area showed that promising zone of unconfined aquifer is located around Khanaqin city within the southern part of the basin, while two promising zones of confined aquifer are located to western part of the basin and near the border within north part of the basin.

Study Area

The study area is located in Diyala governorate in the east of Iraq and bordered by Iraqi - Iranian frontiers from the east and Diyala river from the west while Nadoman anticline fold and Bernand mountain chain surrounding the basin from south and north respectively. The area covers 1920 km^2 within (45º 10'- 45 º 59') E and (34 º 10 ' - 34 º 45') N, Figure-1.

The evaluation of groundwater resources for development requires an understanding of the hydrogeology and hydrogeochemical properties of the aquifer which is the aim of this research. The evaluation shall focus on chemical species of groundwater which is regarded as precious information on the geological history of the aquifers and the suitability of various usages.

Geological Setting:

The exposed geological formations in Khanaqin Area are ranging in age from Upper Jurassic up to Recent. The basin is built up by folded sedimentary sequence. The upper unit of Bai Hassan formation (Upper Bakhtiari formation - Pliocene) which covers the older rocks by clear angular unconformity is considered as Bammu conglomerate (Pleistocene), [11] Figure-2. Structurally, the majority of the basin belongs to the Foot-hill Zone of Iraq [12].

Methodology:

Depending on (43) inventoried wells and (65) wells obtained from hydrogeological data bank, the aquifers were divided into two main units, the unconfined and confined aquifers. The aquifers were investigated during field work where geographical position, elevations, static water levels, depths, thicknesses, maximum yields as well as water sampling have been carried out. Surfer and Grapher software were used to demonstrate the obtained hydrogeological and hydrochmical properties results in contouring maps.

The work plan in the studied area included the following items:
1- Office work including preparing data and preliminary information of the area (wells stratigraphic columns, maps, literature reviews, scientific references, hydrogeological data bank [13]).
2- Field work including:
- Inventory of water wells and measuring water levels in the wells as well as determine geographical positions and levels of (43) water points.
- Water sampling of (34) wells within water surplus and water deficit periods during 2013-2014.
- Laboratory analysis of (68) water samples to measure physical and chemical components and variation of ionic concentrations.

