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Risk assessment of agricultural pollution on groundwater quality in the high valley of Tadjenanet: Chelghoum Laid (Eastern Algeria)

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ABSTRACT

The region of Tadjenanet—Chelghoum Laid is located in the upper valley of Oued Rhumel. It has shown in recent years an important agricultural and industrial development, which resulted in increased occupancy of the natural environment and therefore a deterioration of water quality of surface and underground aquifer located in the alluvium of Mio Plio Quaternary. This study aims to determine the critical impact of natural and anthropogenic pollution on physico-chemical water of the shallow aquifer zone of Tadjenanet—Chelghoum Laid. Chemical analysis of this water showed a rather marked salinity, due to dissolution and leaching of surrounding formations, carbonate, and gypsiferous alluvial. The high concentration of nitrate in irrigated areas at the periphery of Oued Rhumel reflects the agricultural activities, marked by a wide variety of crops, marked by an unmanaged employment of chemical fertilizers, especially nitrogen.

Keywords: Risk; Pollution; Groundwater; Alluvium; Aquifer; Nitrate; Tadjenanet—Chelghoum Laid

1. Introduction

Diffuse pollution from agriculture is a major cause of the deterioration of groundwater quality in rural areas. Nitrates and pesticides are the main source of pollution of aquifers in the region Tadjenanet—Chelghoum Laid [1]. The pollution risk is accentuated further by the lack of protective cover causing pollutants directly into the reservoir formation [2].

Contamination of groundwater in the alluvial aquifer of Tadjenanet Chelghoum Laid by nutrients (nitrate and ammonium) is often related to the misuse of fertilizers in agriculture, the decomposition of plant materials or animal manure, and domestic wastewater and industrial applications [3]. Through a piezometric and hydrochemical studies in the unconfined aquifer and from the results of physico-chemical analysis have provided the data necessary to define the risk caused by the phenomenon of pollution.

In this study we tried to assess the risk of groundwater contamination by nitrates. We should also mention that the concentration of nitrate in groundwater is changing at an alarming rate [1]. Agricultural development, often leads to rapid pollution of groundwater by the chemical forms of nitrogen, especially of nitrates, due to their high solubility and low affinity for ion exchange [3,4]. Nitrates are the most

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oxygenated nitrogen and are a very soluble form; they are the result of the nitrogen cycle which is a nutrient essential to plant life. The spatial variation of nitrate concentrations is mainly related to agricultural activity that develops on the surface, the nature of the formations in the unsaturated zone and the conditions of oxidation–reduction [2].

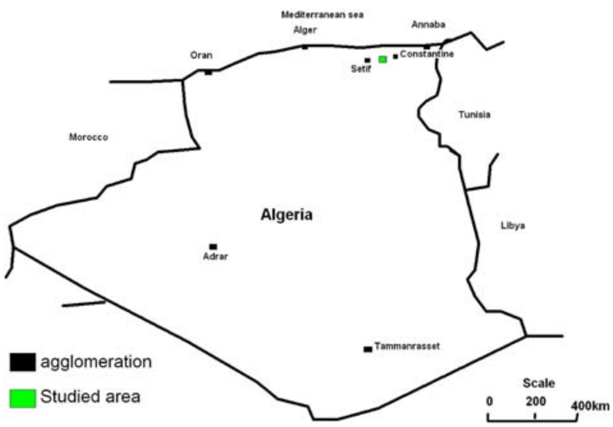

Fig. 1. Location of the studied area.

2. Materials and methods

2.1. Geological and hydrogeological settings

Region Tadjenanet—Chelghoum Laid covers an area of 1,130 km^2. It is part of the western watershed of the great Kabir Rhumel located in eastern Algeria, which drains much of the southern slope of the tell Setif (Fig. 1).

The plain is bounded by a ridge whose edges consist of mountain peaks [Dj. Tnoutit (1,189 m), Dj. Tafrent (1,069), Dj. Ed Dess (1,212 m) and Dj. Grouz (1,188 m)]. The topography of the plain is nearly flat with a slope not exceeding 2%, and altitudes ranging from 920 to 720 m North West and the South East. This morphology is monotonous sometimes interrupted by a few hills scattered across the plain. The area is mainly covered by formations of the Mio-Plio-Quaternary corresponding to clays, marls, silts, alluvium and calcrete. The Eocene limestone outcrops mainly on the boundaries but also in some places in the center of the plain (Fig. 2). The region is drained primarily by Oued Rhumel and some secondary wadis such as El Mehri, and Ouskourt in the south and Maamra, Boutouil, Boumrah, and Dekri in the north. The main river is controlled by the dam of

