Hydrochemistry and Assessment of Ground Water Quality of Al-Shekhan – Bartellah Area (Northern Iraq)

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Abstract

The main source of water in the study area is the ground water and rainfall during wet season. Three main aquifers were identified in the study area, PilaSpi aquifer, Al-Fatha aquifer and Injana aquifer. Ten ground water samples were collected during October 2006 from selected wells distributed within Al-Shekhan–Bartellah area. Temperature, pH, and Electrical conductivity were measured in situ, in addition to major soluble ions (Cations and Anions). Total dissolved solids, were analized in laboratory, and total hardness were calculated. Three water types were recognized; $Ca\text{-}HCO_3$, $Mg\text{-}HCO_3$ and $Mg\text{-}SO_4$. The ionic strength of each sample and saturation indices (SI) of calcite, dolomite and gypsum in aquifers were calculated, it was found that all the water samples were undersaturated with respect to calcite and dolomite except wells (w_4 and w_5) which are in equilibrium state, and all water samples were undersaturated with respect to gypsum. Ground water in study area is potable and suitable for irrigation depending on calculated of sodium percentage (Na%), sodium adsorption ratio (SAR), permeability index (PI) also by using Wilcox diagram and US salinity diagram .

Key word: ground water, aquifer, saturation indices, permeability index

Introduction:

Geochemical processes that control the quality of groundwater are currently a topic of increasing concern elsewhere because groundwater is a blue gold of vital economic and social importance. Water supply of Villages and towns in study area are almost from ground water via wells and springs for drinking and irrigation purposes, the most important economic activity of the area is agriculture, and the main crops are wheat and barley. This study aimed to identify the ground water quality with some geochemical process and to understand the ground water characteristics which is very important for ground water management in the study area.

Study area:

The study area situated (35) Km at North-North East of Mosul city (Northern Iraq). It extend from Ain Al-safra and Bartellah in the South up to Alqosh mountain and Al-Shekhan district center to the North, between longitude (43° 16′)and (46° 37′) East and latitude (36° 14′) and(36° 35′)North (Fig 1). Structurally there are several anticline (Alqosh, Qand, Maqloub, Bashiqa and Ain Al-safra) which considered as recharge areas to outcrop of aquifers in the area. The climate of the study area is considered to be semi-arid, temperature ranges between (7.6)°C in January and (39.1)°C in July. The mean annual precipitation and evaporation are (383) mm/yr and (165) mm/yr (A pan) respectively during the last (20) years according to [1].

Field and laboratory methods:

Ground water samples were collected from ten deep water wells in the study area (Fig 1), after pumping for ten min. sampling was carried out in October 2006, pH, temperature and electrical conductivity were measured in the field using digital meters immediately after sampling.

Total dissolved solid TDS determined in laboratory by evaporation the water to dryness and weighing the residue [2], total hardness TH was calculated using equation TH= (2.49 Ca + 4.11 Mg) [3]. ……..(1)

The major ions (Cations and Anions) were carried out using standard method for water analyses as suggested by the American Public Health Association [2] (Table 1) the laboratory work was completed within a few day of water samples collections.

Table (1) Methods used for major ion analysis of ground water samples

Soluble ions	Methods
Ca and Mg	Titration using EDTA
Na and K	Flamephotometer
HCO_3	Titration using H_2SO_4
Cl	Titration using 0.05N $AgNO_3$
SO_4	Spectrophotometer

Each sample was checked for accuracy by calculating ion-balance

I.B%= [(sum cation –sum anion)/ (sum cation+ sum anion)] * 100……..(2)

It was found that the analytical errors of all samples were less than 5%, which ensured the reliability of the chemical data. All these analyzed were measured at the laboratories of soil and water department, and laboratories of chemistry, Agriculture college at Mosul University. Field work included observation the geological setting and outcrop of geological formation near water wells, plotting the location of wells in topographic map and measuring the yield of some wells using volumetric method.

