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Hydrochemical and Piezometric Study of The Alluvial Aquifer of The Guerrara Region, Algeria

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Abstract: This study is interested in the degradation of the water quality of the alluvial aquifer of Guerrara region, Algeria, and examines the processes that affect the physicochemical and hydrodynamic quality of the waters of this surface water table. 30 water samples were taken in October 2011, 18 in April 2012, 30 in October 2012 and 30 in April 2013. It is a hydro-chemical and hydrodynamic (piezometric) study of groundwater. The parameters studied are EC, pH, mineralization, total hardness and the ionic balance of the water. The physico-chemical study of the waters indicates a great variability of the EC of the water in time and space, with values varying from 0.91 to 11.63 dS / m (October 2011) and from 2.25 to 19.04 dS/m (April 2013). the pH is slightly alkaline, with values changing from 7.4 to 8.4 (October 2011) and from 6.51 to 7.61 (April 2013). The chemical facies of waters is chlorinated and sulphated, and the most represented facies is the sulphated sodium facies. The piezometric study of the aquifer over four companions of monitoring shows that the direction of flow is from South West to North East in a general way. Seasonal fluctuations in the piezometric surface oscillate between 0.2 and 5 m. These fluctuations are subject to the climatic characteristics of the region: low rainfall and high evaporation on the one hand, and on the other hand, and pumping.
Keywords: Alluvial water, physico-chemical quality, piezometry, Guerrara, Algeria.

INTRODUCTION

Guerrara Oasis is dominated by alluvial soils formed of fine materials carried by floods of Zegrir Wadi. The source of water in the region mainly is shallow groundwater with limited numbers of deep wells. The shallow aquifer is captured by wells with depth ranging from (3-30) meters. These wells are sometimes poorly maintained and neglected, plus the use of other irrigation water and the passage of the sewage system in the palm plantation, which has influenced the soil and vegetation. The very few studies on the shallow groundwater of Guerrara have investigated the geological aspects of the aquifer [1,2]. The sandstones are the base of the shallow aquifer and present a variable thickness; the latter is of 15 m (maximum) at the old palm grove of Guerrara [2]. However, many other studies of shallow groundwater has been carried out for other areas through the world [3-7]. These studies demonstrated that groundwater quality depends not only on natural factors such as aquifer lithology, groundwater velocity and quality of recharge waters but also on human activities such as irrigation, source of irrigation water and location of polluting sources. Recently, local farmers believe that the quality of water has changed and becomes unsuitable for irrigation of several crops. They confirm that the salinity of water in wells increased, for that, they stopped using it for irrigation in some cases. The salinity of the water wells has evolved from a low to excessively salty. The salinity of the water flood is seemed to be a problem for the management of soil and irrigation for agriculture purpose. In arid and semiarid areas, primary soil attributes that affect plant productivity are salinity, soil texture and structure, available water, nutrient deficiency, and toxic ions such as Na and Cl [8]. Water quality is important as its quantity and quality as it move through the soils and sediments, and hence, its composition is then changed by chemical reactions such as weathering, dissolution, leaching, precipitation, ion exchange, impact of agriculture and urbanization [4]. Chemical analysis forms the basis of interpretation of the quality of water in relation to source, geology, climate, and use [5]. The objective of this study was to assess the hydro-chemical and piezometric properties of the shallow groundwater in Guerrara region.

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MATERIALS AND METHODS

The study area

The study was carried out in the old palm grove of Gerrara region, which is located at 110 km North-East of Ghardaia, in the South of Algiers, between (3,629,000 - 3,627,500) North latitude and (639000 - 641500) East longitude, and at an average altitude of 303 m (Figure 1).The climate of the study area is arid type with winter rain, and a dry and hot summer. The mean annual rainfall is about 81mm and the annual average temperature is 25°C, according to NOM (2013) [9]. The study area covers around 400 ha (82000 date palms) which includes one soil order such as Fluvisol aridic calcic. According to WRB/FAO classification (1998).The traditional irrigation system operated the shallow groundwater (alluvial), using many wells (1300) and few deep groundwater wells.

