

## HYDROCHEMICAL STUDY OF SOURCES SALINITY IN SHALLOW WATER SPRINGS OF NORTHERN ALGERIAN SAHARA

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Received: 19 February 2019 / Accepted: 26 December 2019 / Published online: 01 January 2020

### ABSTRACT

This study is conducted in The Guerrara Oasis; suffer from high salinity of alluvial aquifer used in drinking and irrigation, the distribution of the drilled wells in the study area is anarchic and water salinity is a subsisting problem all along the year,

To evaluate the problem gravity two hydrochemical campaigns are acquired during wet and dry seasons , the results confirms the presence of saliferous bodies affecting water quality,

The order of abundance of the ions in the ground water samples is  $Cl^- > Na^+ > SO_4^{2-} > Mg^{2+} > Ca^{2+} > HCO_3^- > K^+$  the piper diagram reveals that's the ground water is  $Cl^- - SO_4^{2-}$  and mixed  $Cl^- - Na^+$  indicating a evaporitic hydro-chemical type, Multiariate statistics and special geochemistry diagrams are used to evaluate the chemical process responsible in groundwater salinization.

**Keywords:** drinking; irrigation; hydrochemical; piper diagram; multiariat statistics

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doi: <http://dx.doi.org/10.4314/jfas.v12i1.19>



## 1. INTRODUCTION

The Algerian Sahara desert contains the most important water aquifers, known as terminal complex and continental intercalary deep aquifer, the variability in climate changes affect directly water resources potentialities, the medeteranian countries are the most vulnerable for water stress, the increasing in water demand for fresh water implies a global strategie for water quality preservation.

The alluvium aquifer in Algerian Sahara presents a potential resource for drinking and irrigation purpose, groundwater quality data gives important clues to the geologic history of rock and indication of ground water recharge, discharge and storage [1].

Variation in ground water quality depends on physical and chemical parameters influenced generally by the geological formation and pollution hazard.

According to Babiker et al [2], the chemistry of ground water is not only dependant of geological conditions but also reflects atmospheric inputs and soil weathering effects as well as from pollutant sources (mining industry, Marine intrusion, excessive pumping.....)

Several researchers have developed various indices to evaluate the geochemical process controlling the variance in water quality. Such as sodium adsorption ratio (SAR), Sodium Percentage (Na%) , Magnesium ratio (MAR), Permeability index (PI), Total hardness (TH), Saturation index (SI), Kelly ratio (KR) and Residual sodium bicarbonate (RSBC).

The cited indices were proposed to provide useful and comprehensing guiding tool for water quality evaluation and enverimental management. Water uses standards regulated by world health organisation [3] and united states salinity laboratory (USSL).

Guerrara area is located in northen algerian Sahara (Fig.1) and is considered as an actif metropolitan in agricultural and animal production, For this reason the water quality assesment is a capital action to preserve social and economic activty sectors, due to its bed quality and source contamination the population use ugualy groundwater ressourcees of deep aquiers ,the interaction between the aquiers have not been throughly studied yet and the risk of the contamination of these deep aquiers is present.

The objective of this study is to asses the alluvium water quality and to determine the suitability of the aquifer for various purposes on the basis of different geochemical indices,

Consequently this study serve as areerence base to evaluate the rate o chngement in shallow and deep water ressources

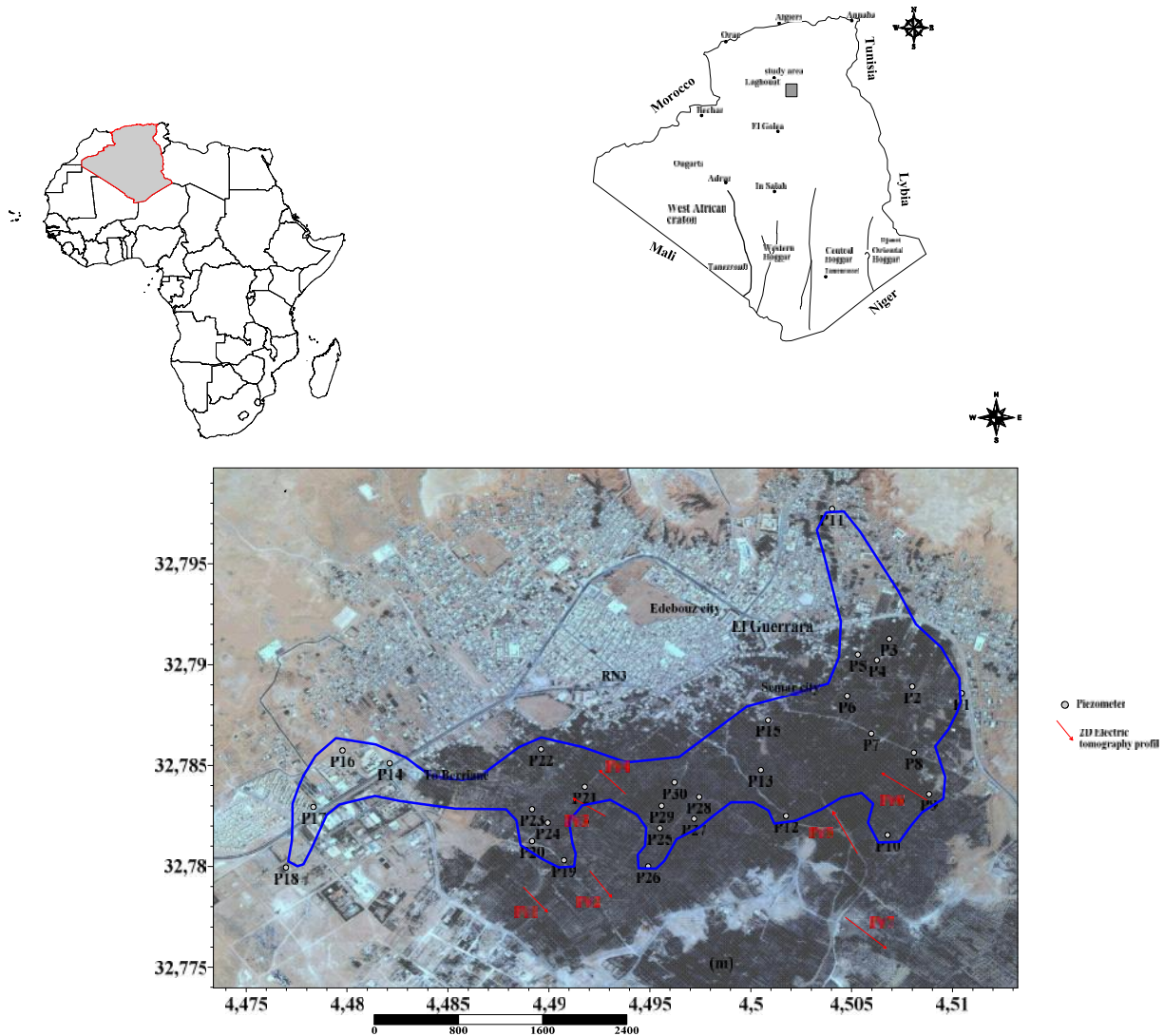


Fig.1. Geographic location of the study area

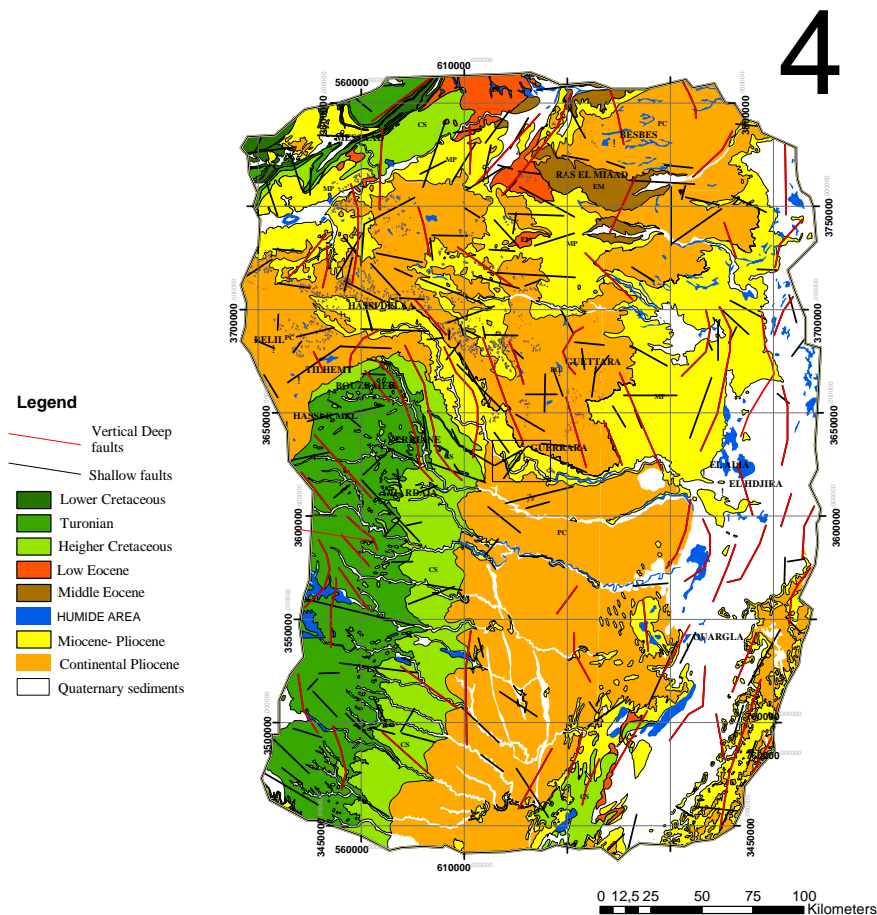
**1.1. Geologic and Hydrogeologic settings**

The study area is located in Ghardaia district between 32,775° and 32,795° North Latitudes and 4,45° and 4,51° East Longitudes covering 42 km<sup>2</sup> (Fig,1) the area is classed as Saharian arid environment with a avearge rainfall of 35mm/y recived during the winter period, The area is characterized by moderate terrain physiography with moderate dissected valleys with both structural and denudational origin; the average altitude is 280-395m above mean sea level.