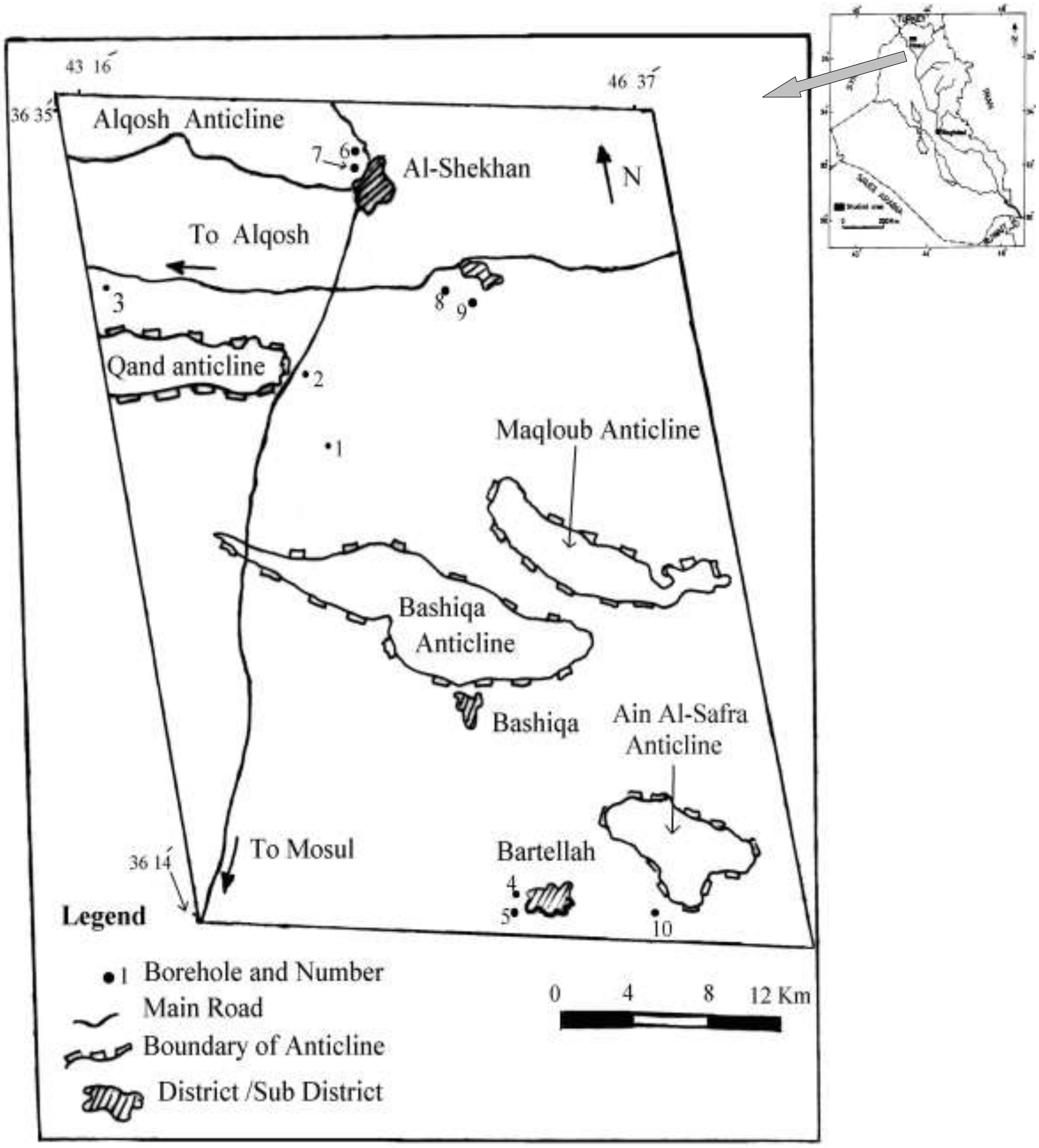

Fig (1) location map of Al - Shekhan – Bartellah area Northern Iraq.

Geology and hydrogeology setting:

The geological sequence in the study area extends from PilaSpi formation which is the older formation outcrops in upland area to quaternary deposits which are mostly covering large area understudy except upland area (Fig2). PilaSpi Formation (middle -upper Eocene age) which form the up land area extend beneath Al-Fatha formation, consist mainly of bedded dolostone and limestone [4], this formation considered as the main productive aquifer in the area, charactized by different structural features such as joints, fractures and faults. This aquifer is presumably considered as artesian aquifer depending upon the hydrostatic pressure. Wells (w_6 and w_7) penetrate this aquifer according to the well lithologic logs and outcrop of limestone, the yield of this wells were (12.3) and (12.2) L/sec respectively. Al-Fatha Formation (middle Miocene age) consist of alternating layers of green marl, limestone, gypsum, red clay and siltstone [5], this formation cropped out along the flanks of the anticlines in the area. This formation considered as the second aquifer which is poor due to variation in hydraulic properties. It contains bad water quality due to the presence of gypsum and marl. The lower part of wells (w_4, w_5 and w_{10}) penetrates this aquifer according to well lithologic logs. Injana Formation of (upper Miocene age)cropped out in several places through the area understudy and extended underneath Quaternary sediment, this formation consist mainly of a series of sandstone, siltstone and claystone [5], this formation considered as the youngest unconfined aquifer. Only the upper part of wells (w_4, w_5 and w_{10}) penetrates Injana aquifer while total depth of wells (w_1, w_2, w_3, w_8 and w_9) penetrates this aquifer. The other formation is Mukdadyah which exposed in some locations in study area. It consists of pebbly sandstone, siltstone and claystone [5]. Quaternary deposits includes slope deposits, some alluvial fans, and residual soil which covers approximately most of study area. Mukdadyah formation and Quaternary deposits are considered as minor shallow aquifers.