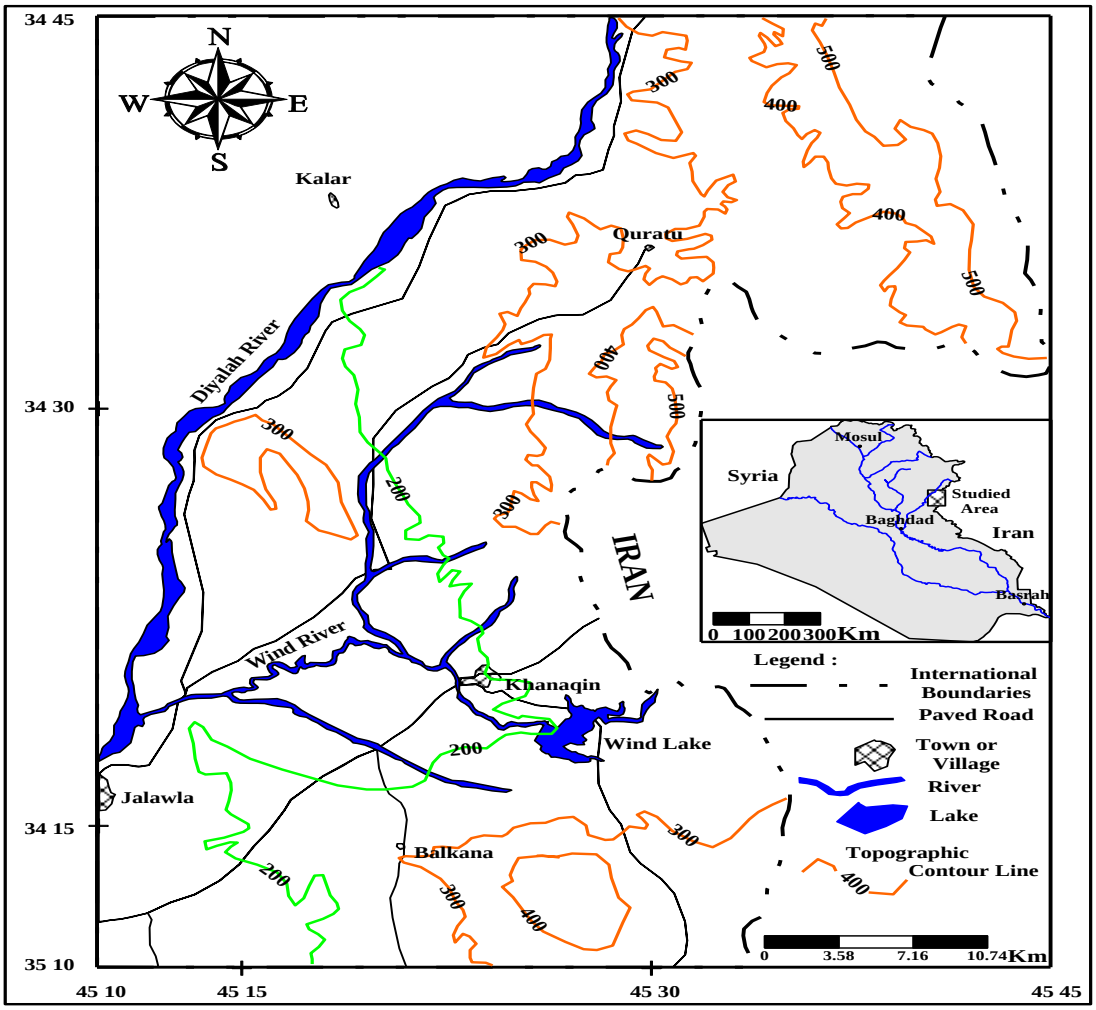

Figure 1- Location and Topography map of Khanaqin Area [8].

Results and Discussion:

1- Hydrogeological properties of aquifer:

According to (90) wells (inventoried and obtained from hydrogeological data bank) the results showed that (38) wells tapped the unconfined aquifer while (52) wells tapped the confined aquifer, Figure-3. The geological formations exposed in Khanaqin area as shown in Figure-2 determines the types of aquifers where unconfined aquifer composite of Quaternary deposits, Bai Hassan and Mukdadiyah formations according to their exposure on surface. Both Bai Hassan and Mukdadiyah formations exposed in specific locations within the basin, represents the unconfined aquifer. On the other hand, whenever Bai-Hassan formation overlying Mukdadiyah formation turned the last one into confined aquifer combined with Injana formation [10]. Figure-2 showed geological formations forming aquifers of the basin where Mukdadiyah and Injana formations are the main unconfined – confined aquifers in southern part of basin while Bai Hassan and Mukdadiyah are the main aquifers in the north and north-east part of the basin.