The drainage is provided by Oued Zegrir along a sandstone plateau, the lower part of the study area is composed by sedimentary rocks resulting from wind and water denudation activity during the Mio-Pliocene period,

The Mzab plateau is affected by compressive movement oriented NW-SE during the Mesozoic-Cenozoic tectonic activity, the atlasic orogeny affecting the North Sahara basement is the principal reason of the apparition of Mzab Mountains and Tadmait depression and the Neogene-Quaternary filling [4].

The geology of the study area comprises Mio-Pliocene sandstones affected by NE-SW, NW-SE faults and fractures creating a large depression composed of alternation between fine sand and silt sandy formation (Fig.2),

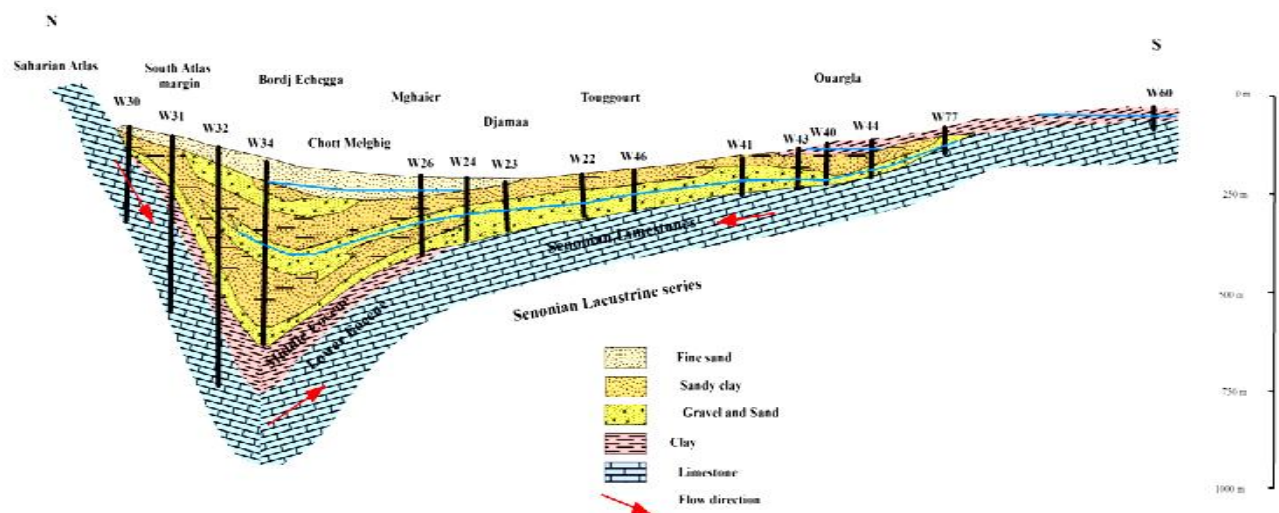


**Fig.2.** Geologic map of the study area

The middle Eocene is formed by gypsum and salty formations however low Eocene is undefined and it is often confused with Senonian limestone.

The hydrogeology within the study area is based on geological materials and the ground water is derived from alteration or fractures, The quaternary aquifer associated with alluvial deposits and weathering crust collecting Oued Zegrir water and supply the water dam named Ahabas in the local language,

The sandstone aquifer is thick and represent an important water resource in the region, the limestone aquifer attributed to the Eocene-Senonian age are composed of fractured and karstic formation, thses three shallow aquifers represents the complex terminal aquifer (CT) while the deepest and the most productive is located at 1000m and is attributed to Albian-Aptian sand (Fig,3) named continental intercalaire (CI).



**Fig.3.** Hydrogeologic cross section of the Algerian Sahara oriented N-S

## 2. METHODS

In order to reach the goal of this study the ground water samples are collected to cover all the area, hence fifty four water samples (54) were collected from shallow traditional boreholes, Two sampling campaigns were conducted (January-July 2013) in both dry and wet seasons the collected water was passed through 0,45 mm membrane filter and stored in 1,5 L polyethylene bottles,

The major cation  $\text{Na}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  and  $\text{K}^+$  were analyzed using 410 Corning flame photometer, the anion concentration  $\text{Cl}^-$ ,  $\text{HCO}_3^-$  and  $\text{SO}_4^-$  were measured using DR2000 (HACH) spectrophotometer, the total hardness were measured using titration method by EDTA

(Ethylene diaminetetracetic acid), the electric conductivity is measured in situ using conductivity meter type CD 4301,

The charge balance error was used to check analysis accuracy, which is calculated for each well using the equation below, the errors were within the limited tolerances  $\pm 5\%$  [5].

$$\%CBE = \frac{meq(cations) - meq(anions)}{meq(cations) + meq(anions)} \times 100$$

### 3. RESULTS AND DISCUSSION

#### 3.1. Hydrochemical classification

The geochemical features of the alluvium aquifer are defined through piper triangular diagram (Fig.4), according to the diagram 14 wells of the study area are classed as Cl-SO<sub>4</sub>-K (Na) type and 17 are classed in Cl-SO<sub>4</sub>-Ca (Mg) type, it was found that Alkali metals such as Na<sup>+</sup>, K<sup>+</sup> were more dominant than Alkaline earth metals such as Mg<sup>2+</sup> and Ca<sup>2+</sup>, and that anions Cl<sup>-</sup> and SO<sub>4</sub><sup>2-</sup> were more dominant than HCO<sub>3</sub><sup>-</sup> and CO<sub>3</sub><sup>-</sup>.

The hydrochemical facies is characterized by the dominance of evaporites minerals resulting from evaporation-precipitation actions during dry and wet seasons; this is in concordance with the climatic condition of saharian arid climat.

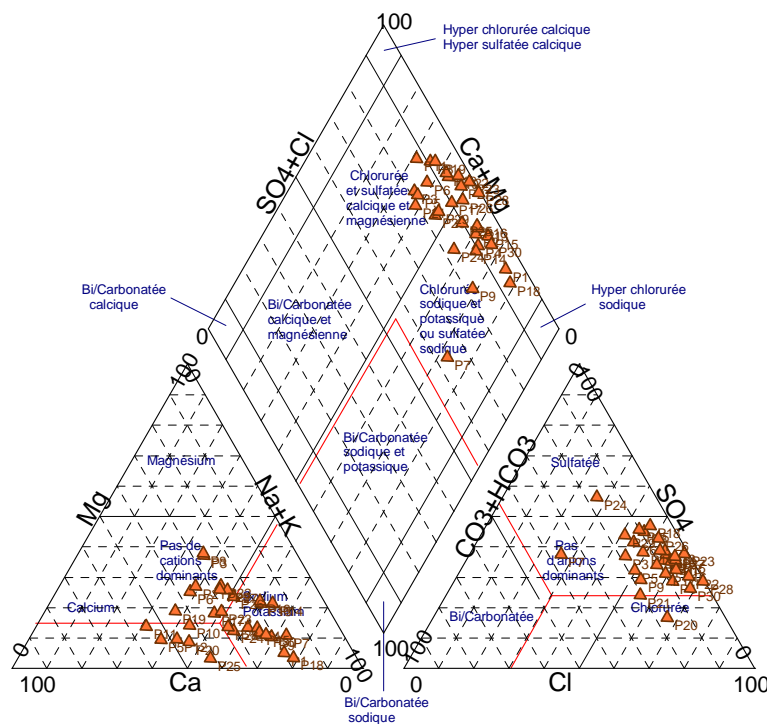
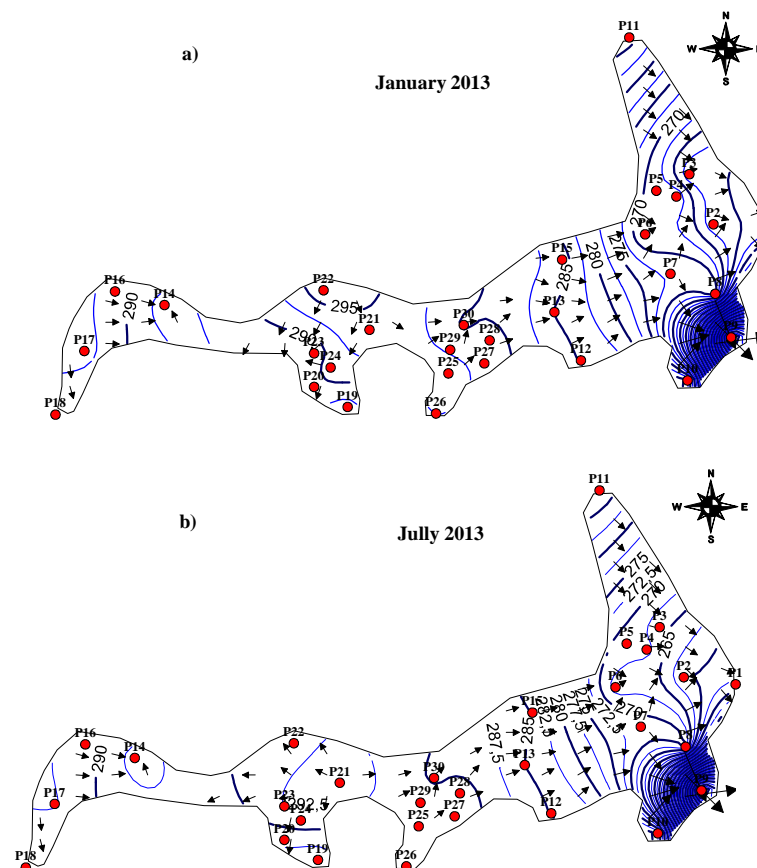


