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Groundwater Quality Evaluation
(Four boreholes from the region of Tebessa - Algeria)

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ABSTRACT

Tebessa is located in the north-eastern of Algeria. It has a semi-arid climate with a water balance deficit. Groundwater is a significant source for drinking water supply and irrigation of agricultural land in many parts of this area. The water quality depends on the geological influence and anthropogenic pollution. Continuously increasing abstraction of groundwater resources to meet rising agricultural and domestic needs leads to a growing deficit of water. The intensive exploitation of the available water resources, coupled with periods of drought, has led to lowering of the water table and increasing the risk of degradation of water quality, especially when abstraction amounts greatly exceed the natural recharge of aquifers. The study of the physicochemical water quality of four boreholes of Tebessa shows that the waters studied are of the same hydro-chemical facies (calcium sulphate). The results of the physicochemical analyses are compared with national and international standards. In addition The Groundwater Quality Evaluation System (Groundwater - QES) is used to classify the waters studied depending on the quality and suitability for the production of drinking water.

Keywords

Groundwater; semi-arid, boreholes; Tebessa; hydro-chemical facies; standards; pollution; Groundwater Quality Evaluation System (Groundwater - QES).

1. Introduction

Water is an essential element for life and for the real and sustainable socio-economic development of a country, it is therefore necessary to have a better knowledge of the existing water resources. Groundwater is considered to be the main source of drinking water because it is more sheltered from pollutants than surface water **(Guergazi & al., 2005).** It constitutes more than 95% of the available fresh water resources. The wilaya of Tebessa in Algeria is a semi-arid zone, it has a significant underground water potential and a water network that covers vast areas, but unfortunately it suffers a water deficit because of the population growth which is increased sharply in recent decades **(Rouabhia & al., 2009),** this growth was accompanied by an evolution in the production of urban waste **(Brahmi & al., 2021)** and caused a serious shortage of water

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supply, especially during the dry seasons **(Hamad & al., 2018a, 2018b)**. In the absence of effective water dams, all the water needs of the wilaya of Tebessa are met by abstraction from the groundwater, which has caused various management problems **(Rouabhia & al., 2012; Dahoua & al., 2018).** The liquid inputs during the last decades of drought have not allowed sufficient recharge of the aquifers in the region, which increases the rate of salinity and could alter the quality of the water **(Rouabhia & al., 2004).** The overexploitation of this precious resource, soil erosion, sediment transport and infiltration, have deployed pollutants both on the surface and in the underground environment **(Hamed & al., 2014, 2017a, 2017b, 2018).** In addition, there are other types of pollution, especially agrarian and urban, given the most marked anthropogenic activities in the region **(Rouabhia & al., 2009a; Zereg et al., 2018).** The suitability of water for drinking, domestic, agricultural and industrial uses implies an understanding of its quality on the basis of national **(OJAR, 2011)** and international standards **(WHO, 2017).**

2. Materials and methods:

2.1. Study area presentation:

Tebessa is located in the North-East of Algeria on the border with Tunisia **(Fig. 1)**, with an area of 13878 Km^2, and more than 750000 inhabitants and drinking water consumption of (168047.9742 m^3/day) shows a deficit of 10 to 15% which could increase with industrialization and demographic change and rural exodus.

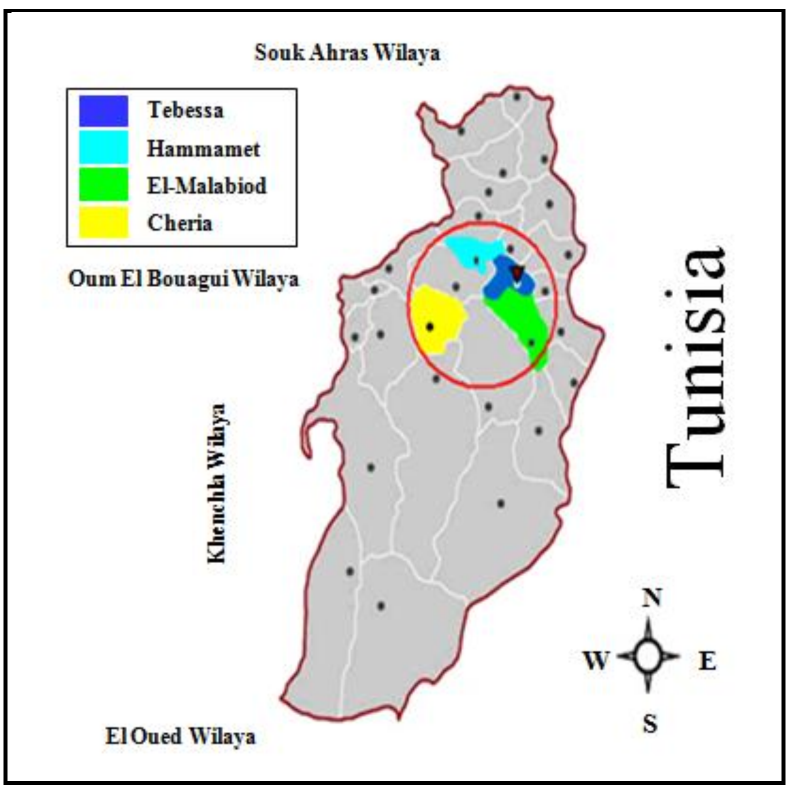

Figure 1. Situation of the study area

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The choice of the study area, namely the aquifers of Cheria, Hammamet, El-Malabiod and Tebessa, was motivated by the importance of their reservoirs in supplying the wilaya with drinking water.