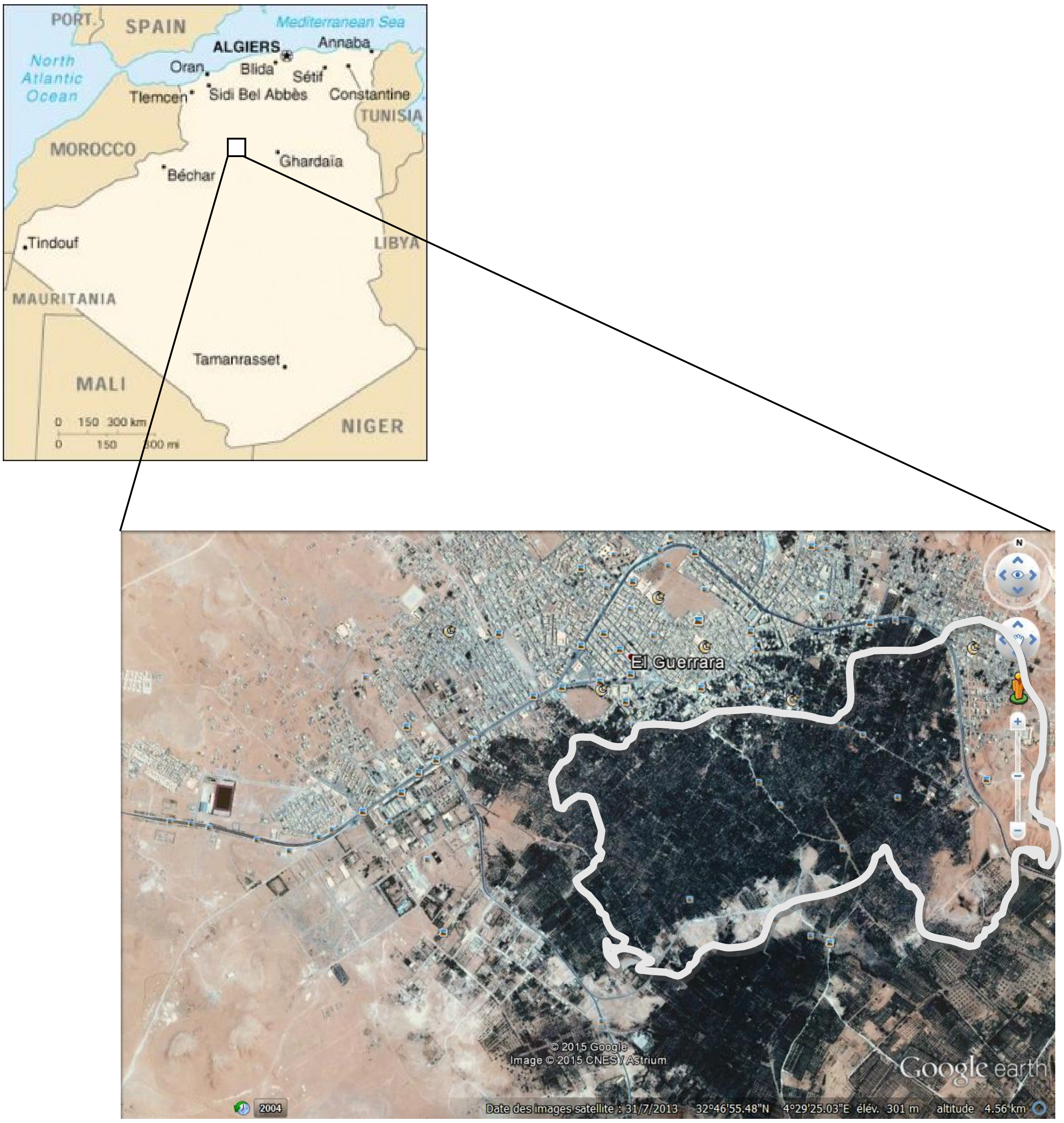

Figure 1. Location of study area

Geology:

The study area has three types of geological formations (Figure 2); the upper cretaceous (CS) from the west to the east and at the Northwestern of Guerrara, the Neogene or Mio-pliocene (mp) and the rest of the field consists of continental Pliocene(pc) as an extended forms of thick and continuous limestone, the continental quaternary (qt) which is presented by the Saharan sedimentary formations as river alluvium [10].

Geomorphology:

The study area has several geomorphologic units:

- **Hamada:** Plate structural, defined by sandy and sandstones and these tiles are a drop of 75 m over a distance which varies from 2 to 3 km,
- **Gara:** tabular plates isolated by erosion and crowned by a table of hard rock. Plain of Daya El Amied is bounded at the south by a series of Gara. These are shaped by the operation of the water system.
- **Daya:** depressions of small dimensions can vary from one to several tens of hectares, which is found everywhere in arid and Saharan areas. The depressions contain water charged with mineral particles of sand and silt.
- **Glacis:** The northern slope of the great depression of Guerrara and has two floor levels glaze (glaze terrace). It is characterized by the outcrop of sandstone bedrock Mio-Pliocene. The latter is characterized by sand and gravel sandstone [11].

Superficial formations:

Upper Glacis formations are mainly sandy, silt to gravel. They are lined with gravel cover that gives an aspect of their Reg. The thickness is considerable while the color is pale white as it appears on the satellite image, what is due to limestone gravel.