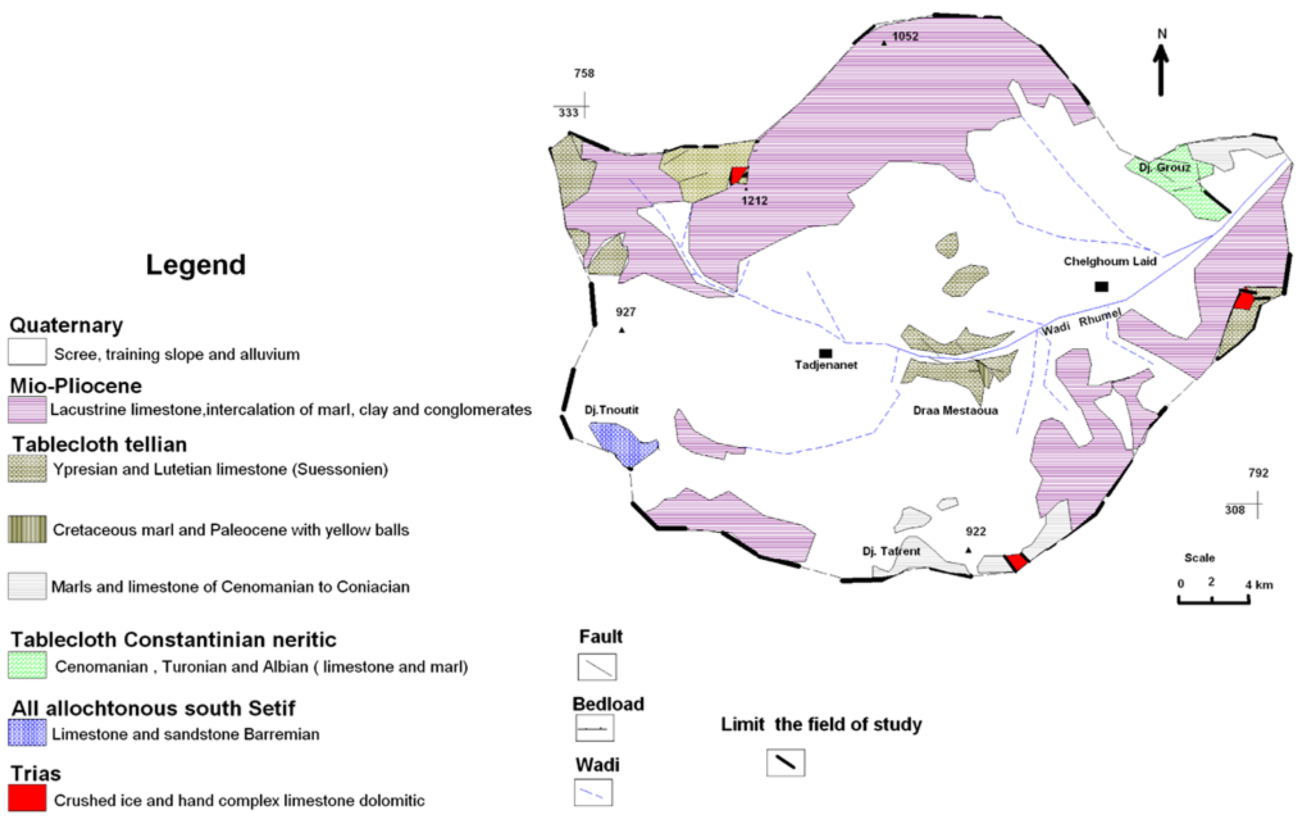

Fig. 2. Geological map of the sub—basin of Tadjenanet—Chelghoum Laid (J.M. Villa 1977).

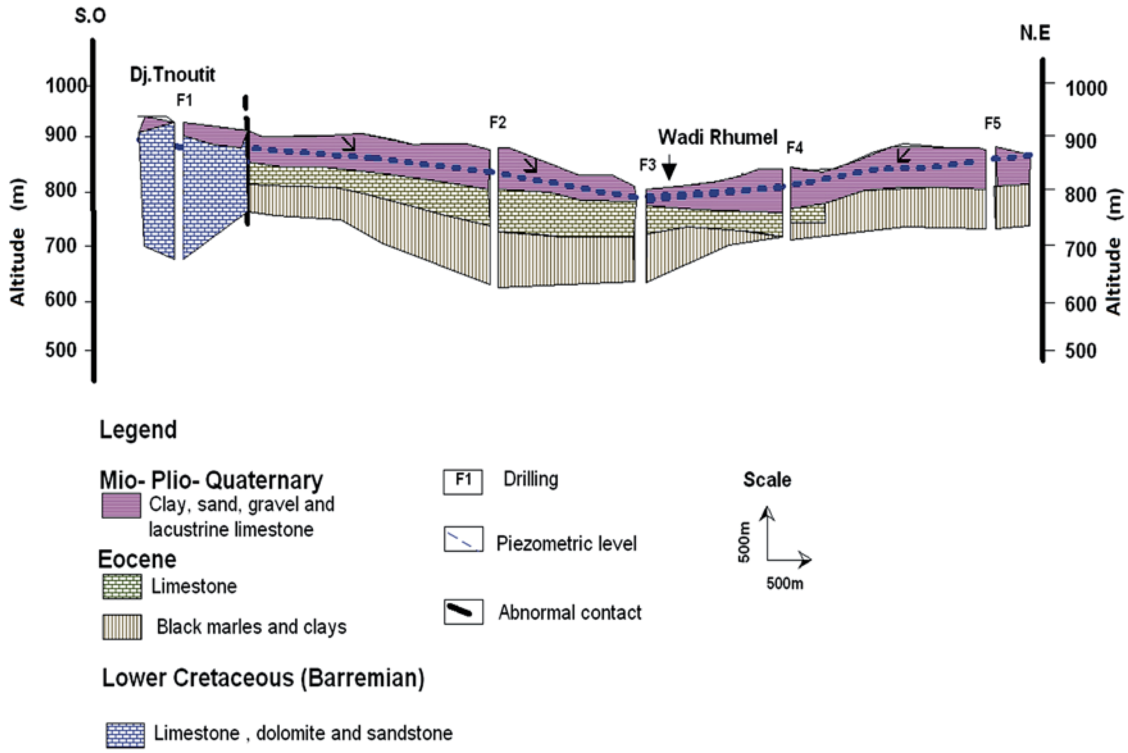

Fig. 3. Hydrogeological section.