2.2. Geology, Hydrogeology and Hydrology of study area:

2.2.1. Geology:

The importance of geological, lithological and stratigraphic studies derives from the fact that water has the ability to dissolve the minerals that make up the rock in contact **(Saadali & al., 2019).** Water acquires its mineralization as a result of the successive interactions between the flow and the different geological formations **(Ahoussi & al., 2010).** On the surface of the study area, outcrops show more or less prominent Cretaceous limestone formations on the edges of the plains and plateaus, and Miocene and Quaternary formations, which occupy all the surfaces of the plains studied **(Rouabhia, 2006) (Fig. 2)**.

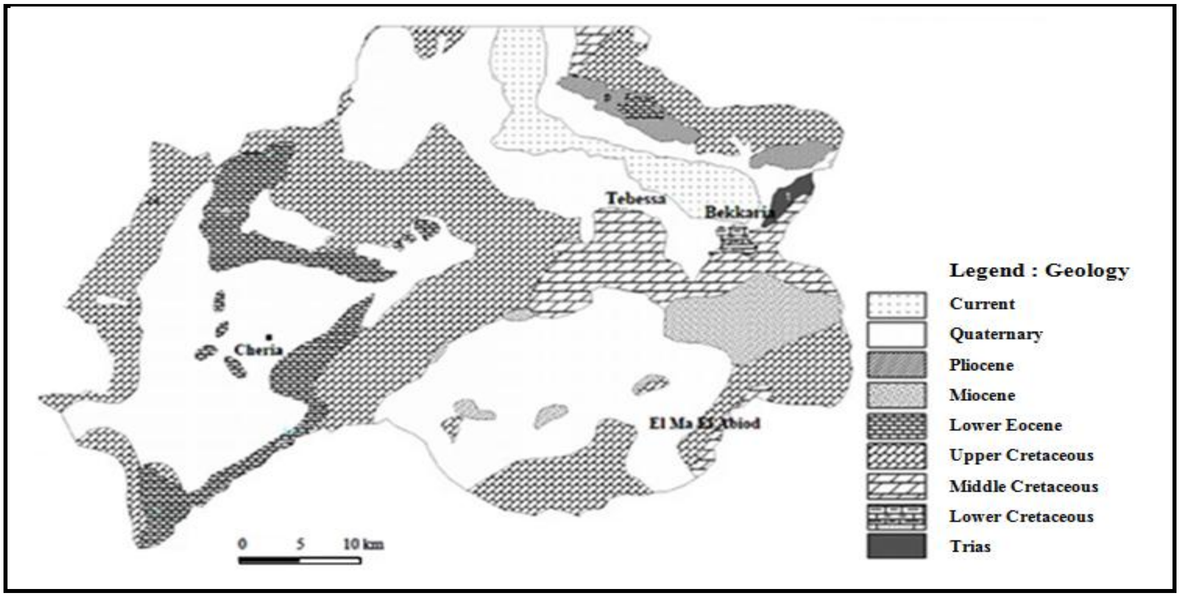

Figure 2. Geological map of the study area **(Zereg, 2010)**

2.2.2. Hydrogeology:

The study area is in the form of juxtaposed depressions more or less marked separated by large limestone massifs, which form natural boundaries **(Zereg, 2010).** Geomorphology is dependent on tectonics and lithology. The main water resources in Tebessa region are El Malabiod plain which is mainly sandy sandstone, Cheria plateau which is karstic and the Hammamet - Tebessa - Morsott ditch. These seem to communicate with each other according to the boundary conditions map and the piezometric map **(Fig. 3).**

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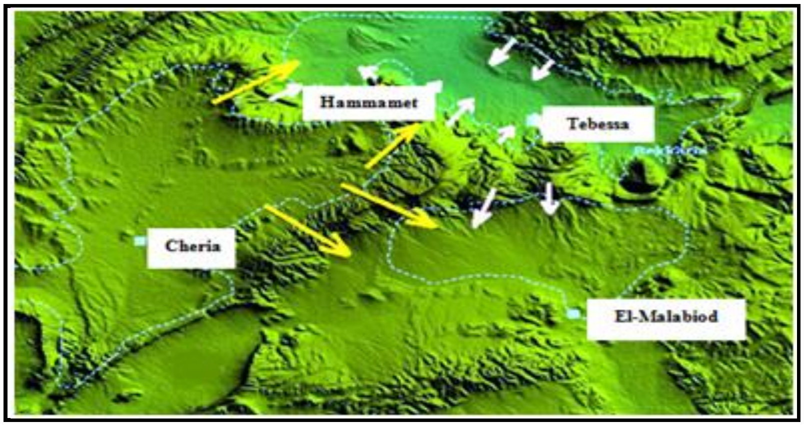

Figure 3. Geomorphology of the study area and the boundary relationship between the studied water tables **(Zereg, 2010)**

2.2.3. Hydrology:

The study area is made up of the following sub-basins: Oued Mellegue, Oued Labiod and Oued Cheria, which are part of the watersheds: Medjerda in the north of the wilaya and Melghir in the south **(Fig 4)**. The importance of the gullying on soft and compact ground testifies to the quantities of solid contributions during the rare torrential floods which characterize the region. **(Seghir, 2008; Zereg, 2010).**

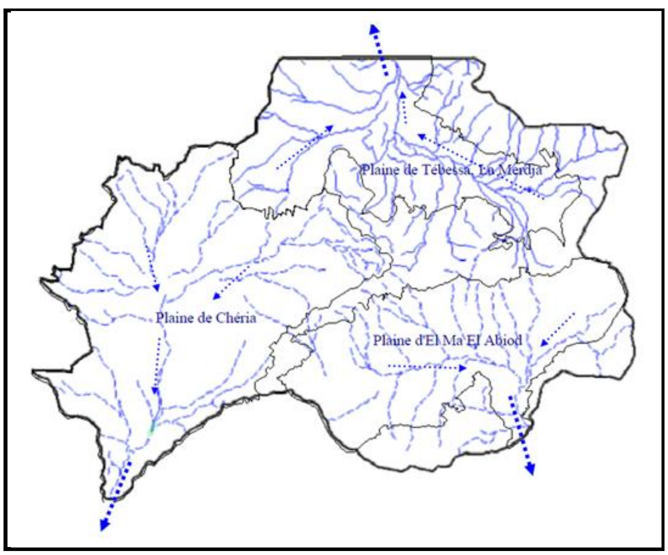

Figure 4. Hydrographic network of the study area **(Zereg, 2010)**

2.3. Sampling:

The choice of water points to be studied is motivated by:

- The importance of their reservoirs in supplying the wilaya with drinking water.
- Position of the borehole in the area.
- Position of probable sources of pollution
- Demonstration of the influence of neighboring water tables.