HYDROGEOLOGY

There are five exploitable aquifers in Guerrara, including the shallow aquifer: The Mio-Pliocene (100 m thick) and Eocene (125 m thick) aquifer which locates in the eastern part of Guerrara. The Senonian aquifer which is found in the western part of Guerrara and is related to the previous two layers and can be operated at about 430 m of depth, the Turonian carbonate aquifer (74 m thick and 500 m deep), characterized the western part of Guerrara, the Continental interlayer or Albian aquifer which is about 500 to 900 m depth, and the shallow Groundwater which is a superficial or alluvial (valley aquifer). It is powered by floods of Zegrir Wadi. The depth of this layer varies according to the season. The surface hydrogeology is presented by Zegrir River which is one of the major rivers crossing the region. It's limited to the height of Guerrara to Ben Filah daya (300m), with 270 km of length, and its origin head of (860m) [11].

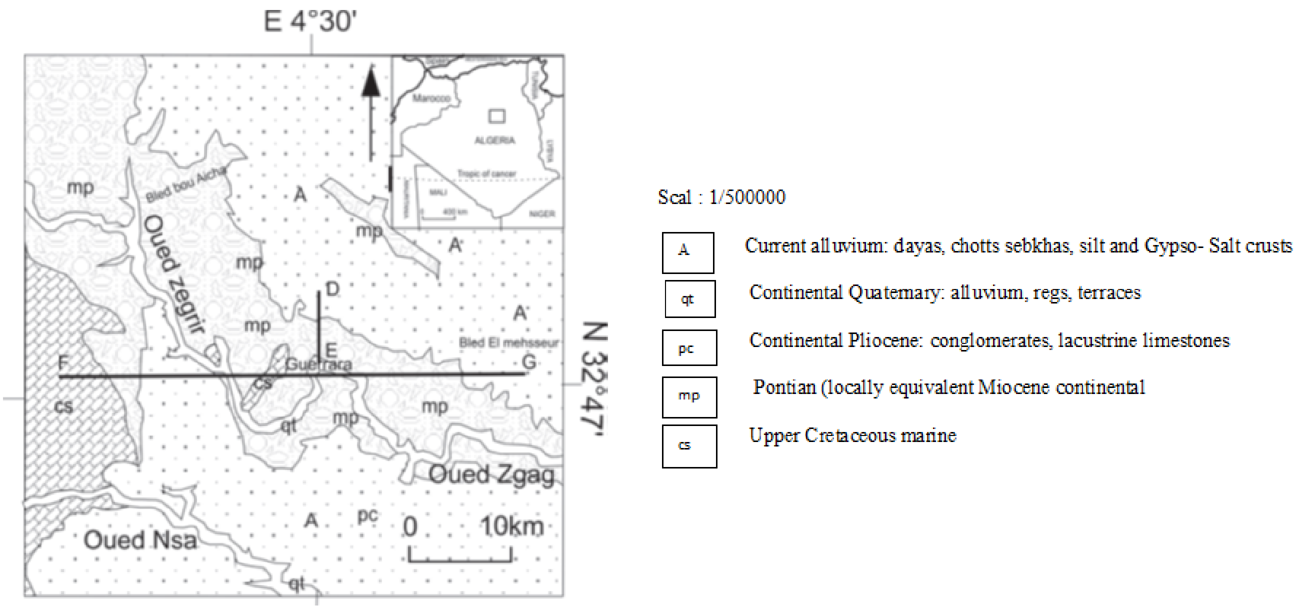

Figure 2. Geological Map of Guerrara Methodology

METHODOLOGY

Methodology

The survey was conducted by a first step of consultation of basic documents available that could give some information on the study area, we consulted a few theses, journals, maps, aerial photographs, satellite and some studies carried out in the study area [1, 2, 10]. The second step is of prospecting-recognition, which consists of a recognition survey of the field, to have a general idea of the study area. 30 wells inside the old palm grove of Guerrara were chosen for the survey (Figure 3). The water quality study concerned the physical and chemical parameters; EC, pH, water temperature, mineralization, hardness and ionic balance (cations and anions).

Sampling and analysis

Water samples were collected from 30 shallow wells and in two periods; the first one was on October 2012 and the second time on April 2013. The hydrodynamic (piezometric) study of the groundwater consist at measure of the depth of water, its coordinates and its rating in each well, in order to determine the direction of flow of the aquifer. Water hardness was calculated by using the following formula: $\mathbf{F = 5 * \sum(Ca^{++} + Mg^{++})}$. With $Ca^{++}$and Mg^{++} expressed in mg/l. The chlorides, carbonates and bicarbonates HCO_3^- and calcium were measured by titration; Chloride was determined by titration with $CaCl_2$, Carbonate and bicarbonate by titration by hydrochloric acid, alkalinity by diluted $H_2 SO_4$ and sulfate by chloride barium. Total hardness was determined by complex metrically. The results of physicochemical analyzes are presented by using computer programs as diagrams that allow easy interpretation of results (Piper diagram and Schoeller-Berkaloff diagram).

