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GROUNDWATER QUALITY ASSESSMENT: A CASE STUDY OF THE TELEGHMA PLAIN, ALGERIA

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Abstract: The Teleghma plain is located in northeastern Algeria, in the upper valley of Oued Rhumel. It is characterised by a semi-arid climate with average annual precipitation of 300 mm/ year. The shallow aquifer of Mio-Plio-Quaternary is powered mainly by carbonate formations of the Eocene surrounding the région. The uncontrolled use of groundwater for irrigation has caused water stress in the area which has threatened the degradation of water quality. On the other hand, the intense use of chemical fertilisers for agriculture aims has caused groundwater pollution by nitrates where concentrations exceeded the standard limit recommended by the world health organisation.

Key words: Groundwater, Hydrology, water, Pollution, Nitrate, Agriculture

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INTRODUCTION

In recent decades, the sharp increase in population in the Mediterranean regions, the rise in the standard of living, the development of irrigated agriculture, and new activities (especially tourism) have radically changed the uses of the land and the water, which make it more difficult to meet water needs in the future because many aquifers are already overexploited and water surfaces are in danger (Cudennen et al., 2007).

Pollution of water by nitrate nitrogen is well known in developed countries as a consequence of excessive fertilisation of industrial crops; on the other hand, the high levels of nitrates in developing countries are relatively due to agricultural activity (Collin and Salem, 1989). Natural processes appearing in aquifers and anthropogenic activities determine the quality of groundwater (Iqbal et al., 2017).

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Today, agriculture in the Teleghma region is an essential activity for more than 72,728 inhabitants (NSO, 2008), this irrigated agriculture has caused water stress due to the overexploitation of aquifers, in particular, that of the Mio-Plio- Quaternary. The results of chemical analyses confirm the pollution of groundwater by nitrates in most of the Teleghma plain. The objective of this article is to appraise the degree of risk of contamination of groundwater in the Telghema region by nitrogenous forms, in particular nitrates, where the concentrations have greatly exceeded the standards recommended by the WHO, especially in areas marked by a wide variety of crops and which irrationally use nitrogen fertilisers (Khedidja and Boudoukha, 2019).

STUDY METHODS

Sample collecting

The campaign of water sampling took place during the recharge period marked by low water availability, where 47 samples was collected for analysis. The samples concerned for analysis are the ones taken from points located on the edge of the bed of the main wadi (Wadi Seguin); these samples were taken and stored following collection and preservation standards (polyethylene bottles, preservation in a cooler, rapid transfer, storage in a refrigerator at four degrees celsius, analysis within two days). Measurements (Temperature, pH, and conductivity) were carried out in situ with a multi-parameter device. The chemical analyses were carried out in a laboratory; the laboratory analyses concern NO3- and major elements (Na+, K+, Mg2+, Ca2+, SO4 2-, HCO3-, Cl-). Cations were measured by several methods, by titration for chlorides and by measurement of alkalinity and spectrophotometry for nitrogenous elements, meanwhile major ions were measured by atomic absorption spectrophotometry (Michener and Lajtha, 2007; Rodier, 2009). The preciseness of the chemical analysis was verified by the ionic charge balance method. The ionic balance is within the thresholds of ± 5% (Domenico and Schwartz, 1998). The statistical processing of the physicochemical data was carried out using XLSTAT 2007.1 software (table1).

Table 1. Statistical characteristics of the physico-chemical parameters of the groundwater of Teleghma

Paremeters	Units	Minimum	Maximum	Average	SD	CV (%)
T	C	8.40	19	15.13	2.45	16.60
pH		6.55	8.70	7.11	0.46	6.70
EC	µs/cm	460	2530	1199.12	462.83	39.40
Ca++	mg/l	56.12	188.38	106.02	31.19	30.1
Mg++	mg/l	10.69	78.96	33.93	15.29	46
Na+	mg/l	10	295	88.17	69.98	81.10
K+	mg/l	0	32	3.02	6.61	223
HCO+++	mg/l	158.6	860	270.95	78	29.40
SO4--	mg/l	20	860	119.64	163.54	139.60
Cl-	mg/l	35.5	319.5	152.26	77.20	51.80
NO3-	mg/l	10	178.97	67.84	45.75	68.90
SAR	%	0.19	2.94	1.35	0.85	63.28
Pl	%	27.98	75.88	42.38	12.61	29.75
KR	%	0.11	1.12	0.32	0.22	70.45

