

Geochemistry of the Groundwater of the Temara Aquifer (North-West Morocco)

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ABSTRACT

Water is a major strategic issue and a key factor in sustainable development for all countries around the world. In Morocco, groundwater has a major importance in the national economic policy. For this reason, sustainable water resources management programs are periodically installed to prevent their qualitative and quantitative degradation, which conditions future development and is part of the research strategy to optimize and mitigate environmental problems. The Temara water table, which extends over nearly 350 km² is part of these water resources that must be preserved. This issue is of increasing concern to researchers and decision makers in the field of water resources management. The hydrochemical study carried out on 48 samples taken in the study area during a sampling campaign carried out during the low water period showed that the water table has facies of chloride and sulphate calcic and magnesian type according to the Piper diagram. While the classification diagrams of Wilcox and Richards waters revealed the suitability of these waters for irrigation except for some points that present high contents of Nitrate (NO₃⁻), Magnesium (Mg²⁺), Sulphate (SO₄²⁻) and Chloride (Cl⁻), linked to both the lithological nature of the enclosing formations and the effect of the agricultural activity which induces the phenomenon of return of irrigation water loaded with salts from the fertilizers used, towards the water table.

Keywords: groundwater, Piper diagram, Wilcox diagram, Richards diagram, hydrogeochemical analysis.

INTRODUCTION

Groundwater is a very precious natural resource. It is becoming increasingly scarce and vulnerable all over the world, due to its overexploitation and its use in domestic, industrial and agricultural fields. The unprecedented demographic and urban growth and the changes in lifestyles, accentuate this problem. In the coming decades, access to drinking water will become one of the major concerns in the world.

Morocco is the 23rd most threatened country by water scarcity according to the latest report of the World Resources Institute [WRI, 2015]. Groundwater resources are not exempt from this problem. They constitute a considerable part of

the hydraulic heritage of the country [Matee, 2001; Belghiti et al., 2013], because of their importance whether in the field of drinking water supply or irrigation. Thus, even if a large part of the population is served with drinking water, the consumption of water from wells and natural springs is still essential in rural areas and even in urban areas when it comes to public use such as public baths [Sadeq et al, 2021].

Despite its deep circulation, which makes it less exposed to the risks of pollution unlike surface water [Li et al., 2018; Wang et al., 2019; Arya et al., 2020], groundwater remains susceptible to intrinsic pollution due to land use and various anthropogenic activities [Voudouris et al., 2010; Aravinthasamy et al., 2019; Tomer et al., 2019].

The Skhirate-Temara region our study area, has rapidly transformed from a rural region with economic activity focused on agriculture, to an urban extension attached to the Rabat prefecture. The only water resource that feeds the area is the water table of Skhirate-Temara. It is a well individualized water table on the hydrogeological level. It is therefore a natural wealth that must be preserved.

The objective of this work is the characterization of the water table of Skhirate-Temara on the hydrogeochemical level by identifying the chemical facies of the water table and determining the factors responsible for their mineralization while assessing the suitability of these waters for irrigation and human consumption.

For this purpose, a sampling campaign was carried out on several waterworks covering the study area. The samples taken were subjected to various physicochemical analyses according to standardized methods [Conture, 2004]. The contents of the different parameters are mapped and then plotted on the different diagrams intended for this type of study (Piper, 1944; Wilcox, 1955; Richards, 1954). The different representations allow to characterize the waters of the aquifer of Skhirate-Temara on the hydrogeochemical level

and to compare them to the quality standards of the WHO (2011). This comparison is based on the use of these waters (irrigation or human food).

STUDY AREA

Geographically, the study area is part of the Skhirat-Temara sector is limited to the Southeast by Oued Akrach, to the Southwest by Oued Ykem and to the Northwest by the Atlantic Ocean. The aquifer belongs to the coastal strip and is part of the Bouregreg watershed which covers an area of about 9,970 km² (Fig. 1). This area has been rapidly transformed from a rural region with economic activity focused on agriculture to an urban extension attached to the prefecture of Rabat. This area includes the city of Rabat, the political capital of the Kingdom, the city of Skhirate-Temara and 13 communes and the overall number of inhabitants amounts to 1,049,672 [RGPH, 2014].

The region is characterized by a Mediterranean type climate, semi-arid with marine influence. The geographical distribution of rainfall highlights the triple influence, of latitude, distance from the sea and altitude. The average annual precipitation is relatively low, reaching 555 mm in the study area,

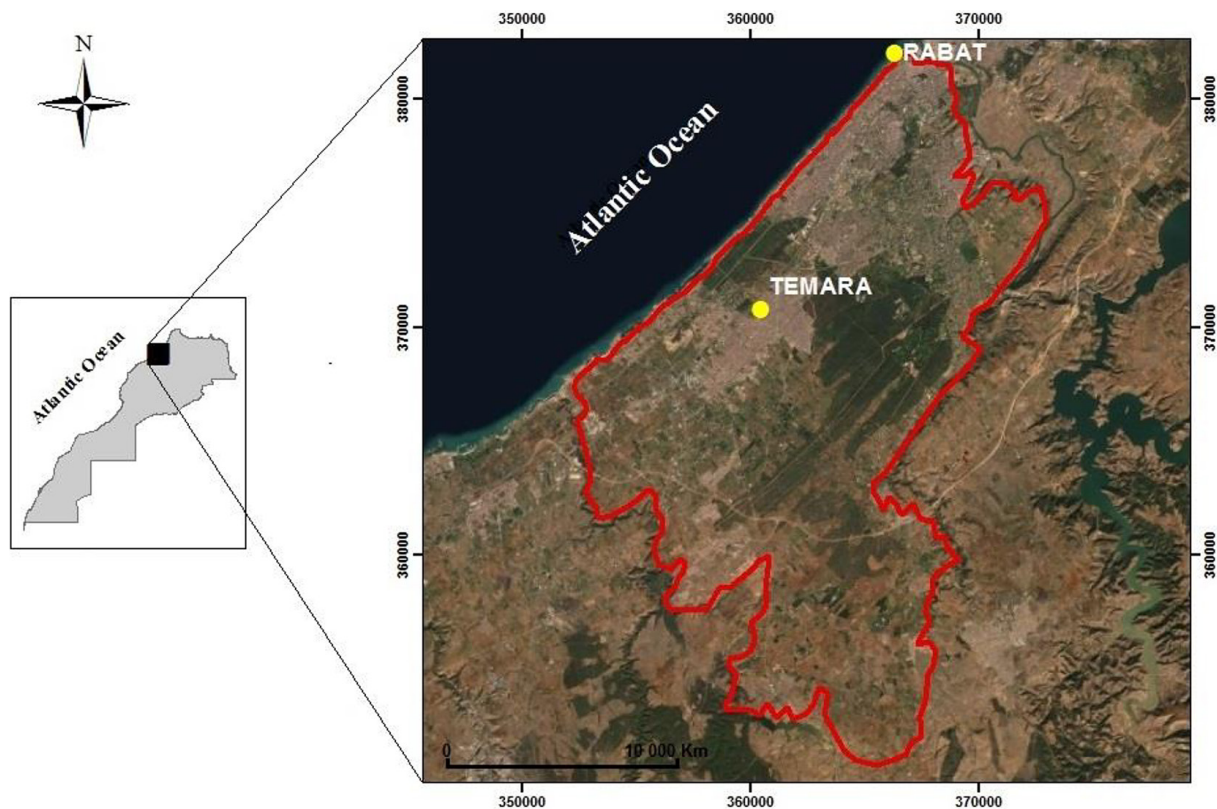


Figure 1. Map of the geographical location of the study area

and the average temperatures reflect a fairly mild climate without extreme temperatures. At the Rabat station, the average monthly temperatures vary from 12.6°C to 24°C [Taazzouzte et al., 2021].