Fig.4. Piper diagram

### 3.2. Geochemical study of water samples

The results of the chemical analysis of water samples are summarized in table 1, the Electric conductivity values ranges between 2250 and 18960 $\mu$ s/cm with mean concentration value of 7565.9 $\mu$ s/cm, The TDS concentration in the study area varies from 1507.5 to 12703mg/l with a mean value of 5069mg/l, the total hardness concentration are between 59.7 and 540mg/l with a mean value of 205,8mg/l.

Generally the groundwater level has the same orientation in wet and dry seasons with slight variation, the piezometric level ranges between 3.25-25.5 m in January and ranges between 4.3-27.3 m in jully, the variation is due to the severe variations in temperatures during the two seasons and the connectios level between the well (Fig.5).



**Fig.5.** Piezometric level of Guerrara alluvium water table

**a)** Water level and flow direction in wet season (January 2013), **b)** direction flow and water level in dry season (July 2013)

**Table 1** Hydro-chemical results of the second Campaign in July 2013 (meq/l)

<b>Label</b>	<b>EC</b> ( $\mu\text{s/cm}$ )	<b>TDS</b> ( $\text{mg/l}$ )	<b>TH</b> ( $\text{mg/l}$ )	<b>Ca<sup>2+</sup></b>	<b>Mg<sup>2+</sup></b>	<b>Na<sup>+</sup></b>	<b>K<sup>+</sup></b>	<b>HCO<sub>3</sub></b>	<b>SO<sub>4</sub><sup>2-</sup></b>	<b>Cl<sup>-</sup></b>
<b>P1</b>	8790	5889,3	227,3	28,80	16,67	43,48	1,28	6,18	31,25	47,86
<b>P2</b>	4470	2949,9	80	10,40	5,60	32,61	0,67	4,52	18,75	30,99
<b>P3</b>	3300	2211	96	10,40	8,80	13,04	0,72	3,87	13,54	15,21
<b>P4</b>	6450	4321,5	139,6	19,60	8,32	34,78	0,97	5,36	21,88	36,62
<b>P5</b>	2250	1507,5	71	9,40	4,80	8,70	0,97	4,85	8,75	12,68
<b>P6</b>	3180	2130,6	81,9	9,20	9,17	13,04	0,82	3,62	13,54	15,79
<b>P7</b>	4360	2921,2	59,7	7,03	4,92	26,09	0,72	12,30	17,71	12,45
<b>P8</b>	4560	3055,2	156,1	12,48	18,75	17,39	0,67	3,79	22,92	27,49
<b>P9</b>	12700	8509	350	24,00	46,00	52,17	0,72	15,74	38,54	80,56
<b>P10</b>	10480	7021,6	125	15,00	10,00	60,87	1,18	2,72	64,20	17,38
<b>P11</b>	5080	3403,6	154	20,80	10,00	17,39	1,13	7,05	20,83	26,76
<b>P12</b>	11120	7450,4	339,5	50,40	17,50	43,48	0,82	6,93	43,75	63,15
<b>P13</b>	15510	10391,7	433,3	20,00	66,67	69,57	0,77	7,79	51,46	87,46
<b>P14</b>	7640	5118,8	220	18,40	25,60	43,48	0,77	5,36	31,25	44,25
<b>P15</b>	12160	8147,2	330,4	47,70	18,38	43,48	1,85	1,64	51,67	69,58
<b>P16</b>	18960	12703,2	455,8	49,83	41,33	69,57	1,54	11,08	58,33	87,89
<b>P17</b>	3790	2539,3	108,2	13,46	8,18	17,39	0,77	6,59	12,50	23,49
<b>P18</b>	16040	10746,8	540	31,00	77,00	52,17	1,79	7,82	34,24	126,7
<b>P19</b>	3990	2673,3	144	8,80	20,00	10,87	0,56	3,62	16,67	17,21
<b>P20</b>	3070	2056,9	71	8,00	6,20	15,22	0,87	3,13	12,50	13,35
<b>P21</b>	6280	4207,6	200	16,80	23,20	17,39	2,15	3,89	20,42	30,99
<b>P22</b>	8140	5453,8	217	28,40	15,00	34,78	3,23	2,05	33,33	49,46
<b>P23</b>	8920	5976,4	200	16,40	23,60	43,48	1,79	1,23	38,52	53,11
<b>P24</b>	3340	2237,8	103	15,20	5,40	17,39	0,97	4,52	17,12	14,24
<b>P25</b>	3470	2324,9	84,1	11,48	5,33	17,39	0,72	2,80	12,50	18,05
<b>P26</b>	7180	4810,6	194,6	12,53	26,40	34,78	1,33	3,70	27,08	41,04



<b>P27</b>	9050	6063,5	260	20,80	31,20	43,48	1,54	4,11	37,50	54,31
<b>Min</b>	2250	1507,5	59,7	7,03	4,8	8,7	0,56	1,23	8,75	12,45
<b>Max</b>	18960	12703,2	540	50,4	77	69,56	3,23	15,74	64,2	126,7
<b>Average</b>	7565,9	5069,2	205,8	19,86	20,52	33,09	1,16	5,42	28,55	41,41

The high values of electric conductivity in ground water indicate the presence of salt or dissolved matter, more than 96% of water samples are Unsuitable according to the electric conductivity classification of Richards [6].

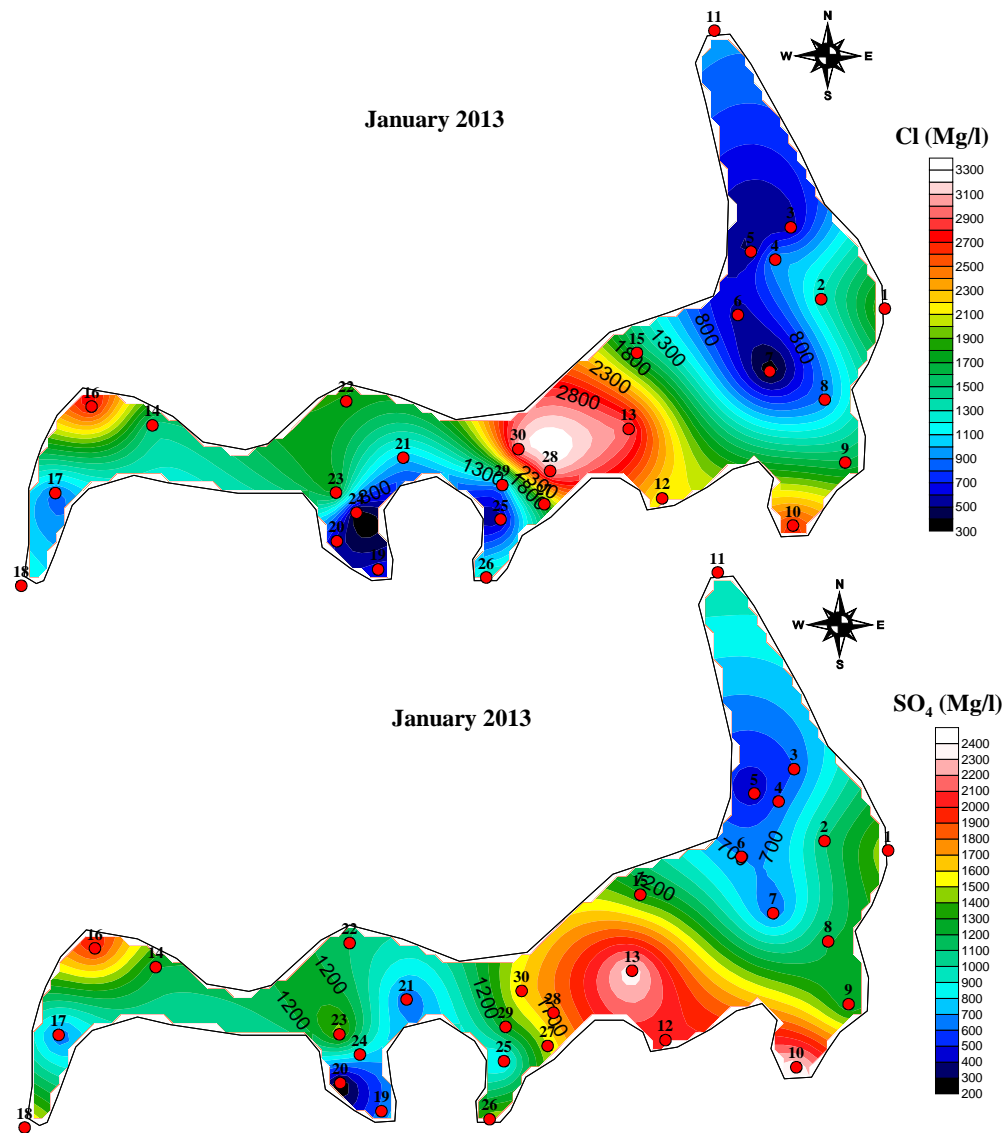
The total dissolved solid content represents the total amounts of inorganic substances mainly salt [7], The ground water of the study area has been classified based on TDS according to the US Environmental Agency [8] procedure and it is clear that 37% of ground water samples are slightly saline, more than 50% are moderately saline and 11% are classed as highly saline.