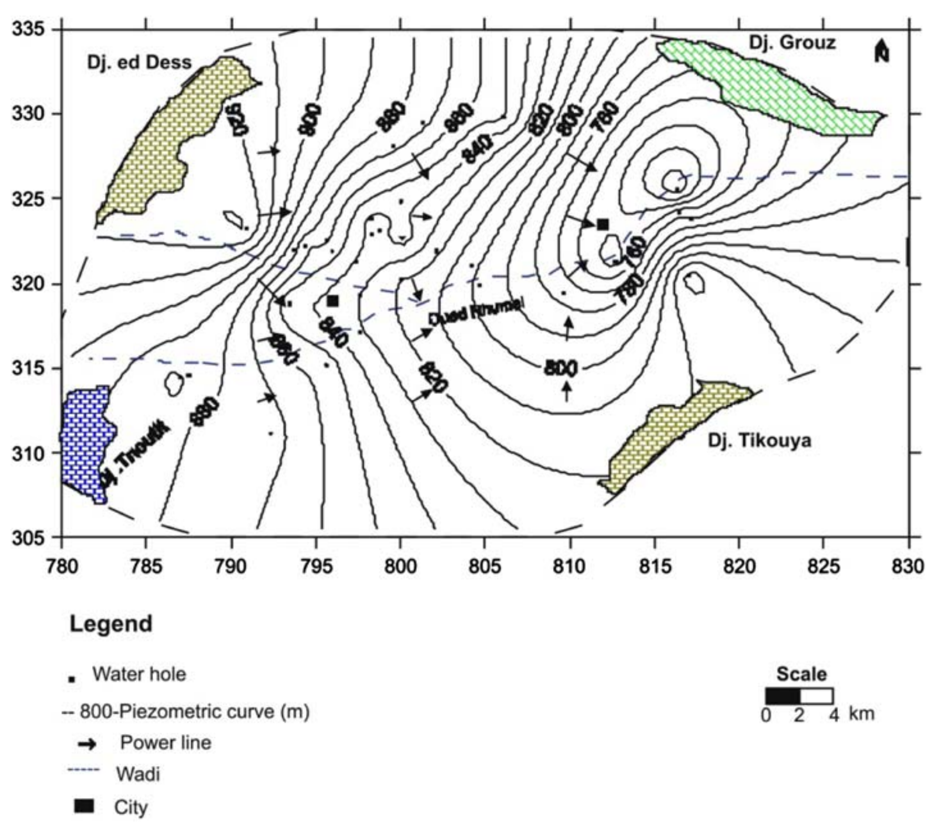

Fig. 4. Piezometric map.

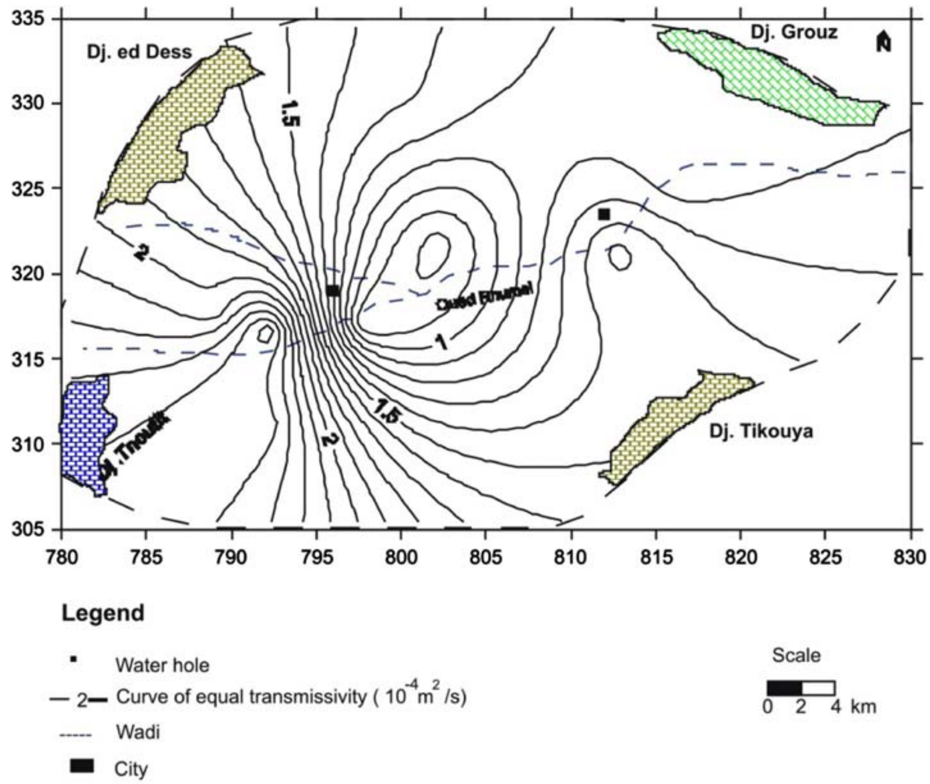

Fig. 5. Map of transmissivity in $10^{-4} m^2/s$.