Geologically, the study area is part of the Moroccan coastal Meseta, which consists of plains and plateaus. The dominant morphology is a stepped morphology sloping towards the Atlantic and extends from Rabat to the vicinity of Safi.

A system of barrier beaches covers these terraces. These strips are composed of calcarenites, plio-quaternary of marine and eolian origin [Beaudet and al., 1967; Beaudet, 1969; Stearns, 1978; Akil, 1980; Lefèvre et al., 2002]. The primary terrains are strongly folded, tectonized and flattened by Hercynian orogeny [Combe, 1963]. Between the primary strand and a line of dead cliffs is a gutter or furrow, a depression more or less parallel to the coastline, commonly referred to as the “Oulja” [Guilcher et al., 1954; Weisrock et al., 1991; Weisrock, 2012] (Fig. 2). The first characterizations of the Quaternary formations that constitute the Moroccan coastline were established by Gentil (1918) and Lecointre (1918–1926) [El Hajraoui and al., 2012].

The determination of the hydrogeological context is made from the examination of geological data that provide information on the geological formations likely to form a reservoir for groundwater.

The aquifer of Skhirate-Temara contains a water table developed in the formations of the Tertiary cover. It is a well individualized aquifer on the hydrogeological level. It extends over nearly 350 km² and is inserted between the deep valleys of Oueds Bouregreg and its tributaries, Oueds Akrach and Ykem and the Atlantic Ocean [Amraoui, 2000]. The Plio-quaternary is present everywhere in the region; however it contains the water table only in some sectors. It is recognizable by its facies formed of sandstone, more or less consolidated sands and sandstone limestones, and covers the entire extent of the Skhirate-Temara nappe. It rests on Miocene gray marls in the part located north of the road Skhirate-Temara-Sidi Yahia Zaër. South of this axis, the Miocene marls are totally eroded and the Plio-quaternary lands rest directly on the Primary formations.

The Skhirate-Temara water table is a free water table fed by rainfall. The piezometric levels in

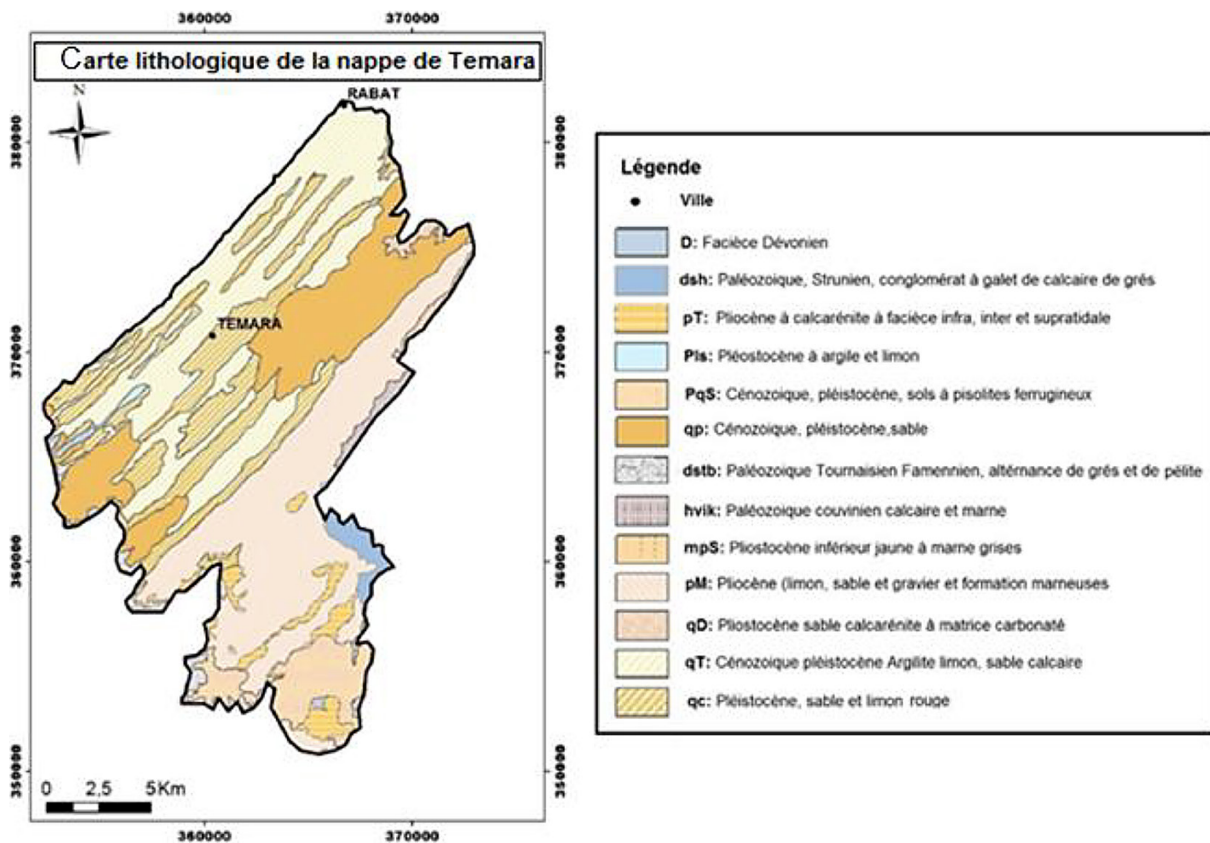


Figure 2. Geological map of the study area (Extracts from the geological maps of Rommani and Rabat at 1:100,000; Modified) [Taazzouzte, 2020]

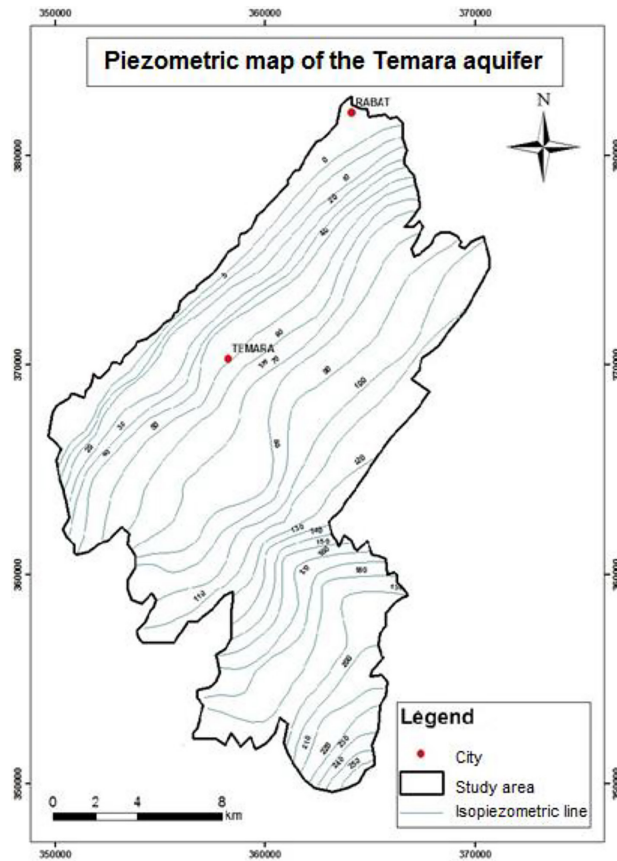


Figure 3. The piezometric map of the study area

48 wells covering the entire water table are obtained from the measurement of the water level in relation to the ground for each water point. In our study, the measurements are taken with an electric probe. From these measurements we have established a piezometric map of the low water period.