Hydrogeochemistry:

The result of hydrochemical analyses of ground water samples are given in (table 2). The pH of analized samples varies from (6.9) to (7.4), this indicates in general that ground water is slightly acidic to neutral. Total dissolved solids(TDS) ranges from(342)to (1169) mg/l, most samples are fresh water (TDS < 1000 mg/l) [6], except water from wells (W_5) which are very slightly above that limit ,but still considered fresh water. The Electric conductivity (EC) varies between (463) to (1602) μmohs cm^{-1}. All samples fall under very hard and hard water according to [7]. Ground water samples shows low to moderate concentration of major ions(calcium , magnesium ,sodium, potassium, chloride, sulphate and bicarbonate, with ranges (40.3-104.9 mg/l, 19.5-78.1 mg/l, 11.6-122.7 mg/l, 0.62-3.1 mg/l, 20.6-200.6 mg/l, 25.4- 288. mg/l and 144.8 to 398.4 mg/l) respectively. Along ground water flow path ,temperature ,EC, TDS, Mg, SO_4, HCO_3 and TH increase from wells (w_6, w_7, w_8, and w_9) toward wells (w_1, w_2, and w_3). The computer program Rockworks [8], had been used for plotting the ground water samples on Piper diagram [9] see (Fig 3). According to this diagram three water types were recognized in this area. These are Ca-HCO_3 ,Mg-HCO_3 and Mg-SO_4. The first type (Ca-HCO_3) belongs to the wells (w_3, w_6, w_7, w_8, and w_9) the domain source of this facies comes from dissolution of limestone in the study area and also found in cementing materials in Injana Aquifer. The second type (Mg-HCO_3) belongs to the wells (w_1, w_2, w_4, and w_5,) the domain source for this facies comes from dissolution of dolomite and some clay minerals. The third type (Mg-SO_4) is unique facies which is found only in (W_{10}). The domain source for this facies comes from dissolution of dolomite and gypsum.