Natural context

The Teleghma Plain is part of the North African Neritic Unit (figure 1). It belongs to a transition zone between the marly facies of the Tellian nappes to the north of the plain and the marly and marl-limestone series to the south (Vila, 1977). The Mio-Plio-Quaternary formations (clays, marls, scree, limestone crusts, and alluvium) extend over the entire plain, the parts of which in relief are marked by traces of tectonic accidents generally faults in the NW-SE direction. The whole is eroded, sometimes causing the appearance of Eocene limestones which outcrops in several places in the plain, such as at Koudiat Timetlas.

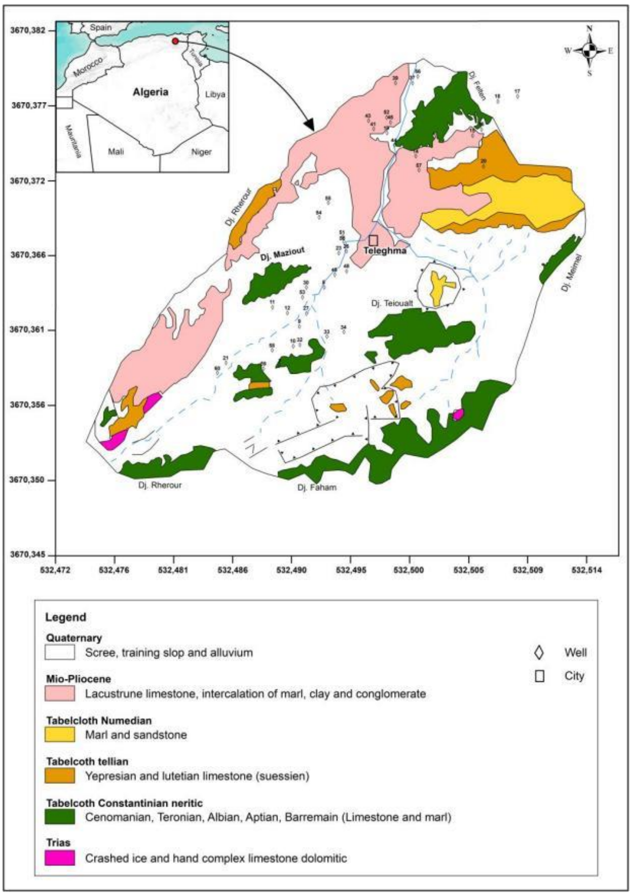

Figure 1. Geological map of plain of Teleghma according to Vila JM
(Source: GGC, 1973; Vila, 1977)

The average annual precipitation recorded at the climatic station of Teleghma reached 331 mm/ year over a period of 34 years (1976-77 to 2010-11) (National Water Resources Agencyof Constantine (NWRA); National Meteorological Office of Algiers (NMO)), and testify to the low rainfall. This region characterising a semi-arid climate. The establishment of the water balance according to the Thornthwaite method and the Tixeron-Berkaloff relations allowed us to quantify actual evapotranspiration about 315 mm with infiltration of 11 mm and runoff of 13 mm.

The Teleghma plain is characterised by the presence of three aquifers which are the shallow aquifer of the Mio-Plio-Quaternary where is composed of limestones and fossiliferous conglomerates, the Eocene aquifer which consists of phosphate limestones with strongly fissured flint, and the Cretaceous aquifer (Albien-Aptian) composed of compact and fissured limestones, and dolomites (Durozoy, 1960; Vila, 1977; General geophysics campaign, 1973; Farah, 1991). In this study, we are interested in the first aquifer of the Moi- plio- quaternary.