The latter allowed us to determine the direction of the general flow of the water table, which is from the southeast to the ocean in the northwest (Fig. 3).

METHODOLOGY

In the present work, a sampling campaign was carried out during the low water period. The said campaign concerned 42 wells and 6 piezometers of control which capture the aquifer of basement of the sector Skhirate-Temara. The following map represents the spatial distribution of the water points (Fig. 4).

The geographical coordinates of the structures were obtained using a GPS (GARMIN) programmed and the samples were taken on the various structures using a shoe and a rope. The samples

were placed in plastic bottles that had been rinsed beforehand. This step is very important and must be done with great care. The samples were then stored in a cooler containing ice and transported directly to the laboratory. During this study, the following parameters were determined.

Physico-chemical parameters

These parameters were measured in situ using a Palin test pH meter and an EUTECH INSTRUMENTS conductivity meter (Cyber Scan com. 110).

The pH is a factor depending on the natural conditions of the environment, such as: vegetation cover, nature of rocks, soil substrate and human activities namely pollution [Reggam, 2015]. It is an indicator of alkalinity and acidity of waters. The pH is the cologarithm of (H^+) and corresponds to the concentration $[H^+] = [OH^-] = 10^{-7}$.

The measurement of the temperature (T°) was made, for each test sample using a temperature probe (thermometer).

Electrical conductivity (EC) is a physico-chemical characteristic. It gives information on the mineralization of water. It is linked to the

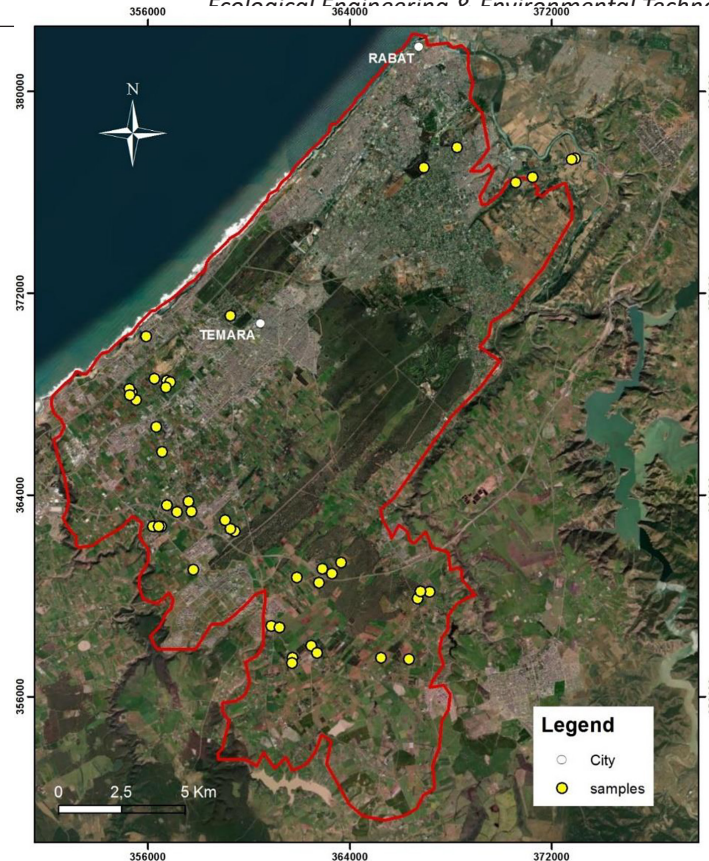


Figure 4. The spatial distribution of the water points

concentration of dissolved substances and their nature. A portable conductivity meter is used to determine the conductivity.

The electrical conductivity is measured after rinsing the electrode several times, first with distilled water and then by immersing it in a container containing the sample. The electrode must be completely immersed. The conductivity result is given in $\mu\text{s}/\text{cm}$ [Rodier and al., 2005].

Calcium (Ca^{2+}) comes from the dissolution of carbonate and gypsum formations [Gouaidia, 2008]. The concentration of Calcium (Ca^{2+}) ions is obtained by complexometry with Ethylene Diamine Tetra-Acetic Acid (EDTA).

Magnesium (Mg^{2+}), from a chemical point of view, is similar to Calcium, it is therefore often present in carbonate rocks, evaporite rocks (magnesium salts), and magmatic rocks. Magnesian minerals are less soluble than calcium-containing minerals. In magnesian carbonate rocks (Dolomite), Mg^{2+} concentrations are of the order of a few tens of mg/l . Evaporite aquifers rich in magnesian minerals can contain high levels of Magnesium, from a few hundred mg/l to a few g/l . In magmatic rocks the concentrations are generally lower, from a few mg/l to a few tens of mg/l [Rodier and al., 2009].

The Mg^{2+} concentrations are obtained by a calculation from the total hardness since it corresponds to the sum of the Calcium and Magnesium concentrations.

Sodium (Na^+) and Potassium (K^+) ions, the 6th and 7th most abundant elements in nature, are in very variable proportions. For drinking water, there are no standards or limits to the concentration of Sodium. Sodium also plays an important role in agriculture for irrigation, because of its action on soil permeability. Potassium, much less abundant than Sodium, is rarely present in water at levels above $20 \text{ mg}/\text{l}$. It does not represent any particular disadvantage although Potassium is one of the possible sources of radioactivity in water [Tardat and al., 1984; Potelon and al., 1998]. In general, the Sodium ion (Na^+) comes from the leaching of evaporitic deposits, from evaporation phenomena, and from sea water. Potassium (K^+) and Sodium (Na^+) concentrations are analyzed by atomic absorption using a HACH flame spectrophotometer.

Chlorides (Cl^-) gives an idea of the aggressiveness and mineralization of water. It even modifies the taste of the water and contributes to the deposition of salts harmful to agriculture at high levels [Mizi, 2006]. Chlorides are

measured in neutral medium by a titrated solution of silver nitrate in the presence of potassium chromate. The end of the reaction is indicated by the appearance of the characteristic red color of silver chromate.

The waters of the free tables as all the natural waters contain sulfates (SO_4^{2-}), in very variable proportion. Their presence results from the solubility of Calcium Sulfates in gypsum rocks and from the oxidation of sulfur-rich sulfides (pyrites (FeS_2)) found in all types of lithology (limestone, sand, magmatic rocks) [L'Hopitault and al, 1981]. In the captive aquifers, sulphates are present in their reduced forms (H_2S) at rather high levels going up to tens of mg/l. Sulfates can also come from the leaching of evaporite formations such as gypsum [$\text{CaSO}_4 \cdot 2(\text{H}_2\text{O})$] with very high levels [Rodier and al., 2009]. The samples were analyzed colorimetrically using a HACH LANGE spectrophotometer.

The alkalinity (HCO_3^-) of a water corresponds to its capacity to react with hydrogen ions (H^+) which is due to the presence of hydrogen carbonate (HCO_3^-), carbonate (CO_3^{2-}) and hydroxide (OH^-) ions.

Depending on the pH, there are two types of alkalinity:

- the alkalinity at the turn of the methyl red: it corresponds to the total alkalinity at pH 4.5, which is to determine the HCO_3^- , CO_3^{2-} and OH^- ions. This alkalinity or full alkalimetric titre TAC [Alloune, 2013].
- alkalinity at the phenolphthalein turning point (composite alkalinity).

It corresponds to the alkalinity entrained by OH^- ions and half of the CO_3^{2-} ions. This

composite alkalinity or alkalimetric titre is null for a water whose pH is lower or equal to 8.3 [Rodier, 1996; Tardat, 1948 and Ronalad, 2003]. The concentrations for this parameter are obtained from titrimetry with sulfuric acid using a HACH digital titrator.