The ground water hardness (TH) is controlled by calcium and magnesium ions produced generally by the dissolution of carbonated rocks, according to the classification of Sawyer et al [9] the total hardness values in the ground water are classed as Safe for 11%, moderate to hard for 33.33%, Hard for 33.33%, and very hard for 22.34% of the samples.

The chlorides concentration varies between 12.5 and 126.7meq/l with an average value of 41.41meq/l (Fig.6), more than 75% of the analyzed samples exceed the maximum allowable limit of 16.9 meq/l in 21 location, the excess in chlorides concentration is found around all the study area except for the wells P5, P3, P6, P7 and P24 proving the presence of salt bodies in the alluvium and quaternary sediments, the use of fertilizers in agricultural activities can justified these excess, generally the excess of chlorides in water is usually taken as indicator of pollution and ground water contamination.

The excess in sulfates concentration react likely with human organs and can causes a laxative effect if the concentration exceed the allowable values 8.33meq/l (400mg/l), the sulfates concentrations from the study area catchment ranged between 8.75 and 64.2meq/l with a average of 28.55 meq/l (Fig.6), according to BIS [10] and WHO [11] classifications all the samples exceed the allowable concentration thus indicate that the ground water in the study

area is affected by evaporates minerals ( $\text{CaSO}_4$ ).



**Fig.6.** Concentrations of chlorides and sulfates in wet season 2013

The bicarbonates ( $\text{HCO}_3^-$ ) and carbonates ( $\text{CO}_3^{2-}$ ) are the main form of carbonates compounds in groundwater, they results from the alteration of carbonates minerals, the observed values of bicarbonates ranges from 1.23 and 15.74 meq/l with a average value of 5.42 meq/l, the bicarbonates in the study area are probably derived from the upstream hydrogeologic flow crossing Senonian and Turonian formations, composed of Limestone, dolomite gypsum and anhydrite, this excess can also be the result of the weathering of local sandstone formation attributed to Mio-Pliocene age cemented by carbonated and gypsiferous compounds

In natural water resources the sodium is found with lower concentration than calcium and magnesium, the concentration of sodium in water samples ranges from 8.7 to 69.56meq/l with a mean of 33.09meq/l, according to WHO [12] standards the permissible limit is 8.7meq/l (200mg/l), regarding this values more than 95% of the local concentration exceed the standards. Thus the water quality in the study site is not suitable for domestic purposes.

The potassium concentration is quite lower compared with the other chemical elements; the concentration in drinking water seldom reaches 0.51meq/l (20mg/l), during the rainy season the concentration ranges between 0.56 and 3.23meq/l with average value of 1.16meq/l, all the collected samples exceed the permissible limit (0.31meq/l).

The origin of this contamination is the excessive use of the potash fertilizer and the presence of sylvite in the underground geology.

In alluvial aquifers the abundance of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  depend on the petrographic nature of Rocks, the concentration of calcium in Guerrara catchment vary from 7.03 to 50.4meq/l with mean value of 19.86meq/l; more than 80% of the total samples exceed the recommended values (9.98meq/l)

The magnesium concentration in the sampled ground water vary from 4.8 to 77meq/l with a mean of 20.52meq/l, more than 50 % of the sampled water exceed the standards (12.5meq/l)

The geomorphologic characteristics of Guerrara depression is an important factor to understand the geochemical proprieties of shallow aquifers, the study are is a small endoreic basin collecting water resources from Oued zegrir floods, the geochemical process are controlled by the evaporation rates, in dry season the temperature exceed 45°C and water mixing with palm grove and plants enriched the chemical composition of the groundwater, the geochemical cycle of the ground water is controlled by two mechanism the evaporation and the dissolution

The Table 2 exposed the obtained results of correlation between the chemical elements and physical parameters of the ground water.

The correlation is a bivariate method applied to describe the relation between hydrochemical parameters; a high correlation coefficient (near -1 or 1) means a good relationship between two variables, values near 0 means there is no relationship between them..

It is clear that strong positive correlation is established between  $\text{SO}_4^-$ -  $\text{Cl}^-$ ,  $\text{Na}^+$ -  $\text{Cl}^-$ ,  $\text{SO}_4^-$ -  $\text{Na}^+$  and Moderate correlation is observed between  $\text{Cl}^-$ -  $\text{Ca}^{2+}$ ,  $\text{Cl}^-$ -  $\text{Mg}^{2+}$ ,  $\text{SO}_4^-$ -  $\text{Ca}^{2+}$ ,  $\text{SO}_4^-$ -  $\text{Mg}^{2+}$ ,  $\text{HCO}_3^-$ - $\text{Mg}^{2+}$

Low correlation is observed between  $\text{HCO}_3^-$ - $\text{Cl}^-$ ,  $\text{K}^+$ - $\text{Cl}^-$ ,  $\text{HCO}_3^-$ - $\text{SO}_4^-$ ,  $\text{HCO}_3^-$ - $\text{Na}^+$ ,  $\text{HCO}_3^-$ -  $\text{K}^+$ ,  $\text{HCO}_3^-$ - $\text{Ca}^{2+}$ ,  $\text{Na}^+$ - $\text{K}^+$ ,  $\text{Na}^+$ -  $\text{Ca}^{2+}$ ,  $\text{Na}^+$ -  $\text{Mg}^{2+}$ ,  $\text{K}^+$ -  $\text{Ca}^{2+}$ ,  $\text{K}^+$ -  $\text{Mg}^{2+}$ ,  $\text{Ca}^{2+}$ -  $\text{Mg}^{2+}$ .

