

## HYDROGEOLOGY AND GEOPHYSICAL INVESTIGATION OF GANAU LAKE, RANYA AREA, IRAQI KURDISTAN REGION

Salahalddin S. Ali<sup>1</sup>, Bakhtiar Q. Aziz<sup>2</sup>  
and Diary A.M. Al-Manmi<sup>3</sup>

Received: 22/ 5/ 2011, Accepted: 6/ 10/ 2011

Key words: Environmental Isotopes, GPR, Hydrogen Sulphide, Karst springs, Karst

### ABSTRACT

The geological and hydrogeological features, which are responsible for the relatively unusual existence of a hydrogen sulphide rich lake in the broad Ranya Plain is the main endeavor of this study. The lake is located 131 Km northwest of Sulaimaniyah city on the northwestern periphery of Dokan reservoir. To investigate the basin configuration and the subsurface setting of the lake and its surrounding area, two GPR profiles were laid out using a band width (Centre Frequency) 100-MHz unshielded antenna. For penetrating more depths; as well as mapping structural and stratigraphic situations of the subsurface that couldn't be achieved by GPR survey, one dimensional resistivity sounding was carried out.

Hydrochemical analysis of the water samples collected from the major lake and the surrounding smaller ones revealed that the water is of CaSO<sub>4</sub> type, with domination of Ca and SO<sub>4</sub> over Na and Cl. Values of  $\delta^{18}\text{O}$  and  $\delta^2\text{H}$  in water samples of Ganau lake, when plotted along the global meteoric water line shows that the two collected water samples from both the major and minor lakes have similar isotopic composition indicating that both of them are receiving water from the same flow zones, with diffuse recharge type. The tritium value indicates that the spring water is modern.

From combining together the acquired field results (geological, hydrogeological, and geophysical investigations); the occurrence of the lake and draining of the sulphuric spring in such a condition is attributed to a probable graben like faults on the crest of Ranya anticline, which facilitate both discharging of the deep artesian water from the underlying bituminous Jurassic rocks; or even from the deeper Triassic rocks. The continuous dissolution and the accompanying collapsing have contributed in formation of this lake and the sinkhole spring.

دراسة هيدروكيميائية والاستكشاف الجيوفيزيائي لبحيرة گناو،  
منطقة رانية، إقليم كردستان العراق

صلاح الدين سعيد علي، بختيار قادر عزيز ودياري علي محمد أمين المنمي

### المستخلص

الظواهر الجيولوجية والهيدروجيولوجية المسؤولة عن وجود النسب غير الاعتيادية من كبريتيد الهيدروجين في البحيرة الموجودة في سهل رانية هي الهدف الرئيسي لهذه الدراسة. تقع البحيرة على بعد 130 كم شمال غرب مدينة السليمانية على الطرف الشمالي الغربي من بحيرة دوكان. لغرض التحقق في شكل قعر الحوض والمنطقة المحيطة به،

<sup>1</sup> Assistant Professor, Department of Geology, School of Science, University of Sulaimani,  
e-mail: Salahsulul@yahoo.com

<sup>2</sup> Assistant Professor, Department of Geology, School of Science, University of Sulaimani,  
e-mail: bakhtiar\_61@yahoo.com

<sup>3</sup> Lecturer, Department of Geology, School of Science, University of Sulaimani,  
e-mail: diary.amin@univsul.net

تم دراسة مقطعين (GPR) باستخدام نطاق ذو عرض (مركز التردد) 100 ميغاهرتز وهوائي بدون درع. ولغرض اختراق أعماق للطبقات ورسم الخرائط التركيبية والطباقية والتي لا يمكن اختراقها بواسطة GPR، تم استخدام طريقة المقاومة الكهربائية ذات البعد الواحد.

تم تحليل الصفات الهيدروكيميائية لعينات المياه الملتقطة من البحيرة الرئيسية والبحيرات الصغيرة المحيطة بها، وكانت المياه من نوع  $\text{CaSO}_4$  وكان أيوني الكالسيوم والكبريتات هما السائدان أكثر من أيوني الصوديوم والكلورايد. عند تسقيط قيم  $\delta^{18}\text{O}$  و  $\delta^2\text{H}$  لعينات المياه الملتقطة من بحيرة گناو على طول خط المياه الجوي العالمي، تبين بأن عينات المياه لها نفس التركيب النظائري وإنها تتغذي من نفس النطاق المائي، ونوع التغذية هو من النوع المنتشر. تبين من قيمة نظير التريتيوم أن مياه الينابيع هي مياه حديثة.

تبين من خلال الدراسات الجيولوجية والهيدروجيولوجية الحقلية إضافة إلى الاستكشافات الجيوفيزيائية وجود منخفض في لب طية رانية المحدبة وهو السبب في ظهور العين الكبريتي المكون لهذه البحيرة، ووجود الفوالق على طرفي المنخفض يساعد في عملية تصريف المياه الارتوازية العميقة في صخور الجوراسي الغنية بالمواد القيرية أو حتى صخور الترياسي الأعماق. إن عمليات الإذابة والتهدم المستمرة أدت إلى تكون هذه البحيرة والينابيع البالوعية.

## INTRODUCTION

Studying the Goggle Earth image of the broad Ranya Plain area, which is 131 Km northwest of Sulaimaniyah city, in Iraqi Kurdistan Region; a small natural lake; 700 m northwest of the Dokan Lake periphery could be seen between latitude  $36^\circ 12' 42''$  and longitude  $44^\circ 56' 35''$  (Fig.1). The occurrence of this lake at this location and its rich hydrogen sulphide nature is somehow exceptional (Al-Manmi, 2008). To investigate the subsurface configuration of this lake and the main factors, which are responsible for its nature and occurrence, a detailed geological and hydrogeological study, supported and integrated with GPR (Ground Penetration Radar) and geo-electrical exploration were performed. The lake, which is a circular depression with a surface diameter of 350 m is supplied continuously through an ascending spring with a small channel outlet; discharging 100 l/sec. Three other smaller lakes; few meters south of the large one exist in the area, the second one discharges to the largest lake while the others have no discharge outlet (Fig.1).

Tectonically, the study area is located in the Zagros Fold – Thrust Belt, directly to the southwest of the main Zagros Suture Zone. Structurally, the area is located at the boundary between High Folded and Imbricate Zones (Buday, 1980, Buday and Jassim, 1987 and Jassim and Goff, 2006). The area consists mainly of high amplitude anticlines and synclines, which have the same trend (northwest – southeast). Many of the anticlines are asymmetrical with the southwestern limbs being steeper than the northeastern ones. The area around the Ganau Lake is covered by alluvial sediments (clay, sand and gravels), which are underlain by the Jurassic formations, in the floor of Ranya valley. These formations (of limestones and dolomites) include Sargelu, Barsarine and Naokelekan formations (Al-Manmi, 2008). In the valley, the Cretaceous formations are exposed along the valley sides, such as Sarmord (marl) and Qamchuqa (dolomitic limestone) formations (Figs.2 and 3).

Hydrologically, the district is situated in the Dokan sub-basin, which is a sub-basin of the Lower Zab River Basin (Jawad, 2008). Hydrogeologically, there are four aquifer systems in the studied area, they belong to different ages that are: Jurassic, Early – Late Cretaceous, Late Cretaceous limestone and Quaternary systems (Al-Manmi, 2008). Groundwater flow occurs from the Ranya Plain, Makook, Handreen and Pelewan anticlines; from northwest towards the Dokan Lake.