The piezometric state of the Mio-Plio-Quaternary aquifer was studied by carrying out one campaign; took place during the high water period (May 2015). The piezometry of the aquifer is marked by a regular shape coincident the closed configuration of the basin (figure 2), with:

- An inflow limit from the carbonate massifs surrounding the plain.
- An outflow limit, through a thin alluvial sill where Oued Seguin flows, which drains the aquifer to the outside of the basin.

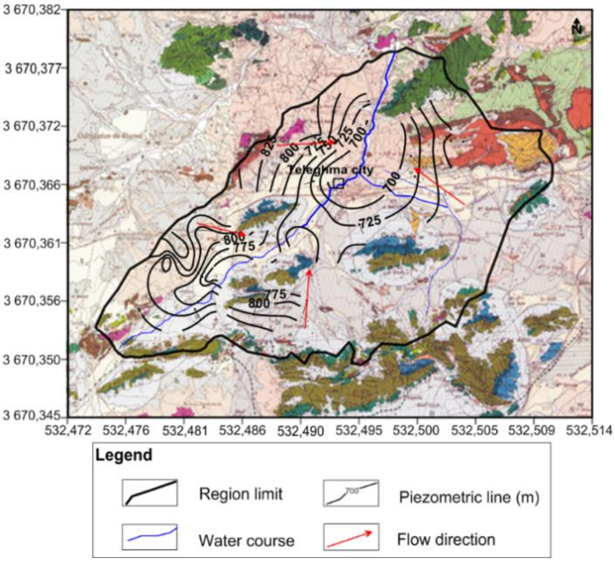

Figure 2. Piezometric map of Teleghma's aquifer

The surface aquifer is fed mainly by effective precipitation and the adjacent formations characterising the carbonate massifs of the Cretaceous. The flow is mainly from the south to the north.

This plain is fed mainly by rainfall and underground inflows from the carbonated massive surrounding region. This groundwater is exploited by more than 300 boreholes, with an average flow of 750 m3 / day, used mainly for the irrigation of cereals and market gardening (mainly garlic and potato; 639,700 quintals of garlic harvested during season 2019-2020) National agricultural land Office (NALO) for a cultivated area of around 4,447 ha (Chamber of agriculture of Teleghma (CAT)). where agriculture is the main source of income in the region.

Agricultural activity

Agricultural activity in the plain of Teleghma is mainly focused on cereal and vegetable crops. These different agricultural activities require the use of chemical fertilisers to improve yields (figure 3). These chemical fertilisers differ depending on the type of crop practiced (table 2).

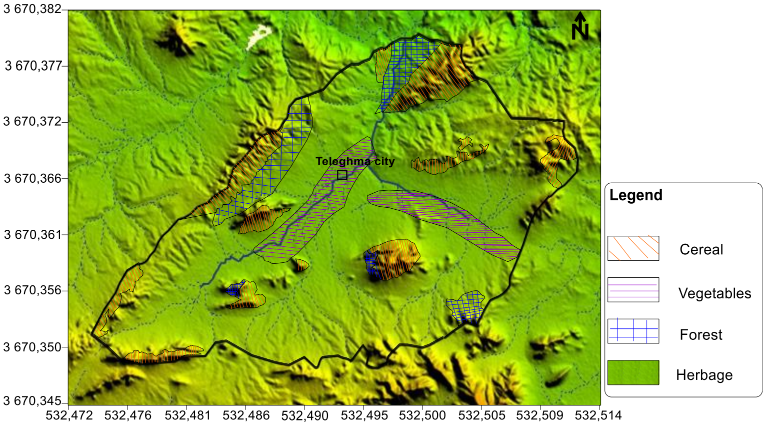

Figure 3. Distribution of Agricultural activities

Table 2. Types of chemical fertilisers used in the Teleghma plain (CAT)

Type of chemical fertiliser	Trade name	Properties
Root Liquid	FERTIACTYL GZB	13 % N, 5% K_2O
Leaf liquid	FERTILEADER 954	9% N, 5% K_2O,
	FERTILEADER 469	4% N,6% P_2O, 9% K_2O
	FERTILEADER Magical	12% CaO, 4% MgO
	FERTILEADER Alpha	6% N, 12% P, 4.2% B
	FERTILEADER Start	3% N, 4% MgO, 30% P
	FERTILEADER Bore	5.7% B
	FERTILEADER Arbo	3% N, 18% K_2O

Chemical fertilisers are defined as organic and inorganic matter added to the soil to enrich certain elements (primarily nitrogen, phosphorus, and potassium) for plant growth (Beaton et al., 2003).

