GROUNDWATER CHEMISTRY OF THE PLIO-PLEISTOCENE AQUIFER OF ERBIL HYDROGEOLOGIC BASIN, N.IRAQ.

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Abstract

The studied aquifer is the Plio-Pleistocene unit of layering mixed facies of gravel, sand, silt and clay with respect to conglomerate. Two hydrochemical groups were identified as bicarbonate and sulphate. Two families in each group are strongly acting with depth and laterally a part from the hydrogeologic boundaries.

The bicarbonate families are Ca-HCO_3 and Mg-HCO_3, while that of sulphate are Mg-SO_4 and Na-SO_4. The distribution map of salinity reflects a trend of increase in salinity which clarify the different flow orientation within the sub-basins. The minimum recorded of salinity is 750 ppm, while the maximum is 7500ppm. The ten folds salinity occurs at the western boundary condition of Avana and Khurmala anticlines, where the Fatha gypsum layers exposed. This condition of salinity coincide's with sulphate distribution below 1 epm toward north –north east and above 1 epm up to 10 epm toward NW, and west. The chloride ionic concentration(isochloride map) shows a restricted area of more than 1 epm up to 10 epm east Khurmale anticline of sulphate.

Water quality of this aquifer system with SAR values less then unity group and more than unity. Most of these waters are marginal good quality for irrigation .The deep groundwater and highly infiltration rate leads to practices of saline water irrigation of sprinkler type.

الخلاصة

الوحدة الصخرية المتكونه من الحصى والرمل والغرين تابعة لعصر البلايستوسين تعتبر مكمن مائي جيد .

تم تميز مجموعتين هيدروكيميائية وهي البابكاربونات والكبريتات وعائلتان في كل مجموعة رئيسية. وهي :
عائلتي Ca-HCO_3 و Mg- HCO_3 وعائلتي Mg- SO_4 و Na- SO_4 .
خارطة توزيع ملوحة المياه الجوفيه ضمن المكمن تعكس زيادة بصورة عامة بالملوحة من حيث اتجاه حركة المياه الجوفيه ضمن الحوض المائي الجوفي حيث ان اقل قيمة سجلت للملوحة هي 750 ppm بينما اعلى قيمة سجلت 7500 ppm وتقع هذه الزيادة في الحدود الغربية للحوض ضمن طيتي افانا وخورماله المحدبتان حيث ان تكون الفتحة يتكشف في تلك المنطقة . هذه الصورة تتوافق مع التوزيع ايون الكبريتات باتجاه الشمال والشمال الشرقي عندما يكون تركيز الكبريتات اقل من 1e.p.m واعلى من 1-10 e.p.m باتجاه الشمال الغربي والغرب من خلال خارطة توزيع تركيز ايون الكلورايد يتبين ان المنطقة المحصورة من (1-10e.p.m) شرق طية خورماله تعتبر المياه الجوفيه ضمن هذا المكمن ذات نوعية جيدة للري ويمكن استخدام المياه الجوفيه الاعمق للري باستخدام تقنية الري بالرش .

INTRODUCTION

Erbil hydrogeological basin lies between latitudes 36^0 30' -35^0 45' N and longitudes 44^0 30' -43^0 30' E. The area of study is bordered naturally by two rivers, namely the Lesser Zab and Greater Zab from south and north respectively (Figure.1)

Kirkuk structure (Avana and Khurmala Domes) restricts the area of study from west and south-west representing the second water divide. The total area of the regional Erbil basin is 3200 km^2 which is divided into three parts according to the ground water flow [1]

The first part is the Kapran basin which occupies the northern sides of the Erbil basin with total area of 915 km^2, the second is Pash Tepa basin which lies in the southern part of the regional Erbil and occupies a total area of 885 km^2, and the third is the central part basin, which is the intermediate basin with a total area of 1400 km^2.

GEOLOGY

Henson [2] indicated that during upper Miocene, Pliocene and Pleistocene, an uplift with intensive folding and thrusting and concurrent subsidence of for deep occurred in N-NE of Iraq. During these intervals the trend of the centre of the depositional basin through Erbil hydrogeological basin with a thickness of about 3048 m (Figure. .2). The sediment is characterized by siltstone, sandstone, and conglomerate Mc McCarthy [3], attributed these conditions to simultaneous sedimentation with gradual rise of the land and restriction of the isolated inland seas. He also mentioned that during the Upper Miocene,muds and sands as erosional products from adjacent hills have accumulated in inland seas ,giving mudstone, shales, and sandstone of the Injana Formation.