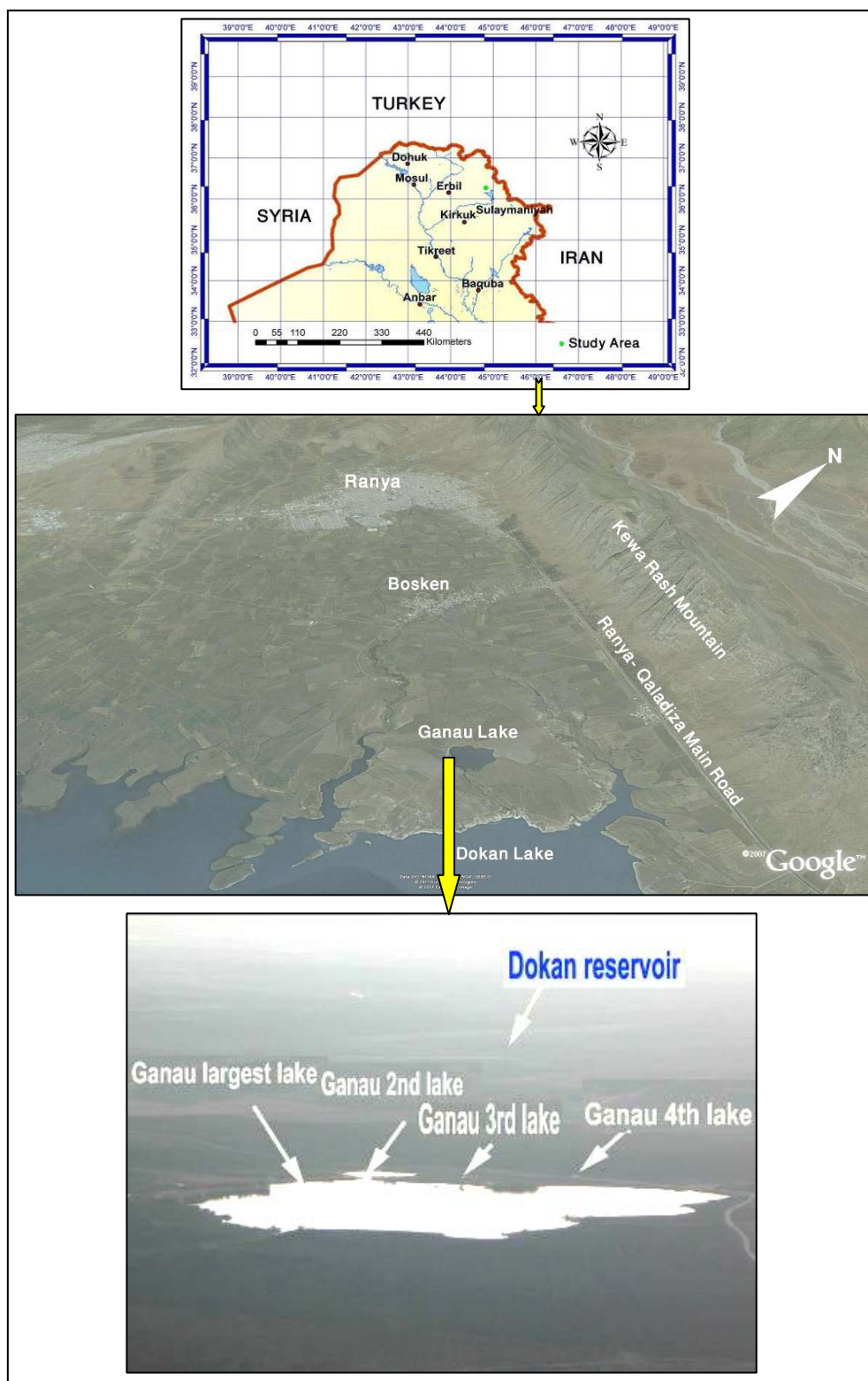


Fig.1: Location map of the study area

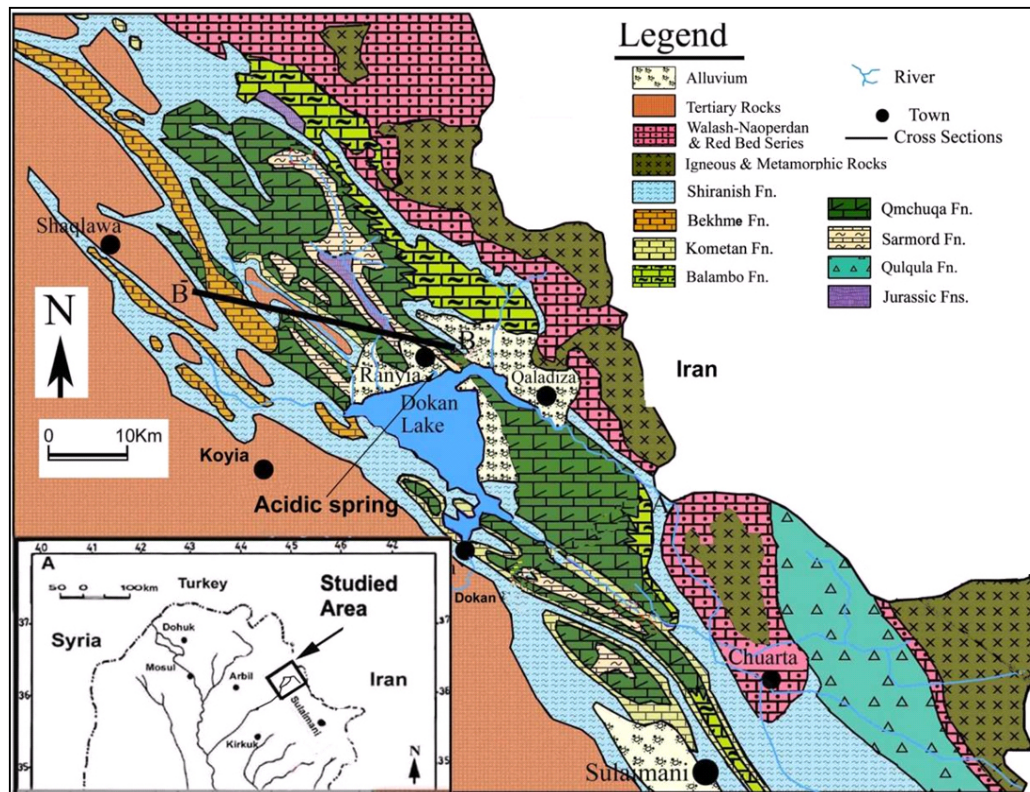


Fig.2: Geological map of Ranya area (after Sissakian, 2000)

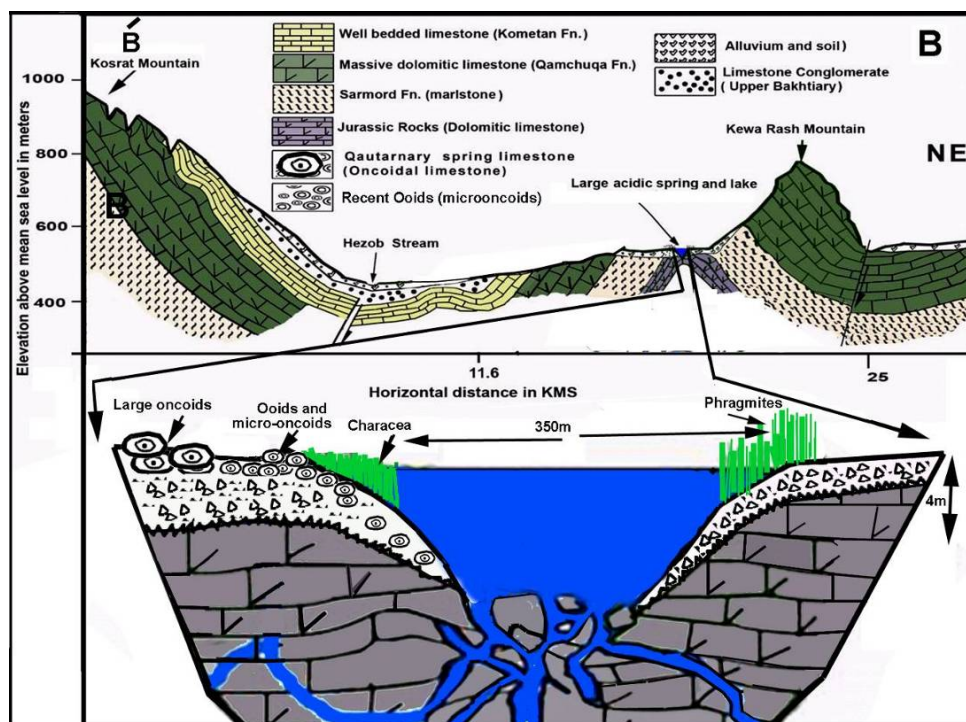


Fig.3: **Top:** Schematic geologic cross section of the study area, passing through Kewa Rash and part of Kosrat Anticlines  
**Bottom:** Ganau Spring, cross section (after Karim *et al.*, 2010)