Nitrates (NO_3^-) are naturally present in water. Excessive or poorly controlled inputs of nitrogenous fertilizers cause an increase in nitrates in the resources. The nitrate concentrations were obtained by colorimetry using a HACH LANGE spectrophotometer.

All these analyses were performed following the protocol described by Jean Rodier (2009).

The data are plotted on Piper, Wilcox and Salinity (SAR) diagrams, using Diagrammer software, a hydrochemistry software that facilitates the representation of results and therefore their interpretation.

The geochemical study carried out in this work focuses on the distribution of physico-chemical parameters of the water table and the comparison of the results obtained with the standards relating to the quality of water intended for human consumption and irrigation.

For this reason, the mapping of the spatial distribution of chemical parameters in the study area will be of great importance before proceeding to the identification of the chemical facies of groundwater and the evaluation of their suitability for irrigation.

The contribution of mapping to the qualitative study is of great use since it allows to have a spatial vision of the distribution of the studied elements in the study area and to quickly evaluate their distributions [Latifi, 2018].

Table 1. Presentation of the values of the different pollution indicator parameters in relation to the WHO standards

Chemical parameters	Ionic concentrations			
	Minimum values	Maximal values	Mean values	Norms (OMS, 2011)
T°C	20.6	31.2	24.46	35
PH	6.65	7.85	7.33	6.5–8.5
CE ($\mu\text{S}/\text{cm}$)	4120	4070	5780	500
Ca^{2+} (mg/l)	10.8	72.8	52.19	200
Mg^{2+} (mg/l)	19.4	49.9	42.2	50
Na^+ (mg/l)	0.61	63.4	15.57	200
K^+ (mg/l)	0.64	96.9	31.57	200
SO_4^{2-} (mg/l)	19.8	116	38.62	250
HCO_3^- (mg/l)	142	392	330.66	500
Cl^- (mg/l)	88.8	671	172.13	250
NO_3^- (mg/l)	0.5	168	91.96	45

RESULTS AND DISCUSSIONS

The concentrations of pollution indicator parameters are measured according to standardized methods (Test method or measurement established by national or international technical rules described by experts) [Conture, 2004].

The following table presents the results of the measurements of the different physical and chemical parameters and the corresponding standards.

Physical parameters

Temperature T° remains standard in the whole area and the average does not exceed 25°C , values below the standards [WHO, 2011].

pH – at the level of the study area, the average values of this parameter are 7.33. This is a slightly alkaline pH that does not represent a large variation for the majority of the water in the aquifer. This alkalinity results from the abundance of limestone formations in the aquifer of Skhirate-Temara.

Electrical conductivity (EC) – the average value of this parameter exceeds $5000\ \mu\text{S}/\text{cm}$. Therefore, the high values of this parameter seem to result from the leaching of the reservoir rock in which the water stayed. A water is contaminated by marine intrusion when its electrical conductivity is greater than $5\ \text{mS}/\text{cm}$ [Najib, 2014].

Spatial distribution of chemical parameters in the study area

Calcium

The highest Ca^{2+} ion values are focused to the southeast of the aquifer and to the south towards the coastline. These concentrations are due to the presence of carbonate formations such as calcite (CaCO_3) and dolomites ($\text{CaMg}(\text{CO}_3)_2$) of the Plio-quadernary which form an aquifer in several parts of the area. They may also have an origin related to the dissolution of gypsum formations (CaSO_4). The average value of $52\ \text{mg}/\text{l}$ observed in the area, does not exceed the WHO standard ($200\ \text{mg}/\text{l}$) for the quality of water intended for drinking water production (Fig. 5).

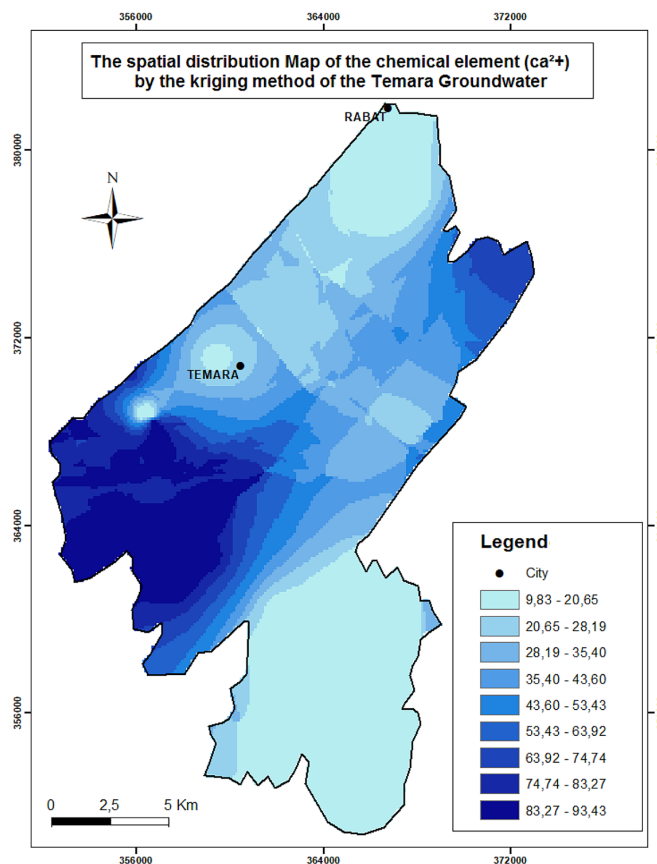


Figure 5. Map of spatial distribution of Ca^{2+} in the study area

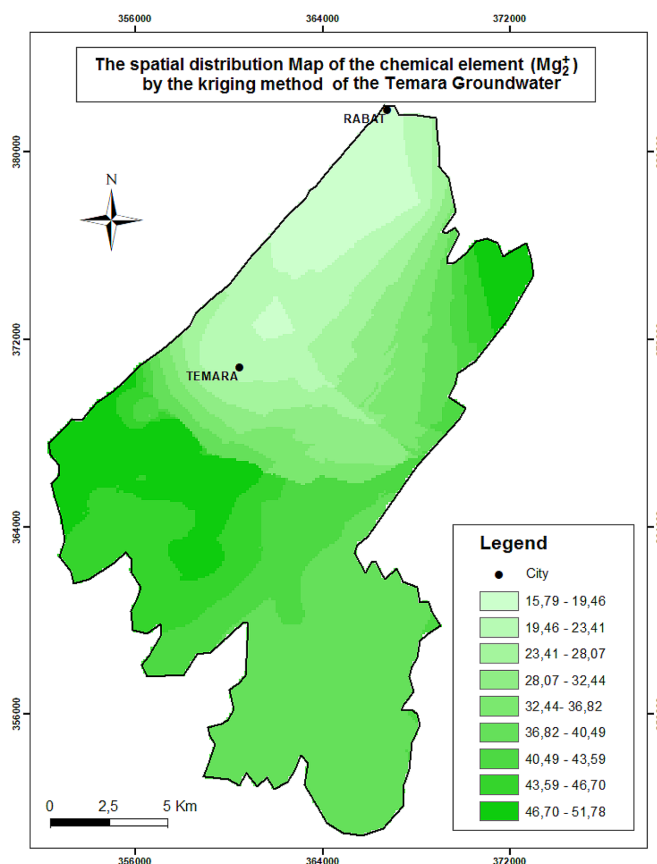


Figure 6. Map of spatial distribution of Mg^{2+} in the study area

Magnesium

Like calcium, magnesium is involved in the total hardness of water. It is present in carbonated limestone ($MgCO_3$) and in gypsum. The highest Mg^{2+} values are concentrated in the South and South-East of the water table and extend towards the coast, while the average value (42 mg/l) is close to the standard set by the WHO (50 mg/l). The spatial distribution of magnesium levels in groundwater is similar to that of calcium levels. This is due to their common origin (Fig. 6).