However, chemical fertilisers cause several problems for soil, plants, and water, its losses are considered to be the main constituent of water pollution (Norse, 2005), where groundwater has been polluted with nitrates due to the form, dose, and timing of chemical fertiliser application (Diaw et al., 2016). Excessive application of chemical fertilisers causes augmentation of acidification of soil as well as widespread eutrophication of lakes with high concentrations of nutrients in groundwater (Cui et al., 2014) (there is a cumulation of superfluous N and P in the soil of intensively cultivated areas which is a source of water pollution) (Smith and Sciliano, 2015). The pollution of groundwater by nitrates, due to the use of chemical fertilisers, is characterised by very high concentrations of nitrates which are directly related to heavy fertilisation (Pawar and Shaikh, 1995).

RESULTS AND DISCUSSION

Water quality

The representation of water points on Piper's diagram shows a tendency to the magnesium pole and calcium pole in the under triangle of cations, while the anions show a dominance of bicarbonate for certain points and a tendency to the calcium sulfate for other points (figure 4).

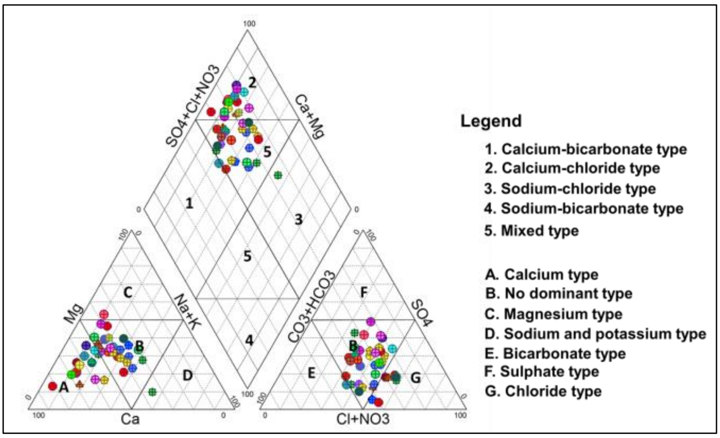

Figure 4. Piper diagram of the water samples

According to the primary distribution of the chemical facies of the plain's waters (figure 5), it appears that the impact of the evaporitic formations is well noticeable in the domination of the cations of sulfate and chloride and by the anions of calcium and anions of magnesium.

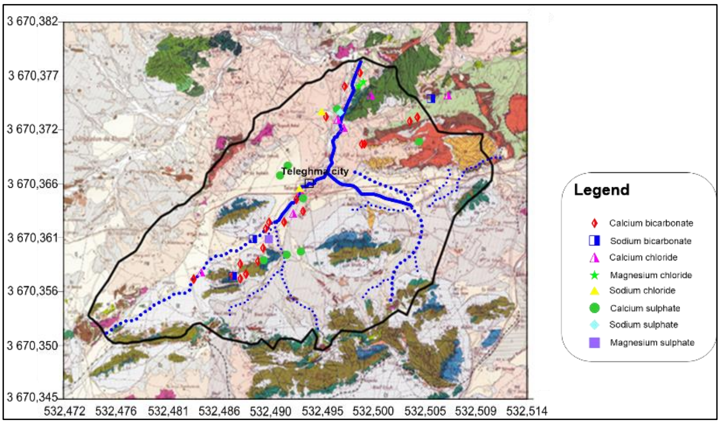

Figure 5. Spatial distribution of chemical facies in Telaghma plain

The analys of the spatial distribution of chemical facies of water from the plain Telghma depending on the electrical conductivity according to the flow axis (figure 6), allowed us to reveal that the calcium bicarbonate facies appearing in the northeast and southwest zone became sodium bicarbonate in the center of the study site from values of electrical conductivity greater than 1500 µS cm-1, resulting in the effect of evaporation as well as the acceleration of the dissolution phenomenon and the exchange effect between basic alkali metals and alkaline earth metals (Khedidja and Boudoukha, 2019).