The main aquifer in Ranya area is the Quaternary sediments, which are tapped by numerous wells to supply surrounding communities. Groundwater is locally used for domestic and irrigation purposes, whereas surface water is used mainly for irrigation. Ganau smaller lakes are more enriched in  $H_2S$  and TDS than the larger one (Al-Manmi, 2008). The water of this flowing lake is never exploited for any purpose; due to its high content of dissolved solids and  $H_2S$  gas. Absence of instantaneous response of the lake discharge to the rainfall events, and relatively stable temperature of the lake water throughout the year indicate deep source of the spring water (Fig.4). It is not clear from where exactly this spring is flowing out, but the bituminous nature and the relatively high organic content of Jurassic rocks, or probably the sulphate rocks of the Triassic rocks might contribute in providing the high content of sulphate, chloride, and gas ( $H_2S$ ) in the water. The lake being located on the crest of the major Ranya anticline with a probable fault zone, which is responsible for pouring out the spring flow; associated with dissolution processes and subsequent collapsing, all these factors have contributed in the development of the present morphology of the lake.

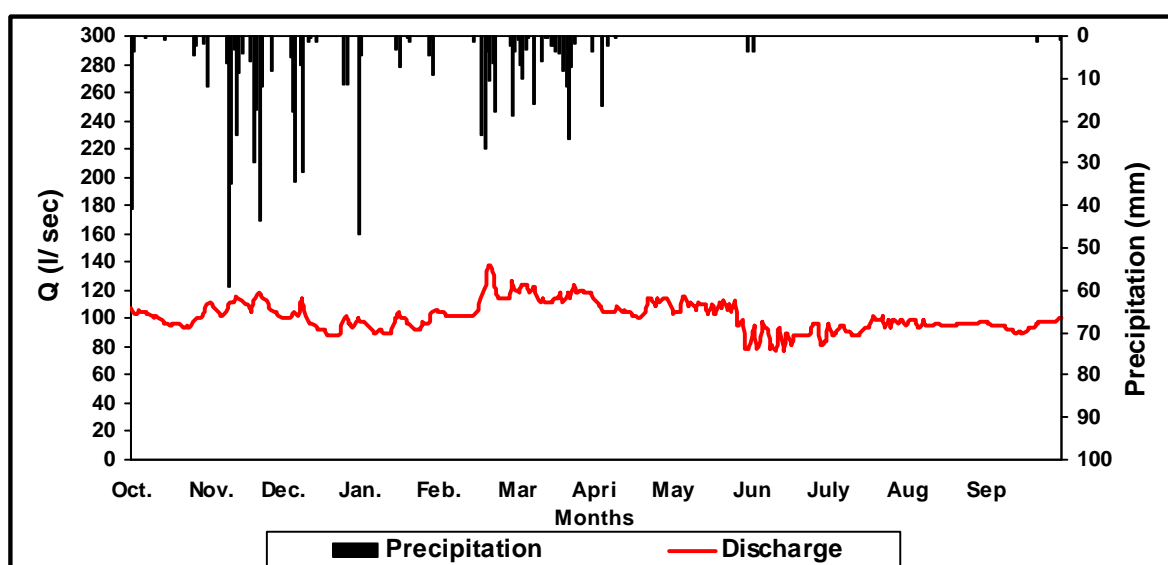


Fig.4: Ganau Lake hydrograph for the year 2002 (FAO, 2003)

## MATERIALS AND METHODS

### ▪ Hydrochemical and Environmental Isotopes Measurements

Samples for hydrochemical and environmental isotopes analysis have been collected from four different sites of the lakes (Fig.1); in October 2009. Samples were collected for isotopic ( $^3H$ ,  $\delta^2H$ ,  $\delta^{18}O$ ), anions ( $HCO_3^-$ ,  $Cl^-$ ,  $SO_4^{2-}$ ,  $PO_4^{3-}$ ,  $NO_3^-$ ), and cations ( $Ca^{2+}$ ,  $Mg^{2+}$ ,  $Na^+$ ,  $K^+$ ) determination. In the field, temperature and pH were measured, using a portable multiparameter analyzer model (TPS/90FL-T Field Lab. Analyzer).

Hydrogen sulphide was stabilized in the field; by pouring a portion of the sample to 100 ml volumetric flask, then adding 4 ml 20% zinc acetate ( $ZnCH_3COO$ )<sub>2</sub> and 1 ml (1N) NaOH, then the volume is completed with water sample. In the laboratory, 4 ml HCl was added to the sample to release  $H_2S$  gas, then 5 ml of 0.01 N iodine solution ( $ZnCl_2 + H_2S = ZnS + 2HCl$ ) was added. The formed ZnS reacted with iodine ( $ZnS + I_2 = ZnI_2 + S$ ), which resulted in the formation of sulphur (Al-Janabi *et al.*, 1992). Cation and anion analysis were conducted at the

Water Quality Laboratory, Twin River Institute (American University in Sulaimaniyah). Cations ( $K^+$ ,  $Na^+$ ,  $Ca^{2+}$ ,  $Mg^{2+}$ ,  $Fe^{3+}$ ,  $Mn^{2+}$ ) and anions ( $NO_3^-$ ,  $Cl^-$ ,  $SO_4^{2-}$ ) were measured using Dionex DX500 ion chromatography system. Anion bicarbonate ( $HCO_3^-$ ) and carbonate ( $CO_3^{2-}$ ) were analyzed by volumetric titration with 0.04N HCl, using Methylorange and Phenolphthaleine indicator (APHA, 1998). Practical detection limits for ions with AA and IC were 0.1 mg/l. A charge balance was calculated for each analysis to evaluate analytical error, and to determine if all the major ions were accounted for in the analysis. Charge balances (CB) were calculated using the following equation (Drever, 1997):

$$CB(as\%) = \left[ (\sum cations - \sum anions) / (\sum cations + \sum anions) \right] \times 100.$$

Charge balances between  $\pm 5\%$  is typically considered to be acceptable for most groundwater analyses.

Isotope analyses were conducted at the University of Waterloo Environmental Isotope Laboratory.  $\delta^2H$  and  $\delta^{18}O$  were made using isotope-ratio mass spectrometry following the procedures of Epstein and Mayeda (1953), Coleman *et al.* (1982), Shakur (1982), Yanagisawa and Sakai (1983), and Eggenkamp (1994), respectively. The results are reported as parts per thousand differences (‰) with respect to Vienna Standard Mean Ocean Water (VSMOW). The analytical precisions for  $\delta^{18}O$  and  $\delta^2H$  are (0.2 and 2.0) ‰, respectively. Tritium concentrations were determined by the electrolytic enrichment method of Taylor (1977), with a lower detection limit of 0.3 tritium units (TU).