Sodium

The origin of sodium is mainly related to the dissolution of salt formations according to the reaction ($NaCl \rightarrow Na^+ + Cl^-$) and to the effect of marine intrusion. It is one of the most undesirable alkali metals for treated and irrigation waters [Conture, 2004]. The highest value of Na^+ (63.4 mg/l), are mainly focused in the southwest of the aquifer (Ain Atig, Mers Elkhir and Tamesna). In this part of the study area, the phenomenon of marine intrusion is very important due to the proximity of the Atlantic Ocean and the presence

of weaknesses related to past tectonic events, and the presence of sedimentary formations of the Plio-quaternary (stratification joints) that rest on the schistous terrain of the Primary [Mohr, 2010], which facilitates the underground flow of water. Added to these phenomena is the over-pumping of the water table in these areas. The average sodium values in the area are estimated at 15.57 mg/l, well below the WHO drinking water standard of 200 mg/l at this low water period (Fig. 7). The main problem that can cause the accumulation of sodium in groundwater (sodification), is the stagnation of water on the surface of the soil, which leads to a high osmotic pressure of the water. This phenomenon prevents the absorption of water by the roots [Rabilou et al., 2018]. For water intended for human consumption, the amount required is less than (200 mg/d) for children and (2000 mg/d) for adults [BelghitI et al., 2013].

Potassium

Potassium (K^+) is quite abundant on earth (silicate minerals, potassium feldspars, micas, clays...). The average content of K_2O is estimated at 3.2%.

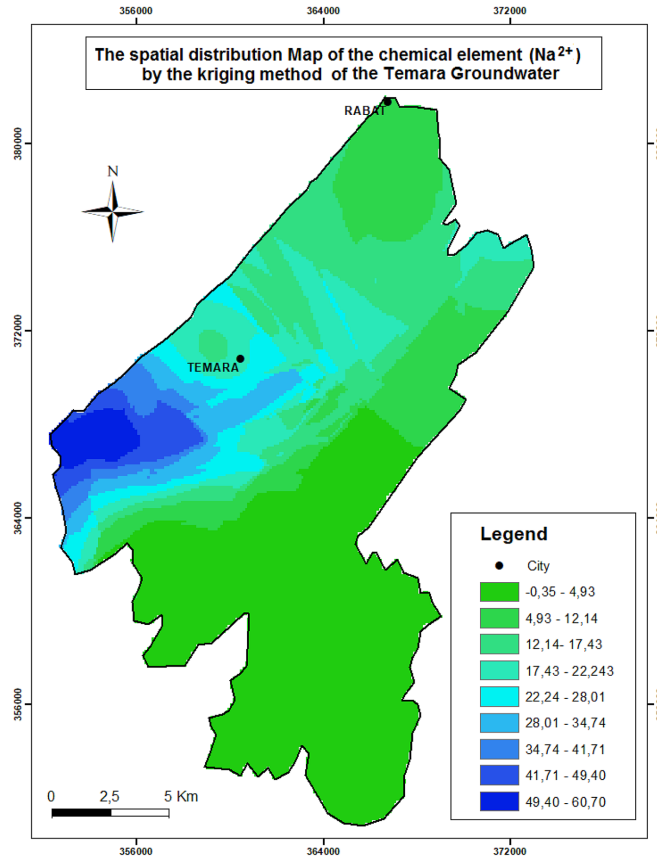


Figure 7. Map of spatial distribution of Na^+ in the study area

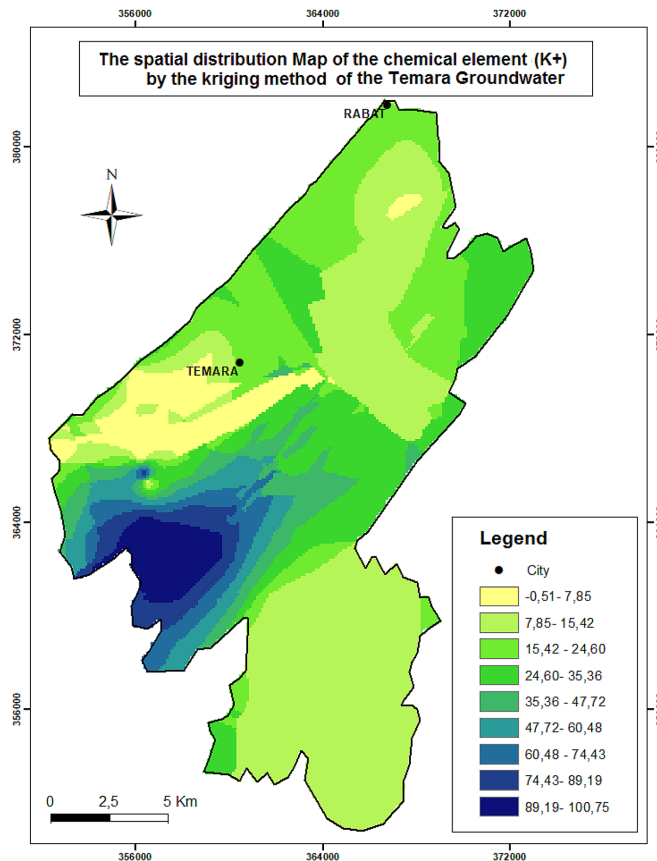


Figure 8. Map of spatial distribution of K^+ in the study area

Potassium can well characterize a soil since an acidic soil is poor in potassium compared to a basic soil [Mhiri, 2002]. It results from the alteration of potassium clays and the dissolution of some chemical fertilizers widely used in vegetable crops such as (NPK).

The highest content (96.9 mg/l) is found in the south-western part of the study area, in Ain Atig, Tamesna and Mers Elkhir. This area rich in agricultural activities produces a large amount of mineral salts from fertilizers and fertilizer. These are reinfiltred into the water table by the phenomenon of backflow or reverse circulation of irrigation water. The average concentration throughout the area is relatively low (31.57 mg/l). In all cases, the K^+ values do not exceed the standards set by the WHO (200 mg/l) (Fig. 8).

Sulfate

Sulfate or sulfuric acid SO_4^{2-} in groundwater can have a geological or anthropogenic origin [Natal, 2000]. The geological origin is related to the dissolution of gypsum which produces equal amounts of calcium ions and sulfate according to the reaction: $CaSO_4 \cdot 2H_2O \rightarrow Ca^{2+} + SO_4^{2-} + 2H_2O$.

[Belkhiri et al., 2014]. In the waters of the aquifer of Skhirate-Temara, the highest value in SO_4^{2-} (116 mg/l) is focused in the Southeast of the aquifer, with an average of 38.62 mg/l. These values are important but remain below the WHO standard (250 mg/l) (Fig. 9).

This part of the aquifer coincides with the mouth of the Bouregreg wadi where large quantities of urban waste are discharged. Thus, in addition to the geological nature of the land (consisting of gypsum), domestic discharges and fertilizers used in agriculture promote the continuous increase of sulfates in the water table.

Bicarbonates

The presence of bicarbonates (HCO_3^-) in the water is due to the dissolution of the abundant carbonates in this part of the area by water containing CO_2 according to the reaction: $CaCO_3 + H_2O + CO_2 = 2HCO_3^- + Ca^{2+}$.