**Table 2:** Correlation matrix of Physic-chemical parameters of alluvium aquifer in Guerrara

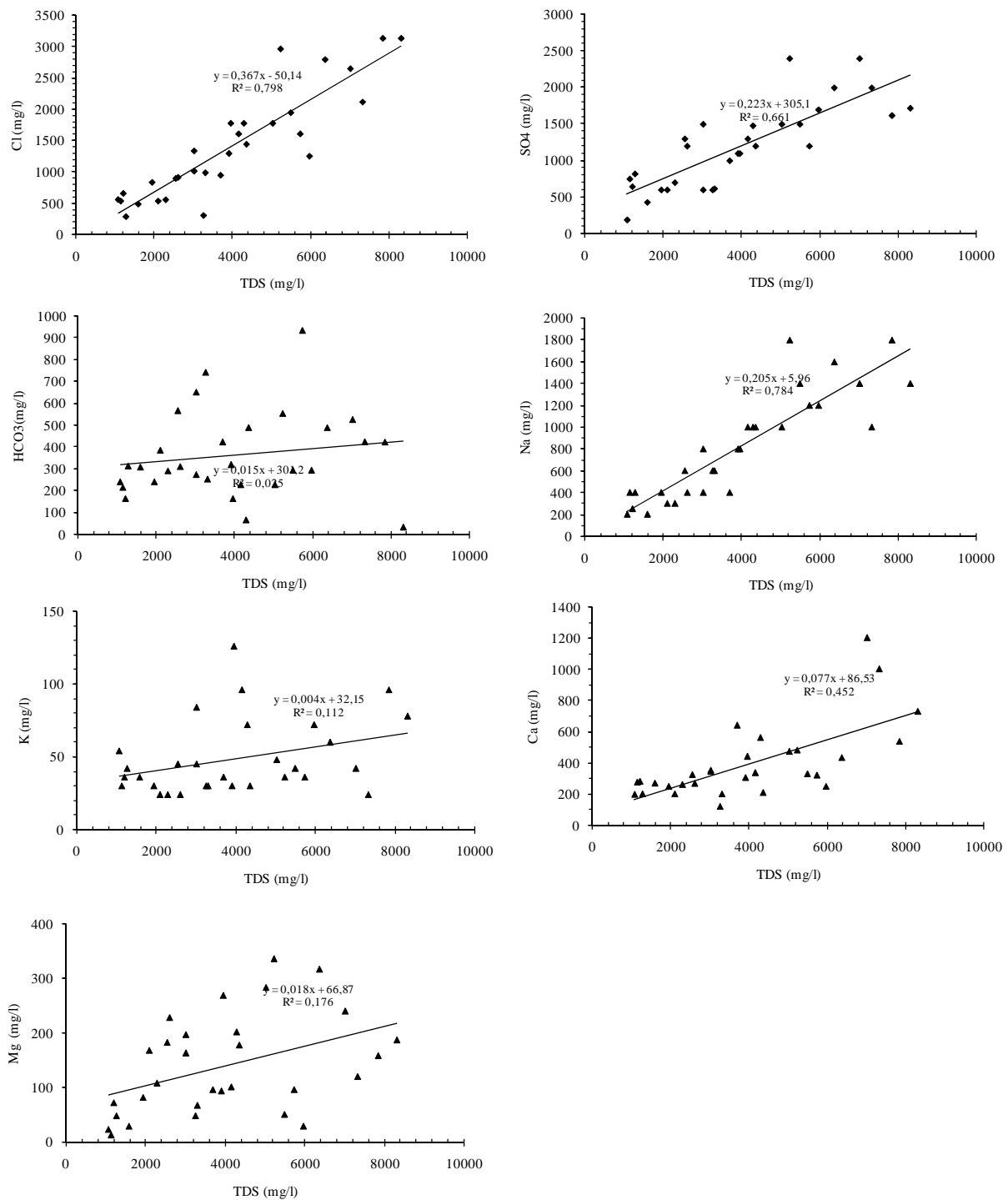
Paralmeters	$\text{Cl}^-$	$\text{SO}_4^-$	$\text{HCO}_3^-$	$\text{Na}^+$	$\text{K}^+$	$\text{Ca}^{2+}$	$\text{Mg}^{2+}$	EC	TH
$\text{Cl}^-$	1								
$\text{SO}_4^-$	0,85	1							
$\text{HCO}_3^-$	0,02	0,10	1						
$\text{Na}^+$	0,92	0,87	0,17	1					
$\text{K}^+$	0,40	0,16	0,23	0,33	1				
$\text{Ca}^{2+}$	0,67	0,70	0,007	0,48	0,14	1			
$\text{Mg}^{2+}$	0,63	0,62	0,67	0,49	0,24	0,42	1		
EC	0,89	0,82	0,15	0,89	0,31	0,67	0,41	1	
TH	0,77	0,78	0,02	0,57	0,21	0,91	0,76	0,67	1

The good correlation of  $\text{Na}^+$  with  $\text{Cl}^-$  indicate the dissolution of halite during the dry season And the enrichment of the aqueous solution,

The good correlation between  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$  indicate the same origin resulting from the simultaneous dissolution process of gypsum and halite causing excess enrichment of the ground water solution.

The significatif correlation between  $\text{Na}^+$  and  $\text{SO}_4^{2-}$  is interpreted by the dissolution of Thernardite ( $\text{Na}_2\text{SO}_4$ ), Mirabilite ( $\text{Na}_2\text{SO}_4 \cdot 10 \text{H}_2\text{O}$ ) and Bloedite ( $\text{Na}_2 \text{Mg}(\text{SO}_4)_2 \cdot 4\text{H}_2\text{O}$ ).

The moderate correlation between the other elements is interpreted by the mixed origin of the chemical elements managed by the dissolution /precipitation rate of each chemical speciation



**Fig.7.** Correlation between TDS (mg/l) and chemical elements of Guerrara ground water in Wet season (January 2013)

The correlation between major elements and TDS can be useful to interpret the hydrogeochemical evolution process of the ground water and can be used to deduce the sources of ions and the origin of the ground water [13,14].

For cations, a good correlation is between  $\text{Na}^+$  and TDS ( $R^2= 0.784$ , Fig 7) the correlation with  $\text{Ca}^{2+}$  is moderate ( $R^2= 0.452$ , Fig 7) and the correlation with  $\text{Mg}^{2+}$  is Poor ( $R^2= 0.176$ , Fig 7). For anions the correlation between  $\text{Cl}^-$  and TDS indicate the highest values ( $R^2= 0.798$ , Fig 7) followed by  $\text{SO}_4^{2-}$  ( $R^2= 0.661$ ) considering the slopes of the fitted lines  $\text{Cl}^-$  increases with TDS more than  $\text{SO}_4^{2-}$ , which means that the rate of dissolution of Halite is higher than gypsum and anhydrite.

The correlation between  $\text{HCO}_3^-$  and TDS is poor this is in relation with the rate of dissolution of carbonates minerals which need more residence time.

### 3.3. Saturation Indices and water mineral equilibrium

The equilibrium state of the water with respect to a mineral phase can be determined by calculating a saturation index (SI) using analytic data [15].

The saturation index of a mineral is obtained by

$$SI = \log \frac{IAP}{KT}$$

Where IAP is the ion activity product and KT is the equilibrium solubility product for the chemical involved at the sample temperature.

The saturation indexes are calculated using PhreeqC for windows using pitzer geochemical bases [16].

saturation index less than zero indicate that the groundwater is under-saturated with respect to the specified mineral, elsewhere an index superior to zero stipulate that the ground water is hyper-saturated with respect to the specified mineral and therefore incapable to dissolving more of the specified mineral, in table 3 the saturation indexes of Calcite, Aragonite, Dolomite Gypsum, and Anhydrite are presented in both dry and wet seasons.

Generally the saturation indexes of the carbonate minerals (calcite, aragonite and Dolomite) are positive over the two seasons except for some wells (Table 3) indicating oversaturation and precipitation for these minerals. In contrast the SI values for evaporitic minerals (Gypsum and anhydrite) are generally negative in the two seasons indicating that gypsum and anhydrite could be dissolved along flow path.

The carbonates minerals in wet seasons present an insignificant correlation with TDS values

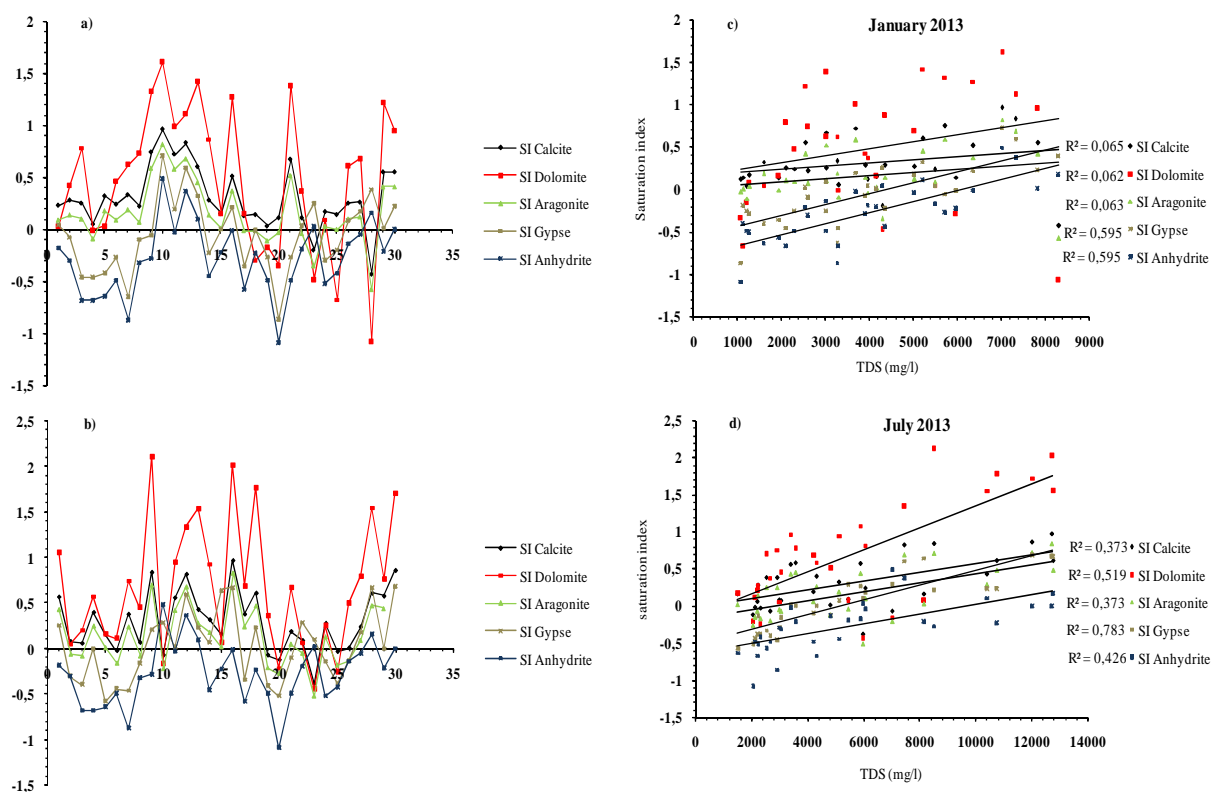
indicating a short time residence and long dissolution process, however in the dry season the behavior of these elements change in respect to TDS changes (Fig 8c,d)

In dry season the hydrodynamic and thermodynamic condition of the alluvium aquifer change and the dissolution of gypsum and anhydrite increase the concentration of Ca in groundwater, which will in turn increase SI values of calcite and dolomite and make them precipitate from the groundwater.