Materials

Measuring of the groundwater depth was carried out by a graduated electrical probe, and geographical coordinates of wells were measured by GPS. Samples were subjected to physical and chemical analyses in order to have an idea about the water quality. It concerned T, pH, EC, mineralization, hardness, ionic balance and geochemical facies, by using standard water sampling method; water temperature was measured at laboratory by using thermometer. EC and pH were determined by using a pH meter and an EC meter respectively. Ca^{++}, Mg^{++}, Na^+ and K^+ were determined by flame spectrophotometer.

RESULTS AND DISCUSSION

The result showed that there is a permanent relationship between the alluvial aquifer and Zegrir Wadi that resulting in a dynamic equilibrium. Water geochemistry provides additional information on the structure and functioning of aquifer systems from the hydro-chemical study which gives information on hydrogeology. The chemistry of the groundwater depends, mainly, of the litho-logical composition of the layers traversed and the water residence time. This interaction influences the content of major elements (Ca^{++},Mg^{++},Na^+, K^+, Cl^-, SO_4^-, HCO_3^-...). The concentrations of these natural elements are conditioned by factors such as climate parameters, human activities, exchanges between aquifers and surface water [12]. Through this study, we try to explain the behavior and the evolution of chemical elements to understand the quality of the alluvial groundwater.

According to the dispersion of points on the plots of the relationship cations /EC, one can remark that there are inversely positive proportional relationship between cations and EC. There was an increase in concentrations of Na^+ and Mg^{2+} accompanied by an increase of the EC, which indicates excessive mineralization of the waters of the aquifer led to a major electrical conductivity of water from. It is influenced by evaporates that by carbonates. There was a positive proportional relationship of Cl^- and SO_4^{2-} with the electrical conductivity, and negative proportional relationship between HCO_3^- and EC. There was an increase of Cl^- and SO_4^{2-} concentrations, accompanied with EC increase. The high mineralization of the groundwater was influenced by chlorides that by sulphates. The dry residue is obtained by drying at 110 ° C; it matches all dissolved salts and thus gives an idea of the degree of water mineralization. During the first companion values were between 1.23 and 10.55 g/l, and the highest values were noticed in wells 10, 12 and 28. The lowest value of mineralization was in well 20 (1.23 g/l). For the second companion, the values of mineralization were higher than the first one, with a maximum of 16.19 g/l. There was a proportional relationship between dry residue and the electrical conductivity, with a good correlation of r = 0.99**.**

The figure 3 showed the variation of dry residue during the two companions.

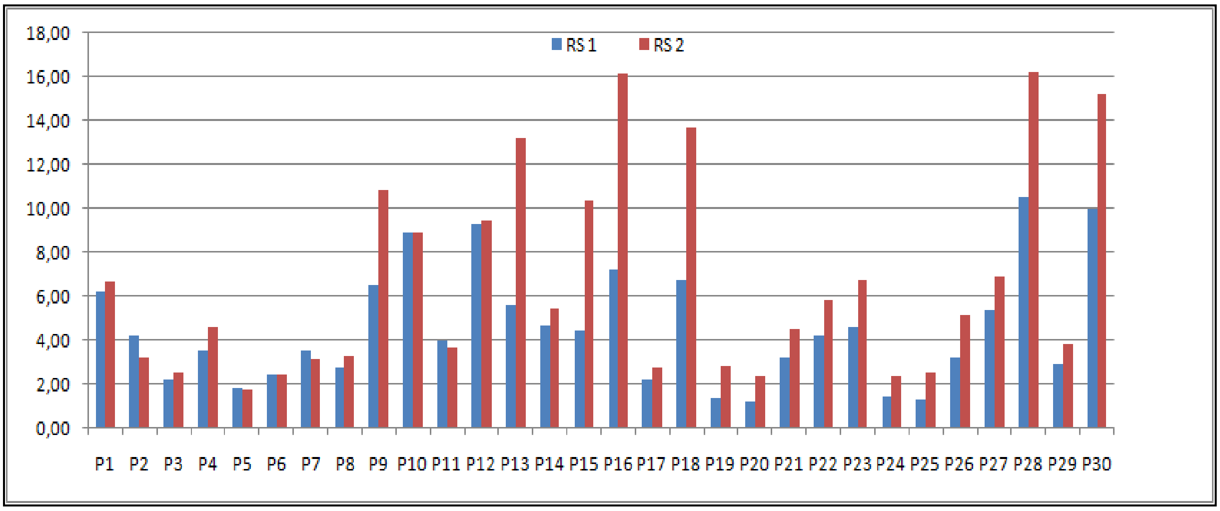

Figure 3. Variation of the dry residue of groundwater during the two companions

Hardness (Total Hardness Degree) (DHT)

It indicates the total content of calcium (Ca^{++}) and Magnesium (Mg^{++}) salts in water. It is expressed in French degrees (° F) and is calculated using the formula:

$$DHT = 5\ (r\ Ca^{++} + r\ Mg^{++})\ °F$$

$r\ Ca^{++} + r\ Mg^{++}$ are the amounts in response to calcium and Magnesium meq / l respectively.