#### ▪ Geophysical Surveys

– **Ground Penetrating Radar Survey:** The RAMAC/GPR CUII system, which is manufactured by Mala GeoScience Inc., in Sweden was used. The band width (Center Frequency) 100-MHz; unshielded antenna (Bistatic Mode) connected to the DAEWOO-type laptop, dragged parallel to the direction of the movement. This arrangement has been proved to provide the optimal compromise between investigation depth and resolution (Annan, 2001 and Geo-Sense, 2007), so spacing between traces was 20 cm, and 2 stacks were used for each trace. The number of samples was 505. The antennas were fixed with 1 m separation. The sampling time window was set on 456 ns, providing a maximum investigation depth of about 30 m. The GPR antennas were placed directly on the floor of a boat and moved along the survey line. Ground vision software was used for collecting data and RadExplorer software was used for interpretation. Ground Penetrating Radar (GPR) profiles were collected along mid of Ganau Lake. These profiles were laid out to demonstrate the basin configuration of the lake as well as the structural situation that was caused the formation of the lake. Profile-1 trending NE – SW has length of about 345 m, while profile-2 was laid out perpendicular to profile-1 and has a length equal to 240 m (Fig.5).

– **Electrical Resistivity Survey:** One dimensional (1D) resistivity sounding was carried out for penetrating more depths; as well as mapping structural and stratigraphic situations of the subsurface that couldn't be achieved by GPR survey. Two vertical electrical sounding points were laid out near the lake bank by about 15 m; the distance between them was equal to 110 m (Fig.5). Schlumberger technique was used for the total spread of AB, equal to 800 m.

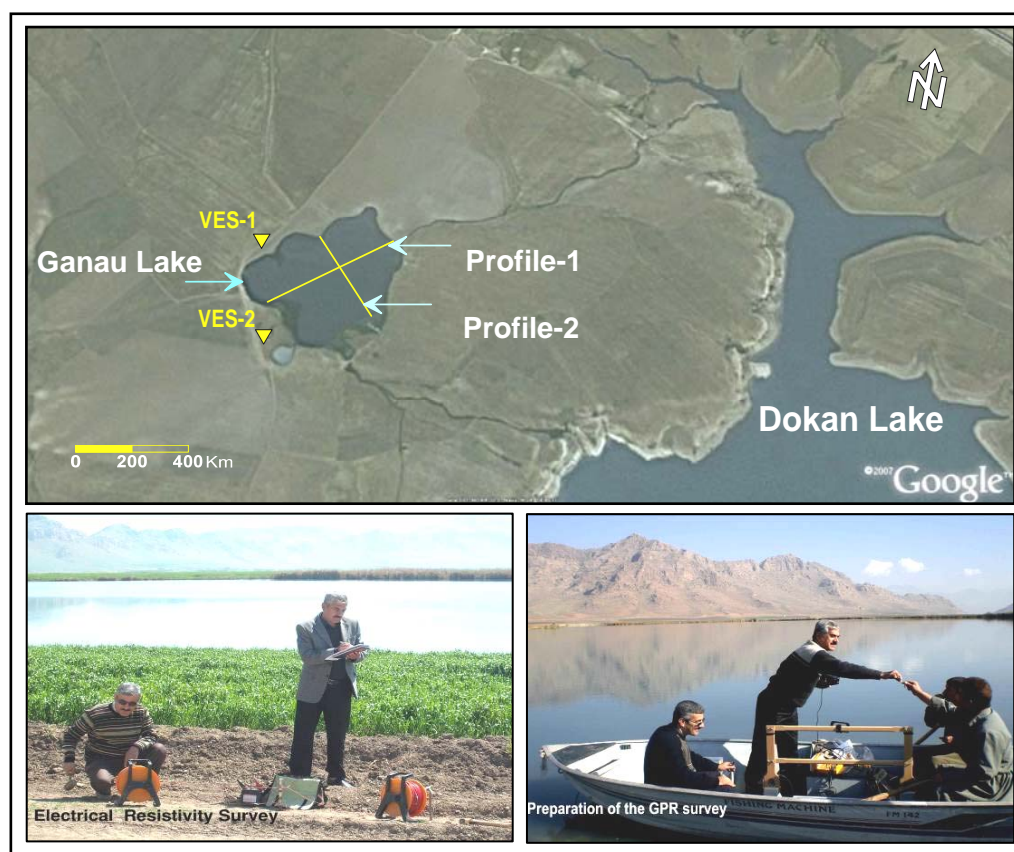


Fig.5: Location of GPR and VES traverses and the GPR and VES survey in progress

## RESULTS AND DISSCUSIONS

### ▪ General Evaluation of the Water Analyses Major Ions

The results of chemical analysis of water samples are tabulated in Tables (1 and 2).  $\text{Ca}^{2+}$  and  $\text{SO}_4^{2-}$  are the dominant ions; the second species in abundance are  $\text{Na}^+$  for cations and  $\text{Cl}^-$  for anions. The relatively high content of  $\text{Ca}^{2+}$ ,  $\text{SO}_4^{2-}$  and  $\text{Cl}^-$  is expected to be issued from either bituminous layers of Jurassic rocks or the evaporates of deeper Triassic rocks. When the water samples are plotted on the Piper diagram (Fig.6), all samples are located in the field number six, which means that the secondary salinity (non-carbonate hardness) exceeds 50%, and the water type is  $\text{Ca} - \text{SO}_4$ . The high value of  $\text{NO}_3^-$  is attributed to the fertilizers, which are used in the surrounding agricultural areas.

### ▪ Dating of Spring Waters

Tritium in the atmosphere precipitation peaked or 'spiked' in 1963 – 1964 as a result of atmospheric testing of thermonuclear bombs. Concentrations of tritium, with a half life of about 12.3 years, are used as a dating technique for spring water samples. The basic approach assumes that infiltrating precipitation enters the groundwater system with a characteristic tritium concentration attained from atmospheric deposition (Knowles *et al.*, 2010). The groundwater is subsequently isolated from the atmosphere and the isotopic 'clock' begins as tritium radioactively decays to helium (Zuber *et al.*, 2001). The 1963 – 1964 tritium spike decreases by one to two orders of magnitude from the northern to southern hemisphere, and continental precipitation is typically two to four times enriched relative to marine stations at the same latitude (Doney *et al.*, 1992).

Although these proximal data exist, the low tritium values in modern precipitation and missing data during the critical spike period from July 1964 to January 1965 (IAEA/ WMO, 2007) mean it is not possible to state precise ages based on the measured tritium values. It is possible, though, to bracket the age of samples by classifying water as being modern and pre-bomb. Tritium values greater than 0.3 TU are used to represent modern water (i.e. recharge after 1965) and values less than or equal to 0.3 TU to represent pre-bomb spike recharge (i.e. recharge before 1965) (Mckenzie *et al.*, 2010). The tritium value indicates that the spring water is modern.

Table 1: Physical parameters and major ions' concentrations of water samples

Parameter	Unit	Ganau 1	Ganau 2
<b>T</b>	°C	23.2	22.8
<b>pH</b>		6.8	7.0
<b>EC</b>	μS/cm	2396	2620
<b>TDS</b>	mg/l	1533.44	1676.8
<b>Ca<sup>2+</sup></b>	ppm	250.8	263.2
	epm	12.54	13.16
	epm %	48.73	47.15
<b>Mg<sup>2+</sup></b>	ppm	62.2	70.6
	epm	5.18	5.88
	epm %	20.14	21.1
<b>Na<sup>+</sup></b>	ppm	166.8	185.7
	epm	7.25	8.07
	epm %	28.17	28.93
<b>K<sup>+</sup></b>	ppm	29.75	31
	epm	0.76	0.79
	epm %	2.96	2.85
<b>Sum of Cations</b>	ppm	509.5	550.5
	epm	25.7	27.9
	epm %	100	100
<b>SO<sub>4</sub><sup>2-</sup></b>	ppm	692.45	775.6
	epm	14.43	16.16
	epm %	67.29	68.66
<b>Cl<sup>-</sup></b>	ppm	158.78	167
	epm	4.41	4.64
	epm %	20.57	19.71
<b>HCO<sub>3</sub><sup>-</sup></b>	ppm	158.78	167
	epm	2.6	2.74
	epm %	12.14	11.63
<b>CO<sub>3</sub><sup>2-</sup></b>	ppm	0	0
<b>Sum of Anions</b>	ppm	1010	1109.6
	epm	21.44	23.53
	epm %	100	100