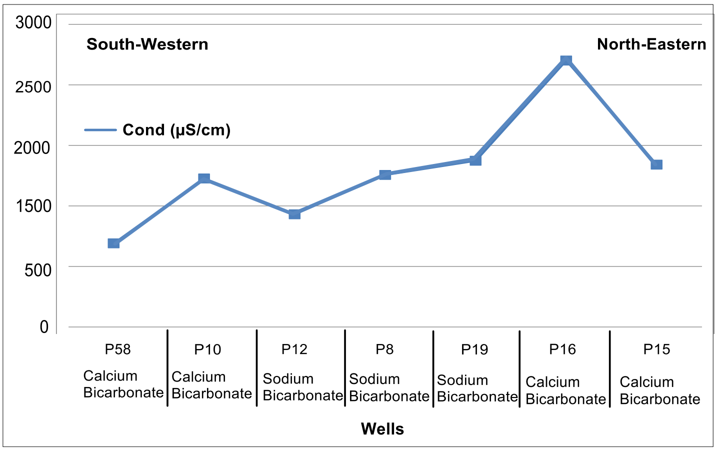

Figure 6. Spatial distribution of chemical facies of Mio-Plio-Quaternary aquifer

SALINITY INDEX

The Electrical conductivity (EC) is a useful parameter in categorising salinity hazard as well as the adequacy of water for irrigation purposes (Farah, 1991); it is defined as the rate of cations (Mg^{++}, Ca^{++}, K^+, and Na^+) and anions (SO_4^-, Cl^-, HCO_3^- and CO_3^-) soluble in water (Natural Resource Conservation Service, 2011). The groundwater samples were classified according to Bauder et al. in 2007. The values of electrical conductivities are between 460 and 2530 µS cm-1 with a 1199.125 µS cm-1 as an average, the waters of the plain are ranged between good quality (83.33 %) and admissible quality (16.66 %) (table 3).

Table 3. Classification of water according to the EC

EC (µs/cm)	Water quality	Number of samples%
< 250	Excellent	0
251-750	Good	16.66
750-2000	Admissible	83.33
2001-3000	Doubtful	0
>3000	Unsuitable	0

According to the direction of flow, the groundwater becomes more and less loaded with salts explaining by the decrease in electrical conductivity from the southwest to the northeast of the study region resulting in the phenomenon of dissolution (figure 7).

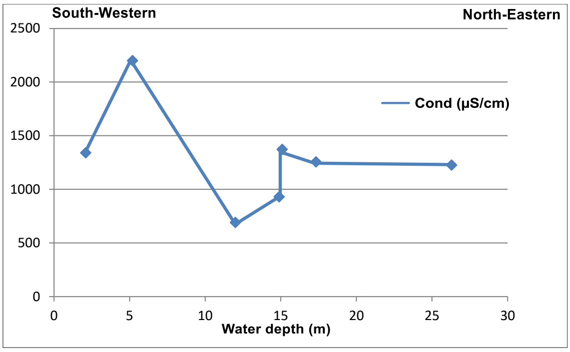

Figure 7. Spatial evolution of conductivity as the water depth

Total hardness (TH)

The hardness of water is the outcome of the divalent metallic cations existence (Mg2+ and Ca2+), it is calculated as the sum of the concentrations of these last in meq l-1 as equivalent to CaCO3 (Todd, 1980). The equation that follows expresses it:

$$TH = 2.5 \times Ca^{2+} + 4.1 \times Mg^{2+}$$

This is usually classified according to United states environmental protection agency (U.S. E.P.A.) in1986 as soft (0-60 mg/l), moderately hard (60 - 120 mg/l), hard (120 - 180 mg/l), and very hard (>180 mg/l).