**Table 3** representation of the phreeqc simulation

Label	SI Calcite		SI Aragonite		SI Dolomite		SI Gypsum		SI Anhydrite	
	January	July	January	July	January	July	January	July	January	July
<b>P1</b>	0,23	0,57	0,09	0,43	0,03	1,06	0,04	0,26	-0,18	0,04
<b>P2</b>	0,28	0,08	0,14	-0,06	0,42	0,04	-0,08	-0,3	-0,3	-0,52
<b>P3</b>	0,25	0,06	0,1	-0,08	0,78	0,2	-0,46	-0,39	-0,68	-0,61
<b>P4</b>	0,05	0,4	-0,09	0,25	-0,01	0,57	-0,46	0	-0,68	-0,22
<b>P5</b>	0,32	0,16	0,18	0,01	0,03	0,16	-0,42	-0,58	-0,64	-0,8
<b>P6</b>	0,24	-0,02	0,09	-0,16	0,46	0,11	-0,27	-0,44	-0,49	-0,66
<b>P7</b>	0,33	0,38	0,19	0,24	0,62	0,74	-0,65	-0,46	-0,87	-0,68
<b>P8</b>	0,22	0,07	0,07	-0,08	0,73	0,45	-0,1	-0,16	-0,32	-0,38
<b>P9</b>	0,74	0,84	0,59	0,7	1,32	2,12	-0,06	0,21	-0,28	-0,01
<b>P10</b>	0,96	-0,07	0,82	-0,22	1,61	-0,17	0,71	0,29	0,49	0,07
<b>P11</b>	0,72	0,56	0,58	0,42	0,99	0,95	0,19	0,02	-0,03	-0,2
<b>P12</b>	0,83	0,82	0,68	0,68	1,11	1,34	0,59	0,6	0,37	0,38
<b>P13</b>	0,6	0,43	0,45	0,28	1,42	1,54	0,32	0,23	0,1	0,01
<b>P14</b>	0,28	0,32	0,14	0,18	0,86	0,93	-0,23	0,07	-0,45	-0,15
<b>P15</b>	0,15	0,16	0,01	0,02	0,15	0,07	0	0,64	-0,22	0,42
<b>P16</b>	0,51	0,97	0,37	0,83	1,27	2,02	0,21	0,67	-0,01	0,45
<b>P17</b>	0,13	0,38	-0,01	0,24	0,15	0,69	-0,36	-0,34	-0,58	-0,56
<b>P18</b>	0,14	0,61	-0,01	0,47	-0,3	1,78	-0,01	0,23	-0,23	0,01
<b>P19</b>	0,03	-0,07	-0,11	-0,21	-0,17	0,36	-0,27	-0,41	-0,49	-0,63
<b>P20</b>	0,11	-0,12	-0,03	-0,27	-0,35	-0,22	-0,87	-0,52	-1,09	-0,74

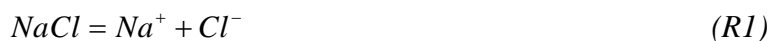
<b>P21</b>	0,67	0,19	0,52	0,05	1,38	0,67	-0,27	-0,1	-0,49	-0,32
<b>P22</b>	0,11	0,09	-0,04	-0,05	0,37	0,06	0,03	0,29	-0,19	0,07
<b>P23</b>	-0,2	-0,38	-0,35	-0,52	-0,48	-0,45	0,25	0,1	0,03	-0,12
<b>P24</b>	0,17	0,28	0,03	0,13	0,09	0,25	-0,3	-0,14	-0,52	-0,36
<b>P25</b>	0,14	-0,03	0	-0,18	-0,68	-0,26	-0,2	-0,38	-0,42	-0,6
<b>P26</b>	0,25	0,01	0,1	-0,13	0,61	0,5	0,08	-0,13	-0,14	-0,35
<b>P27</b>	0,26	0,24	0,12	0,09	0,68	0,8	0,17	0,18	-0,05	-0,04



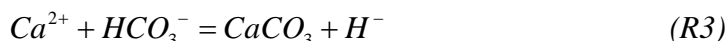
**Fig.8.** Representation of SI calculation

a) Variation of saturation indices of different mineralization in January 2013, b) variation of saturation indices of different mineralization in July 2013, c) Correlation between SI and TDS in January 2013, d) Correlation between SI and TDS in July 2013

The correlation between the major ions and TDS and the saturation indices of the minerals (Table 3) suggest the following reaction along the flow path







### 3.4. Suitability for Irrigation

#### Sodium adsorption ration

The classification of water suitability for irrigation depends on the mineral constitution of soil and plants [17], the USSL diagram [18],[19] relates sodium adsorption ratio SAR to electric conductivity EC, if used water for irrigation is high in sodium and low in calcium content, the exchangeable calcium in soil replace sodium by base exchange reaction in water this can destroy the soil structure owing to dispersion of clay particles [20],[21], the SAR values are calculated using the formula

$$SAR = (Na^+) / \sqrt{(Ca^{2+} + Mg^{2+}) / 2}$$

In the study area the SAR values ranges from 2.86 to 19.18 with an average value of 7.49 (table 4), More than 65% of the water samples are excellent for the irrigation purpose, more than 25% are good and 7% are doubtful, More than 50% of the water samples caused permeability problem and shrinking and swelling type's clayey soils (Fig 9a)

The plotted data in USSL diagram [6], show that 45% of the water samples are classed in the field of C4S4 (very high salinity and very high alkali hazard)

**Table 4** Results of the different irrigation indices

Labe	SAR	Na%	MAR	RSBC	PI	KR
<b>1</b>						
<b>P1</b>	18,97	75,04	20,39	-11,60	79,69	2,95
<b>P2</b>	10,26	60,72	33,91	-9,97	66,94	1,51
<b>P3</b>	3,77	36,27	58,33	-3,71	43,75	0,54
<b>P4</b>	9,34	63,26	35,90	-5,87	70,16	1,67
<b>P5</b>	3,09	37,84	15,19	-8,36	50,44	0,55
<b>P6</b>	3,93	38,30	40,91	-8,24	47,51	0,59
<b>P7</b>	11,67	72,87	40,01	6,16	79,08	2,61

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<b>P8</b>	4,32	35,74	58,69	-8,30	42,30	0,54
<b>P9</b>	15,06	68,87	33,33	-0,70	73,74	2,17
<b>P10</b>	9,62	43,64	25,00	-51,39	48,71	0,76
<b>P11</b>	3,89	31,41	20,00	-25,07	40,16	0,43
<b>P12</b>	7,94	42,36	16,67	-43,07	48,85	0,72
<b>P13</b>	15,35	60,36	53,85	-14,93	63,84	1,51
<b>P14</b>	12,25	63,71	58,73	-2,40	68,00	1,73
<b>P15</b>	12,25	64,58	33,33	-13,08	69,28	1,73
<b>P16</b>	14,20	59,70	55,00	-13,60	63,12	1,45
<b>P17</b>	5,61	48,61	35,42	-8,47	57,15	0,91
<b>P18</b>	19,18	78,49	16,22	-7,60	83,16	3,53
<b>P19</b>	3,44	37,09	30,00	-11,33	47,33	0,54
<b>P20</b>	3,58	46,08	16,25	-5,95	57,77	0,74
<b>P21</b>	4,43	38,82	44,16	-6,53	44,69	0,56
<b>P22</b>	7,38	46,13	50,45	-19,33	49,85	0,78
<b>P23</b>	9,19	50,29	37,50	-26,93	55,25	0,97
<b>P24</b>	6,57	56,88	28,57	-4,89	65,48	1,24
<b>P25</b>	6,38	55,00	7,29	-10,26	65,44	1,17
<b>P26</b>	8,44	51,38	48,24	-13,12	56,67	1,02
<b>P27</b>	8,95	48,64	50,00	-19,88	53,31	0,92

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### Sodium percentage (Na%)

The sodium percentage (Na %) is an important factor to evaluate the water suitability for irrigation, excess in sodium changes and affects soil proprieties such as clogging in soil particles as a result of reacting sodium with soil, sodium adsorption by clay particles leads to displacing  $Mg^{2+}$  and  $Ca^{2+}$  ions thus reduce the soil permeability and cause poor internal drainage [22],[23], the Na % can be calculated by the following formula

$$Na\% = (Na^+ + K^+) \times 100 / (Ca^{2+} + Mg^{2+} + Na^+ + K^+)$$

In the study area the Na % values ranges between 31.41 and 78.49 % according to Wilcox

classification :0% of water sample is classed as excellent, more than 25% is classed as good ,more than 40% are classed as permissible and more than 33% is classed as doubtful (Table 4)

The spatial distribution of Na% in the alluvium ground water is shown in Figure 9b

### **Magnesium Ratio**

The magnesium ratio (MAR) can be calculated using the formula

$$MAR = (Mg^{2+}) \times 100 / (Ca^{2+} + Mg^{2+})$$

Excess concentration of magnesium in the soil causes infiltration problem and can lead to reduced crop yield [24], MAR is considered unsuitable for water irrigation, the values of magnesium ratio in the present study ranges between 7.29 and 58.73 %, 74% of the water samples are suitable for irrigation while 26% are considered as unsuitable (Table 4), the MAR distribution in the study area is shown in figure 9c.