Table 2: Minor ions' concentrations, and TU of water samples

Parameter	Unit	Ganau 1	Ganau 2
<b>PO<sub>4</sub><sup>3-</sup></b>	mg/l	0.44	0.3
<b>NO<sub>3</sub><sup>-</sup></b>	mg/l	337.29	286
<b>H<sub>2</sub>S</b>	mg/l	45.6	53.3
<b>Turbidity</b>	NTU	13	16



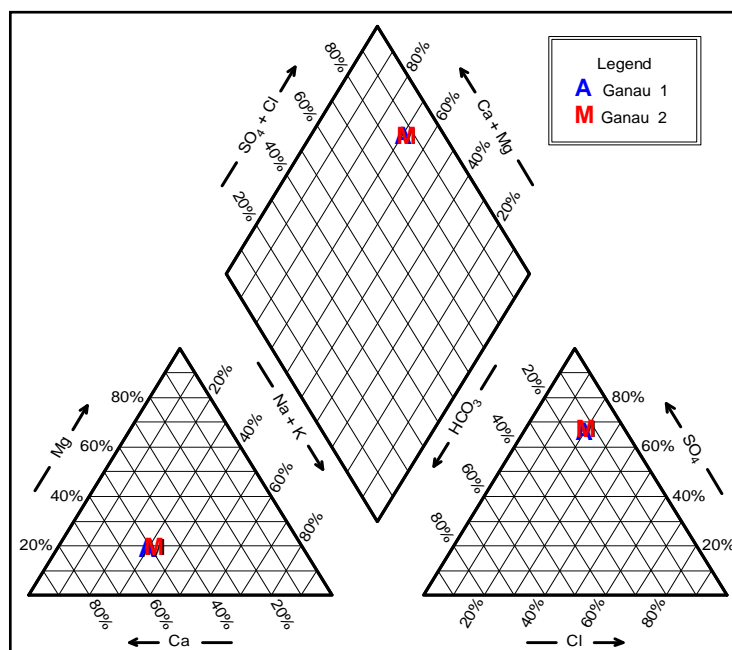


Fig.6: Piper diagram (plot) of the hydrochemical data

#### ■ Isotopic Composition of Spring Waters

The stable isotope results are listed in Table (3) and displayed on a meteoric water plot in Fig. (7). When the data plotted on a bivariate plot ( $\delta^2\text{H}$  vs.  $\delta^{18}\text{O}$ ), the separation between the two samples is very apparent. The water of Ganau 1 falls below the global meteoric water line (GMWL), whereas the water of Ganau 2 falls between the global meteoric water line (GMWL) and the Erbil Meteoric Water Local (EMWL) (Fig.7). Sample of Ganau 1 that is below the GMWL should indicate that the water has underwent significant evaporation due to its larger surface area than others, because due to isotopic kinetic fractionation during water phase change, evaporation results in greater relative enrichment in  $^{18}\text{O}$  than  $^2\text{H}$  in residual water, which alters the  $^2\text{H}$ - $^{18}\text{O}$  relationship (Mckenzie *et al.*, 2010).

From the isotopic data, it is concluded that the recharge of the aquifer is a diffused recharge, because the groundwater that is recharged by diffusion recharge is more enriched in stable isotopes than that which is recharged directly (Kebede *et al.*, 2008).

Table 3: Environmental isotopes data of Ganau Spring

Name	Coordinate		Elevation (m)	T (°C)	EC (μS/cm)	$^{18}\text{O}$ (‰)	$^2\text{H}$ (‰)	D-excess (‰)	$^3\text{H}$
	Lat.	Long.							
Ganau 1	36° 12' 42"	44° 56' 35"	510	23.2	2396	-5.61	-36.72	8.16	<0.6
Ganau 2	36° 12' 46"	44° 56' 21"	515	22.8	2620	-7.1	-43.55	13.25	—

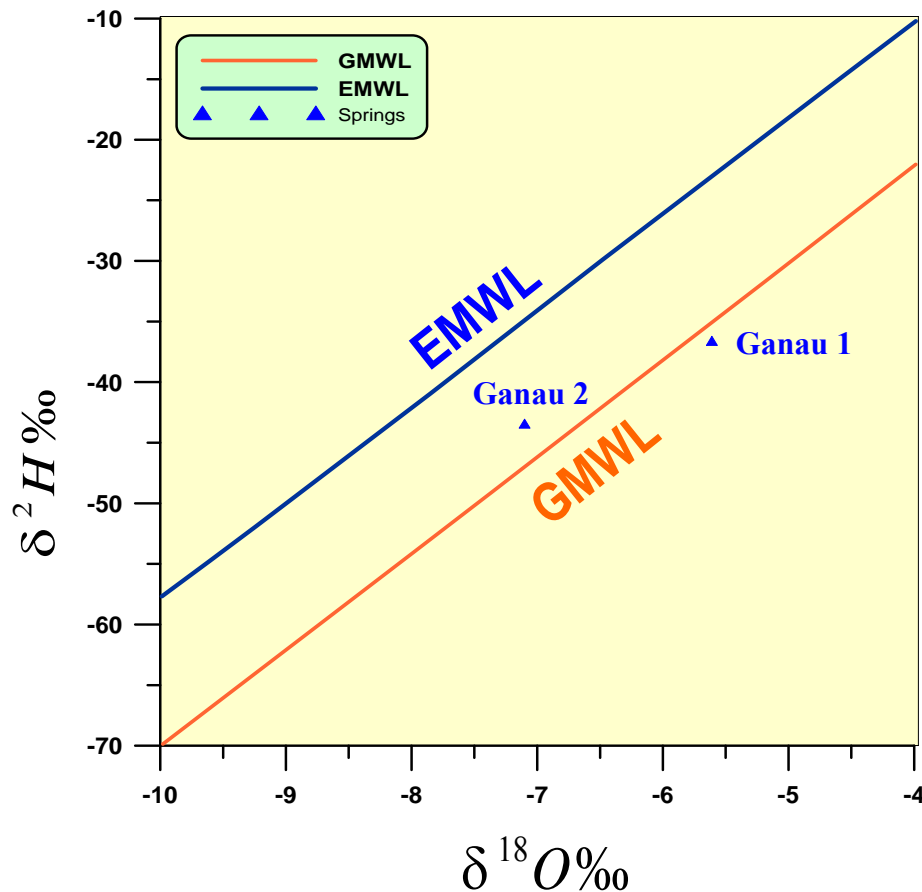


Fig.7: A plot of  $\delta^2\text{H}$  vs.  $\delta^{18}\text{O}$  of the collected water samples with the Global Meteoric Water Line (GMWL) and the Erbil Meteoric Water Local (EMWL) (from Mawlood, 2003)

#### ▪ GPR Interpretation

The approach adopted is to characterize the basin configuration and the possibility of vertical movements along the Jurassic rocks. Furthermore, the influence of these variations could be mapped using Ground Penetrating Radar (GPR) in order to examine any subsidence in the area beneath the lake. The high attenuation ratio of the GPR signals were recorded due to high conductivity of the lake water, so the reflection signal from the basin of the lake is very weak; as shown in Fig. (8). Nevertheless, two locations of discontinuity of the signals were identified, which represent locations of faults subjected to the flanks of the lake basin. A simple assumption, from the structural point of view is adopted, which is a relative subsidence within the lake basin, it might resulted in the existence of the lake in the area. The fault planes act as a convenient zone for flowing water from deeper aquifers to the surface.