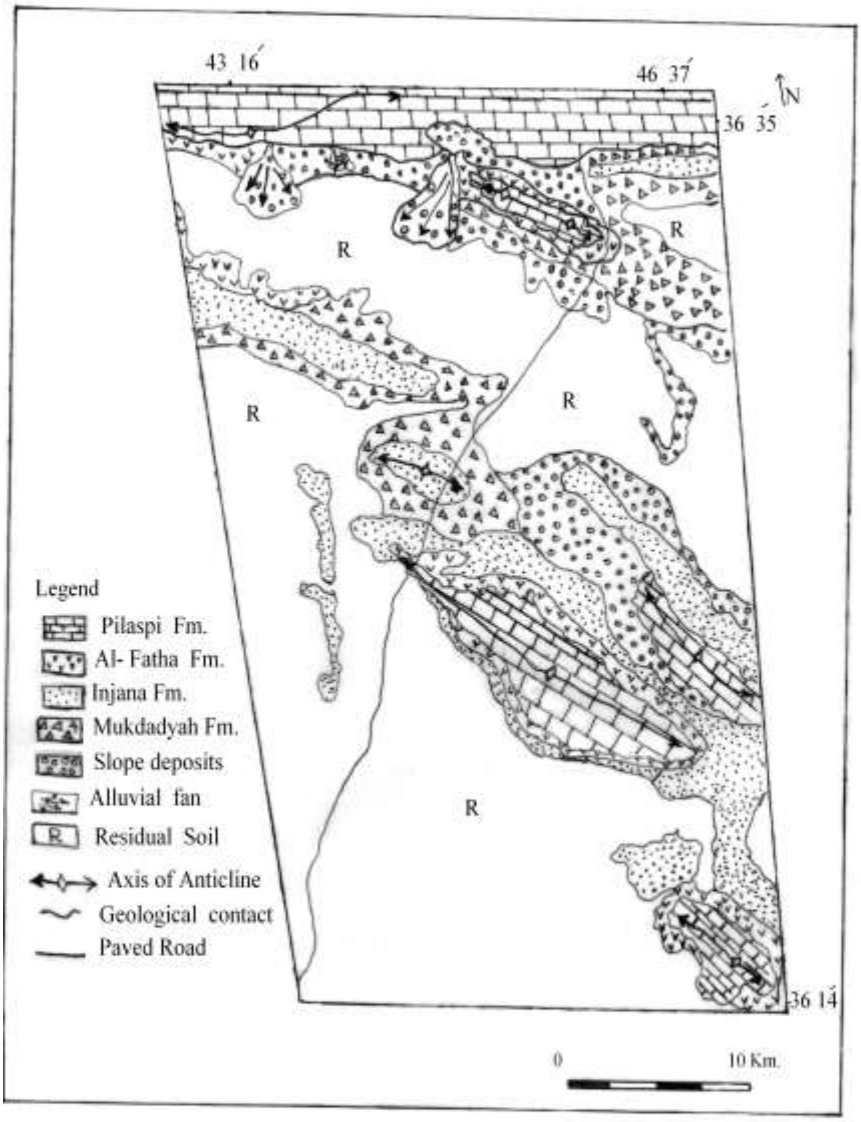

Fig (2) Geological map of study area [10]

Table (2) Chemical analysis of ground water and other parameters in study area

Well Name & No. / Parameters	Taq Harb W_1	Sheaf shrean W_2	Lambakre W_3	Kazna Tapa 1 W_4	Kazna Tapa 2 W_5	AlShekhan 1 W_6	AlShekhan 2 W_7	Mahd 1 W_8	Mahd 2 W_9	Bizgirtan W_{10}
pH	6.9	7.2	7.0	7.1	7.2	7	7.2	7.4	7.3	7.2
Temp.	22.5	22.3	21	22.6	21.5	19.5	18.8	18.5	18.9	22.7
EC	908	878	748	1491	1602	484	485	463	548	938
TDS	642	591	682	875	1169	408	362	342	398	686
Ca^{+2}	40.3	56	94.3	80.5	104.9	64.6	64.7	43.3	53.6	96.2
Mg^{+2}	48.6	48.3	53	78.1	73.2	24.3	19.5	22.5	23.2	63.7
Na^{+}	61.1	32.6	18.9	44.2	122.7	28.9	11.6	17.4	19.8	31.6
K^{+}	3.1	1.8	0.73	2.3	0.9	0.62	1.1	0.9	0.8	1.3
Cl^{-}	60.5	50.1	52.6	120.9	200.6	100.2	30.6	20.6	22.5	120
SO_4	117.3	120.4	58.4	170.1	288.4	25.4	28.5	26.2	37.1	216.2
HCO_3	300.2	272.8	398.4	365.4	390.2	180.9	208	196.7	221.4	144.8
* TH	300	340	496	491	560	260	266	239	218	495
** E%	1.91	0.9	3.5	2.05	4.12	1.48	4.90	4.99	4.1	3.07
*** PI%	56.23	43.11	34.12	35.31	47.37	45.91	43.99	53.46	50.74	25.5
Water type	$Mg\text{-}Hco_3$	$Mg\text{-}Hco_3$	$Ca\text{-} Hco_3$	$Mg\text{-}Hco_3$	$Mg\text{-}Hco_3$	$Ca\text{-} Hco_3$	$Ca\text{-} Hco_3$	$Ca\text{-} Hco_3$	$Ca\text{-} Hco_3$	$Mg\text{-}So_4$

Units: concentration in mg/l, except pH, EC (μmohs cm^{-1}),
*TH Total hardness , ** E% Error percent , *** PI % Permeability index.

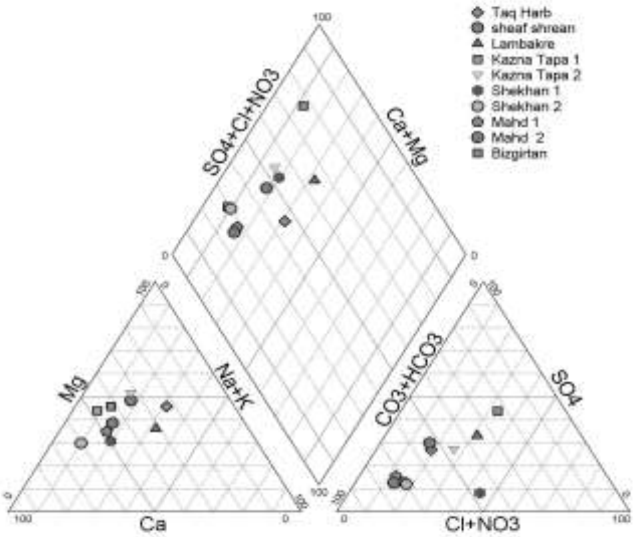

Fig (3) ground water samples plotted in Piper diagram

Calculation of saturation index of selected minerals in aquifers:

The following steps were used to calculate saturation index for selected minerals in aquifer [11]. To calculate saturation index (SI), the ionic strength (I) was calculated for each sample according to equation:

$I = 0.5 \sum m_i z_i^2$ ….…. (٣)

where m_i is the concentration of a given ion in molality and z_i is the charge of that ion. The ionic strength (I) of ground water ranges between (0.00683 - 0.02594) according to [12], the ionic strength for freshwater is normally less than (0.02) while seawater has ionic strength of about (0.7). (Fig 4) shows very good direct relationship(r =0.94) between electrical conductivity (EC) and ionic strength (I). Due to that the ionic strength of each sample is (0.1) or less, the activity coefficient of each individual ion of each sample at ground water temperature measured can be calculated using Debye-Huckel equation.

$$- \log \gamma_i = \frac{A z_i^2 \sqrt{I}}{1 + a_i B \sqrt{I}} \quad \text{.........} \ (٤)$$

Where γ_i is the activity coefficient of the ion, A and B are constant which is temperature –dependent, (Table 3), (a_i)is the effective diameter of the ion .

Then calculate the activity α of each ion from equation

$\alpha = \gamma_i \ m_i$ ………(٥)

α is the chemical activity of ion , then calculate ion activity product which is the product of measured activities (K_{iap}) for selected minerals in the aquifer (calcite, dolomite and gypsum). The saturation index (SI) is the logarithm of the ratio of the ion activity product to mineral equilibrium constant at a given temperature .

$SI = \log_{10} (K_{iap} / K_{SP})$ ……… (٦)

Where K_{iap} is the ion activity product, K_{SP} solubility product. If the SI equal to zero, it reflects the solubility equilibrium with respect to mineral phase of the water. A negative value indicates undersaturation (possible mineral solution) and a positive value indicates supersaturation (possible mineral precipitation).

Equilibrium is taken to be between SI= -0.1 to 0.1 [13] .By using saturation index approach , it is possible to predict the reactive mineralogy of the subsurface from ground water data without collecting samples of the solid phase and analizing the mineralogy [14]. The saturation indices are summarized in (Table 4) and (Fig 5). The values in this table shows that the water samples were undersaturated with respect to calcite and dolomite except wells (w_4 and w_5)which are reach to equilibrium state, due to dissolution of carbonate rock surrounding the wells causing increase in concentration of Ca, Mg, HCO_3,while all water samples were undersaturated with respect to gypsum, The saturation index calculation is quitly coincident with gypsum and calcite equilibrium diagram [15], which found the result of plot on diagram agree with saturation index calculation (Fig 6) . PHREEQE software program [16] was used to calculate saturation indices of Minerals.

Table (3) values for constants A,B and ai in the Debye –Huckel equation [17]

Temperature ^oC	A	B		Ion	ai
0	0.4883	0.3241		Mg	11
5	0.4921	0.3249		Ca	6
10	0.4960	0.3258		Na^+, SO4 , HCO_3	4
15	0.5000	0.3262		K^+ , Cl^-	3
20	0.5042	0.3273			
25	0.5085	0.3281			
30	0.5130	0.3290			
35	0.5175	0.3297			
40	0.5221	0.3305			