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Four boreholes were chosen for the production of drinking water from four sites in the study area: **F1** (Tebessa), **F2** (Hammamet), **F3** (El-Malabiod) and **F4** (Cheria). These four boreholes are considered to be the most representative from the standpoint of the groundwater quality study.

The samples were taken directly from the taps of boreholes. The containers used are bottles of mineral water of 1.5 liter washed and excellently rinsed with studied water before each filling; the bottles were kept out of the sun and temperature's differences and hermetically closed without air bubbles, and stored in a cooler (2 to 4 °C).

2.4. Analyses:

The analyses of boreholes water were carried out at the laboratories of the National Agency for Hydraulic Resources - East Region (NAHR - East Region) in Constantine - Algeria.

The selection of the parameters to be analyzed was motivated by the type of contamination (natural or anthropogenic) most likely for each zone. As being the region of Tebessa has an agricultural character and breeding; we analyzed the undesirable elements (phosphates, nitrites and nitrates) which are the most expected, in addition to the major elements (anions and cations), were determined.

The analyses concerned the quantification of the following physico-chemical parameters: temperature, turbidity, water acidity (pH), electrical conductivity (EC), dry residue, total hardness (TH), total alkalinity (TAC) , and the global mineralization balance composed of cations (Calcium, Magnesium, Sodium and Potassium) and anions (Bicarbonates, Sulfates and Chlorides), and the undesirable elements (Phosphate, Ammonium, Nitrites and Nitrates) found in fertilizers, Animal waste and decomposing organic matter, in addition to certain heavy metals (Iron, Zinc, Lead) produced by vehicle exhausts, and (Cadmium and Arsenic) as a safety measure given their potency of toxicity.

2.5. Evaluation method of Water quality:

The water quality is the appreciation of the physico-chemical and biological parameters according to the reference values given by the regulations and the recommendations national and international. The chemical composition of the water must correspond to precise standards. This evaluation is based on the uses of the water.

The evaluation of the groundwater quality is the determination of the water ability according to its quality to satisfy certain uses, mainly the production of drinking water **(Fournier, 2001; Cadilhac, Albinet & al., 2003; Miquel & al., 2003).**

To qualify water, water Quality Evaluation System (QES) is used, it allows a precise diagnosis of the water quality and contributes to define the corrective actions necessary for its improvement according to its desired uses **(Simonet, 2001).**

The originality of the Groundwater - SEQ is to assess the quality of water by "class" and by "alteration". An "alteration" is a degradation of water estimated from a grouping of parameters of

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the same nature or having the same disruptive effect with regard to the same use. Several parameters can contribute to the same alteration, for example ammonium and nitrites contribute to the same "Nitrogenous matter excluding nitrates" alteration **(HBA - CSM, 2009; Cadilhac, Albinet & al., 2003; Miquel & al., 2003; Fournier, 2001).**

The (SEQ) is based on the following rules :

- The quality of the water is defined in relation to a certain number of uses selected in the QES **(Fournier, 2001; Cadilhac, Albinet & al., 2003);**
- The evaluation of water ability for uses is the determination of the ability of water according to its quality to more or less satisfy certain uses **(Fournier, 2001; Cadilhac, Albinet & al., 2003);**
- The water quality is estimated for each alteration, without taking into account other alterations **(HBA - CSM, 2009);**
- Each quality class is defined by a set of threshold values that the different parameters of the different alterations must not exceed **(Fournier, 2001; Cadilhac, Albinet & al., 2003);**
- The quality by alteration is determined by the most downgrading parameter, that is, the one that defines the ability class or the least good quality class **(HBA - CSM, 2009);**
- The ability of the water for use, for the alteration considered, is determined by the most downgrading parameter, that is, the one that defines the worst ability class. The global ability of the water to satisfy the use, which takes into account all the alterations, is determined, for a water withdrawal, by the ability class of the most downgrading alteration; it is that is, the one that defines the worst aptitude class **(Fournier, 2001).**
- The water classification varies according to its use, of which there are four quality classes for the ability to produce drinking water; for each alteration (**Cadilhac, Albinet & al., 2003);**
- Waters are devised into classes, each of which is marked with a color, from blue which means a water of very good quality to red which indicates a water of very bad quality **(HBA - CSM, 2009; Cadilhac, Albinet & al., 2003; Miquel & al., 2003).**

According to the Groundwater - Quality Evaluation System (Groundwater - QES) adopted by the Algerian Hydrographic Basin Agency - Constantinois - Seybous - Mellegue (HBA - CSM), the quality of water intended for the production of drinking water is defined for each alteration in four quality classes **(Tab. 1)**. The alterations considered are listed in **(Tab. 2) (HBA - CSM, 2009);**

Table 1. Water quality classes with their ability for use in the drinking water production according to the Groundwater - QES adopted by the Algerian (HBA - CSM) (HBA - CSM, 2009).