**Profile-1** runs NE – SW, it is characterized by the existence of two faults identified on flanks of the floor of the lake (Fig.8), at a horizontal distance 45 m and 310 m (from NE), respectively. The greatest depth of the basin detected equals to 22.5 m, it occurs at a horizontal distance of about 220 m (Fig.8).

**Profile-2** runs NW – SE, the interpretation of this profile shows steep slope of the basin near the two banks of the lake. The deepest detected point of the basin equals to 24 m at horizontal distance of 150 m (Fig.9).

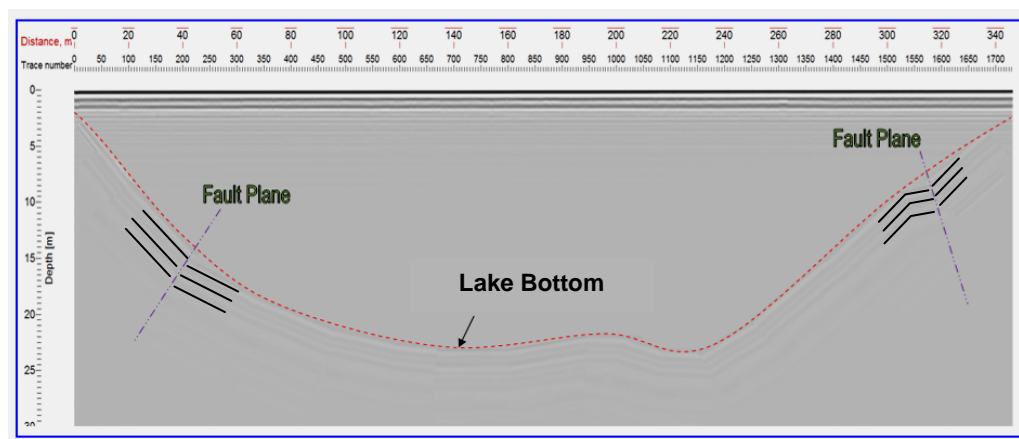


Fig.8: Interpretation of Profile-1, showing the configuration of the Lake Basin in the NE – SW direction

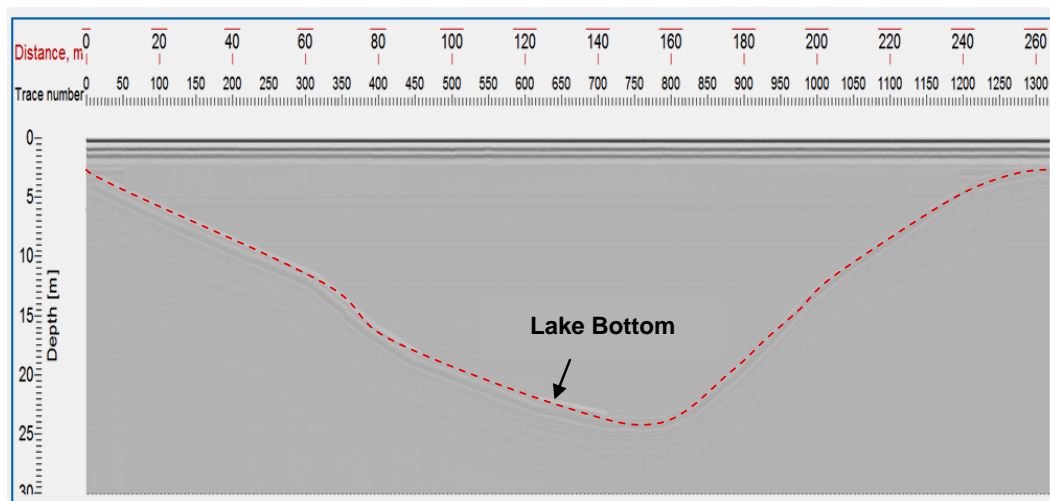


Fig.9: Interpretation of Profile-2, showing the configuration of the Lake Basin in the NW – SE direction

#### ▪ VES Interpretation

The sounding points were interpreted by using IPI2 win software (IPI2 win, 2004); they reveal the existence of five layers. The first layer of the VES-1 (Fig.10), is a top soil surface, has resistivity equals to 16.2 Ohm.m and thickness of about 0.8 m, it is composed of clay with silty clay. The second layer shows higher resistivity (57.6 Ohm.m); due to increase of coarse materials; it has a thickness of 4.4 m. The third layer is composed of clay and has resistivity equals to 12.5 Ohm.m and thickness of about 83.8 m; in the location of the sounding 1, and 55.4 m in the location of the sounding 2. The fourth layer has thickness of 74 m and higher resistivity; due to increase of more coarse materials, such as silt and gravel. The last layer shows high resistivity of 82.4 Ohm.m, most probably it represents saturated limestone of Jurassic age.

The VES-2 (Fig.11) shows the same trend, except the larger resistivity of the first and second layers; due to appearance of recent Calc-Rock at the surface of the area. The first layer shows resistivity equals to 100 Ohm.m, while the second layer has a higher resistivity of 347 Ohm.m.

A geo-electrical section was drawn between VES-1 and VES-2 (Fig.12). The fault plane is detected at the same location that appears on the GPR section (Profile-1, Fig.8), the fault plane extends to the Upper Jurassic limestone that make a suitable path for following brine water to the lake. The detected throw is about 30 m, in the limestone, while this amount decreases towards the surface due to the friable property of the recent sediments.

On the bases of the results obtained from both GPR and 1D resistivity surveys, a schematic geological model is drawn for the area of the lake and it's surrounding. Figure (13) shows the movements of hydrogen sulphide rich and fresh water from Upper Jurassic limestone and recent sediments through the planes of the faults following to the surface.