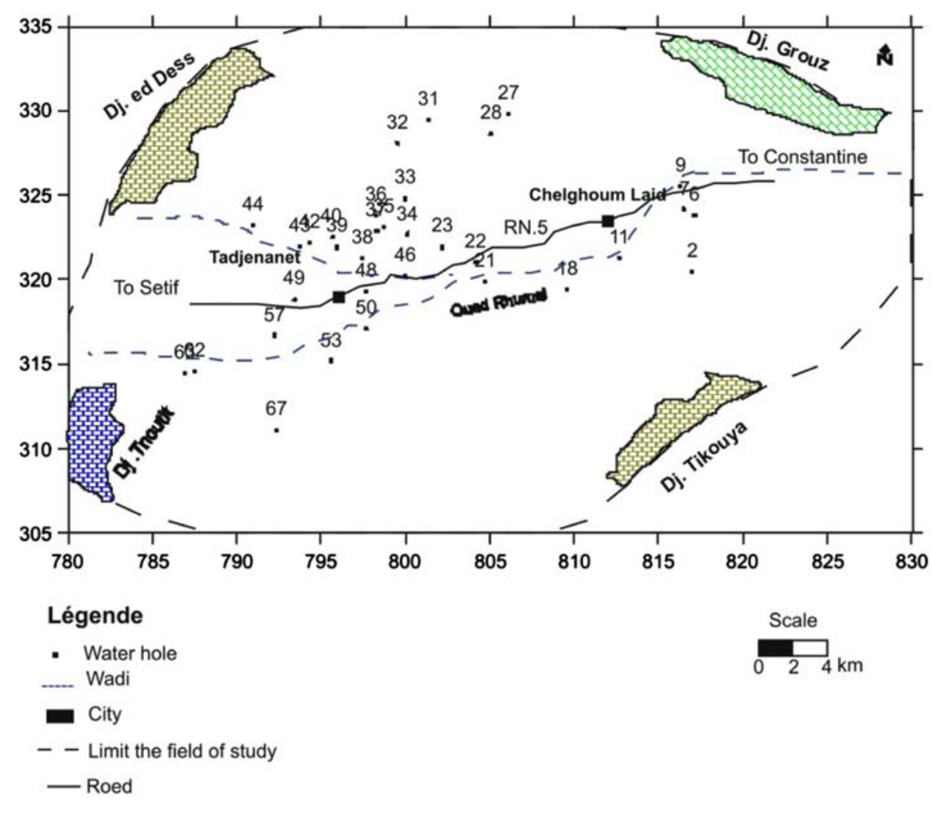

Fig. 6. Inventory map of the water points which have been the subject of a physico-chemical analysis.

Table 1
Change in physicochemical parameters in the alluvial aquifer of Tadjenanet—Chelghoum-Laid (May 2007)

N° water hole	pH	Cond µs/cm⁻ à25°c	T°c	Ca^{++} (mg/l)	Mg^{++} (mg/l)	Na^{+} (mg/l)	K^{+} (mg/l)	HCO_3^{-} (mg/l)	SO_4^{-} (mg/l)	Cl^{-} (mg/l)	NO_3^{-} (mg/l)	NO_2^{-} (mg/l)	NH_4^{4} (mg/l)	PO_4^{--} (mg/l)
2	7.52	1,846	17.9	175.2	96.35	102.35	11.2	485.5	430	291.3	142.2	0.01	0.1	1.2
6	7.6	1.071	18.6	220.3	123.2	109.2	7.8	245.6	375	310.1	34.11	0	0	0
7	7.56	1.285	18.4	254.22	111.25	106.3	10.2	310.3	560	302.6	97.9	0	0	0
9	7.5	2.530	19	259.71	122.64	115.6	8.9	230	1.100	298.2	107.65	0.03	0.1	1.1
11	7.52	3.170	16.9	256.54	114.96	143.8	10.2	512.4	640	319.5	134.23	0.02	0.56	0.8
18	7.12	3.610	17.5	304.6	172.44	132.7	11.3	340.6	910	337.25	126.7	0.05	0.3	0.5
21	7.2	1.529	19	291.61	165.43	65.8	4.5	430.2	530	250.3	58.48	0	0	0
22	7.48	1.018	18.1	182.34	109.65	75.3	6.7	245.1	135	185.6	182.07	0.03	0.2	0.5
23	7.52	3.020	17	272.54	111.12	121.6	9.9	165.5	910	339.15	486.41	0.05	0.56	2.2
27	7.5	863	17.6	135.4	85.91	75.6	5.8	265.3	280	105.6	126.7	0.01	0.1	0.4
28	7.6	1.330	16.8	115.25	65.01	61.2	6.9	201.3	320	185.75	91.7	0	0	0
31	7.54	1.698	17.3	125.04	61.32	95.9	9.2	322.4	390	223.56	135.11	0.01	0.4	0.9
32	7.41	1.032	15.6	120.24	43.05	48.7	4.3	226.08	50	88.75	100.35	0	0	2
33	7.29	1.445	18.5	104.2	50.28	61.6	6.8	256.2	380	142	91.7	0	0	0
34	7.42	1.356	15.4	115.81	41.39	51.2	4.5	212.1	45	101.35	174.98	0.02	0.1	0.8
35	7.2	950	15.5	121.84	32.49	59.9	5.8	221.2	30	117.15	73.09	0	0	0
36	7.66	1.170	19.2	110.53	41.2	62.3	5.9	231.5	48	109.16	86.38	0	0	0
37	7.5	745	19	95.42	35.07	53.1	4.2	220.6	42	96.58	87.27	0	0	0
38	7.35	1.230	15.1	88.17	48	63.6	7	244	48	152.65	94.8	0	0	0
39	7.45	1.121	16.9	87.35	39.08	53.7	6	236	46	143.4	93.03	0	0	0
40	7.48	1.190	18.2	81.25	38.25	56.2	4.8	255.75	66	148.5	131.57	0	0	0
42	8.27	990	16	96.21	35.21	55.2	4.9	265.2	45	128.6	105.81	0.01	0.2	0.6
43	7.8	1.047	16.4	128.25	30.6	56.7	6.1	180.6	29	131.35	98.78	0	0	0
44	8.63	910	17	145.6	45.94	65.2	7.3	220.8	52	158.6	47.84	0	0	0
46	8	1.719	18.8	91.15	50.2	70.25	7.5	256.2	48	165.3	57.59	0	0	0
48	8.5	2080	16.6	171.54	87.24	106.3	8.8	475.8	680	294.65	52.27	0	0	0
49	7.9	1.717	17	155.42	45.2	93.5	7.9	196.29	51.2	176.4	142.65	0.03	0.1	0.4
50	7.8	1.109	17.5	128.25	33.48	81.7	7.8	175.68	34	156.2	116.51	0	0	0
53	7.6	1.100	17.5	65.68	96.58	96.33	3.9	135.25	170.6	250.75	22.2	0	0	0
57	7.9	1.079	17.4	105.81	46.92	60.8	6.1	170.8	39	142	27.5	0	0	0
62	7.8	983	16.9	96.35	44.53	72.39	7.1	271.2	153.25	126.2	13	0	0	0
63	7.4	1.083	17	108.2	45.02	26.35	0.4	122	159.55	180.65	18.31	0	0	0
67	7.5	1.330	17.5	86.92	63.42	39.2	1.9	134.75	200.3	163.18	29.35	0	0	0