According to WHO, the drinking water of good quality have a total hardness less than 15 °F, but acceptable to 50 °F. If it exceeds this value, use becomes extremely difficult and causes problems for consumption and for certain domestic uses [13]. In the studied waters, this parameter has a large variation which would be linked to lithology of the aquifer and in particular its composition of magnesium and calcium. The results of water hardness and their variation during the survey are given are in figure 4.

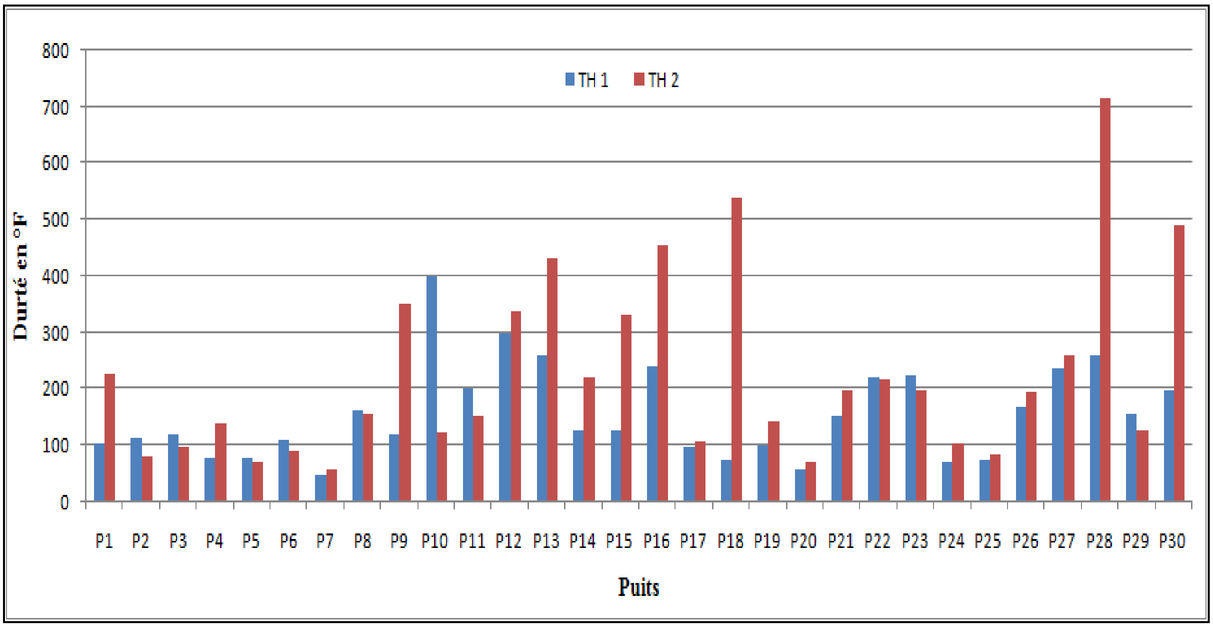

Figure 4. Variation of water hardness for the two companions of the survey

Waters were very hard, it may reach a maximum of 715, and they were between 50 and 715. The lowest values were of the first companion, with a minimum of 50°F in the well 7. The most of wells had very hard water (hardness> 54°F).

The chemical study of groundwater allowed to determine the chemical facies of water and to understand the relationship existing between the chemical parameters of water and their origins. The table 1 showed the results of ionic balance of groundwater. The chemical study of settings showed calcium levels superiors to irrigation water standard (150 mg/l). The highest values with a maximum of 1202,4 mg/l were recorded at the center of the study area and the lowest values, with a minimum of 120 mg/l are observed the wells located at the edges of the palm grove, with some increase of values in the second campaign from those of the first. The sodium was in high concentration in water and it exceeded the irrigation standard (50 mg / l), with maximum values of 1800mg / l., and lowest values of 200 mg / l in the wells P20 during the first companion and P5 during the second one. Magnesium values are generally lower than those of calcium, with an average of 139.4 mg / l during the first companion and 277.58 mg / l in the second. The highest values are those at the center of the region. Values had increased in the second companion relative to the first.

The potassium values are relatively between 22 mg/l - 45.86 mg/l with an average of 45.86 mg/l. The highest values of potassium were observed during the second companion with an average of 40.1 mg/l. Generally, the highest values are observed in the East of the palm grove while the lowest values were distributed in the West. The chlorine levels recorded throughout the observation period showed important values that exceeded the irrigation standard (140 mg/l), with a maximum concentration of 3869 mg/l during the first companion. The lowest concentrations recorded in the first companion with 288.7 mg/l in the well 24. The sulphates are strongly present in the waters and the highest values are recorded in the second companion, with an average of 2800 mg/l. The lowest values are found in the second companion with (120 mg/l). It is reported that all the values exceeded the irrigation norms (240 mg/l), except the well 20 in the West, which had a value of 120 mg/l. Bicarbonates are low distributed compared to other existing anions in the water during the observation period. The values recorded during the first companion were higher compared to the second, with maximum values of 933.33 mg/l and 960 mg/l, respectively. The majority of wells exceeded the irrigation norms and values of low concentrations are located in the west of the palm grove.