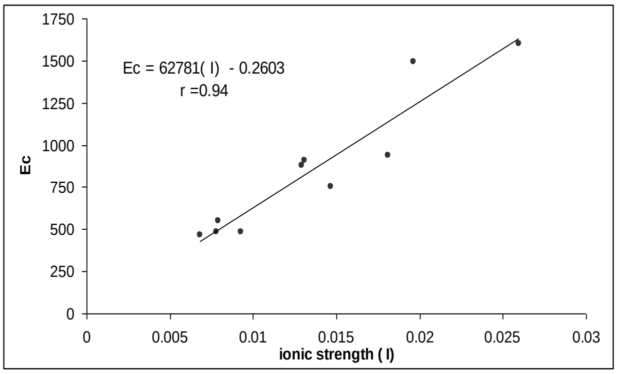

Fig (4) relation between ionic strength and electrical conductivity

Table (4) Saturation indices for selected minerals in ground water samples

Well No.	Ionic strength (I)	SI *calcite*	SI *dolomite*	SI *gypsum*
W_1	0.0131	-0.58	-0.77	-1.85
W_2	0.01293	-0.18	-0.22	-1.70
W_3	0.01468	-0.25	-0.21	-1.82
W_4	0.01966	-0.05	0.01	-1.50
W_5	0.02594	0.09	0.03	-1.21
W_6	0.00926	-0.48	-1.11	-2.23
W_7	0.00781	-0.22	-0.69	-2.15
W_8	0.00683	-0.21	-0.44	-2.33
W_9	0.00792	-0.25	-0.45	-2.12
W_{10}	0.0181	-0.26	-0.38	-1.29

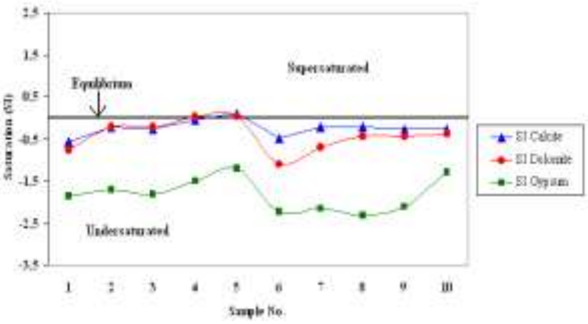

Fig (5) Saturation indices of minerals related to interactions with water samples

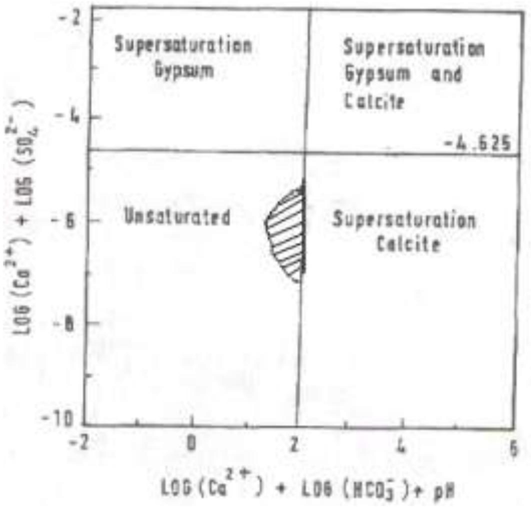

Fig (6) Calcite and gypsum equilibrium limits, 25^{0}C and 1 atmosphere pressure after [15]. Samples fall in the cross hatched area.

Drinking water quality:

Depending on [18] standards it was found that all ground water samples were suitable for drinking except well(w_5) in which the total hardness values slightly more than the maximum permissible limit, but still drinkable by the villagers (personal communication).

Table(5)Maximum permissible limits prescribed by WHO for drinking purpose [

Quality	Maximum permissible
pH	9.2
Total dissolved solid (mg/l)	1500
Total hardness asCaCO3(mg/l)	500
Calcium (mg/l)	200
Magnesium (mg/l)	150
Sodium (mg/l)	200
Chloride (mg/l)	600
Sulfate(mg/l)	400

Water quality for irrigation:

Excessive amounts of dissolved ions in irrigation water affect plants and agricultural soil physically and chemically, thus reducing the productivity. The physical effects of these ions are to reduce the osmostic pressure in the plant, thus preventing water to reaching the branches and leaves. The chemical effects disrupt plant metabolism. It is the quantity of certain ions, such as sodium and boron, rather than the total salt concentration that affects plant development [19]. Parameters such as electrical conductivity EC, sodium percentage (Na%), sodium adsorption ratio (SAR) and permeability index (PI) were used to assess the suitability of ground water for irrigation purposes.

Sodium content:

Sodium concentration is important in classifying irrigation water because sodium reacts with soil to reduce its permeability. The percent of sodium is obtained by the equation:

$$\%Na = \frac{Na+K}{Ca+Mg+Na+K} \times 100 \quad \text{......... (7)}$$

where all ionic concentrations are expressed in (epm)
The EC and Na% values plotted on Wilcox diagram [20]. The results summarizes in (Table 6) illustrate that wells (w_3, w_6, w_7, w_8 and w_9) water fall in the fields Excellent to good and wells (w_1, w_2, w_4, w_5 and w_{10}) water fall in the fields of good to permissible (Fig7).
Sodium Adsorption Ratio:
(SAR) can be calculated using the formula

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}} \quad \text{......... (8)}$$

Where all ionic concentrations are expressed in epm. The EC and SAR%)values plotted on the US salinity diagram [21] and results summarized in (Table 6) illustrate that the waters of the wells (w_3, w_6, w_7, w_8 and w_9) fall in the field of C_2-S_1, indicate water of medium salinity and low sodium adsorption ratio which is very good for irrigation, while wells (w_1, w_2, w_4, w_5 and w_{10}) fall in the field of C_3-S_1, indicate water of high Salinity and low sodium adsorption ratio, which can be used for irrigation in all types of soil with Low hazards of exchangeable sodium, (Fig8).