### **Residual sodium bicarbonate**

The residual sodium bicarbonate (RSBC) is defined by Gupta and Gupta [25] by the formula

$$RSBC = (HCO_3^- - Ca^{2+})$$

The RSBC values varied from -51.39 to 6.16 according to Gupta and Gupta [25] all samples (more than 96%) were found to be satisfactory (<5mg/l).The special distributions of RSBC in the study are described in figure 9d.

### **Permeability Index**

The soil permeability decreases due to excessive irrigation practices and is defined depending on quantity of Sodium, bicarbonate, calcium and magnesium in water, the permeability index [26] can be calculated using the empiric formula

$$PI\% = (Na^+ + \sqrt{HCO_3^-}) \times 100 / (Ca^{2+} + Mg^{2+} + Na^+)$$

Where concentrations of all ions have been expressed in meq/l.

In the study area the values of permeability index PI ranges from 40.16 to 83.16 (table 4), PI is classified under class I (>75% permeability), class II (25-75% permeability), class III (<75% permeability), where class I and II are good for irrigation and class III water is unsuitable for irrigation with 25% maximum permeability, according to Doneen's chart [26] (Fig.10),the

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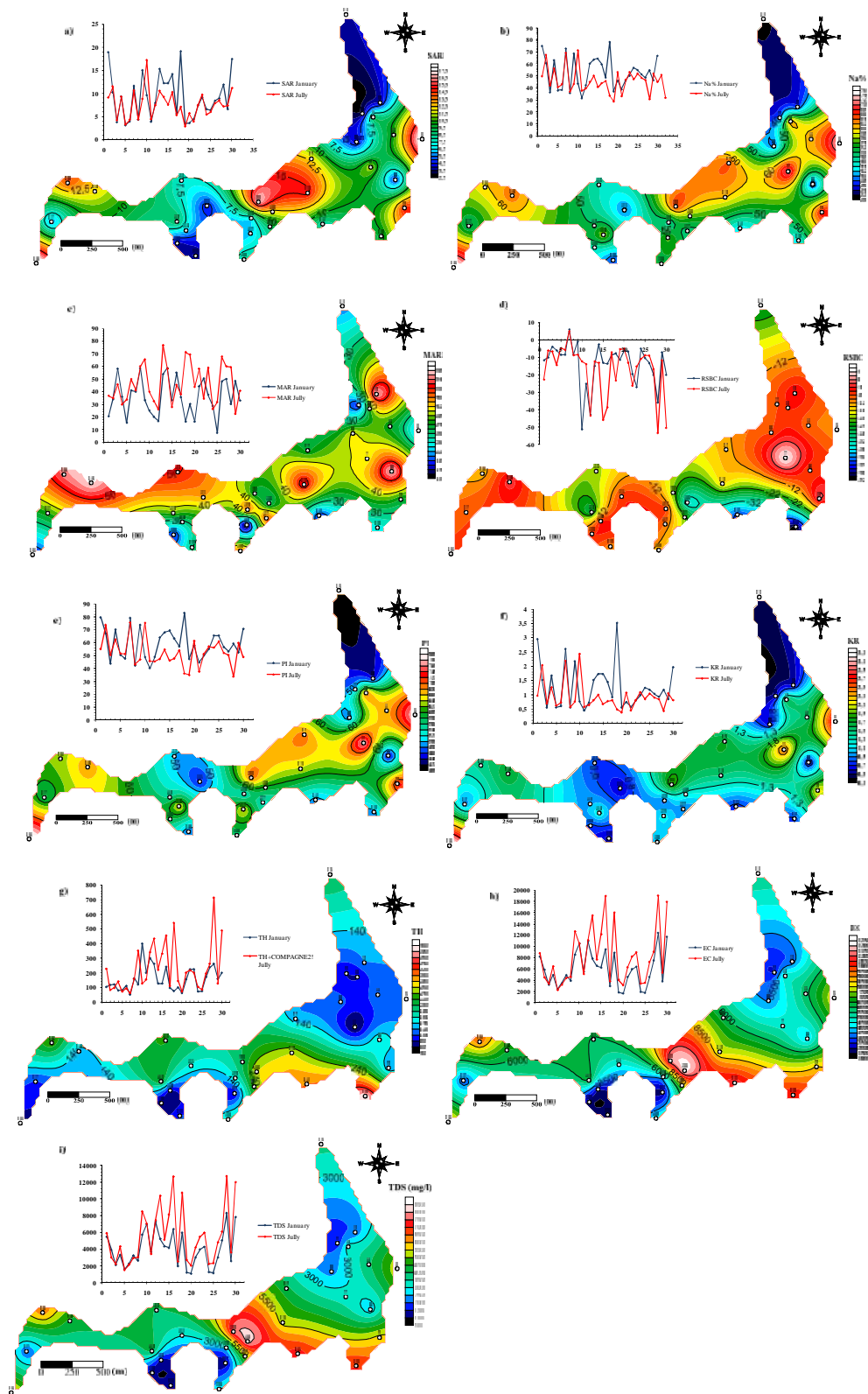
spatial distribution of PI in the study area is exposed in figure 9e

### **Kelly's Ratio**

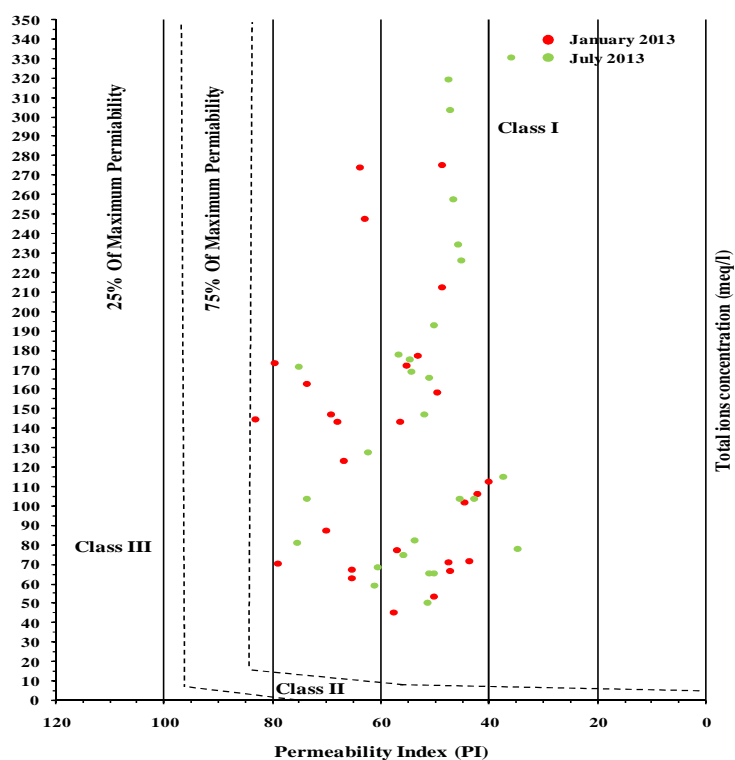
Kelly ratio (KR) is used to define the suitability of water for irrigation, if KR is more than 2 which means excess in sodium values and the water is not suitable for irrigation, if KR is between 1-2 that means the water quality is marginal, If KR is less than 1 the water quality is suitable for irrigation [27], KR can be calculated using the following formula

$$KR = (Na^+) / (Ca^{2+} + Mg^{2+})$$

In the study area 51% of the water samples are suitable for irrigation, 34% are marginal and 15% are unsuitable for irrigation (Table 4), the KR distribution in the study area is shown in figure 9f.