Class	Water Quality Class	Ability to produce drinking water
Blue	**Very good quality**	**Optimal quality water for consumption.**
Green	**Good quality**	**Water of acceptable quality to be consumed but which**

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		may, if necessary, be the subject of a disinfection treatment.
Yellow	**Bad quality**	**Non-potable water requiring treatment.**
Red	**Very bad quality**	**Water unsuitable for the production of drinking water.**

Table 2: Alterations considered in Groundwater - QES adopted by the Algerian (HBA - CSM) with their quality classes **(HBA - CSM, 2009).**

- **Mineralization alteration:**

Parameter	**Unity**				
Conductivity	**µS/cm**	**[180 - 400]**	**]400 - 2500]**	**< 180 or]2500 - 4000]**	**> 4000**
Chlorides	**mg/l Cl^-**	**25**	**200**		**>200**
Sulphates	**mg/l SO_4^{2-}**	**25**	**250**		**>250**

- **Nitrogenous matters alteration except nitrates :**

Parameter	**Unity**				
Ammoniums	**mg/l NH_4^+**	**0,05**	**0,5**	**4**	**>4**
Nitrites	**mg/l NO_2^-**	**0,05**	**0,1**	**0,7**	**>0,7**

- **Nitrates alteration:**

Parameter	**Unity**				
Nitrates	**mg/l NO_3^-**	**25**	**50**	**100**	**>100**

3. Results and discussion:

3.1. Physico-chemical analyses:

The results of the physico-chemical analyses of each borehole studied are represented in **Figures 5 and 6.**

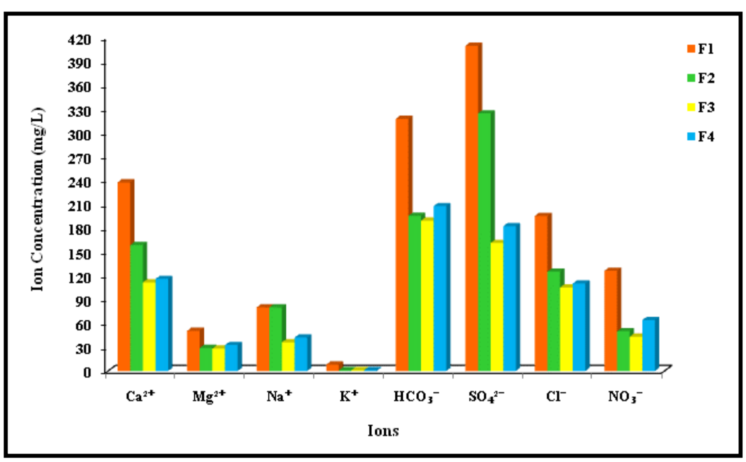

Figure 5. Physico-chemical analyses of the major elements of the four boreholes

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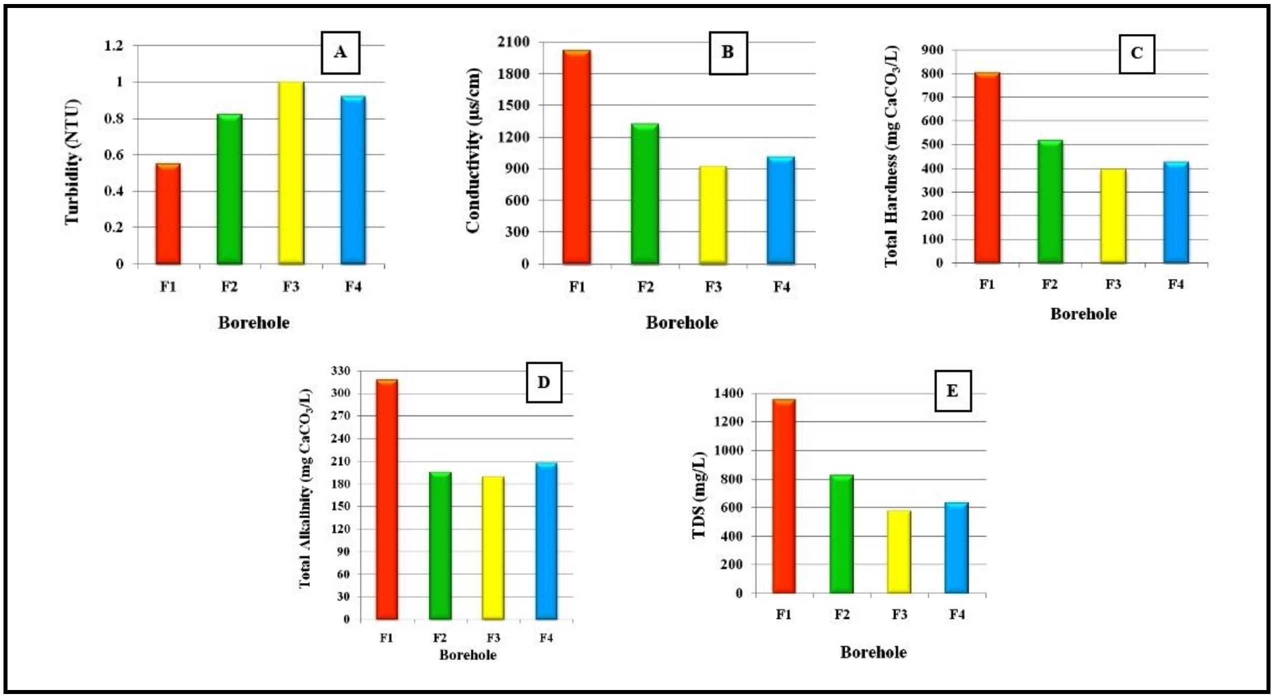

Figure 6. Graphic representations of the physico-chemical parameters of the water from four boreholes studied

A. Turbidity , B. Conductivity , C. Total Hardness (TH) , D. Total Alkalinity , E. TDS

3.2. Reliability of analyses:

The calculation of the ionic balance (IB) which is the relative difference between the sum of the cations (calcium, magnesium, sodium and potassium) and the sum of the anions (chlorides, sulphates, nitrates and bicarbonates) makes it possible to check the reliability of the analytical methods used and the validity of the chemical determinations **(Labadi & Hammache, 2016)**. The ionic balance (IB) is given as a percentage and calculated according to the following relation proposed by **Freeze & Cherry (1979):**

$$IB = \frac{\Sigma\, cations - \Sigma\, anions}{\Sigma\, cations + \Sigma\, anions}\, X\, 100$$