Schoeller defined in 1943, the index of Base Exchange (IBE) by the following formula:

$$I.E.B = rCl^- - r(Na^{++} + K^+) / rCl^-$$

The index base exchange or index chloro-alkaline imbalance (IBE) was > 0 in 73,33% of wells (22) wells for the two companions, and this indicated that K^+ and Na^+ in the water are exchanged against Ca^{2+} and $Mg^{2+}$of the surrounding ground.IEB <0 was found in 26.6% (8) of wells during the first companion, and it concerned wells P1, P7, P9, P14, P15 , P18, P24 and P25, and 16.66 % (5 wells) during the second companion; P2, P7, P10, P20 and P24. It indicated that Ca^{2+} and Mg^{2+}in water were exchanged against the Na^+ and K^+ of surrounding ground.IEB=0 was the case of only 3 wells (10%) during the second companion (P14, P25 and P29), where there was no cationic exchange between water and soil.

The figure 5 showed the water families of the first companion given by Piper diagram.

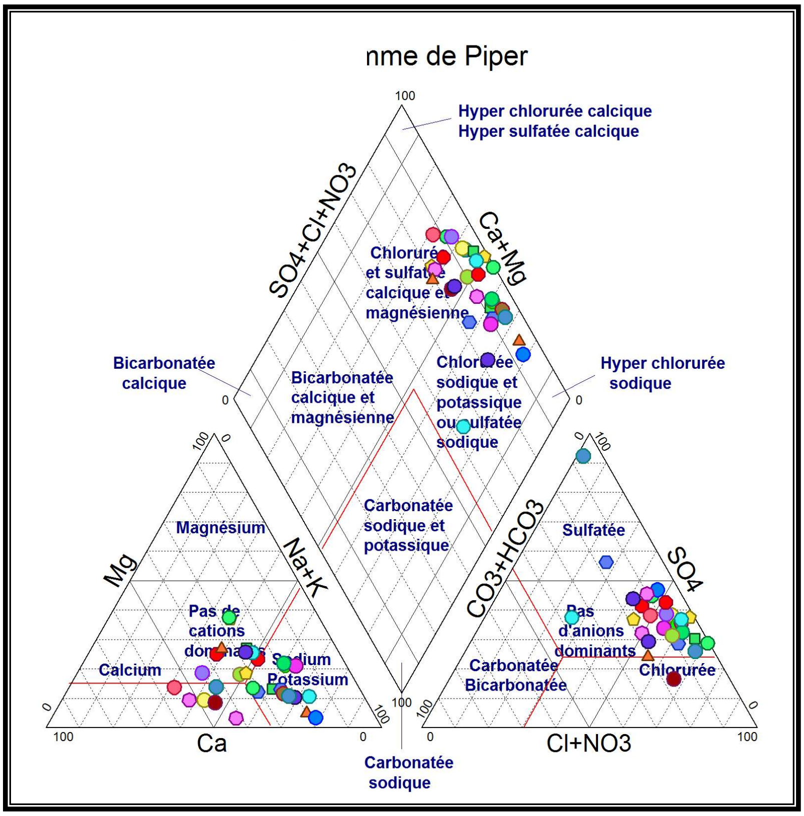

Figure 5. Piper diagram

Waters are grouped into three families: The family of chlorinated sodium, the family of chlorinated and sulfated calcic and magnesium, and the family of sulfated calcic and magnesium. Piper diagram of the first companion showed that there is point cloud towards chlorides, sulfates, and approaching to the zone of no any dominant anion. However, for cations, we observed a tendency towards sodium in slightly closer to calcium, to the zone of no any dominant cation. There is a predominance of Na^+ ions relative to Ca^{2+} and Mg^{2+}, among the cations, as well as the abundance of Cl, and SO_4^{2-} for the anions in the waters of this aquifer. The ratio rSO4 / rCl showed values below 1, indicating a chlorine ion enrichment, whereas the ratio rNa / rCa showed values greater than 1, indicating a sodium enrichment, and the rNa / rMg ratio is also higher than 1.This explains the predominance of the sodium chloride facies observed on Figure 5.

The representation of the chemical content of the water points on Schoeller-Berkaloff diagram showed the same pace as the Piper diagram, and the dominant facies is the sodic chlorinated facies. During the second companion, the high concentrations of Cl^-, SO_4^{2-}, (Na^++ K^+) gave a dominance of chlorinated sodium facies; followed by sodium and calcium sulphate and chlorinated facies. These results do not represent a major change from the first companion. It is reported that the bicarbonate content is low compared to that of other anions, which explains the very low allocation of bicarbonate facies.