Continental environment prevailed during the pliocene period, with the deposition of the fluviatile and estuarine sediments of the Bai-assan Formation.El-Kiki, et al [4] postulated that , at least, the upper part of the Injana Formation is of continental origin. Accordingly , the none marine environment of the basin of deposition started before the deposition of the Bai-Hassan Formation. The coarse pluvial and fine inter pluvial (Older Alluvium Terraces) pebbly sand and silty sediments characterize the Pleistocene period.

REGIONAL HYDROCHEMICAL INTERPRETATION

Groundwater Classification:

Schoeller [5] classified the groundwater in a decreasing order of the ionic concentration of the cations and the anions and he arrived to (36) water types.

The available data since of October 1976 to October 2000, has been used to classify the groundwater of the Erbil hydrogeological basin [6], the groundwater of the Erbil basin can be classified into two groups according to the prevailing anion, these two groups is further divided into families when the predominant cation is involved. The bicarbonate group is divided into calcium-bicarbonate and magnesium-bicarbonate families (Table 1). The sulphate group is divided into magnesium-sulphate and sodium- sulphate families. These families have a given type according to the ratio of Scholler's classification. Johns [7] classified the water according to the ratio of sodium to chloride and magnesium to chloride.

The geographic repartition of these two water groups is controlled by the lithological framework and flow direction. The bicarbonate facies represent the plio-pleistocene sediments as well as the flow pattern from east recharging zone toward west.

Table (1): Hydrochemical Water Types.

Group	**Family**	Water type according to:		Index
		Schoeller	Johns	
Bicarbonate	$Ca\text{-}HCO_3$	$HCO_3>SO_4>CL$: $Ca>Mg>Na$	$MgCL_2$ $CL/Na>1$	A1
			Na_2SO_4 $CL/Na<1$	A2
	$Mg\text{-}HCO_3$	$HCO_3>SO_4>CL$: $Mg>Ca>Na$	Na_2SO_4 $CL/Na<1$	A3
Sulphate	$Mg\text{-}SO_4$	$SO_4>HCO_3>CL$: $Mg>Ca>Na$	Na_2SO_4 $CL/Na<1$	B1
		$SO_4>HCO_3>CL$: $Mg>Na>Ca$	Na_2SO_4 $CL/Na<1$	B2
	$Na\text{-}SO_4$	$SO_4>HCO_3>CL$: $Na>Mg>Ca$	Na_2SO_4 $CL/Na<1$	B3

The sulphate group. (which occupies quarter of the basin surface area) indicats the influence of the Fatha Formation and controlled by the flow from the western recharge zone toward east. The groups and their water types are shown in Figure (3).

The water type of ($MgCL_2$) hypothetical salt combinations represents only 5% of the whole water samples and with a limited distribution. The maximum and minimum concentrations of the anions and cations for each water type are given in Table (2). Figure. (4.1) and (4.2) shows the water types according to Schoeller's classification.

Table (2):Maximum and Minimum Ionic Concentration.

Index	Range	rNa	rMg	rCa	rCl	rSO_4	$rHCO_3$	$Ecx10^6$
A1	Max.	1.40	3.26	7.36	2.02	2.16	7.46	2360
A1	Min.	0.15	0.74	2.63	0.21	0.28	3.00	701
A2	Max.	2.30	4.73	6.72	0.92	5.3	6.75	2670
A2	Min.	0.26	1.05	2.00	0.42	0.42	2.90	680
A3	Max.	4.10	8.70	4.40	2.06	6.97	7.50	3770
A3	Min.	1.95	3.73	3.25	1.00	3.26	4.36	1750
B1	Max.	10.0	19.27	12.23	2.02	29.22	9.15	8200
B1	Min.	2.25	7.30	6.0	1.18	9.29	4.91	3090
B2	Max.	18.8	28.98	11.03	4.92	37.3	9.3	11000
B2	Min.	8.6	9.6	6.8	2.12	15.39	5.0	4700
B3	Max.	19.6	10.0	6.8	4.84	21.47	10.74	7300
B3	Min.	3.85	3.15	2.0	0.85	5.21	3.85	1890