Hammam Grouz in the North East. The average annual rainfall reaches 372 mm estimated over a period of 16 years (1988/1989–2003/2004) at the station Grouz Hammam. Establishing the water balance using Thornthwaite and relationships Tixeron-Berkaloff shows that the actual evapotranspiration is the order of 343 mm contrary infiltration does not exceed 6 mm, while the runoff can reach 24 mm.

The various geological, geophysical and hydrogeological activities in the region [1,5–7] showed the existence of three permeable geological formations.

- An aquifer in the fractured limestone formations of the Cretaceous that characterizes tablecloth constantinian neritic and all allochtonous South Setif [1,5,8,11].
- A shallow aquifer in the Quaternary alluvium developed at Oued Rhumel which is in destocking phase.
- A continuous aquifer formations in fluvio-lacustrine Mio-Pliocene age. The first part covers the entire North Eastern region in the Cretaceous carbonate massif of Djebel Grouz. The second aquifer is thin and closely linked to waterways. In times of low water, it feeds the rivers, on the contrary in times of high water the reverse occurs. Along the Oued Rhumel, this sheet is partly fueled by neritic limestone aquifer of Cretaceous age. However, it is interesting to note that some of the alluvial aquifer has high mineralization following an intense evaporation, [1]. Its groundwater level is relatively close to the surface, from 0 to 3 m [9], it has little interest in terms of hydrogeology.

The third aquifer located in the formations of the Mio-Pliocene has good potential. The thickness of the aquifer varies from 100 to 150 m and consists of fluvio-lacustrine usually with reddish coloration quite pronounced. These formations crop out much more on the periphery of the watershed. These lacustrine limestone, red marl, silt and sand red are shown in Fig. 3.

The state of the groundwater was analyzed using two piezometric campaigns, the first conducted at the end of the period of low water (September 2006) and the second at the end of the recharge period (May 2007). Analysis of piezometric maps of two periods (Fig. 4) showed that the water has kept the same structure with:

- A limit to inflow from the massive carbonate that surrounds the plain to the north, south-west and north;
- A limit to outflow to the North East is the outlet of Oued Rhumel;
- A tight boundary east of the field characterized by the presence of impermeable formations and marl. The bedrock is formed by clays and marls;
- A low piezometric confused with the bowl of the dam.

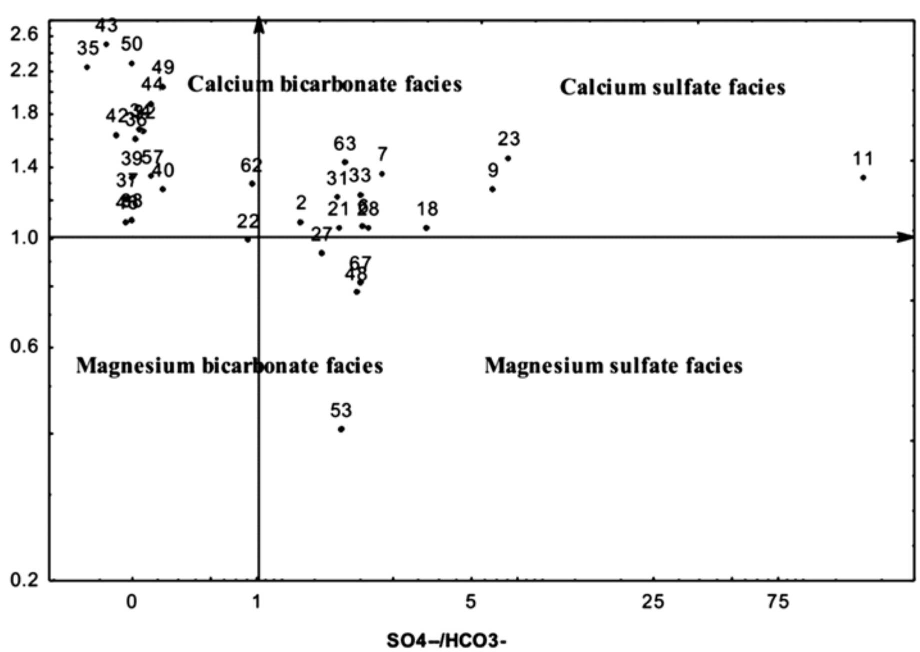

Fig. 7. Distribution of facies among chemical water points.