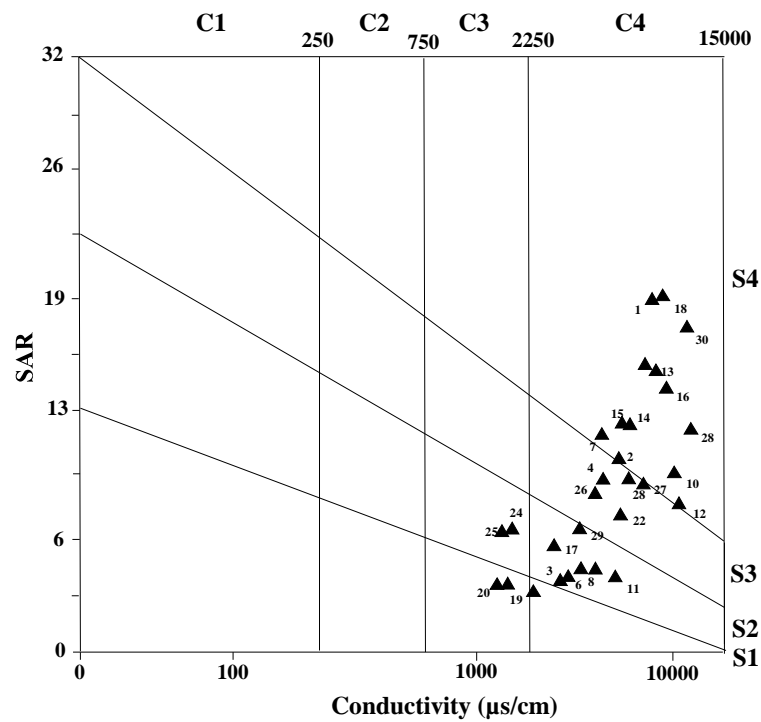
**Fig.9.** Parameters or irrigation suitability. a) Sodium adsorption ratio map, b) sodium percentage map, c) Magnesium ratio map, d) Residual sodium bicarbonate map, e) Permeability index map, f) Kelly ratio map, g) total hardness map, h) electric conductivity map, i) total dissolved solid map



**Fig.10.** Doneen’s chart for water irrigation suitability

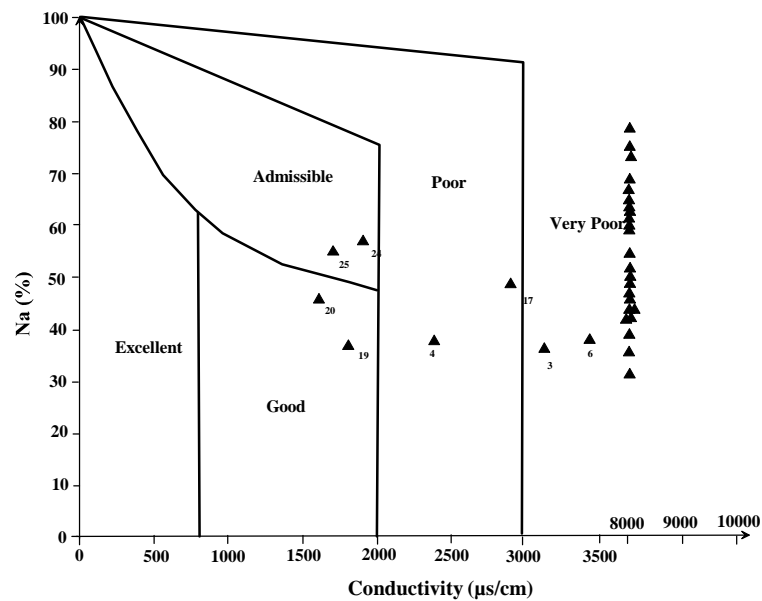
In USSL diagram (Fig.11) the concentration of soluble salts in irrigation water termed as low ( $EC < 250 \mu S/Cm$ ), Medium ( $250-750 \mu S/Cm$ ), High ( $750-2250 \mu S/Cm$ ) and very high ( $EC > 2250 \mu S/Cm$ ), there is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil, high sodium and low calcium in water raises the cations exchanges and is responsible for saturated sodium in an irrigation area, this can destroy the soil structure due to dispersion of Na in the clay particles.

The projected water samples in USSL diagram show that 45% of water samples are in S4C4 Class (very high alkalinity hazard and very high salinity hazard), 16% are in C4S3 class (high alkalinity hazard and very high salinity hazard), 22.5% are in C4S2 class (moderate alkalinity hazard and very high salinity hazard), 6% are in C3S2 and C3S1 classes respectively (moderate alkalinity hazard and high salinity hazard, low alkalinity hazard and high salinity hazard) and 3% are in C4S1 class (low alkalinity hazard and very high salinity hazard)



**Fig.11.** USSL diagram

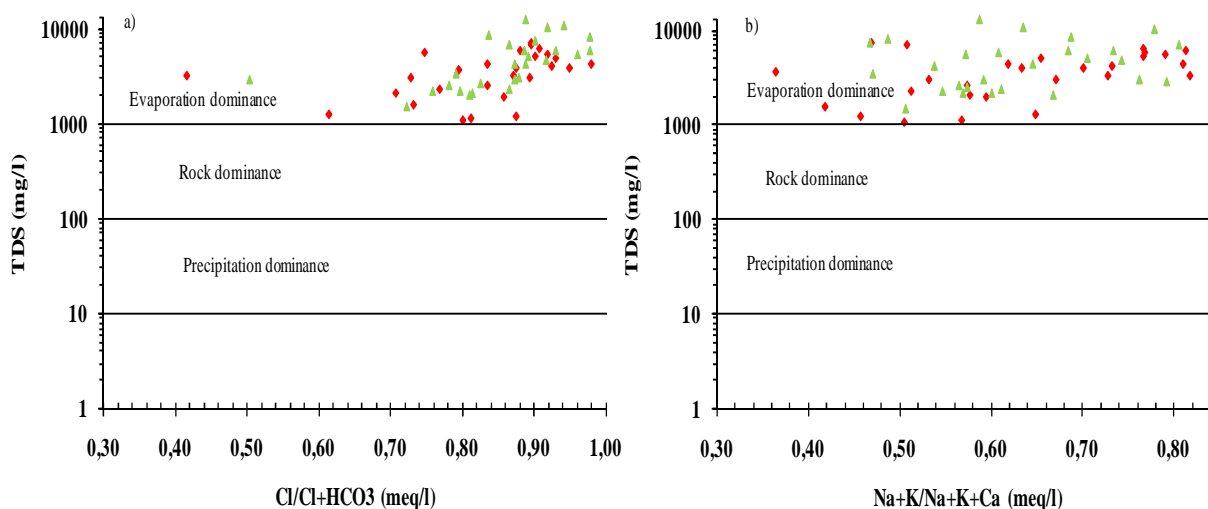
The Wilcox diagram [28] relates plot of EC and Na% to designate irrigation water quality, Fig.12 infers that more than 77% of water samples are classed as very poor and unsuitable for irrigation purpose, 7% are classed as poor, admissible and good for irrigation use respectably.



**Fig.12.** Wilcox diagram

### 3.5. Mechanism controlling ground water chemistry

To know the relationship of the chemical components of water to their respective aquifers such as chemistry of the rock type, chemistry of the precipitated water and the rate of evaporation, Gibbs diagram [29] was used to determine major process controlling ground



**Fig.13.** Gibbs diagrams.a) for anions, b) for cations

Water chemistry, the data chemistry on Gibbs diagram (Fig.13) suggest that groundwater chemistry is controlled by evaporation crystallization action by causes of the arid climate condition and surface morphology of Guerrara basin, the excessive use of fertilizer in groundwater can be a associated factor to increase salinity with  $\text{Na}^+$ ,  $\text{Cl}^-$  due to evaporation The dispersion of water samples in Fig.12b may be due to other anthropogenic activities.

## 4. CONCLUSION

Analysis of hydrochemical data of the alluvial aquier indicate that the main type of water is  $\text{Cl}^- \text{SO}_4^- \text{Ca}$  and  $\text{Cl}^- \text{SO}_4^- \text{K}$  and the main process controlling groundwater geochemistry are Eaporation –crystallization of evaporate minerals such as halite gypsum and anhydrite.

The sequence of the abundance of the major ions is in the following order  $\text{Cl}^- > \text{Na}^+ > \text{SO}_4^- > \text{Mg}^{2+} > \text{Ca}^{2+} > \text{HCO}_3^- > \text{K}^+$

The correlation matrix between the Physiochemical parameters show the influence of evaporitic mineralization expreed by high correlation degrees, the obtained information



suggests the presence of saliferous bodies at shallow deep that contaminates the alluvial aquifer during the wet seasons the dissolution of halite and gypsum minerals enriches the water with sulfides and chlorures exceeding the international standars, the saturation indices and gibbs diagrams calculated for wet and dry seasons confirms the dominance of evaporation-precipitation wich is a cyclic phenomenon related to the climate nature in arid region.

Water quality for irrigation was evaluated using several indices (SAR, Na%, MAR, PI, TH, SI, KR, and RSBC) all parameters show that the water is suitable for irrigation in the highest regions of the study area and are charachterized by a moderate suitability in the lower depression of guerrara (the palm grove area).

As shown in the preliminary results the salt bodies are localized in the central part of the study area more details can be obtained using geophysical sub-surface methods such as Ground penetrating radar and 2D electric tomography.

## 5. ACKNOWLEDGEMENTS

In therme of this work we would like to thank the national agency of hydrogeologic resources Ouargla (ANRH Ouargla) for thier help.

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**How to cite this article:**

Melouah O, Zerrouki H. Hydrochemical study of sources salinity in Shallow water springs of Northern Algerian Sahara. J. Fundam. Appl. Sci., 2020, 12(1), 291-317.