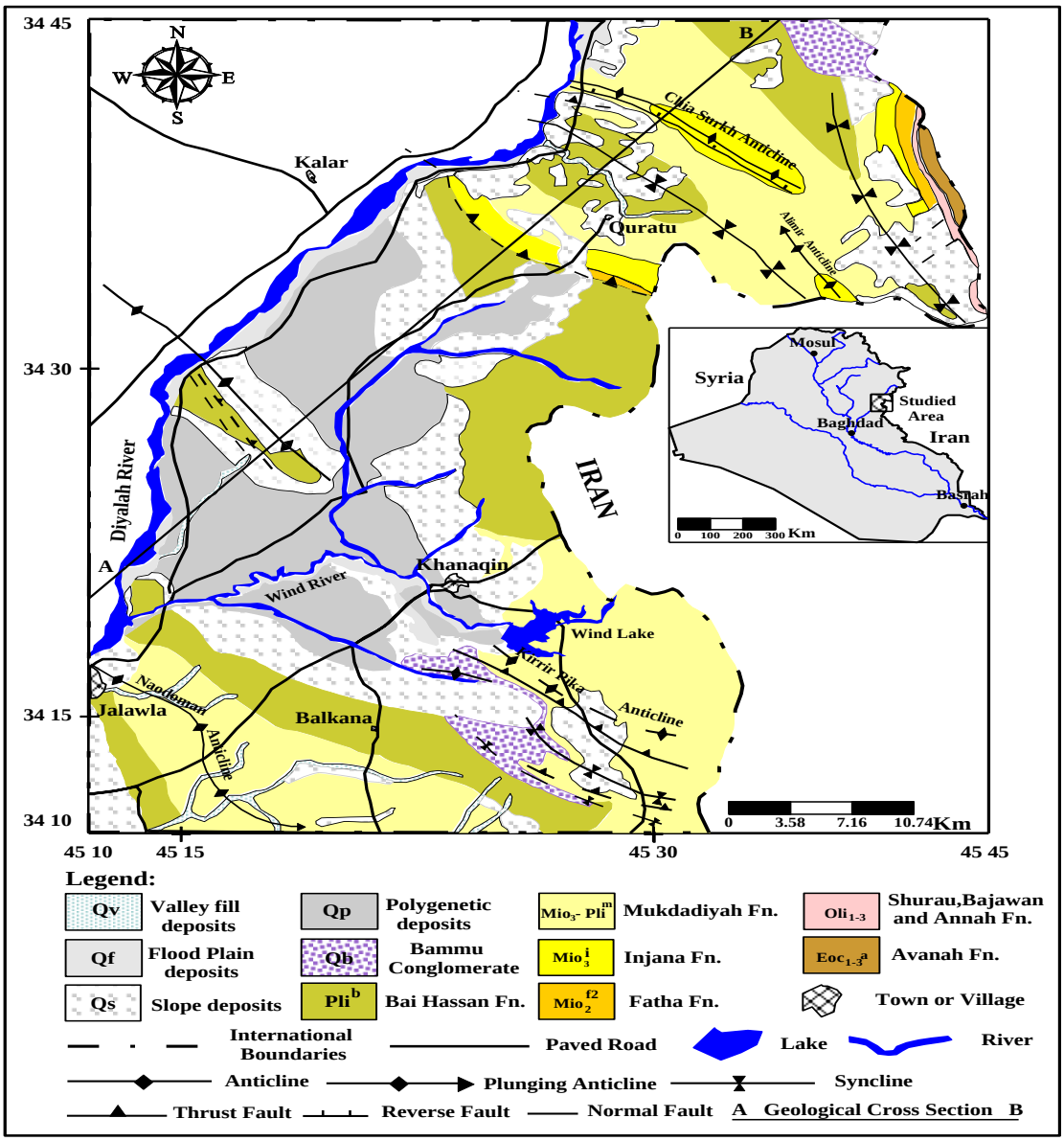

Figure 2- Geological Map of Khanaqin Area [11].

2- Groundwater Chemistry:

The sampling campaigns conducted during two seasons (dry and wet seasons). The water samples collected from (34) wells as shown in Fgure-3 while Table-1 shows the statistical data of hydrochemical groundwater properties. The ranges of pH, electrical conductivity (EC) and total dissolved solids (TDS) represented as minimum and maximum were (7.1) to (7.6) and (283) to (3070) µmhos/cm, (200) to (2370) mg/l respectively within the two mentioned periods. These values indicate that groundwater is fresh (TDS < 1000 mg/l) to brackish types where (TDS > 1000 mg/l) [14].