The highest values of HCO_3^- (330.66 mg/l) are concentrated in the south-east of the aquifer and at Sidi Yahya Zaër, Mers Elkhir (Fig. 10).

These values result from chemical exchanges between rocks and groundwater. The

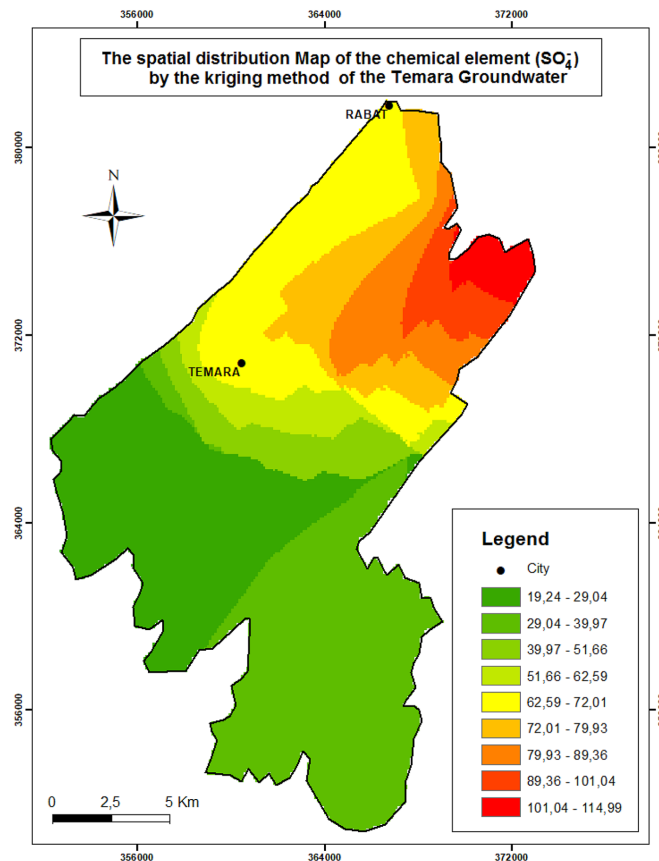


Figure 9. Map of spatial distribution of SO_4^{2-} in the study area

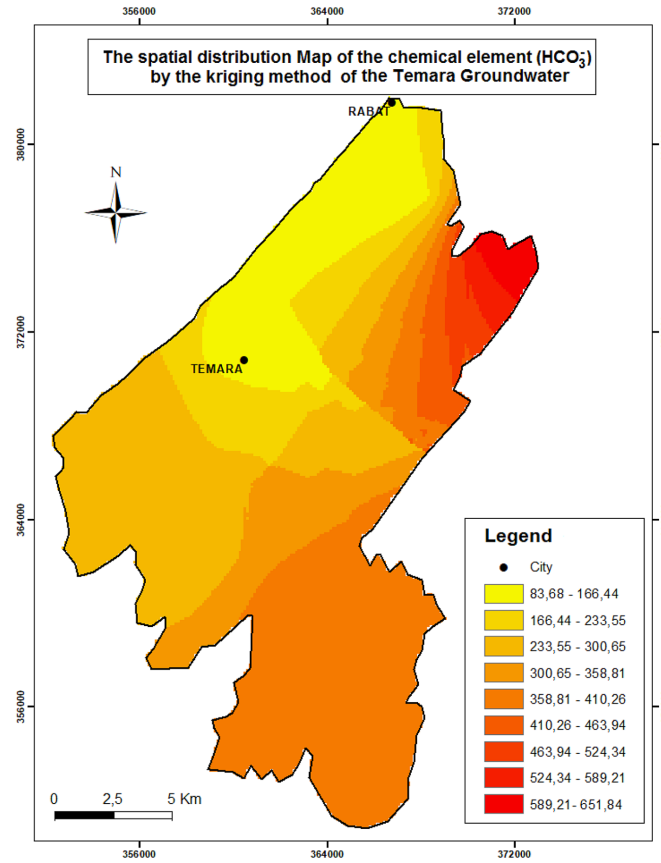


Figure 10. Map of spatial distribution of HCO_3^- in the study area

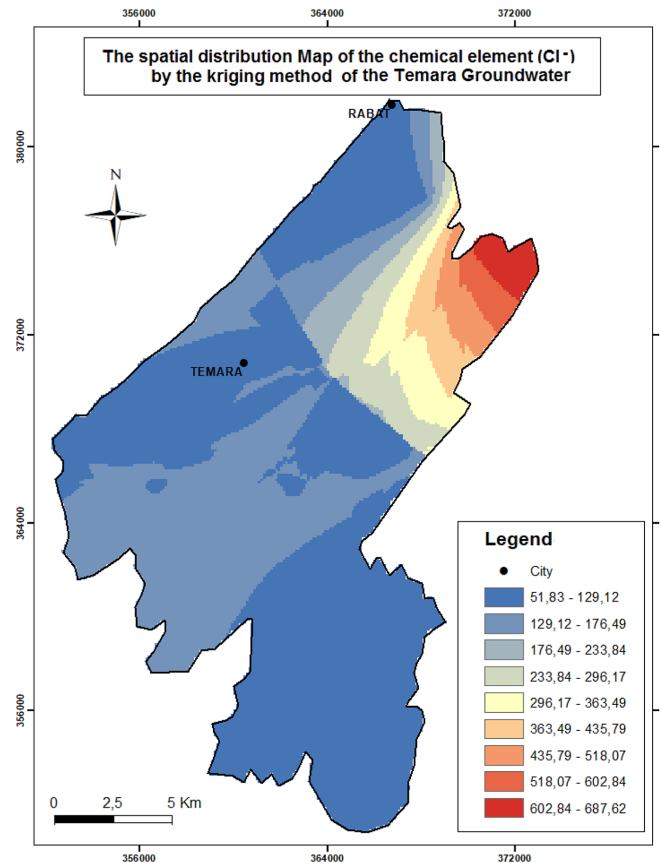


Figure 11. Map of spatial distribution of Cl^- in the study area

HCO_3^- ions could also come from the process of transformation of carbonic acid into bicarbonate as well as from the hydrolysis of silicate minerals that produces bicarbonate [Bekkousa et al., 2013].

Chlorides

Chlorides are always present in natural waters in highly variable proportions [Najib, 2014]. The highest values of Cl^- are focused in the southeast of Rabat and around Bouregreg. The highest value is 671 mg/l. Generally, the high chloride contents may be due to the dissolution of natural salts from the leaching of the Miocene marl (gray marl) and clay formations present in this part of the area. These values can cause acidification of water and soil. The majority of the area of the water table has low piezometric levels, so that the return of irrigation water to the water table in this period of low water, easily generates the infiltration of this water loaded with salts. For the rest of the study area the average is 172.13 mg/l, below the WHO standards (250 mg/l) (Fig. 11).

Nitrate

Nitrates are good indicators of any pollution related to agriculture. Nitrate concentrations in groundwater are related to the intensive use of nitrogen fertilizers. These concentrations are increasingly high in shallow aquifers where there is a continuous input of nitrogenous fertilizers from agriculture [Mariotti, 1994].

Far from the northern part where urban development is intense, the south-western areas of the aquifer up to the coast (Ain Atig, Mers Elkhir, Sidi Yahya Zaïre) have a significant agricultural activity. This activity combined with the low depth of the water table favors the infiltration of irrigation water rich in nitrates, especially during the low water period, during which the leaching caused by rainwater is absent. The highest concentration of NO_3^- in the waters of Skhirate-Temara is (168 mg/l) while the average is (91.96 mg/l). These levels far exceed the standard of potability (50 mg/l) (Fig. 12).