The ionic balance is considered as a main criterion for the evaluation of the quality of the results. If the (IB) is less than 10 % the analyses are considered to be of good quality. **(Ayouba Mahamane & Guel, 2015).**

According to the results of the analyses obtained, the ionic balance is less than 5 % **(Dougna & al, 2015), (Essouli & al, 2019)**, which confirms the reliability of the analyses carried out **(Tab. 3)**

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Table 3. Reliability of water analyses

Borehole	Ionic balance (IB) (%)	Reliability of analyses
F1 Tebessa	**1.381**	**Very reliable**
F2 Hammamet	**1.351**	**Very reliable**
F3 El-Malabiod	**0.533**	**Very reliable**
F4 Cheria	**0.328**	**Very reliable**

3.3. Determination of chemical facies using Excel:

According to the percentages of cations and anions of the waters of the boreholes studied **(Fig. 7)**, we notice that the percentage of calcium is the highest among the cations and the sulfates are the highest among the anions, therefore the hydro-chemical facies of the waters studied is sulfated calcium.

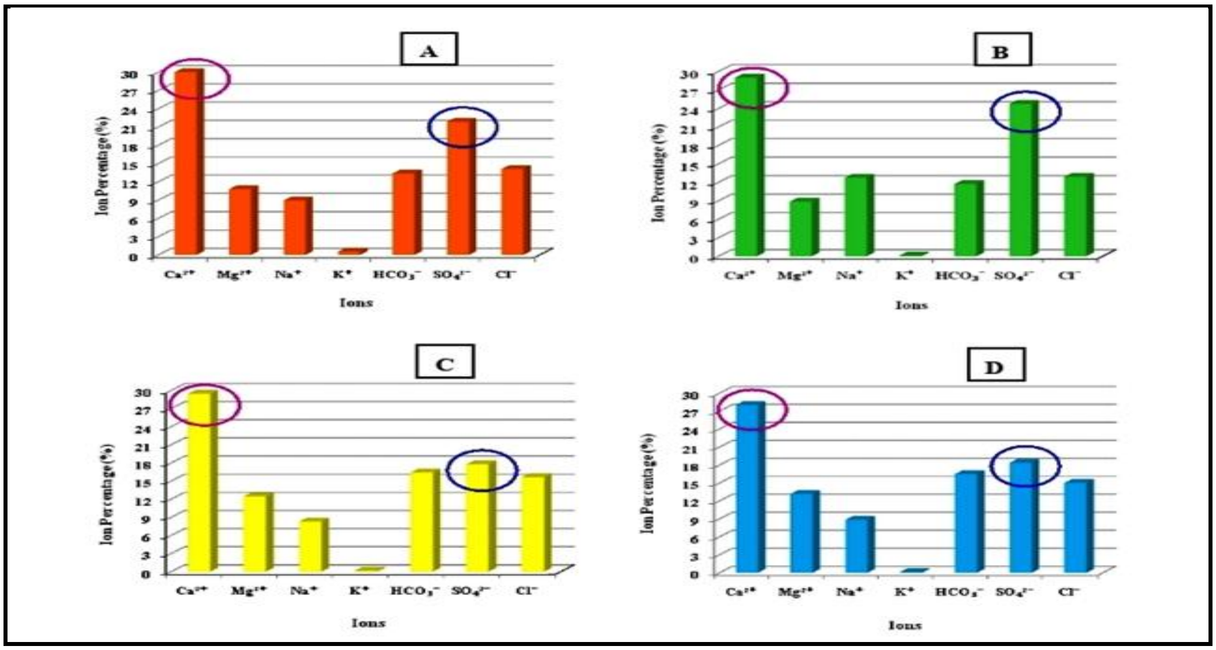

Figure 7. Water radical values of the boreholes studied
A. Borehole F1 – Tebessa , B. Borehole F2 – Hammamet ,
C. Borehole F3 - El-Malabiod , D. Borehole F4 – Cheria

It is quite normal for calcium to show the highest value among the cations of all samples; we are in limestone country. The geological and geomorphological study of the boreholes sites all show a position near an underground supply from a limestone border and the borehole records show a significant limestone component at the level of the water tables **(Ahoussi & al, 2010; Drias, 2013; Zereg & al 2018).** The sulphates are due to the frequent gypsum passages especially in layers of 2 to 3m placed on the Turonian and Triassic limestones of the region. The presence of sulphates is due also to the dissolution of the gypsum contained in the gypsiferous marls and to the leaching of evaporates **(Gouaidia & al, 2017).**

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At first glance, all the facies are sulphated calcium, but if we reconsider the values of the radicals by comparing those of each sample with each other we find that, arranged on a diagram, their curves are not identical and that each borehole carries the footprint of its own geological and anthropogenic environment **(Gouaidia & al, 2017; Touati & al, 2018; Mehdaoui & al, 2019).**

3.4. Graphical representations:

The reliability of analyzes results is checked by a program developed with Excel, and the graphic representations are made by software "Diagrams" of Roland Simler from Hydrogeology Laboratory of Avignon.

- **Confirmation by Piper and Schoeller diagrams:**

The results obtained are confirmed by the "diagrams" software used by hydrogeologists for the determination of the chemical facies of water and the graphic representation of the chemical elements, anions and cations, which compose them. The Piper's diagram places the symbols of the four samples analyzed in the calcium sulfate area **(Fig. 8)**.