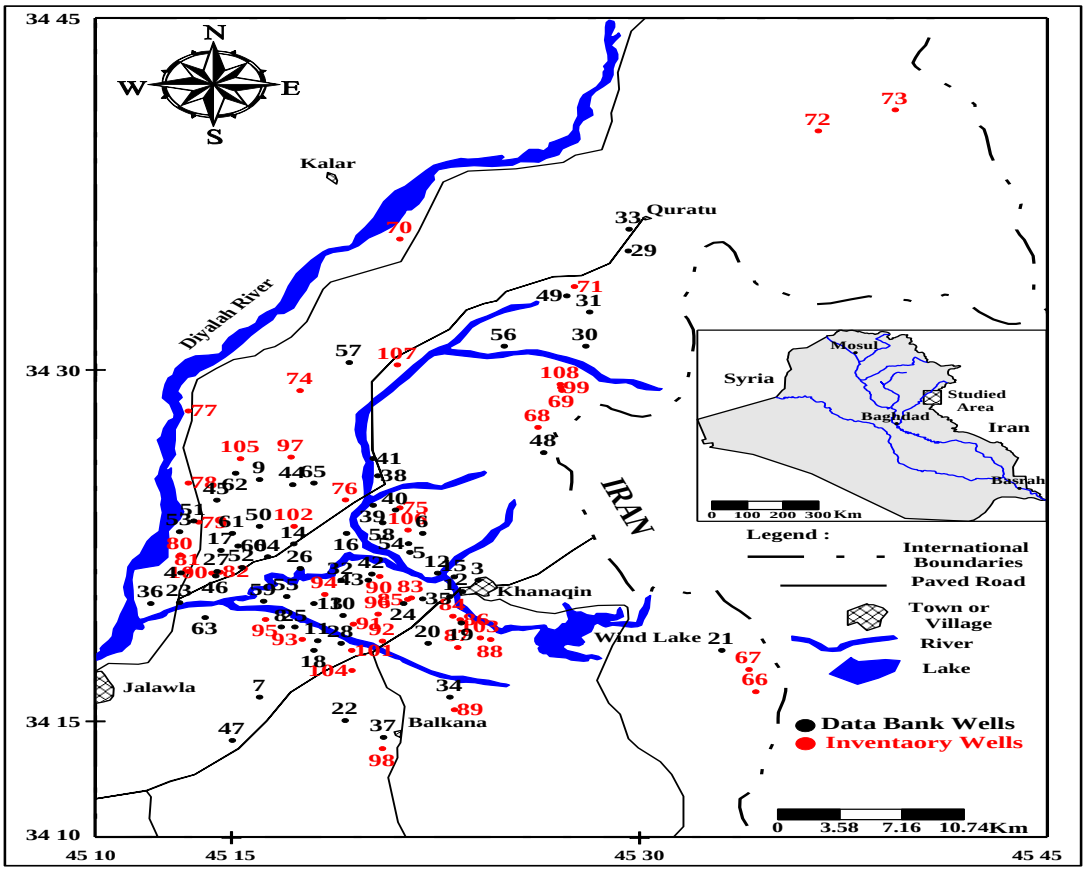

Figure 3 - Inventory and data bank wells in Khanaqin Area [10].

Table 1- Physicochemical analysis of groundwater properties in the Basin

Statistics	Date	PH	E.C. (µmoh/cm)	TDS (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	HCO3 (mg/l)	SO4 (mg/l)	NO3 (mg/l)	SAR
No. of samples		34	34	34	34	34	34	34	34	34	34	34	33
Minimum	20/10/2013	7.11	368	312	28	10	22	0.6	60	14	10	1	1.03
	20/4/2014	7.1	283	200	10	10	16	0.3	33	6	10	0.4	0.65
Maximum	20/10/2013	712	3070	2370	193	94	428	15	449	369	681	9	9.67
	20/4/2014	7.6	2620	1823	180	115	255	14	568	211	580	9	8
Mean	20/10/2013	29.98	1194.8	1036	67.96	36.9	125.8	4.179	167.7	92.71	259	3.12	3.55
	20/4/2014	7.295	1020.7	755.65	64.85	39.85	88.82	3.56	164.9	61.85	206.4	2.74	2.27
Standard deviation	20/10/2013	121.1	744.41	616.54	45.89	26.3	103.6	3.659	103.2	83.01	211.8	1.93	2.46
	20/4/2014	0.1658	629.44	436.41	44.63	30.67	62.66	3.54	113.4	48.41	192	1.94	1.29

3- Distribution of Groundwater Salinity within the basin:

Salinity as expressed in total dissolved solid (TDS) is the most important parameter in groundwater hydrochemical studies, where salinity of the groundwater changes by location and time within the hydrogeological basin and water depth in aquifer. The salinity is the first element in determining the validity of groundwater use for different purposes. The geological and topographical conditions play an important role in changing salinity due to effects of exposed geological formations, quality of recharged water, and the topography of the basin [15, 16].