Permeability index:
The irrigation waters can be classified depending on the permeability index (PI), and can be estimated using the formula:

$$\text{Permeability Index (PI)} = \frac{Na+\sqrt{Hco_3}}{Ca+Mg+Na} \times 100 \quad \text{... (9)}$$

Where all ionic concentrations are expressed in (epm) [22]. According to PI values (Table 2), all ground water samples in the study area can be designated as class II (25–75%) implying that the water is of good quality for irrigation purposes with 75% or more of maximum permeability.

Table (6) Ground water classification for irrigation according to Wilcox and US salinity diagram

Well No.	EC	Na %	SAR%	Water class	
				Wilcox diagram	US salinity diagram
W_1	908	31.27	1.53	Good to permissible	C_3- S_1 high EC low SAR
W_2	878	17.76	0.77	Good to permissible	C_3- S_1 high EC low SAR
W_3	748	8.46	0.38	Excellent to good	C_2- S_1 medium EC low SAR
W_4	1491	15.92	0.84	Good to permissible	C_3- S_1 high EC low SAR
W_5	1602	32.23	2.24	Good to permissible	C_3- S_1 high EC low SAR
W_6	484	19.55	0.77	Excellent to good	C_2- S_1 medium EC low SAR
W_7	485	9.9	0.32	Excellent to good	C_2- S_1 medium EC low SAR
W_8	463	16.24	0.53	Excellent to good	C_2- S_1 medium EC low SAR
W_9	548	16.09	0.56	Excellent to good	C_2- S_1 medium EC low SAR
W_{10}	938	12.27	0.612	Good to permissible	C_3- S_1 high EC low SAR

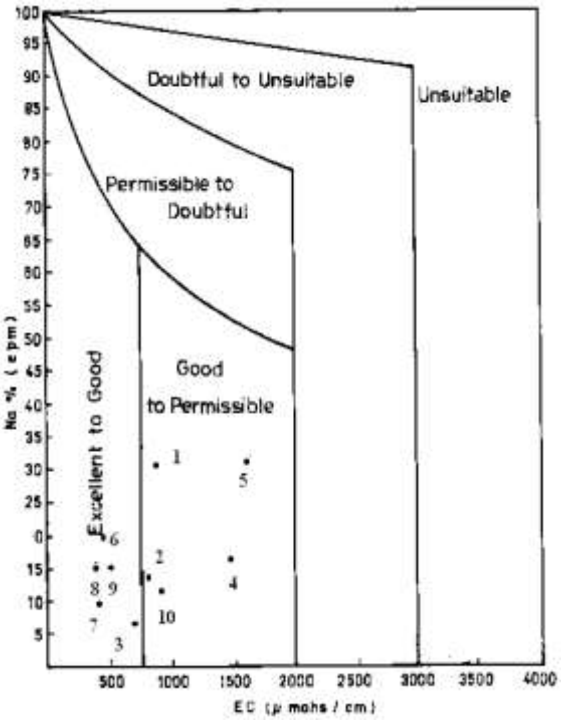

Fig (7) Suitability of groundwater for irrigation in Wilcox diagram

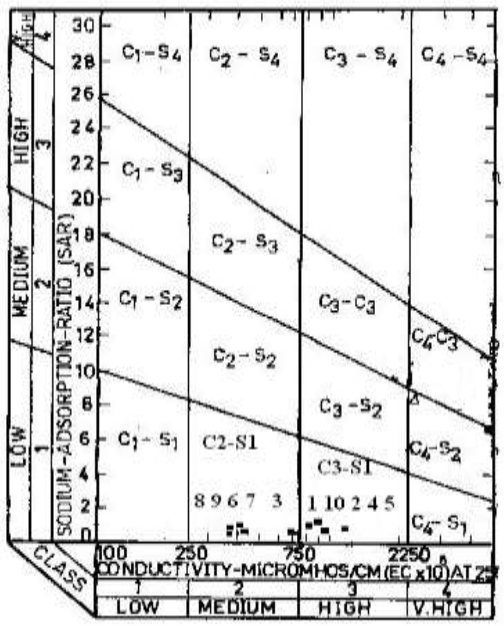

Fig (8) Salinity and alkalinity hazard of irrigation water in US salinity diagram