The range of total hardness values for water in the plain of Teleghma is ranging from 45 mg/l to 61 mg/l, with an average of 40 mg/l, which is adequate to WHO limits.

The classification of the calculated total hardness, according to Sawyer and McCarthy in 1967 shows that 12.5 % of the water samples are hard and that the rest (87.5 %) is considered very hard, which revealed that the study region has very hard water (table 4).

Table 4. Classification of water by total hardness.

Total hardness (mg/l)	Classification	Collected samples %
<70	Soft	0
70-150	Moderately hard	0
150-300	Hard	12.5
>300	Very hard	87.5

Analysis by ascending hierarchical classification

Cluster analysis is a multivariate statistical approach, applied to objects to be compiled based on their similar characteristics (Hou et al., 2017).

The cluster analysis has been used mostly and considered in the groundwater hydrochemistry of aquifers as a fine representer of spatial variations (Khanoranga and Khalid, 2019).

The method is chosen in the ascending hierarchical classification (CAH) for our case is that of Ward. According to Saporta in 1990, it constitutes the best method of hierarchical classification on Euclidean data. We used this classification for the variables Na, Ca, K, Mg, SO4, HCO3, NO3, Cl and electrical conductivity.

Analysis of this classification reveals three chemical groups (figure 8):

- The first includes the parameters Mg, SO_4, and Cl, these are waters influenced by the dissolution of evaporitic rocks, which come from the Trias which outcrops in places at the level of the limits of the Teleghma plain.
- The second group is characterised by bicarbonates and calcium, this group is the result of the dissolution of carbonate rocks at the level of the feeding zones located at the level of the Felten, Fahem, and Maziout djebels.
- The third group includes sodium, potassium, and nitrates, it would seem to be largely linked to pollution of agricultural origin by the leaching of surplus chemical fertilisers of the NPK type in the soils, as well as the return of water from the soil. irrigation to the water table. More than 70 % of the water samples analysed have a nitrate content greater than 50 mg/l (standard accepted by the WHO).

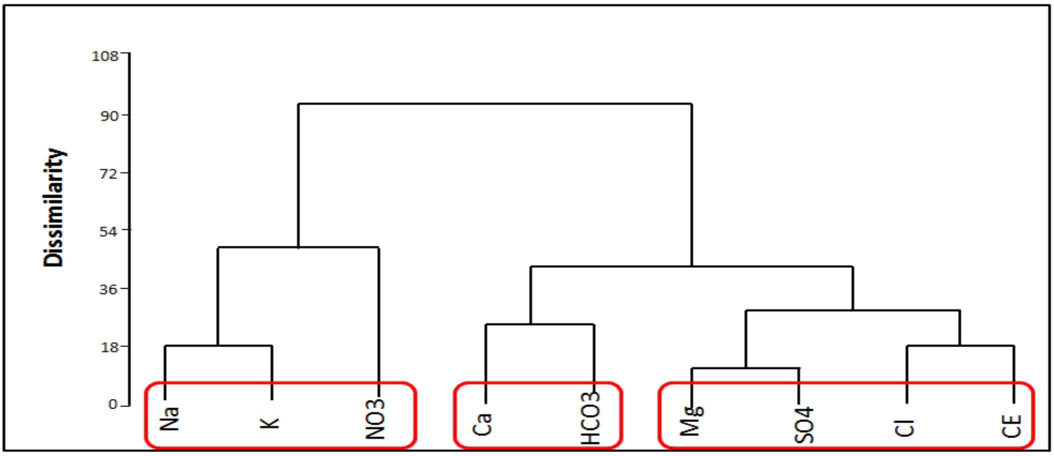

Figure 8. Hierarchical cluster analysis: dendrogram of water sample

Pollution by nitrates:

The review of the map drawn from the data sampling campaign in May 2015 (figure 9) shows that the area most vulnerable to pollution by nitrates are in the north part of the plain, mainly due to the alluvial nature of the terrain that favors immigration of nitrogenous elements to the saturated zone under the effect of the intensification of agriculture and excessive pumping with a content of 180 mg/l. Low concentrations are stored in the southwest part of the land given the high groundwater level and the clayey nature of the roof of the web, which protects groundwater against infiltration of nitrate ions. The low concentration is around 10 mg/l. Chemical analysis showed that nearly 85% of water points have values greater than 50 mg/l.

The examination of the figure of the evolution of the nitrate contents along the flow axis, allowed us to see that the very high nitrate concentrations are located at the level of the northeastern part of the study region coincide with the preferential direction of the groundwater orientation south west-north east whose aquifer has a shallow depth (figure 10).

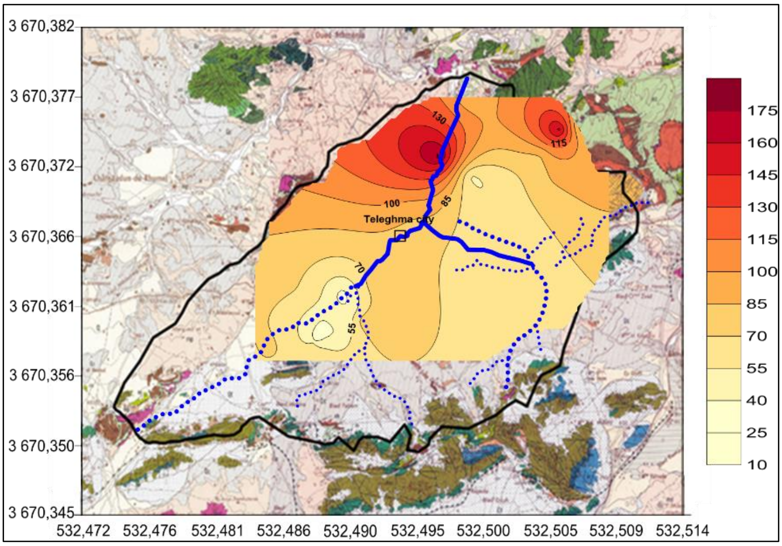

Figure 9. Map of nitrates distribution in Teleghma plain

The type of crop and its sequence are main factors in water pollution (Shepherd and Lord, 2009): the type of crop determines the type and quantity of fertilisers used (in the case of potato uses 12 Kg ha-1 of NPK fertilisers and for the case of garlic uses 6 Kg ha-1 (C.A.T), however, if the sequence of crops that need fertilisers is too long (potato for example) the risk of pollution will be greater because there will be no possibility for the soil to release the surplice nutrients.

The types and quantities of chemical fertilisers used are not directly related to the cultivated areas but rather related to the type of crop practiced and especially to the expected yield (table 5).

Table 5: Average fertilised area of the main crops grown in the plain and the quantity of chemical fertilisers used (2014 to 2019) (CAT)

Culture	Region					
	Teleghma		Oued Seguin		M'chira	
	Area (ha)	Quantity of fertiliser (Qts)	Area (ha)	Quantity of fertiliser (Qts)	Area (ha)	Quantity of fertiliser (Qts)
Potato	387	4644	113	1356	33	396
Garlic	431	3879	41	369	40	360
Onion	211	1899	17	153	17	153
Total	1029	10422	171	1878	90	909

Water pollution is becoming more and more worrying because of the increase in fertilised areas (11,900 hectares in 2015) (CAT).

On the other hand, the low solubility of the phosphate-soil reaction products formed during the application of chemical fertilisers reduces the efficiency of its use by the plants which requires the addition of additional doses of chemical fertilisers to achieve the desired volumes (Savci, 2012). The effectiveness of fertilisers can be improved by applying them more spaced out over time, thereby reducing the amounts used, to give the plants time to assimilate these nitrogenous fertilisers. (Stanford et al., 1970).