The groundwater salinity distribution within the area has been illustrated in Figures-(4 and 5). It can be seen that salinity has the maximum values during water deficit period within southern east part of the basin near the international border of Iraq and Iran (Figure- 4), while a north-west south-east pattern of highly salinity values was indicated in the basin during water surplus period (Figure- 5). Figure-2 showed geological formations forming aquifers of the basin where Mukdadiyah and Injana formations are the main unconfined – confined aquifers in southern part of area while Bai Hassan and Mukdadiyah are the main aquifers in the north and north-east part of the area. The influence of topography and structural factors are the major factors controling groundwater movement, where topography effects on groundwater recharge rate from rainfall [17]. Groundwater flow direction is towards west of the basin as shown in Figure-6. As shown in Figure-1, the groundwater recharge rate increased as surface area slope towards west where the ratio of water surplus calculated from annual rainfall was (13.15%) helps dilution groundwater and changing the chemical properties as well as decreases salinity concentration within area and time [9].

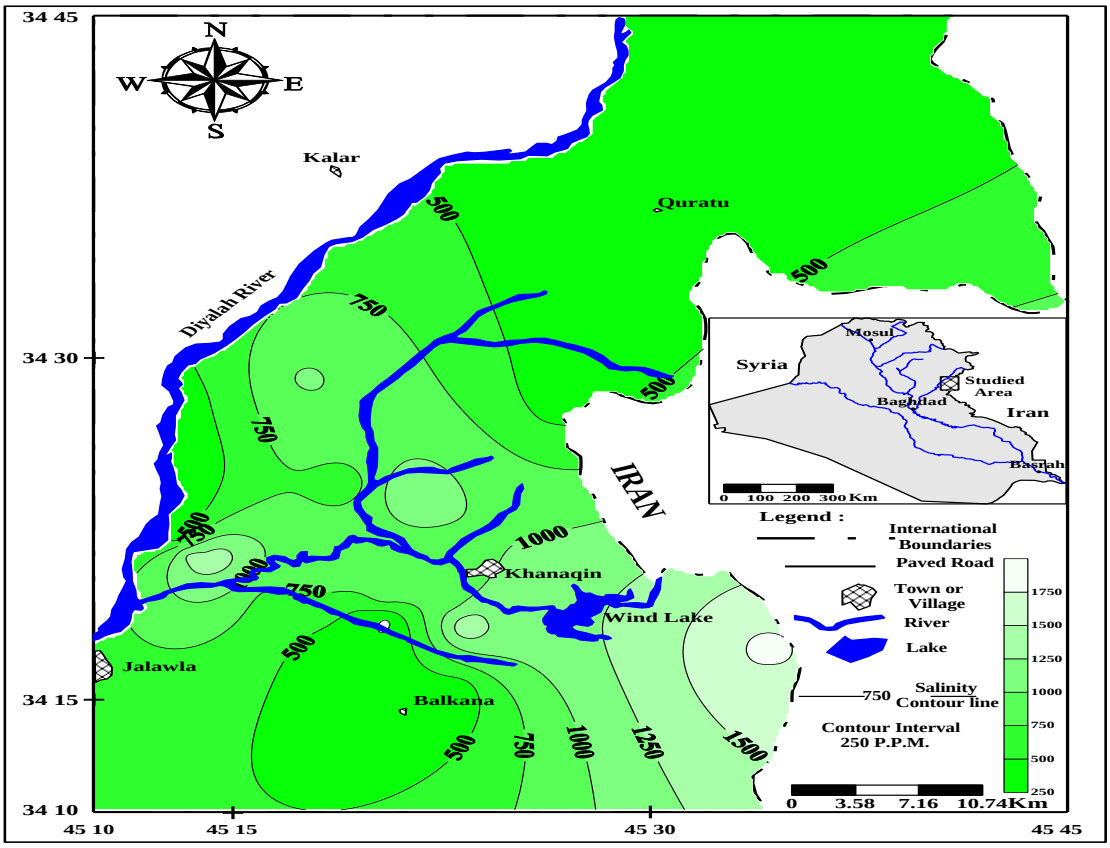

Figure 4 - Groundwater salinity distribution within the area (water deficit period)

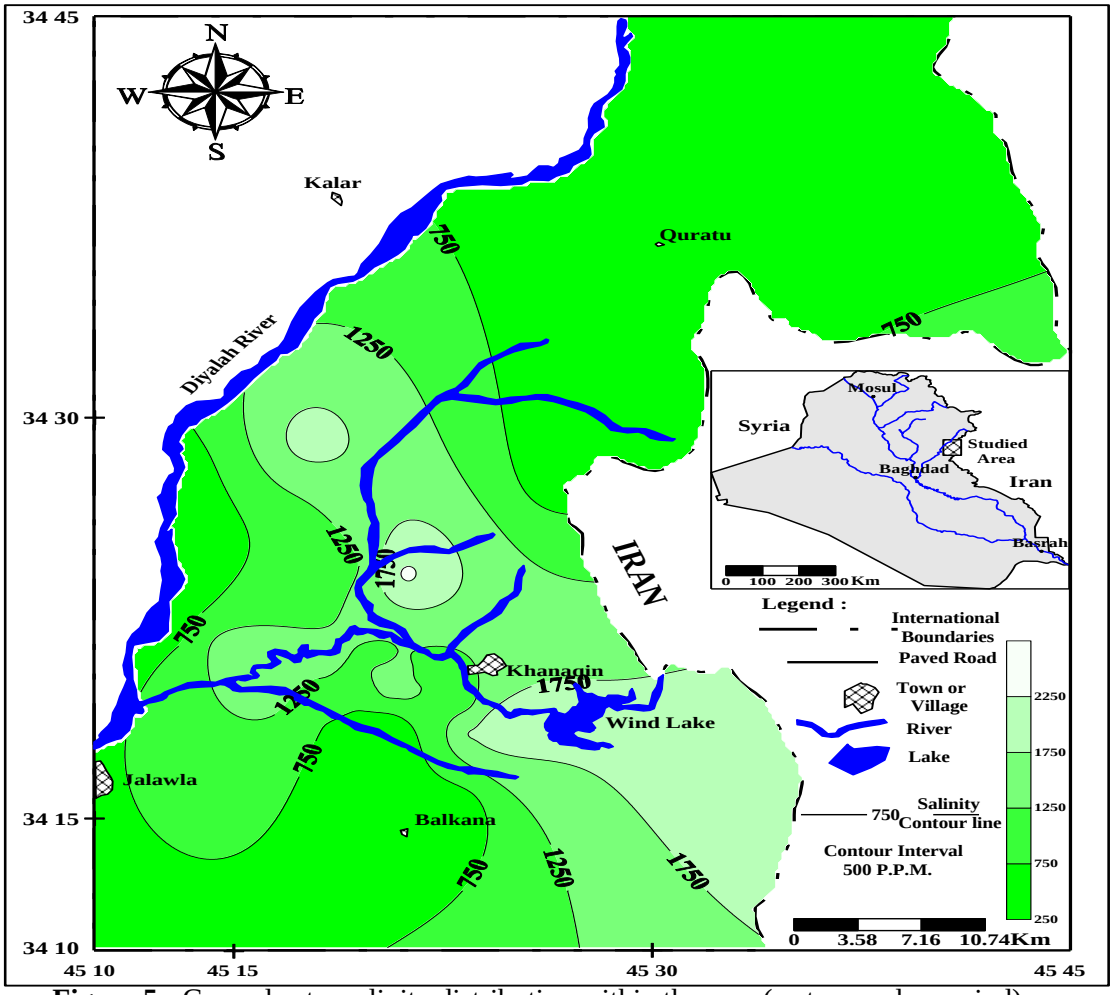

Figure 5 - Groundwater salinity distribution within the area (water surplus period)