Map of The Repartition of The Total Soluble Salts (TSS)

The distribution of Total Soluble Salts (TSS) is shown in Figure.(5).In the northern part of basin (Kapran) there is a decrease in the value of the (TSS) from 400ppm to 250ppm with the flow direction. This anomalous decrease may be due to the effect of the direct infiltration as well as the possible different water horizons especially near the perched zone at Demir Dahg, which mostly act as impermeable boundary condition. It also shows that the groundwater salinity in the area increases with surface flow direction along the Greater Zab River.

In central part basin and in the Bash Tepa basin the (TSS)increases with the groundwater flow direction from 250ppm to more than 2000ppm.The increase is observed in two directions, the first starts from the recharge zone at the eastern part along the Pastura Chai and Shelga valleys while the second flow direction begins from SW-NW along the Kirkuk structure. The meeting of both waters that come opposite sides makes a mixture and a variation of the (TSS) as shown in Figure. (5). The area of the mixing is closer to the Kirkuk structure and along its extent. The gradient of the (TSS) contours is gentle (37.5ppm/Km) near the mixing zone, but at a shorter distance away it becomes higher (166.6 ppm/Km). The limit of the change is the line of the 1000 ppm.

The convergence of both structures Khurmala and Demir Dahg toward the outlet of the basin is also reflected by the (TSS) contoures at the northwestern part of the basin. This convergence allows a certain of the groundwater to pass as a subterranian discharge. The balance of the water will be converted to be a surface discharge through the Kurdala Wadi near outlet of the basin as it is verified during the fieldwork.

Repartitions of The Sulphate and Chloride Ions

The map of the repartition of the chloride Figure (6) shows, as a general phenomena, an increase of chloride concentration with the flow direction except in some local areas. The same remark is also pointed out about the repartition of the sulphate Figure(7). Here, we may explain the decrease of the concentration with the flow direction as the following. The anomalies, where this phenomena is occurring, are located over the perched zones, on the recharge area, along the eastern and southwestern watershed.In this area the infiltrated water has an independent flow from the underlying groundwater body. Accordingly, it is mixed with more concentration existing water leading to the decrease in the concentration. These local abnormalities are still and a normal evolution is continuing with the flow direction.

Regional Picture of The Groundwater Chemistry

The infiltrated meteoric water from the eastern recharge zone through the sediments of the Plio-Pleistocene time unit is characterized by the Bicarbonate group with a water type of (HCO_3>SO_4>Cl:Ca>Mg>Na).The hypothetical salt combination (Na_2SO_4) indicates [8] a deep percolation of the infiltrating water (A2).This water type changes with depth and salinity to (A3) of the character (HCO_3>SO_4> Cl:Mg > Ca > Na). The variation in the groundwater salinity is combined by the increase of the magnesium ion and sodium with respect to the calcium ion. In general, when the salinity is more or less equal to (600) ppm, then the calcium ion is of higher concentration than the sodium or magnesium ions. Thus the water type will be of the (A1) or (A2). As the salinity increases above (600) ppm, with the flow direction depth, then the magnesium or the sodium ions will prevail over the calcium ion concentration. The water type will be (A3), (B1),(B2) and(B3). The following tables (3 and 4) clarify these relations.

Water quality classification for irrigation is based on the hydrochemical parameters which have an effect on soil property nearer to crop root zone and finally on the plant up take [9]. accordingly, there are different water quality classification for purpose of irrigation water based on the hydrochemical parameters used. Among these parameters are the sodium adsorption, alkalinity, chloride, boron, residual sodium carbonate, salinity, and specific conductance.

The Sodium Adsorption Ratio (SAR) is an important hydrochemical parameters as it is directly related to the adsorption of sodium by soil. The (SAR) represents the index of the sodium as hazard of the water [10].