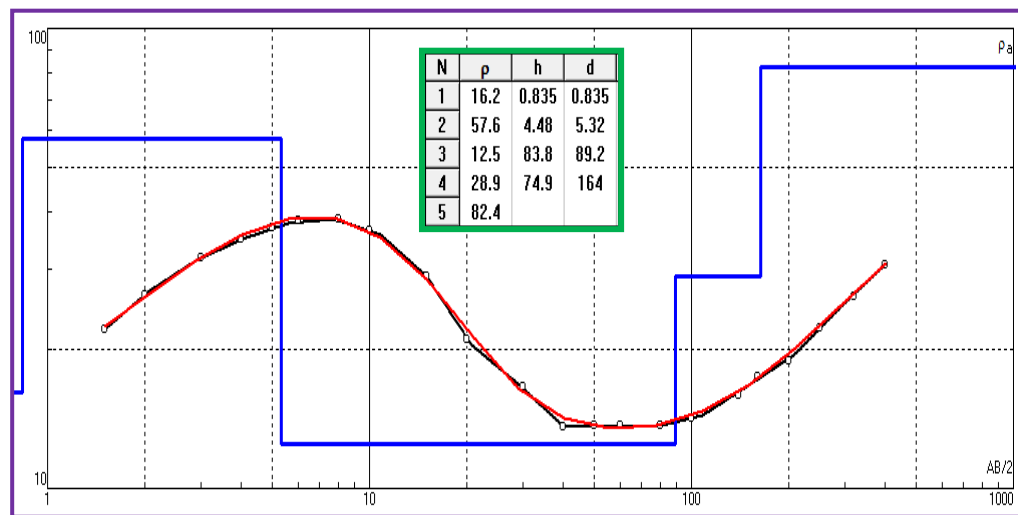


Fig.10: Interpretation of VES-1

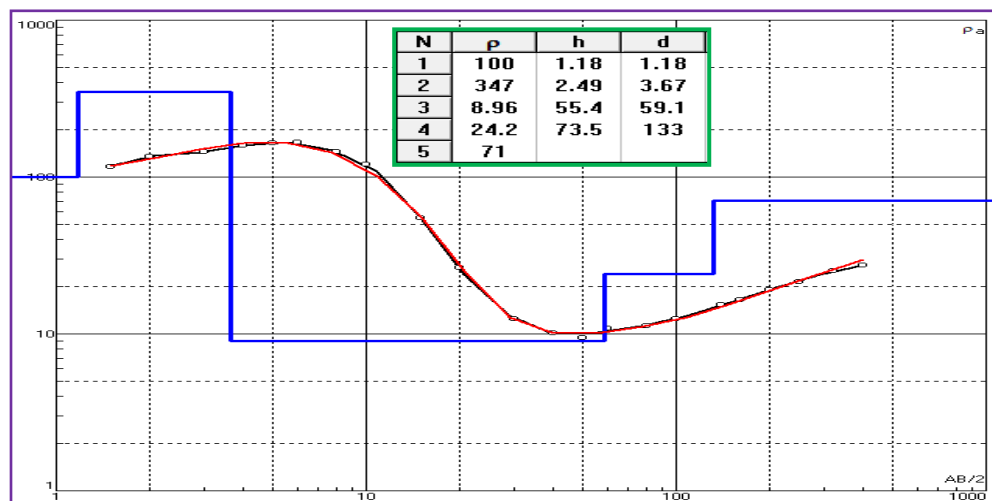


Fig.11: Interpretation of VES-2

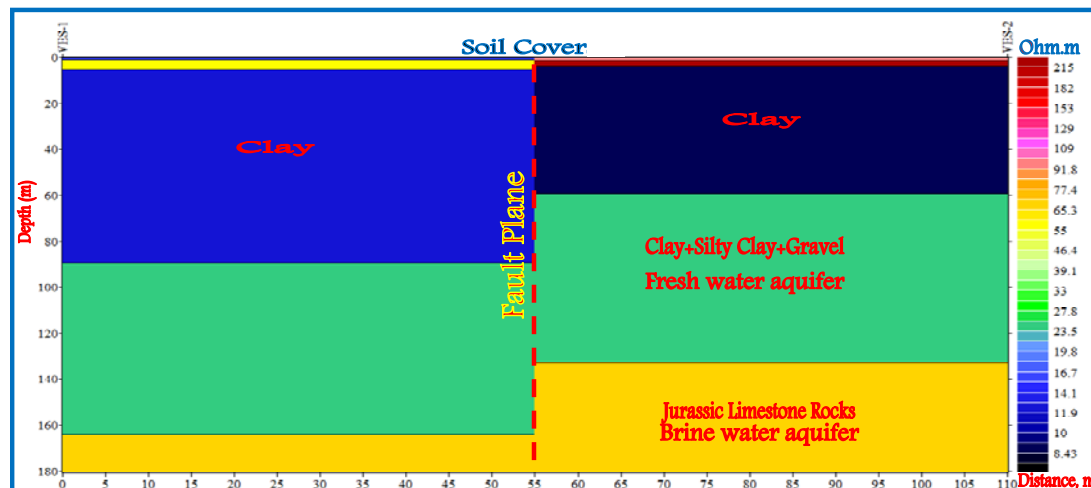


Fig.12: Schematic geological model based on geoelectrical sections of VES-1 and VES-2

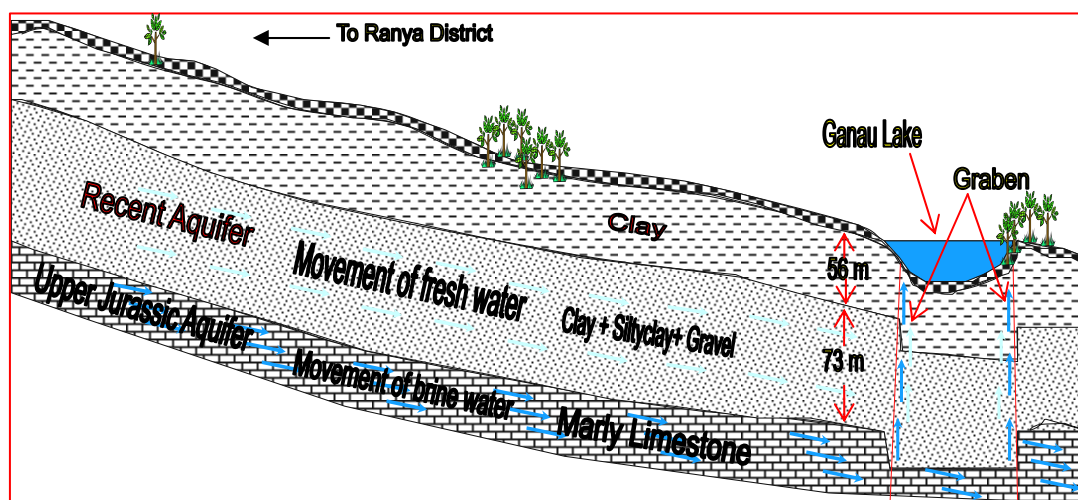


Fig.13: Schematic predictable geological model of the study area; as inferred from the geophysical and geological investigation, interpretation and discussion

## CONCLUSIONS

The following conclusions are acquired in this study:

- $\text{Ca}^{2+}$  and  $\text{SO}_4^{2-}$  are the dominant ions; the second species in abundance are  $\text{Na}^+$  for cations and  $\text{Cl}^-$  for anions. The relatively high content of  $\text{Ca}^{2+}$ ,  $\text{SO}_4^{2-}$  and  $\text{Cl}^-$  is expected to be issued from either bituminous layers of Jurassic rocks or the evaporates of deeper Triassic rocks. When the water samples are plotted on the Piper diagram all samples lay in the field number six, which means that the secondary salinity (non-carbonate hardness) exceeds 50%, and the water type is  $\text{Ca} - \text{SO}_4$ .
- The tritium value indicates that the spring water is modern.
- When the data is plotted on a bivariate plot ( $\delta^2\text{H}$  vs.  $\delta^{18}\text{O}$ ), the separation between the two samples is very apparent.
- Ganau 1 sample that is located below the GMWL indicates that the water has underwent significant evaporation due to its larger surface area; than others.
- From the isotopic data, it is concluded that the recharge of the aquifer is a diffuse recharge.



- The depth of the basin of the lake is obtained from GPR survey. It approaches 24 m at the center. In addition, the GPR sections show the existence of two faults at horizontal distances of 45 m and 310 m from NE, respectively.
- Thick Recent sediments (130 m) are detected. They cover Jurassic limestone. They are composed of two main layers, the first has low resistivity and represents pure clay, and it has a thickness of about 83.8 m in the location of the sounding 1, and 55.4 m in the location of the sounding 2. The second layer is composed of clay, silty clay and gravels, and has a thickness of about 74 m. It forms the main aquifer of fresh water.
- The upper surface of Jurassic limestone is detected at depth of about 133 m. The low resistivity of these rocks denotes the existence of brine water.
- The 1D resistivity survey emphasized the location of the faults and shows the extension of these faults to the deeper part beneath the lake; as a result the origin of the lake is due to a detected graben within the Upper Jurassic limestone. The maximum detected throw of the faults is about 30 m.
- Both brine and fresh water is flowing through the fault planes to the lake; due to the semi confined property of the aquifers in the area. The fresh water, which comes from Quaternary aquifer has great role in diluting brine water; continuously in the lake.