The change of transmissivity (Fig. 5) was analyzed using nine pumping tests conducted at a constant flow in small diameter wells distributed over the majority of the during the month of May 2007. The interpretation using the Theis model showed that the values of transmissivity decrease with the flow direction from upstream to downstream. This decrease is due to lateral changes in lithology resulting variation of hydrodynamic parameters of 2.5×10^{-4}–$1 \times 10^{-4}\,m^2/s$ [1].

2.2. Sample collection

All hydrochemical work involves collecting water samples, while respecting the collection techniques prescribed. The analysis of water samples can be employed:

- To have an idea about the identity of physico-chemical water and its mode of spatial distribution in the environment.
- To show the effects of groundwater quality on the risk of degradation of agricultural land.
- To approach the problem of potable water in the region.

To achieve this goal, a sampling campaign was conducted during the recharge period (May 2007). According to a mesh size of about $1\,km^2$, we were able to select 34 samples collected at water points (wells and boreholes) that we have previously selected (Fig. 6).

Chemical analysis was performed at the laboratory of waste water treatment principal of Batna and in a private laboratory analysis of soil and irrigation water. The chemical elements were measured were: Ca^{++}, Mg^{++}, Na^{+}, K^{+}, HCO_3^-, SO_4^{--}, Cl^-, NO_3^-, NO_2^-, NH_4^+, PO_4^{---}.

The physico-chemical parameters (T°C, pH and conductivity) are measured *in situ* using a pH meter and a conductivity type wissenschaftlich technische werkstâtten. Major ions (Na^+, K^+, Ca^{++}, Mg^{++}, HCO_3^-, Cl^-, and SO_4^{--}) were determined by atomic absorption spectrometer for cations, by titration for chloride and alkalinity. Nitrogen elements were determined by spectrophotometry; nitrate in the presence of silicate gives paranitosalicylate sodium, colored in yellow (415 nm) [10].

3. Results and discussion

Water chemistry of the alluvial aquifer is characterized by a wide variation in concentrations of chemical elements: Na^{+-} (51–143 mg/l) and Cl^- (88–339 mg/l), SO_4^{--} (30–1100 mg/l), Ca^{++-} (65–304 mg/l), Mg^{++-} (30–172 mg/l), and HCO_3^- (122–512 mg/l), NO_3^- (13–486 mg/l), NO_2^-, NH4$^+$, PO_4^{3-} (0.01–2.2 mg/l) (Table 1).

The origin of these chemicals is linked to the geological nature of the land to contact with water by dissolution of gypsum in the Triassic and Quaternary formations, dissolution of limestone and dolomite characteristic of the Cretaceous formations at the periphery of the study area. Only nitrogen compounds have a different origin, related to the use of

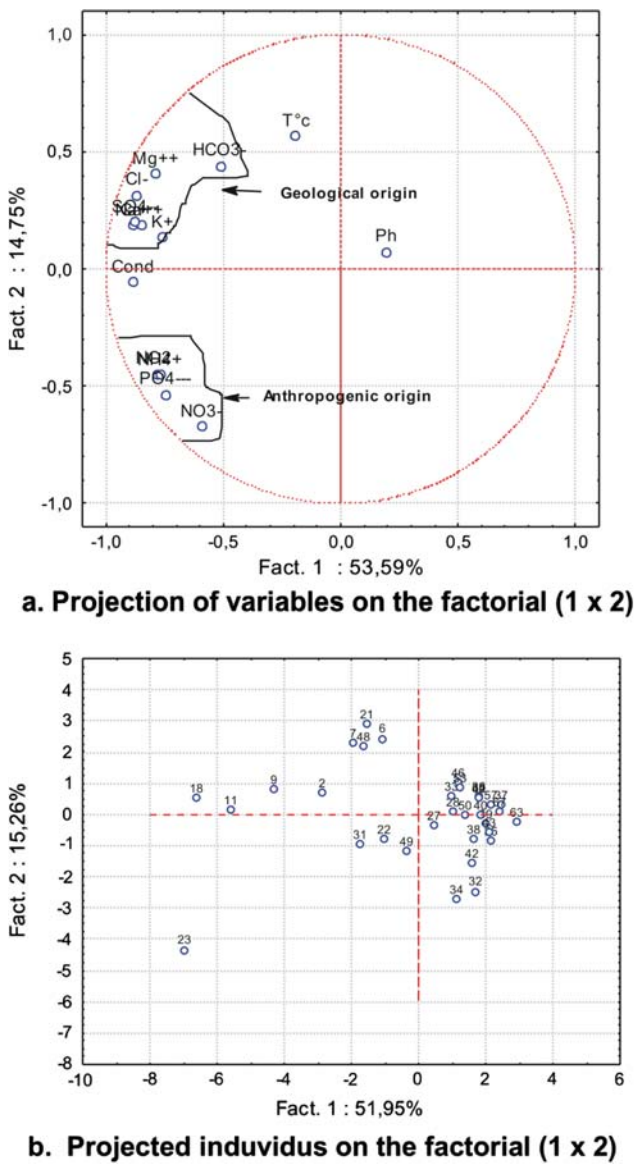

Fig. 8. ACP graphical representation of chemical data May 2007.

chemical fertilizers and/or organic agriculture and the decomposition of organic matter.

3.1. Facies chemical and potable water

The postponement of the test results on physico-chemical digraph logarithmic (Fig. 7) shows the existence of two major water types: calcium bicarbonate and calcium sulfate. The calcium bicarbonate facies is the most dominant, with 51% of water samples analyzed. This group has a very high hardness (>30° F), which provides water to the water quality average to poor irrigation with high salinity risk and low risk of sodicity.