In general, the distribution of chemical parameters by order of highest content, shows interference since the south-eastern part which extends from the south of El Menzeh to the mouth

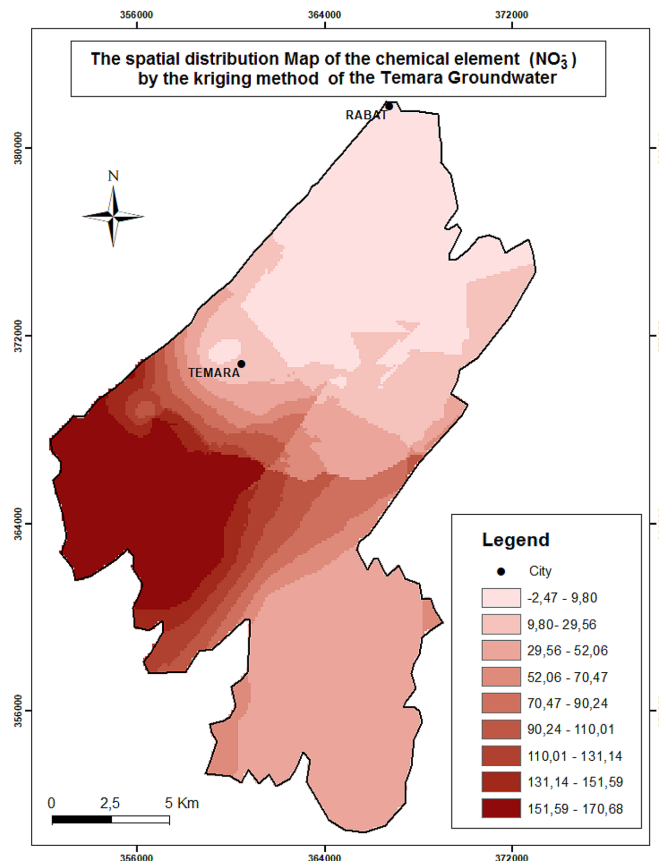


Figure 12. Map of spatial distribution of NO_3^- in the study area

of the Bouregreg river, knows very high content of HCO_3^- , Mg^{2+} , Cl^- and SO_4^{2-} . The same elements are found with high concentrations in the south-western area covering Tamesna and the limits of the Ykem wadi towards the coast. The southern part (represented by Sidi Yahya Zaër) shows average levels for all elements.

While the northern and central parts show low levels because they are occupied by the forest of El Menzeh is the settlements (City Skhirate-Temara and Harhoura and Rabat).

IDENTIFICATION OF THE CHEMICAL FACIES OF THE WATER TABLE AND CLASSIFICATION ACCORDING TO THE DEGREE OF SUITABILITY FOR IRRIGATION

The results of the analysis of chemical parameters, are reported on diagrams specific to any geochemical study that aims at the classification of groundwater through the software “Diagrams”. This facilitates the exploitation and processing of analytical results.

Identification of the chemical facies of the groundwater

The representation of the chemical data on the Piper diagram makes it possible to determine the chemical facies of all the water samples. This diagram is made up of two triangles representing the cationic and anionic facies and a rhombus synthesizing the overall facies [Piper, 1944] (Fig. 13).

In general, the distribution of chemical parameters in order of highest content shows great interference. The south-eastern part which extends from the south of El Menzeh to the mouth of the Bouregreg river, which has very high levels of HCO_3^- , Mg^{2+} , Cl^- and SO_4^{2-} . The same elements are found with high concentrations in the southwestern area covering Tamesna the limits of Oued Ykem going to the coast. The southern part (represented by Sidi Yahya Zaër) shows average levels for all elements.

While the northern and central parts show low levels of the fact that this part is occupied by the forest of El Menzeh, forest Skhirate-Temara

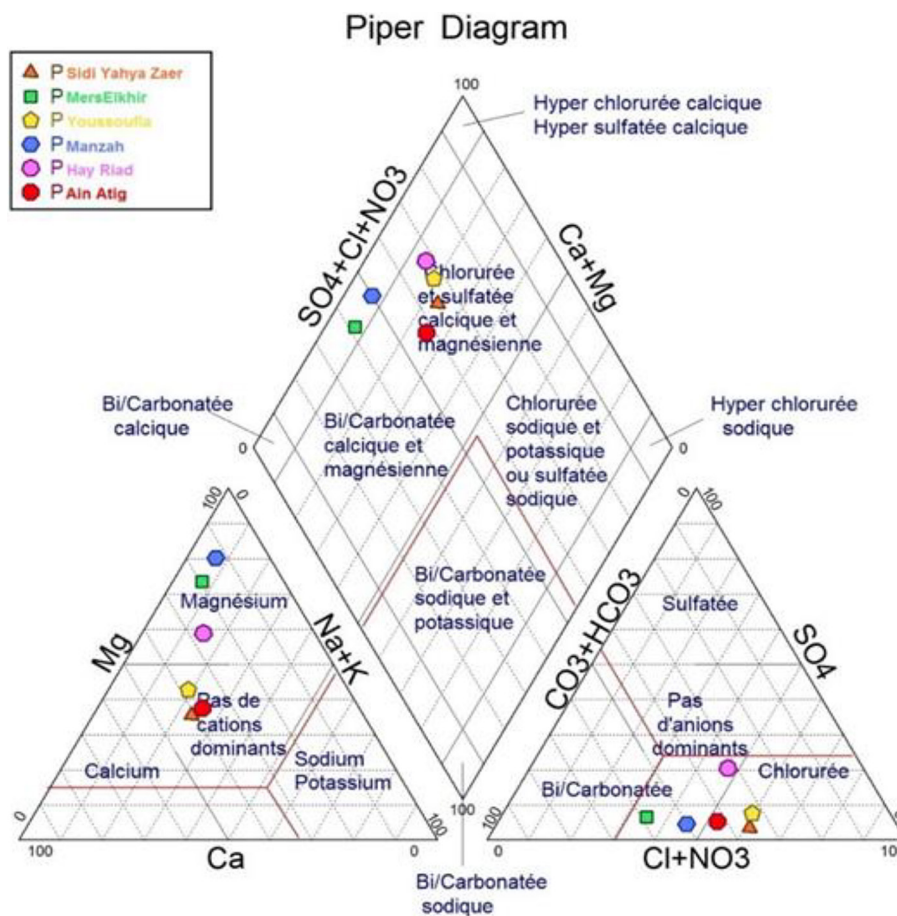


Figure 13. Chemical facies of the waters in the study area

and Harhoura which reduces the anthropic impact is the settlements.

Classification according to the degree of suitability for irrigation

Classification according to the Wilcox diagram – the diagram of (Wilcox, 1955; Todd, 1980) allows the evaluation of the salinity of groundwater for irrigation by representing the percentages of sodium (Na⁺) in the water according to the electrical conductivity (Fig. 14).

This percentage is calculated according to the following formula (Equation 1) [Wilcox, 1955]:

$$\% NA = \frac{Na^+ + K^+}{(Ca^{2+} + Mg^{2+} + Na^+ + K^+)} \times 100 \quad (1)$$

The classification according to the Wilcox diagram allows to estimate the suitability of the water table for agricultural use according to the following Table 2.

The Wilcox diagram shows that the majority of points are located in the category of good quality 44% and excellent 24%. This is justified by the fact that the campaign is carried out in low water period at the level of Ain Atig, and Oulad Kassem. On the other hand, the water points 9, 16, 17 present a poor quality with a high conductivity and significant sodium content. These are located in areas with agricultural vocations (market gardening) that use sodium-based fertilizers.