## **REFERENCES**

- Al-Janabi, Y., Al-Sa'adi, N., Zainal, Y., Al-Bassam, K. and Al-Delaimy, M., 1992. GEOSURV Work Procedures, Part 21: Chemical Laboratories. GEOSURV, int. rep. no. 2002.
- Al-Manmi, D.A.M., 2008. Water Resources Management in Rania Area, Sulaimaniyah, NE Iraq, Unpub. Ph.D. Thesis, College of Science, University of Baghdad, 225pp.
- Annan, A.P., 2001. Ground Penetrating Radar Workshop notes, Sensors and Software INC., 1091 Brevic Place, Mississauga, Ontario-L4W, 3R7-Canada, 192pp.
- APHA, 1998. Standard Methods of the Examination of Water and Wastewater, 20<sup>th</sup> edit. Washington D.C., American Public Health Association.
- Buday, T., 1980. The Regional Geology of Iraq, Vol. I, Stratigraphy and Paleogeography. In: I.I.M., Kassab and S.Z., Jassim (Eds.). GEOSURV, Baghdad, Iraq, 445pp.
- Buday, T. and Jassim, S.Z., 1987. The Regional Geology of Iraq, Vol.II, Tectonism, Magmatism and Metamorphism. In: I.I., Kassab and M.J., Abbas (Eds.). GEOSURV, Baghdad, Iraq, 352pp.
- Clark, I. and Fritz, P., 1997. Environmental Isotopes in Hydrology. Lewis Publishers, New York, 328pp.
- Coleman, M.L., Shepherd, T.J., Durham, J.J., Rouse, J. and Moore, G.R., 1982. Reduction of water with zinc for hydrogen isotope analysis. Anal. Chem., Vol.54, p. 993 – 995.
- Craig, H., 1961. Isotopic variations in meteoric waters. Science, Vol.133, p. 1702 – 1703.
- Doney, S.C., Glover, D.M. and Jenkins, W.J., 1992. A model function of the global bomb tritium distribution in precipitation. Jour. Geophys. Res., Vol.97, p. 5481 – 5492.
- Drever, J.I., 1997. The Geochemistry of Natural Waters: Surface and Groundwater Environments, 3<sup>rd</sup> edit. Prentice Hall, Englewood Cliffs, NJ.
- Eggenkamp, H.G.M., 1994. The geochemistry of chlorine isotopes. Ph.D. Thesis, Utrecht University, the Netherlands, 234pp.
- Epstein, S. and Mayeda, T.K., 1953. Variations of the <sup>18</sup>O/<sup>16</sup>O ratio in natural waters. Geochim. Cosmochim. Acta., Vol.50, p. 1561 – 1563.
- Geo-Sense., 2007. Ground Penetrating Radar (GPR), Environmental and Engineering Geophysical Center. [www.geo-sense.com](http://www.geo-sense.com).
- Guay, B., Eastoe, C. and Austin, L.B., 2006. Identifying Sources of Groundwater in the Lower Colorado River Valley, USA, with  $\delta^{18}\text{O}$ ,  $\delta\text{D}$  and  $^3\text{H}$ : Implications for river water accounting. Hydrogeology Jour., Vol.14, p. 146 – 158.
- IAEA/WMO, 2007. Global network of isotopes in precipitation. In: The GNIP Database. <http://isohis.iaea.org>. Cited, November 2007.
- IPi2win, 2004. ID Interpretation of VES Profile, user manual for 1D automatic and manual interpretation of field curves. Moscow State University, Russia.
- Jassim, S.Z. and Goff, J.C. (Eds.), 2006. Geology of Iraq. Dolin, Prague and Moravian Museum, Brno. 341pp.

- Jawad, S.B., 2008. Toward a National Groundwater Monitoring Network. Proceeding from the first conference on Environmental Challenges in Iraq. Iraq, Sulaimaniyah, 11-12/1/2008.
- Karim, K.H., Khanaqa, P.A. and Ameen, B.M., 2010. Types of Recent Microbailite in Slightly Acidic Spring in Ranyia area, Kurdistan, NE Iraq. *Iraqi Bull. Geol. Min.*, Vol.7, No.2, p. 27 – 40.
- Kebede, S., Travi, Y. and Asrat, A., 2008. Groundwater origin and flow along selected transects in Ethiopian Rift Volcanic Aquifers. *Hydrogeology Jour.*, Vol.16, p. 55 – 73.
- Knowles, L.J., Katz, B.G. and Toth, D.J., 2010. Using multiple chemical indicators to characterize and determine the age of groundwater from selected vents of the Silver Springs Group, Central Florida, USA. *Hydrogeology Jour.*, Vol.18, No.5, p. 1825 – 1838.
- Mawlood, D., 2003. Application of isotope hydrology studies considering the specific climate, hydrogeological and geological conditions in order to research underground water resources in a specific area in the Near East. Unpub. Ph.D. Thesis, Vienna University of Technology, 306pp (in German).
- Mckenzie, J.M., Mark, B.G., Thompson, L.G., Schotterer, U. and Lin, P., 2010. A hydrogeochemical survey of Kilimanjaro (Tanzania): Implications for water sources and ages. *Hydrogeology Jour.*, Vol.18, No.4, p. 985 – 995.
- Piper, A., 1944. A graphic procedure in the geochemical interpretation of water analysis. *Trans. Am. Geophys. Union.*, 25, p. 914 – 928.
- Shakur, M.A., 1982.  $\delta^{34}\text{S}$  and  $\delta^{18}\text{O}$  variations in terrestrial sulfates. Ph.D. Thesis, Univ. Calgary, Canada, 195pp.
- Sissakian, V.K., 2000. Geological Map of Iraq, sheet No.1, scale 1: 1000000, 3<sup>rd</sup> edit. GEOSURV, Baghdad, Iraq.
- Taylor, C.B., 1977. Tritium enrichment of environmental waters by electrolysis: Development of cathodes exhibiting high isotopic separation and precise measurement of tritium enrichment factors. In: *Proc. of the Int. Conf. of Low-Radioactivity Measurements and Applications*. Slovenski Pedagogicke Nakladatelstvo, Bratislava, Slovakia, p. 131 – 140.
- Yanagisawa, F. and Sakai, H., 1983. Thermal decomposition of barium sulfate vanadium pentaoxide silica glass mixtures for preparation of sulfur-dioxide in sulfur isotope ratio measurements. *Anal. Chem.*, Vol.55, p. 985 – 987.
- Zuber, A., Michalczyk, Z. and Maloszewski, P., 2001. Great tritium ages explain the occurrence of good-quality groundwater in a phreatic aquifer of an urban area, Lublin, Poland. *Hydrogeology Jour.*, Vol.9, p. 451 – 460.

**About the authors**

**Dr. Salahalddin S. Ali** graduated from Sulaimani University in 1982 with B.Sc. degree in Geology, and M.Sc. in Engineering Geology in 1987 from Mosul University, and Ph.D. degree in Hydrogeology from Belgrade University, Serbia in 2007. Currently, he is the Dean of School of Sciences, Sulaimani University. His major fields of interest are hydrogeology and engineering geology.

**e-mail:** Salahsulus@yahoo.com

salahalddin.ali@univsul.net

**Mailing address:** 211 Tooe Maleek, 67 Av., House No.4, Sulaimani



**Dr. Bakhtiar Q. Aziz** graduated from University of Salahaddin in 1983 with B.Sc. degree, and M.Sc. in Geophysics in 1986 from Mosul University, and Ph.D. in 2004 in Geophysics from Sulaimani University. Currently, he is working as Assistant Professor in Sulaimani University, School of Science, Geology Department. He has 13 published articles in geophysics. His major field of interest is geophysics.

**e-mail:** bakhtiar\_61@yahoo.com

**Mailing address:** Iraq, Sulaimaniyah, Sulaimani University, School of Science, Geology Department



**Dr. Diary Ali M.A. Al-Manmi** graduated from University of Baghdad in 1989 with B.Sc. degree in Geology, and M.Sc. in Hydrogeology in 1989, and Ph.D. degree in Water Resources from University of Baghdad in 2008. Currently, he is working as Lecturer in Sulaimani University, School of Science, Geology Department. He has 6 published articles and 6 others are under press. His major fields of interest are hydrogeology and environmental pollution.

**e-mail:** diary.amin@univsul.net

adiary22@gmail.com

**Mailing address:** Sulaimaniyah, Grdy Sarchinar, Mashkhalan-123, street 91, House No.16