The principal component analysis was performed on an array of 33 samples and 14 variables: Ca^{++}, Mg^{++}, Na^{+}, K^{+}, HCO_3^{-}, SO_4^{--}, Cl^{-}, NO_3^{-}, NO_2^{-}, NH_4^{+}, PO_4^{---}, pH, T°C, Cond. Several significant correlations were found between different chemical elements, with a strong correlation ($r > 0.6$) observed between Ca^{++}, Mg^{++}, Na^{+}, K^{+}, SO_4^{--}, Cl^{-} and conductivity. Other less significant correlations were found between conductivity and nitrate ($r = 0.475$) indicating the high use of fertilizers (chemical and/or organic) in agriculture.

Negative correlations were observed between pH and Ca^{++}, Mg^{++}, SO_4^{--}, Cl^{-}, NO_3^{-}, NO_2^{-}, NH_4^{+}, PO_4^{---} indicating the role of pH in the dissolution of evaporite formations above.

The analysis was carried out to two factors and only 68% of the total variance could be casted (Fig. 8 (a)).

- The horizontal axis expresses F1 53% of the variance and is related to Ca^{++}, Mg^{++}, Na^{+}, K^{+}, HCO_3^{-}, SO_4^{--}, Cl^{-} and Cond.
- The vertical axis F2 which represents 15% of the variance is marked by opposition to elements of the temperature of anthropogenic NO_3^{-}, NO_2^{-}, NH_4^{+} and PO_4^{---}. The projection of individuals has revealed that water points characterized by these elements are located in the center field and near the wadi where the use of chemical fertilizer is intense (Fig. 8(b)).

3.2. Study of nitrate

An examination of the map plotted from data sampling campaign in May 2007, (Fig. 9) shows that the area's most vulnerable to nitrate pollution are

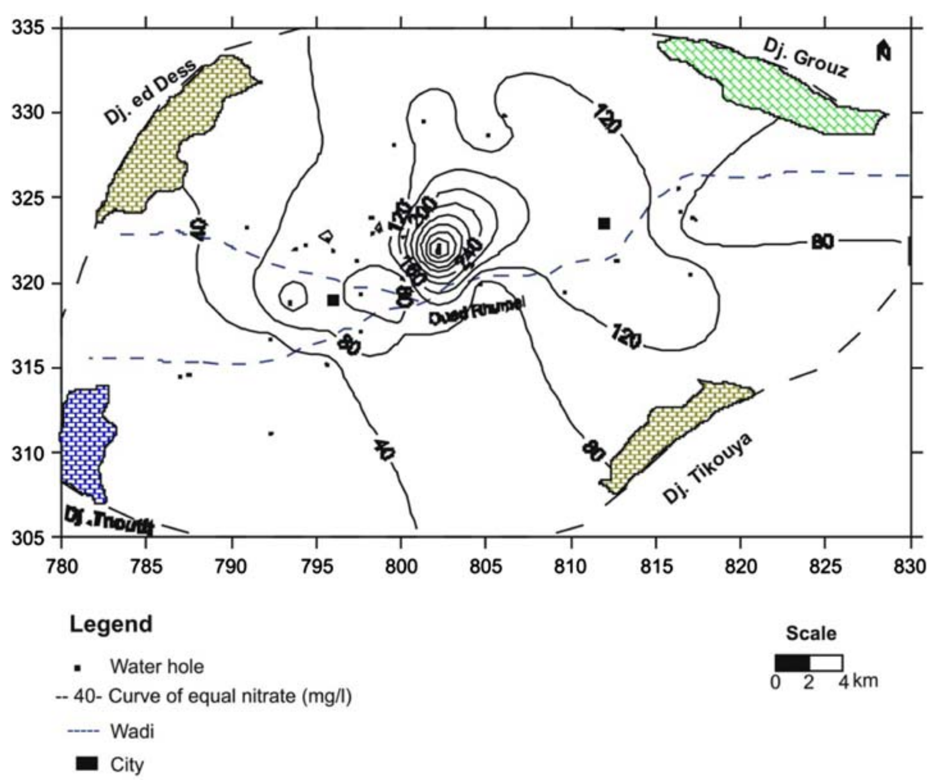

Fig. 9. Variation of the nitrate concentrations in alluvial groundwater.

located in the central part of the plain. This zone is characterized by the presence of a thick permeable layer that promotes the migration of nitrogen compounds to the saturated zone, following a continuous supply of nitrogen fertilizers. Strong content is recorded in the well No. 23 with a concentration of over 486 mg/l low levels are recorded in the south-western part of the land. This zone is characterized by a relatively deep groundwater level (75 m) and by the existence of a thick clay layer that protects the water against the infiltration of fertilizers. The lowest value was recorded in well No. 62 with a concentration of about de13 mg/l. The chemical analysis showed that nearly 79% of water points have values higher than 50 mg/l.

3.2.1. Influence of water depth on the content of nitrogen

An examination of the graph on the evolution of the concentration of nitrate according to the depth of groundwater level (Fig. 10) shows that most water points are aligned around a positive slope which indicates an opposite trend of the nitrate content according to the depth of the water. This phenomenon is due to nitrate reduction following a decrease in oxygen content. This state is clearly visible especially in the western part of the land where the permeability is important. Points situated at great depths have been observed by high nitrate levels, this is due to the effect of the intensive use of chemical fertilizers and high soil permeability, which allows nitrate to seep deep.