Origin of water chemistry

The origin of water chemistry was determinate by the spatial repartition of dominant chemical elements. Calcium is released by the dissolution of gypsum rocks and by the attack of water in the presence of carbon dioxide (CO_2) in the case of carbonic rocks. Determining the origin of each Ca^{2+} concentration is necessary to know the mechanisms of the chemistry of the groundwater. The figure 12 represents the calcium relative to bicarbonates and sulphates, and the analysis of graph showed that 70% of samples (21) had carbonated origin. There was a linear distribution of Na^+ and Cl^- which indicates the common sodic chlorinated origin (Halite) of these two chemical elements. The increase of the Na^+ which accompanied to the high content of Cl^- is due to Base Exchange phenomenon because clays geological formations can release Na^+ after fixing calcium. The excess of Ca^{2+} intake in SO_4^{2-}indicated the evaporate origin of Ca^{2+} by gypsum, and it's interpreted as the result of the dissolution of carbonate formations. The graphical representation of the relationship between SO_4^{2-} and Mg^{2+}showed that the majority of the points are in linear form which confirms the same origin, the dissolution of salts $CaSO_4$ (Gypsum).The evolution of the calcium content relative to SO_4^{2-} result of both calcium origins one is by evaporate salts $CaSO_4$, and the other is carbonated by the dissolution of carbonate formations such as dolomite, calcite, anhydrite and aragonite.

To study the quality of water we used the diagram of Durand (1958), to determine the qualities of irrigation water after determining the SAR with the EC in ds/m. There is a significant relationship between sodium adsorption ratio (SAR) values for irrigation water and the extent to which sodium is adsorbed by the soils. If water used for irrigation is high in sodium and low in calcium, the cation exchange complex may become saturated with sodium, which can destroy the soil structure owing to dispersion of clay particles [3]. The results obtained showed that the EC values in ds / m of water from the alluvial aquifer are well above 5 leading to excessive salinity. SAR values were between 2.86 and 18.96 which indicate that waters of this aquifer are sodium to sodium greatly.

Figure 6 gives the water classification according to its degree of suitability for irrigation.

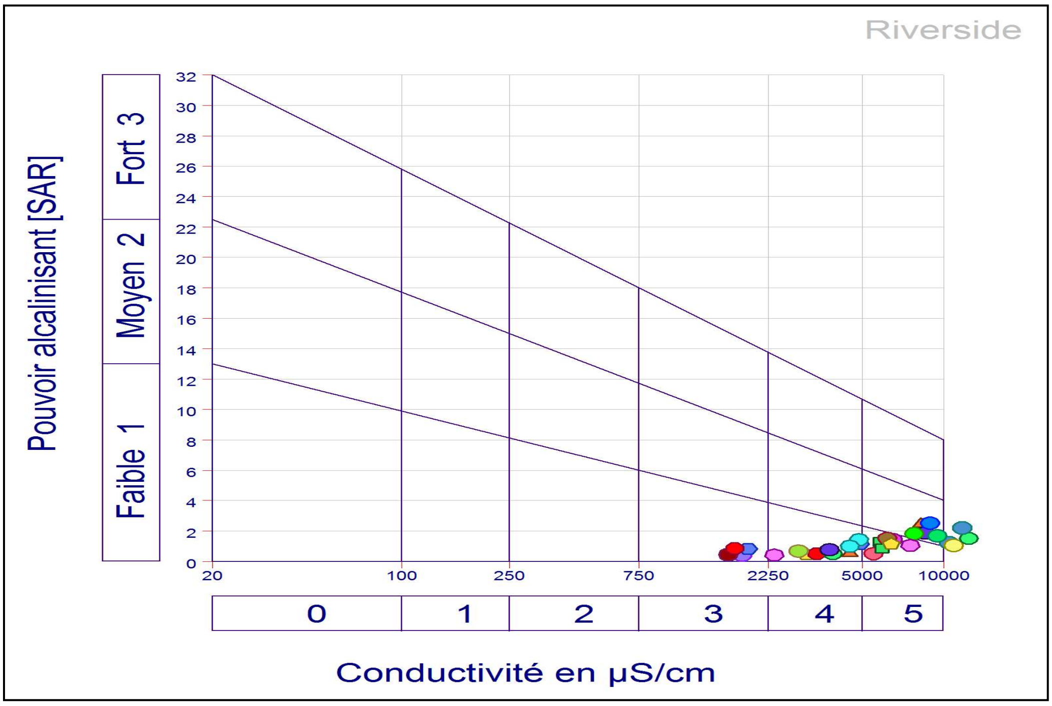

Figure 6. Diagram of Riverside (October 2012).

During october 2012 and april 2013, waters are generally located in four main classes:C3-S1: Permissible quality water suitable for irrigation of salt tolerant crops on well-drained soils, changes in salinity, however, must be controlled; C4-S1: poor water quality, high mineral content that may be suitable for irrigation of some species much salt tolerant and well-drained soils and leached waters of the alluvial aquifer; C5 and C5-S1-S2: poor water quality, highly mineralized not be suitable for irrigation.