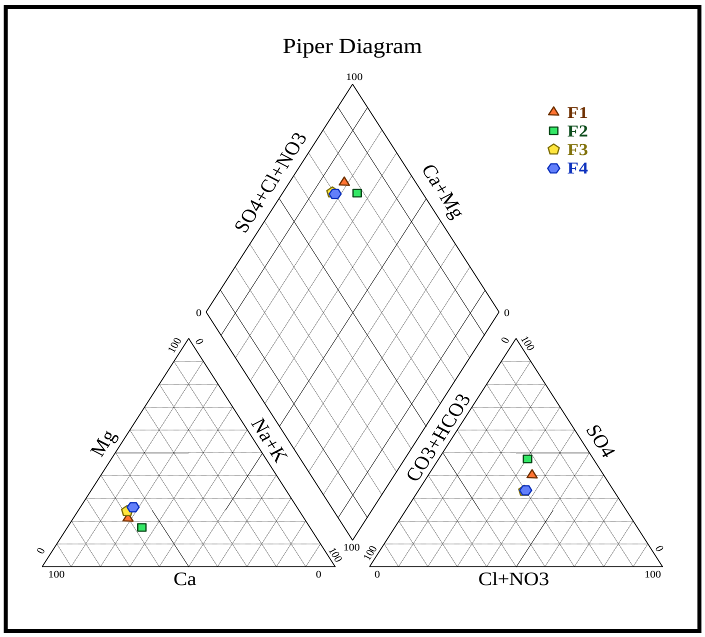

Figure 8. Hydro-chemical facies of the boreholes studied according to Piper diagrams

There is a relative grouping of the waters of the different samples analyzed, which clearly indicates that they are from the same hydrochemical family. But when we are interested in the elements of the analyses, namely TDS (total dissolved solids) **(Fig. 9)** or the distribution of anions and cations **(Fig. 10)** or even the Schoeller's diagrams **(Fig. 11)** where the distribution of their concentrations is represented, we see that each site has a composition that is specific to it and that can be explained by its general geology, which is supported by the boreholes records.

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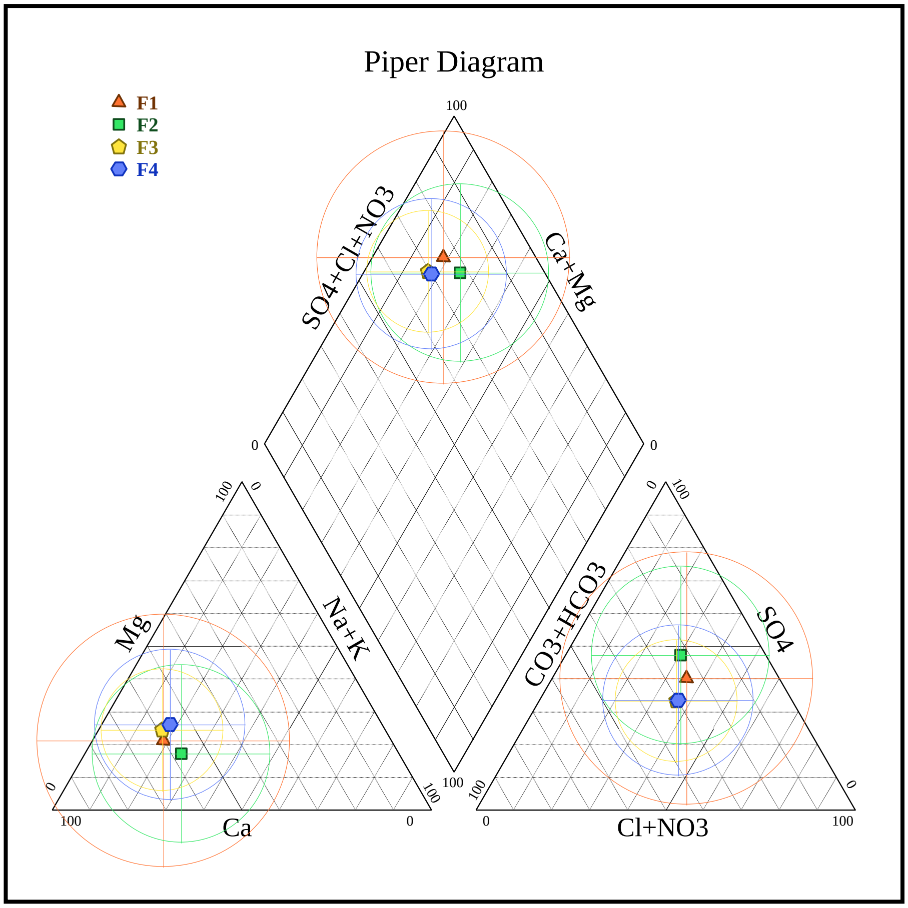