Inputs of nitrogen in organic form in the soil are by anthropogenic amendments, returned to the soil of crop residues, and/or restitution of animal waste. The constitution of the stock of mineral nitrogen in the soil is derived from synthetic fertiliser inputs in the form of ammonium nitrate and urea.

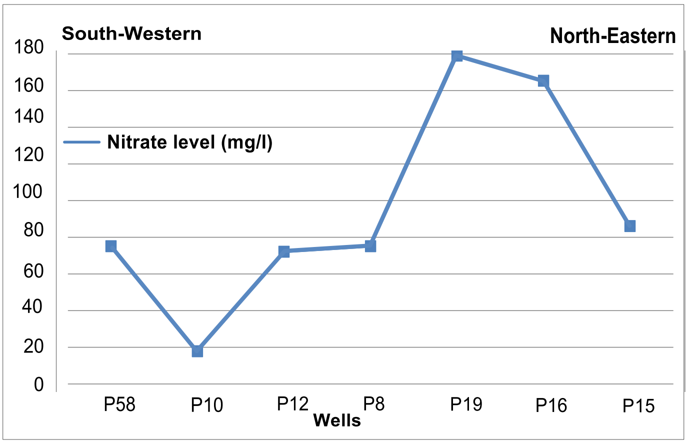

Figure 10. Spatial evolution of nitrate contents as the flow axis

This state is visible especially in the northern part of the land, this is due to the effect the intensive use of chemical fertilisers and the low vulnerability to pollution of these locations by nitrates, which allows nitrates to easily infiltrate the aquifer. Water points located at great depths located in the southwest part, where the northeast at have low nitrate contents (figure 11) due mainly to the self-purification phenomenon of the unsaturated zone (Wang and Chu, 2016), this zone is characterised by deeper piezometric levels reaching 100 m.

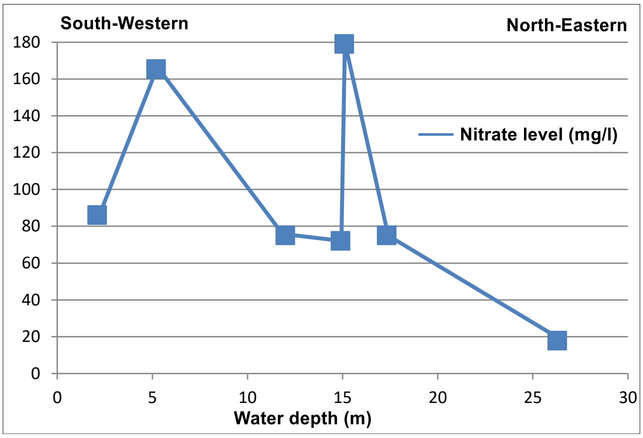

Figure 11. Relation Nitrate- water depth

CONCLUSION

The Mio-Plio-Quaternary aquifer is the most exploited aquifer in the Téleghma region. The depth of the water level is fifty meters but has experienced drawdowns that can reach twenty meters, due to its overexploitation.

The concentrations of major elements reveal fairly homogeneous hydro-chemical facies (three main facies: calcium bicarbonate, calcium chloride, and calcium sulfate which testify, according to their distribution, to the geological nature of the region. influence of the evaporite formations of the Triassic is indicated by sulfate domination.

The pollution by nitrates of the groundwater of the plain mainly results from the heavy application of chemical fertilisers in agriculture. The problem is worrying in the northern part of the plain where vegetable crops are cultivated in particular and cereals which need nitrogen fertilisation.

Nitrate pollution can be reduced in the region through more appropriate agricultural practices such as:

- Crop rotation, which consists of cultivating successively different crops on the same land, to preserve the soil's production capacity and to cultivate crops that require less fertiliser to reduce pollution (Eghball et al., 2000).
- provide strips of grass between fields and streams, and the use of plants that create an intermediate layer to trap nitrates (according to Eghball et al. these strips of grass can reduce concentrations of nitrates by twenty-one percent).

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