Piezometric study

The figure 7 showed the results of measurements of geographical coordinates of wells and depths that allowed the tracing of piezometric maps of the groundwater.

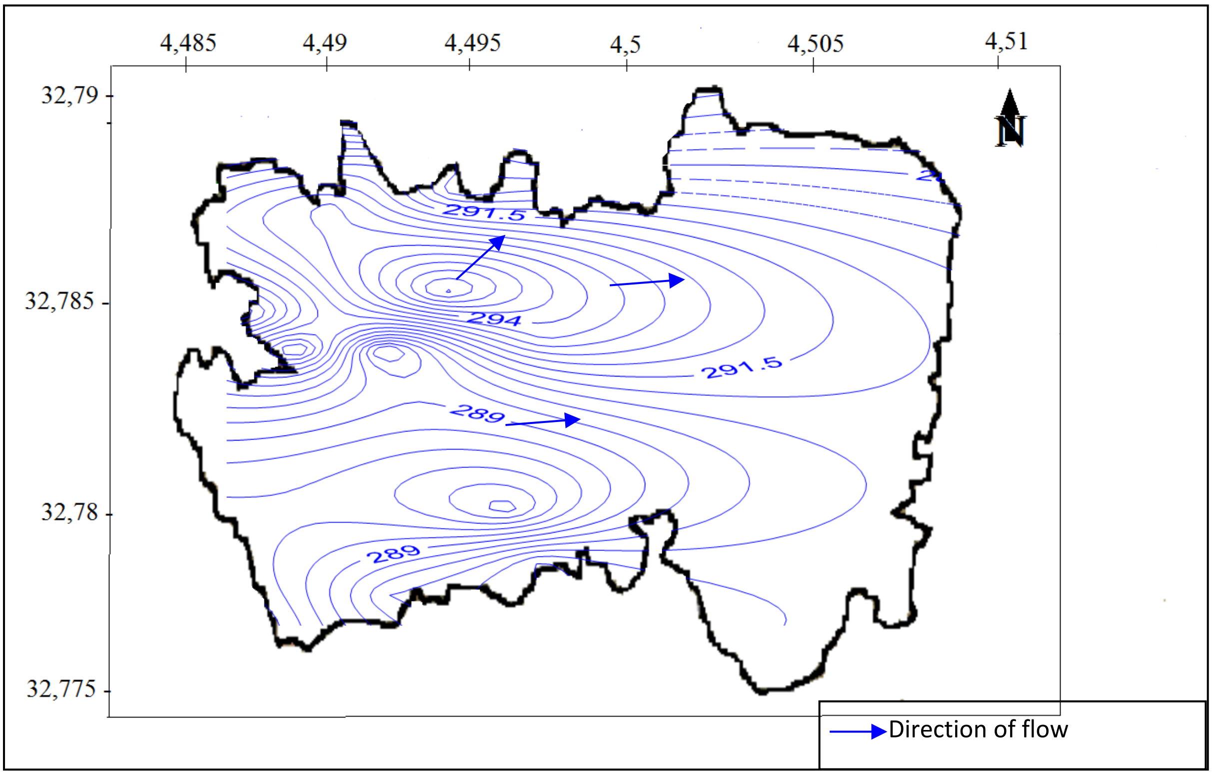

Figure 7. Piezometric map (October 2012)

The piezometric map of groundwater established during october 2012, shows that the direction of the main flow of water from the alluvial groundwater is generally a direction Southwest to Northeast and East. The piezometric map drawn up in April 2013 has the same piezometric morphology than the previous map; this is due to the low charging which cannot bridge the drainage of the groundwater. However, there were fluctuations of the groundwater at the west side of the study area and sometimes a few disturbances due to pumping.

CONCLUSION

The quaternary aquifer of Guerrara region consists of alluvial sandy and clay in some places, with an average thickness of 20 to 35m, and containing an alluvial (shallow) groundwater. Thirty water samples investigated along the study area.The results have identified many differences level of pH values, temperature and electrical conductivity (EC). EC has a significant representation in the sample water and reached 11.63 dS/m. The chemical survey of groundwater enabled to identify the natural mineralization of water, which determined by the lithological formations enclosing hydrodynamic conditions of the groundwater following climatic factors. The statistical survey showed that EC was highly correlated with total mineralization of the water. Piper diagrams suggest that most of the samples are chlorinated and calcium sulfate and magnesium types. The waters of this alluvial aquifer are hard to very hard, often encrusting and used for irrigation with a moderate risk of alkalizing soil. The piezometric survey consisted to measurements of geographical coordinates, altitude and depth of water in each well. This allowed to tracing of piezometric maps of the two companions and determining the direction of flow. Finally, it should be noted that the work on the shallow (or alluvial) aquifer of Guerrara needs to be pursued by other studies on functioning of these shallow aquifer.

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