The sulphate water group is restricted to the south-western water divided, where the Fatha group cropping out. As the sediments of this

Table (3):Water Type and Salinity(Hand-Dug Wells)

Locality	TSS	rNa	rMg	rCa	rCl	rSO_4	$rHCO_3$
C.P.B							
KUNAGARK	335	0.42	1.3	3.1	0.35	0.7	3.8
Jimka	371	0.80	1.2	4.1	0.55	1.3	3.5
Qojabilbas	314	0.80	2.2	3.4	0.75	1.3	4.0
Kaor	686	2.50	4.1	3.5	1.60	4.0	3.0
Tel al-barror	745	2.52	4.3	3.3	1.80	5.2	4.8
Gaedli	701	4.20	3.8	2.6	1.60	5.1	4.2
Nogharan	1098	2.3	7.3	7.0	1.30	10.0	5.3
Mastawa	1680	4.8	13.0	7.6	1.70	11.0	12.2
Tendora	1114	2.80	8.1	5.1	1.30	5.5	8.7
Kapran							
Kelkan	266	0.28	1.20	2.60	0.25	0.53	3.63
Aghulan	371	0.63	1.81	3.15	0.32	1.00	4.65
Topzawa kichka	396	0.92	1.93	3.2	0.33	1.35	4.80
Girad chal	934	2.50	5.30	5.00	2.10	2.52	8.1
Rashwan	1854	12.7	9.50	6.20	5.50	17.72	3.40
Pertpan	731	4.23	3.8	3.65	1.60	4.2	5.10
Bash Tepa							
Shikan	471	1.35	2.70	4.20	1.20	1.05	5.50
Girda soor	295	0.48	1.23	2.40	0.38	0.51	3.50
Sebra	418	0.96	2.92	3.54	0.06	1.33	4.80
Girda lanaka	651	2.00	4.80	3.30	1.50	3.40	5.30
Shreawa	553	2.00	3.10	3.05	0.67	2.65	4.8
Kushagln	777	2.00	5.30	4.10	1.2	4.30	6.20
Qozi khana	2496	19.3	10.2	7.0	4.0	21.6	11.0
Jideda	2780	1403	21.8	10.7	3.07	36.0	8.2

Table (4):Water Type and Salinity(Drilled Wells) See Figures 4.1 ,4.2.

Locality	TSS	rNa	rMg	rCa	rCl	rSO_4	$rHCO_3$
C.P.B							
106	3074	14.0	20.1	12.0	5.50	31.0	9.0
268	2910	30.1	9.0	8.0	3.3	38.7	5.8
57	1753	9.0	10.6	8.0	3.5	15.0	9.0
130	1225	3.30	10.0	6.5	2.3	11.5	6.0
59	1094	5.0	6.0	4.8	3.0	9.0	4.0
123	1050	3.1	10.0	5.5	2.0	10.0	7.0
60	940	2.30	7.6	5.30	1.5	4.3	9.8
203	361	0.9	2.0	2.5	0.6	0.3	4.5
230	298	0.45	2.0	2.2	0.35	0.15	4.0
233	271	0.52	1.7	2.0	0.45	0.1	3.5
54	589	2.5	3.5	4.0	1.3	2.9	5.6
Kapran							
144	400	0.98	2.1	3.1	0.55	0.75	4.6
139	260	1.15	1.25	2.0	0.5	0.1	3.4
62	410	2.05	2.85	3.25	0.7	1.55	5.52
102	350	0.52	2.2	2.7	0.5	0.68	4.35
Bash Tepa							
258	283	0.55	0.2	0.2	3.7	0.05	3.8
53	380	0.85	1.9	3.1	0.6	0.5	4.42
114	4660	2.0	2.5	2.8	0.7	2.3	4.0
115	470	1.9	2.1	3.4	1.00	1.2	4.2
99	490	1.15	3.2	3.8	0.7	2.0	4.8
98	360	0.54	1.2	2.6	0.5	0.1	3.2
261	600	3.0	2.60	2.4	1.0	3.6	3.8
196	240	0.53	1.1	2.4	0.5	0.13	3.2

group are mainly marine, then the original marine solution which is trapped in this sediments affect the existing water today. The original marine solution may be of the type of Ca-Mg-Sodium: HCO3-SO_4 – Chloride , according to Sulin's classification . Due to the infiltrated meteoric water, the original marine solution mixed and diluted to give the Ca-Mg-Sodium: CL-HCO_3-Sulphate which is the first stage in the development of the family (B_3).