4- Groundwater Origin and Quality:

Some of the hydrochemical formula used to determine the origin of continental and marine groundwater, based on chloride, sodium and sulphate ions concentrations measured in the epm [18,19]. The Kurlov formula is used to determine groundwater quality based on the concentrates of positive and negative ions in epm% [20]. The continental deposition environment of Bai Hassan, Mukdadiyah and Injana formations which forming the main aquifers in the basin control the groundwater origin where all trapped water within aquifers lithologies which consists of sandstone, siltstone, conglomerate and pebbly sandstone are of continental origin. These waters were formed at the same time as geological formation deposit.

Table -2 shows Kurlov formula determining the groundwater types in the basin where the major type of groundwater was (NaCl) of (19) wells followed by ($NaSO_4$) type of (9) wells. The groundwater types reflect the water origin where hypothetical proposed salt depends on the lithology nature of geological formations forming aquifers

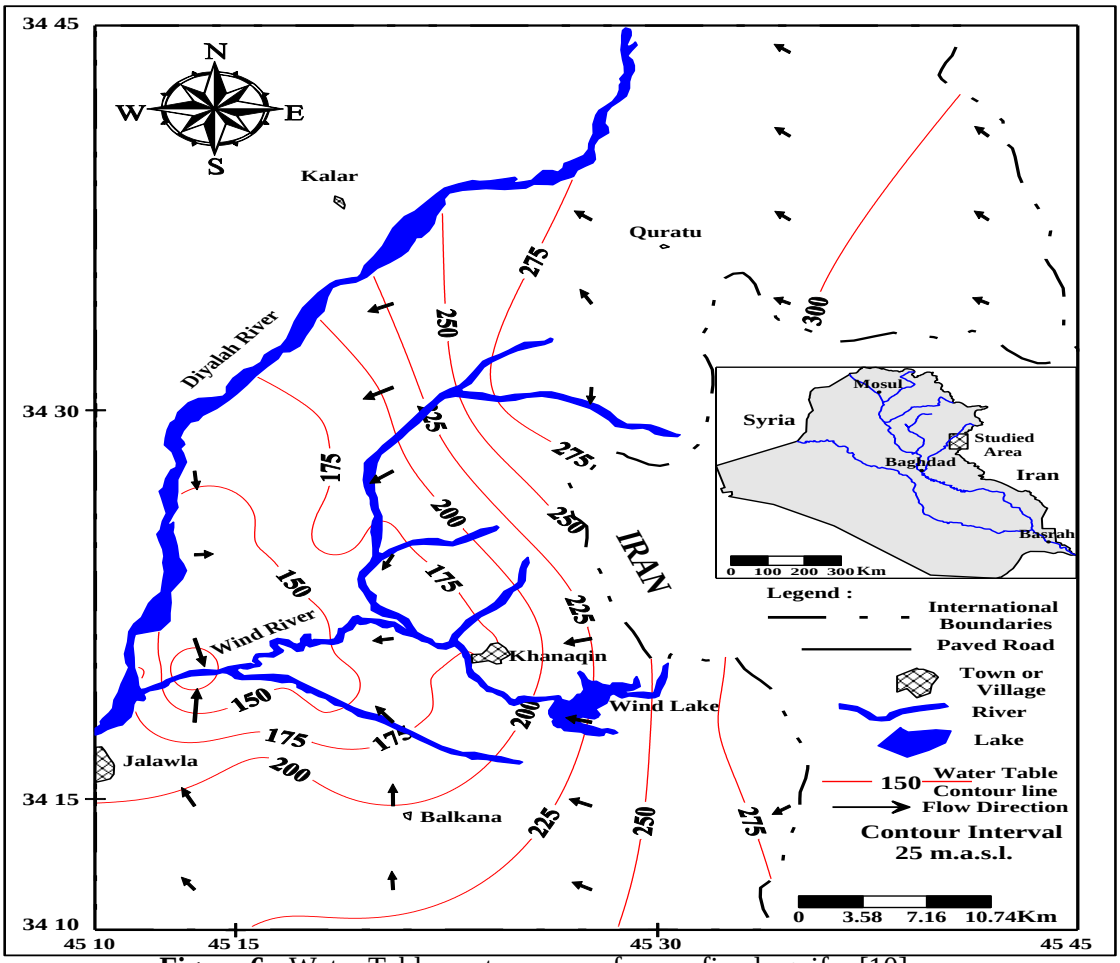

Figure 6 - Water Table contour map of unconfined aquifer [10].

Table2 - Groundwater types in Khanaqin Area

Statistics	r(Na) epm	r(Ca) epm	r(Mg) epm	r(SO_4) epm	r(Cl) epm	Kurlov Formula	Sum of wells
Minimum	1.52	1.44	0.54	0.2	1.52	Na_Chloride	19
Maximum	6.95	3.04	3.04	5.41	6.14		
Mean	3.14	2.019	1.71	2.30	3.26		
Minimum	5.65	2.49	1.97	8.02	4.5	Na_sulphate	9
Maximum	18.5	11.22	8.71	16.04	14.92		
Mean	12.33	6.46	5.49	11.86	9.22		
Minimum	3.78	5.43	5.5	7.89	5.09	Mg_sulphate	3
Maximum	5.78	6.43	7.15	11.47	6.81		
Mean	4.46	5.763	6.08	9.08	5.68		
Minimum	1.39	1.74	1.64	0.49	2	Ca_Chloride	2
Maximum	1.73	1.74	1.64	1.77	2.3		
Mean	1.56	1.74	1.64	1.13	2.15		
	3.86	5.43	5.5	7.91	5.21	Mg_Chloride	1

5- Groundwater Utilization:

Depending on Table-3, groundwater utilization indicated that it can be used for animal purposes while (19) wells were not suitable for drinking purposes. There are only (10) wells that can not be used for agriculture as a result of high salinity and some ions concentrations.

Table 3 - Groundwater Utilizations standards

Parameter	PH	E.C. (µmoh/cm)	TDS (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	NO_3 (mg/l)	SAR	Number of suitability wells	Utilization
Number of samples	34	34	34	34	34	34	34	34	34	34	34	33	34	
Minimum	7.1	283	200	10	10	16	0.3	33	6	10	0.4	0.65		
Maximum	7.12	3070	2370	193	94	428	15	449	369	681	9	9.67		
WHO (2011) [21]	6.5-8.5	-	1000	75	125	200	12	250	200	250	50	-	17	Human Purposes
IQS [22]		-	1000	50	50	200	12	250	200	250	50	-		
Standard FAO/1989 [23]	-	-	2000	40	5	20	-	30	10	20	-	15	24	Irrigation purposes
Standard FAO/1989 Poultry + Livestock [23]	-	5000	-	-	250	-	-	-	-	-	100	-	34	Animal purposes

Conclusions

1- Physicochemical analysis in Diyala basin indicates that groundwater is brackish.
2- The map of groundwater salinity distribution within area salinity has the maximum values in water deficit period within southern east part of the basin, while a north-west south-east pattern of highly salinity values was indicated in the basin within water surplus period.
3- Groundwater type is (NaCl) as major type followed by ($NaSO_4$) as second type.
4- The continental deposition environment of the Geological formations forming aquifers in the basin controls the groundwater origin where trapped water within aquifers was continental origin.
5- All groundwater samples are suitable for livestock uses and just (19) wells were not suitable for drinking purposes. All samples are suitable for agriculture except for (10) wells due to high salinity and some ions concentrations.

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