Figure 9. Graphic representation of TDS by Piper diagram

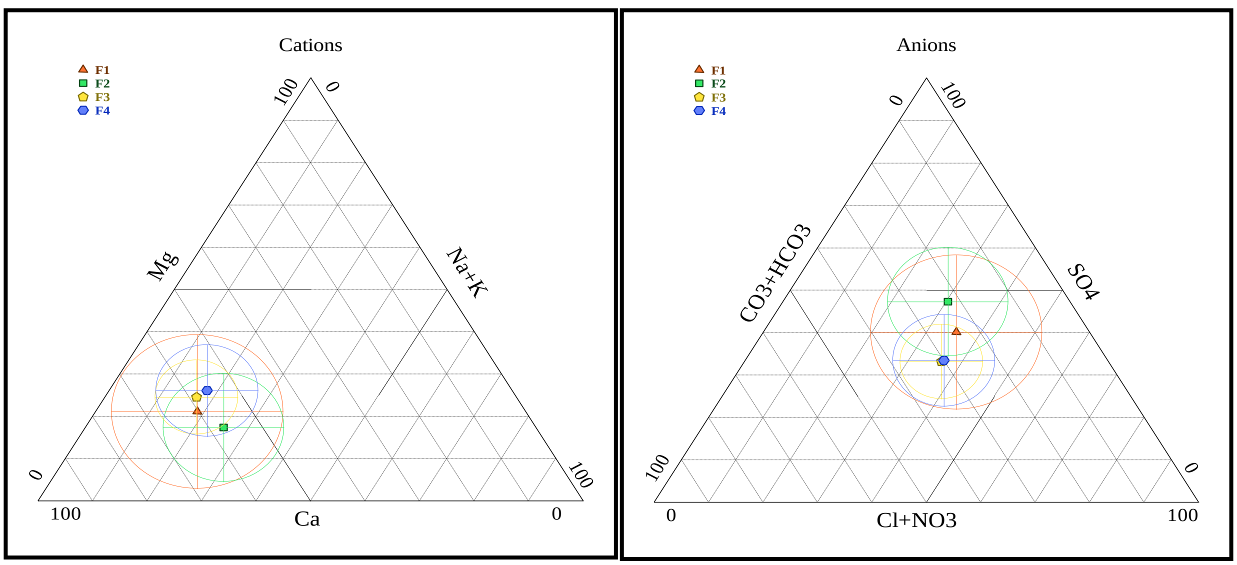

Figure 10. Graphic representations of cations and anions according to Piper diagram

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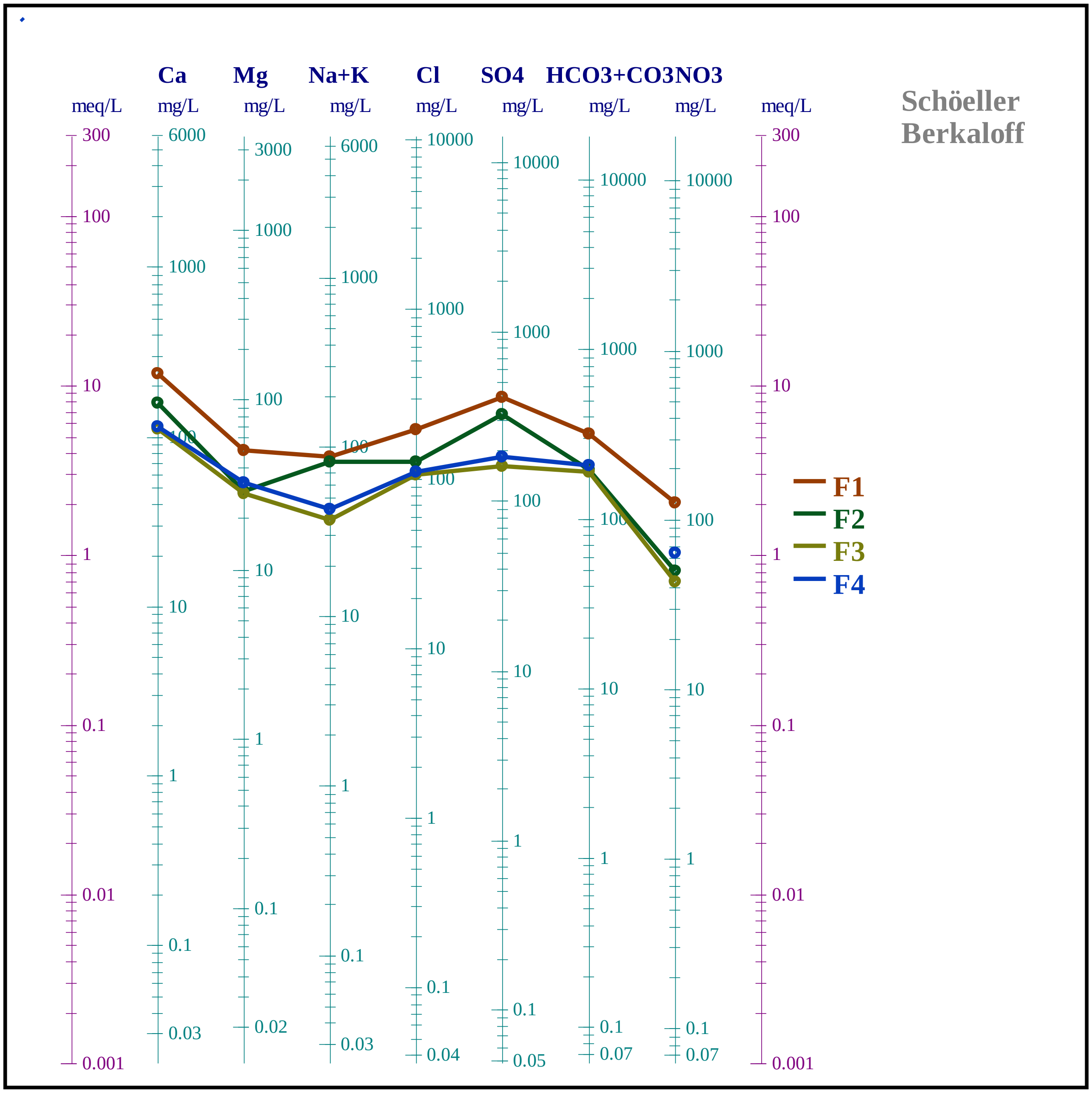

Figure 11. Graphic representation (Schoeller diagrams)

The graphic representation of Schöeller Berkaloff shows an almost perfect superposition of the two samples from **F3** and **F4**. According to the **Fig. 11**, **F1** and **F2** have the same type of geological environment and show a similar appearance in terms of the relative values of their chemical components. While **F1** presents a hyper concentration of almost all the major elements.