Later on with time the mixing and dilution processes continue to change the water to Ca-Na-Magnesium: CL-HCO_3-Sulphate, which is the type (B_2). This is another possible source for the water type (A3) due to the circulating water within a deeper gravel layer taking its origin toward east and reappears again near the discharge zone both water are mixing. This water during its deep and solw percolating is affected by the increase of its total soluble salts as a result of dissolution and exchange due to its contact with the clay and shale sediments, which act as a filter.

The distribution of the (SAR) for Erbil groundwater is given in Figure. (8) reflecting the two water groups. The lowest values of the (SAR) occupies the area of the bicarbonate water group. Data obtained are used to calculate the (SAR) for different water types. The results are given in the table (5), with its validity for irrigation.

Table (5):Validity of Water Types For Irrigation.

Water type	ECX10^6 mmhos/cm	SAR	Validity
A1 max.	2360	0.61	S1 C3 marginal
A1 min.	701	0.11	S1 C2 Good
A2 max.	2670	0.96	S1 C4 marginal
A2 min.	680	0.21	S1 C2 Good
A3 max.	3370	1.60	S1 C4 marginal
A3 min.	1750	1.05	S1 C3 marginal
B1 max.	8200	2.52	S1 C4 marginal
B1 min.	3090	0.87	S1 C4 marginal
B2 max.	11000	4.20	S1 C4 marginal
B2 min.	4700	3.00	S1 C4 marginal
B3 max.	7300	6.76	S1 C4 marginal
B3 min.	1890	2.40	S1 C3 marginal

Marginal water type is used for irrigation of certain crops, where the salinity is the only factor, which is not suitable for irrigation. Todd [10] clarify that the sodium concentration in term of alkalinity is controlling factor in judgment of water suitability probably to reduce the soil permeability and finally the plant uptake. The most well known water quality classification is that one given by Richard classification which is based on (SAR) and the specific conductance (Ec) at 25^0c, [11]. The combination of (SAR) and (Ec) in this classification is more relevant for drainage and irrigation purposes. These two parameters are grouped into four categories as shown in table (6). This classification leads to 16 water types.

Table (6):SAR and Ec*10^6 mmhos/cm Water Classification (After Richard,1954).

Group	SAR		EC	
Low	S1	<10	C1	100-250
Medium	S2	10-18	C2	250-750
High	S3	18-26	C3	750-2250
Very high	S4	>26	C4	>2250

CONCLUSION

According to the results obtained from the hydrochemistry of Erbil basin the cations, the anions and the salinity; it's possible to indicate two water groups, Scholler's classification. These families are grouped into types according to decreasing order of the ionic concentrations. The water types are related to the prevailing salinity with respect to the flow direction as well as to the depth and distance of the water migration .In general, it is observed: when the salinity is equal or less than 600 ppm, the prevailing water types are the

$rHCO_3$>rSO_4>rCL;rCa>rMg>rNa;rCL>rNa(A1) ,and
$rHCO_3$>rSO_4>rCL;rMg>rNa;rCL<rNa(A2).
Also the calcium ion concentration is predominant. The other water types are associated with a higher value of salinity. The problem of occurrence of the sodium ion instead of calcium in the subfamily rSO_4>$rHCO_3$>rCL;>rNa>rMg>rCa;rCL<rNa(B3) is the only phenomena that disagree with the general hypothesis of the salinity relation to the water types. This has been shown due to ion exchange, which takes place between the sediments and the water for a long period of contact. It is further deduced that the sodium-sulphate family their origin from the eastern recharge zone. After a deep percolation and migration, this water appears again near the surface at the southern west where this water type is prevailing. The problem of mixing the two water that come from opposite sides indicate possible water pollution in the central basin.

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59	1094	5.0	6.0	4.8	3.0	9.0	4.0
123	1050	3.1	10.0	5.5	2.0	10.0	7.0
60	940	2.30	7.6	5.30	1.5	4.3	9.8
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54	589	2.5	3.5	4.0	1.3	2.9	5.6
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144	400	0.98	2.1	3.1	0.55	0.75	4.6
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