Classification of irrigation water according to the Richards Richards diagram

The SAR (Sodium Absorption Ration) or classification diagram of irrigation water or alkalizing power. It reports the ratio of sodium and alkaline earth concentration to the conductivity of the applied water [Latifi, 2018]. This classification is used to determine the sodification risks of waters (Fig. 15) [Todd, 1980; Souleymane et al., 2020].

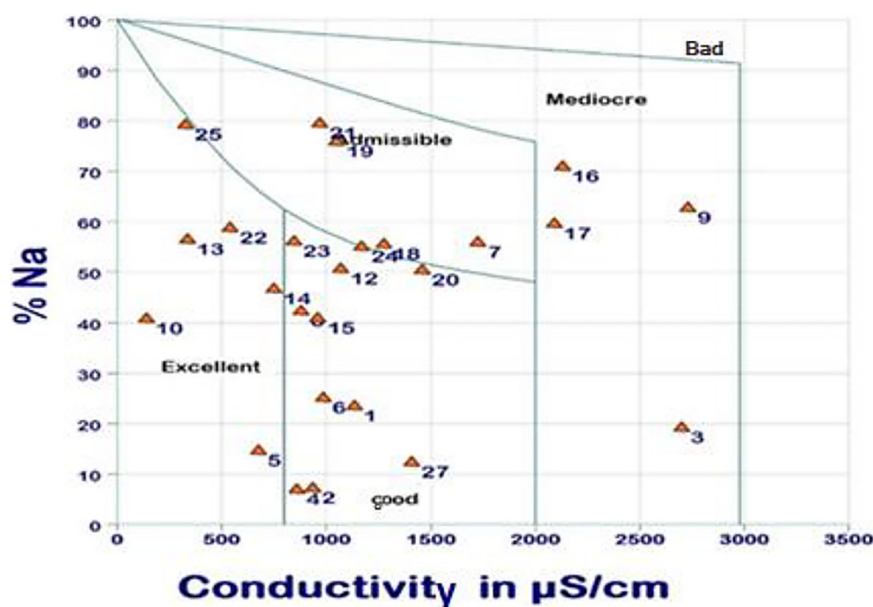


Figure 14. Representation of the results of analysis by Wilcox diagram

Table 2. Classification of the water table of Skhirate-Temara according to the Wilcox diagram

% Na/Conductivity (Wilcox, 1955)	Category	Numbers of water installations	Proportion
<20	Excellent	6	24%
20–40	Good	11	44%
40–60	Eligible	4	16%
60–80	Poor	4	16%
>80	Poor	-	-

Table 3. Classification of water table Skhirate-Temara according to the diagram of (Richards, 1954)

SAR/ Conductivity (Richards,1954)	Category	Numbers of water installations	Proportion %
0–6	Excellent	21	84
6–9	Bonne	3	12
>9	Admissible	1	4

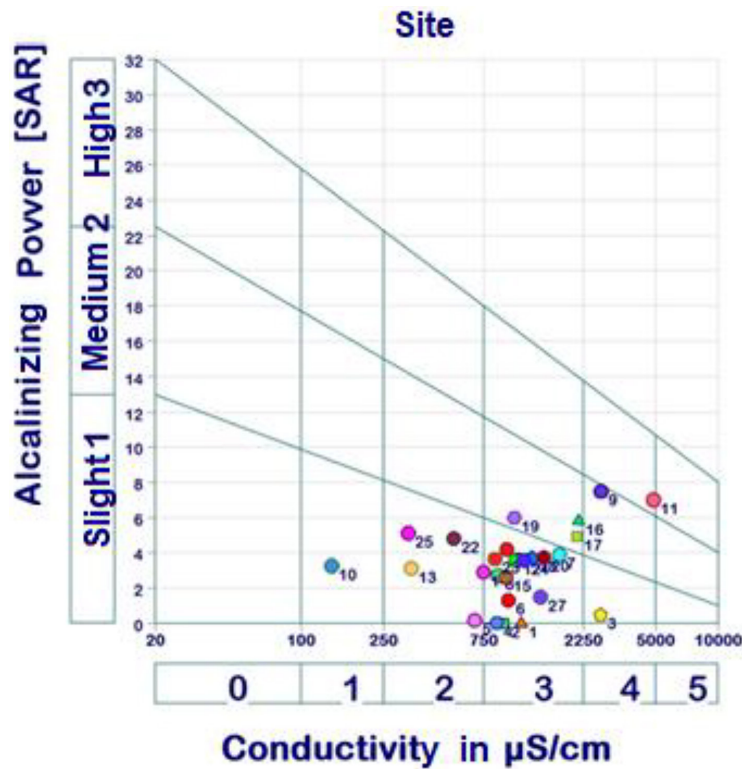


Figure 15. Representation of the analytical results by Richards diagram

SAR is calculated from the following formula (Equation 2) [Richards, 1954].

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

Table 3 presents the classification of the water table from the point of view of quality according to the diagram [Richards, 1954].

The majority of points 84% have an excellent quality for agricultural use with some exceptions, 3% are classified in the good category and 1% in the admissible category.

DISCUSSION

The transfer of analytical results on the Piper diagram shows that the waters of

Skhirate-Temara have a chloride, sulfate, calcium and magnesium facies in the majority of the study area. This facies results in a significant mineralization and consequently a high conductivity.

The characterization of the waters of the water table of Skhirate-Temara on the hydrochemical level by the classification diagrams of waters [Wilcox, 1955; Richards, 1954] reveals the suitability of these waters for irrigation except for some points that present high levels of Nitrate (NO₃⁻), Magnesium, (Mg²⁺) and Sulfate (SO₄²⁻) and chloride (Cl⁻) linked both to the lithological nature of the encasing formations and to the effect of the agricultural activity which induces the phenomenon of return of irrigation water loaded with salts from fertilizers to the water table. These levels, although high, remain below the WHO standards (2011).

CONCLUSIONS

The mapping of the results of analysis of each chemical parameter according to its content, reveals similarities in the distribution of some parameters.

In general, the distribution of chemical parameters in the Skhirate-Temara aquifer by order of highest content shows great interference. The South-East part which extends from the South of El Menzeh to the mouth of the Bouregreg river, knows very high contents of HCO_3^- , Mg^+ , Cl^- and SO_4^- . The same elements are found with high concentrations in the south-west zone covering Tamesna the limits of Oued Ykem going to the coast. The southern part (represented by Sidi Yahya Zaër) shows average levels for all elements, while the northern and central parts show low levels due to the fact that this part is occupied by the forest of El Menzeh, forest of Skhirate-Témara and Harhoura which reduces the anthropic impact.

The Piper diagram shows a facies of chloride and sulphate calcic and magnesian type for the majority of waters in the study area.

These levels, although high, are still below the WHO standards (2011). The Wilcox diagram shows that the majority of points are located in the category of good quality 44% and excellent 24% while the classification of the water of Skhirate-Témara according to the Richards diagram shows that the majority of points 84% have an excellent quality for agricultural use with some exceptions, 3% are classified in the good category and 1% in the category admissible.

Thus, the characterization of the water table of Skhirate-Temara reveals their suitability for irrigation except for a few water points scattered in the area.

That said, the pollution of groundwater Skhirate-Temara is related to both the lithological nature of the enclosing formations (limestone, dolomite, marl, sandstone, sand.), and the effect of agricultural activity (market gardening, arboriculture, fodder...), which uses fertilizers rich in salts. The irrigation of these crops in periods of low water, induces the phenomenon of return of irrigation water loaded with salts, and its infiltration through the soil causing the contamination of groundwater.

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