Conclusions and recommendations:

From the field work and lithology log of wells; three main aquifers were recognized, the older is PilaSpia limestone (confined) aquifer, the middle is Al-Fatha (semiconfiend) aquifer which consist of alternated layers of marls, limestone, gypsum and red clay, the younger is Injana sandstone (unconfined) aquifer. Ten ground water samples were collected from selected wells distributed through the study area. Along ground water flow path ,temperature ,EC,TDS,Mg,SO_4,HCO_3 and TH increases from wells (w_6, w_7, w_8, and w_9) toward wells (w_1, w_2, and w_3). Relative high concentration of almost soluble ions and other parameters in wells (w_4, w_5 and w_{10}) compared with other wells and this is due to direct contact with Al-Fatha Formation. According to Piper diagram three water types were identified Ca-HCO_3, Mg - HCO_3 and Mg-SO_4. Ionic strength for each sample had been calculated and ranged between (0.00683-0.02594 molarities), EC when plotted against ionic strength shows strong correlation between them (r=0.94). All water samples are undersaturated with respect to calcite and dolomite except wells (w_4 and w_5) which are in equilibrium state, due to the dissolution of carbonate rock of the upland area which causes an increase in concentration of Ca, Mg HCO_3, the lower part of these wells penetrates Al-Fatha Formation leading to the increase of concentration of EC, TDS, Ca, Mg, Na, SO_4, HCO_3 and TH. While all water samples were undersaturated with respect to gypsum. These water samples are potable except water from (w_5) in which its total hardness slightly exceed maximum permissible limit. These water samples are suitable for irrigation purposes depending on calculations of sodium percentage, sodium adsorption ratio and permeability Index (PI) using Wlicox and US salinity diagram.

It is recommended:

1- Setting up a ground water monitoring network for each aquifer in the region. The monitoring program includes wells with their records of the amount of water pumped, water level in the wells, general quality of the water (be obtained Quaternary) pumping information, and also observation point source of contaminations which can impact on ground water quality .

2- It is recommended also to not drill and product from Al-Fatha aquifer due to its bad water quality which causes deterioration of ground water.

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هيدروكيميائية وتقيم نوعية المياه الجوفية في منطقة الشيخان– برطلة (شمال العراق)

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(تاريخ الاستلام: / /٢٠٠٧ ، تاريخ القبول: / / ٢٠٠٧)

الملخص:

أن المصدر الرئيس للمياه في منطقة الدراسة هو المياه الجوفية بالإضافة الى الإمطار في الأشهر الرطبة .تم تميز ثلاثة خزانات رئيسية حاملة للمياه في منطقة الدراسة وهي خزان البلاسبي،خزان الفتحة وخزان انجانة. جمعت عشر نماذج مائية خلال شهر تشرين الأول ٢٠٠٦ من أبار مائية موزعة في منطقة الدراسة لتحديد نوعية المياه وتقيم استخداماتها للإغراض المختلفة، حيث تم قياس درجة حرارة ،الدالة الحامضية والتوصيلية الكهربائية للنماذج المائية في الحقل ، بالإضافة الى تحليل العناصر الرئيسية والملوحة في المختبروحساب درجة العسرة للمياه . حيث تم تميز ثلاثة أنواع من المياه وهي: كاربونات الكالسيوم ، كاربونات المغنسيوم وكبريتات المغنسيوم . كذلك تم حساب القوة الأيونية لكل نموذج وحساب معامل التشبع لمعادن (الكالسايت ، الدولومايت والجبسوم) المذابة في الخزانات المائية لمنطقة الدراسة حيث وجد أن معدن الكالسايت والدولومايت كانا في حالة تحت الاشباع لجميع النماذج باستثناء النماذج(٤ و٥) فقد وصلا الى حالة التوازن بينما كانت جميع النماذج في حالة تحت الاشباع بالنسبة لمعدن الجبسوم . كما تم تقيم المياه الجوفية في المنطقة حيث ظهرت بأنها صالحة للشرب و للري بالاعتماد على حساب النسبة المئوية للصوديوم، نسبة امتزاز الصوديوم ومعامل النفاذية وكذلك باستخدام مخطط وليكوكس ومختبر الملوحة الأمريكي.