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3.5. Comparison of sample results with national and international standards:

Analyses of a number of physico-chemical parameters of water sampled from boreholes **F1, F2, F3** and **F4** are compared with the maximum admissible values set by Algerian **(OJAR, 2011)** and WHO **(WHO, 2017; WHO-ROE, 2017)** standards **(Tab.4)** :

Table 4. Comparison of analyzes with potability standards

Element	Algerian standards	WHO standards	Observations
T (°C)	**25**	**-**	All boreholes are acceptable according to Algerian standards.
Turbidity (NTU)	**5**	**-**	F4 is outside of Algerian standards.
pH	**≥6,5 and ≤9**	**>6,5 and <9,5**	All boreholes are acceptable according to Algerian and WHO standards.
Conductivity (µS/cm)	**2800**	**-**	F1 acceptable according to Algerian standards but it is the highest which means that it is the most loaded with mineral salts.
TDS (mg/l)	**1500**	**< 1000**	F1 is acceptable according to Algerian standards but it is the highest compared to other boreholes, on the other hand, it is outside of the WHO standards.
Total Hardness (mg $CaCO_3$ / L)	**200**	**200**	All boreholes are outside of Algerian and WHO standards except F1.
Total Alkalinity (mg $CaCO_3$ / L)	**500**	**-**	All boreholes are acceptable according to Algerian standards.
Ca^{2+} (mg/l)	**200**	**-**	F1 is outside of Algerian standards, it is more loaded with calcium.
Na^{+} (mg/l)	**200**	**200**	All boreholes are acceptable according to Algerian and WHO standards.
K^{+} (mg/l)	**12**	**-**	All boreholes are acceptable according to Algerian standards. But it is the highest.
SO_4^{2-} (mg/l)	**400**	**500**	F1 is outside of Algerian standards but it is acceptable according to WHO standards. The others are acceptable according to Algerian and WHO standards.
Cl^{-} (mg/l)	**500**	**250**	F1 is acceptable according to Algerian standards, but it is the highest.
PO_4^{2-} (mg/l)	**5**	**-**	All boreholes are acceptable according to Algerian standards but F1 is

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			the highest. PO_4^{2-} does not exist in F3.
NH_4^{2+} (mg/l)	**0,5**	**-**	All boreholes are acceptable according to Algerian standards. But Ammonium exists only in F1.
NO_2^- (mg/l)	**0,2**	**0,2**	All boreholes are acceptable according to Algerian and WHO standards. Nitrites only exist in F4.
NO_3^- (mg/l)	**50**	**50**	F1 is outside of Algerian and WHO standards. F2 at the limit of Algerian and WHO standards.
Fe (µg/l)	**300**	**300**	All boreholes are acceptable according to Algerian and WHO standards but F4 is the highest among the four boreholes.
Zn (µg/l)	**5000**	**3000**	Zinc is higher in F3 (acceptable according to Algerian and WHO standards), and does not exist in F1 and F2.
Pb (µg/l)	**10**	**10**	All boreholes are acceptable according to Algerian and WHO standards. Lead appears in traces in F3 only (acceptable).
Cd (µg/l)	**3**	**3**	Cadmium and Arsenic do not exist in all boreholes.
As (µg/l)	**10**	**10**	

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3.6. Water quality evaluation:

The application of the Groundwater - SEQ adopted by the Algerian (HBA - CSM), made it possible to determine the water quality of the sampled boreholes and their aptitudes for the production of drinking water for each borehole from their physico-chemical analyses **(Tab. 5)**.

Table 5. Determination of classes of quality and ability for the production of drinking water

Borehole	Alterations	Alteration Class	Quality class in relation to the use for the production of drinking water	Ability to produce drinking water
F1	Mineralization	Very Bad	Very Bad	Borehole unsuitable for the production of drinking water.
	Nitrogenous matters except nitrates	Very good		
	Nitrates	Very Bad		
F2	Mineralization	Very Bad	Very Bad	Non-potable water without treatment.
	Nitrogenous matters except nitrates	Very good		
	Nitrates	Good to Bad		
F3	Mineralization	Good	Good	Water of acceptable quality for consumption.
	Nitrogenous matters except nitrates	Very good		
	Nitrates	Good		
F4	Mineralization	Good	Bad	Non-potable water without treatment.
	Nitrogenous matters except nitrates	Very good		
	Nitrates	Bad		

The results obtained by comparing the analyses of the four boreholes water samples following the comparison of their physico-chemical data with the Groundwater - SEQ, allow the water from their respective boreholes to be classified according to their quality to produce drinking water **(Tab. 6)**.

Table 6. Classification of boreholes sampled according to their quality classes

Borehole	Zone / Area	Quality class	Ranking
F3	El Ma El Abiod	Good quality water	1

F4	**Cheria**	**Bad quality water**	**2**
F2	**Hammamet**	**Very bad quality water**	**3**
F1	**Tebessa**	**Very bad quality water**	**4**

Conclusion:

The selected areas contain the largest water reserve in the wilaya of Tebessa, from which they supply certain towns by transfer. Their study showed the susceptibility of groundwater and their sensitivity to contaminants induced by human activities and the nature of the surrounding land.

The physical and chemical characteristics of the samples analyzed by the NAHR regional laboratory show, by comparison with each other and by confrontation with Groundwater - SEQ adopted by the Algerian (HBA - CSM) that:

- All the samples analyzed are from the same hydro-chemical facies "calcium sulphate".
- The waters at the points studied are of different qualities with respect to the potability function.
- The water from the **F3** borehole at El-Malabiod is of good quality. It is the only water that can be drunk without any treatment.
- Two boreholes, **F4** of Cheria and **F2** of Ain Chabro-Hammamet, have poor water quality that can be improved to good quality.
- The water from the Tebessa borehole **F1** is of very bad quality. The sulphate and nitrate values are very high. It is the most loaded with mineral salts and dry residues among the four boreholes, it is very hard.

Finally, the elements observed, which have the greatest influence on the chemistry of water, are the leaching of agricultural fertilizers, the Triassic contributions of Dj Djebissa and urban and industrial pollution.

It should be noted that:

- There is no relationship between the colors of the graphic representations and the colors of the water quality classes.

- The F1 borehole was decommissioned from the production of drinking water and closed pending the study of a probable reuse in a less sensitive field.

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