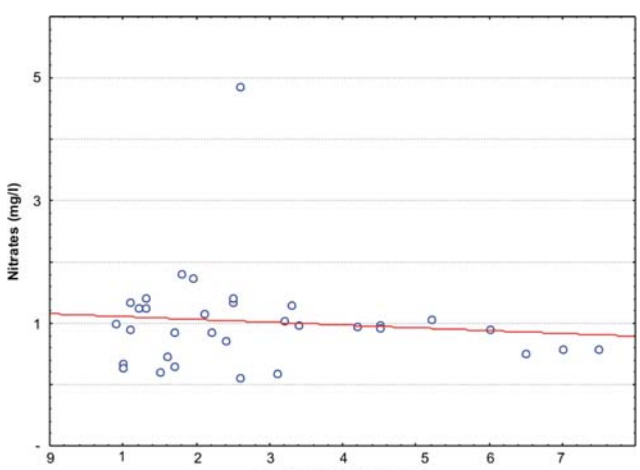

Fig. 10. Relation nitrate—depth of the water point.

3.2.2. Relationship nitrate–nitrite and ammonium nitrate

The other two nitrogen forms (nitrite and ammonium) appear from a certain concentration limit for nitrate (100 mg/l). They are mainly due to the reduction of the nitrate form. Pairing these two forms only in the central part of the land (Figs. 11 and 12).

3.2.3. Effect of hydraulic head on the content of nitrates

The infiltration of water from rainfall and irrigation in the water plays a major role in the variations of nitrate content, as a result of charging.

The representation of nitrates according to the static level of all water points (Fig. 13) shows that the points of water with low static level have a high con-

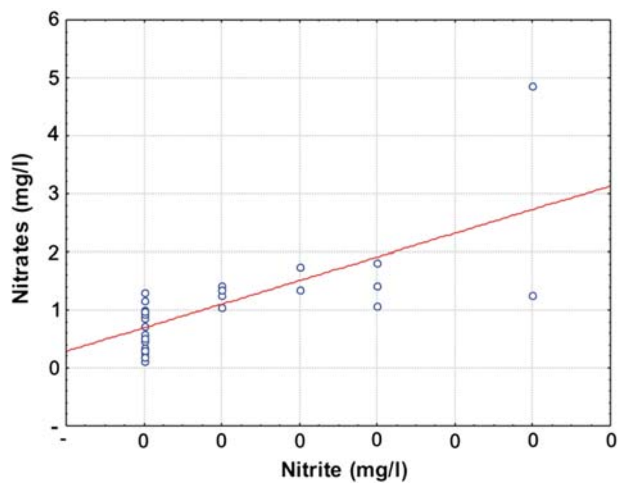

Fig. 11. Relation nitrate—nitrite.

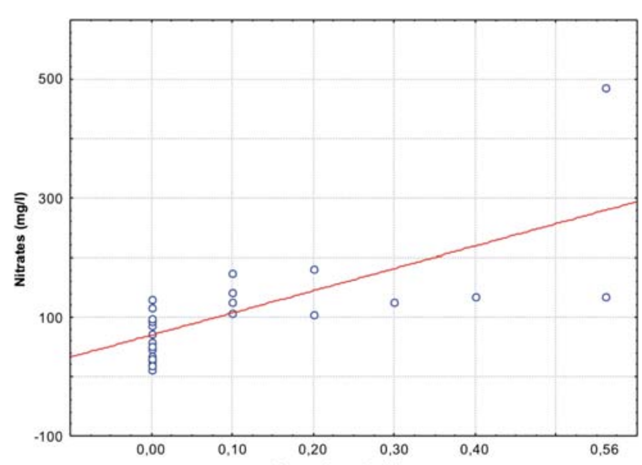

Fig. 12. Relation ammonium—nitrate.

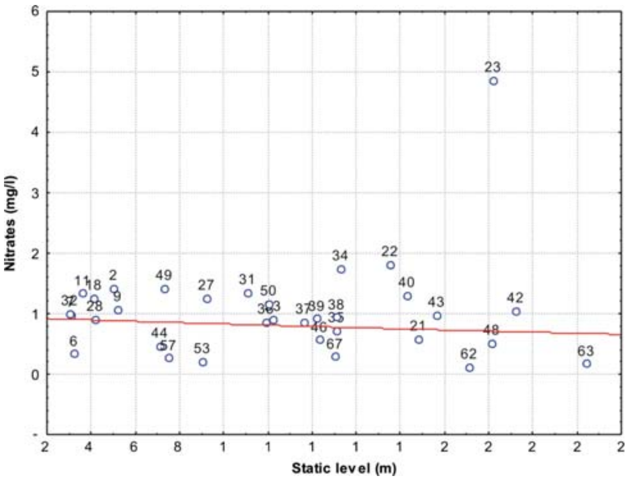

Fig. 13. Relation nitrate—static level (May 2007).

tent of nitrates due to the ease of ion nitrate to be transported by water through the unsaturated zone of small thickness. With a particular case that characterize water points located in central and eastern plains results in the presence of a large hydraulic gradient and the effect of intense pumping causes a leaching of agricultural land whose use of chemical fertilizers (N, P and K) in these locations is in an abusive manner.

4. Conclusion

The study area is characterized by the presence of a sedimentary formation of the Mio-Plio-Quaternary. We also note the presence of carbonate formations of the Cretaceous on the east and west edges of the field. These courses play an important role in feeding the alluvial aquifer.

The water table of the web showed the presence of a groundwater flow direction West–East supported by a supply from carbonate formations surrounding plain.

The water chemistry was used to assess the physical and chemical quality of these waters. The dominant facies of the waters of this aquifer is of type calcium bicarbonate to calcium sulfate in association with gypsiferous clays Mio-Plio-Quaternary.

The practice of intensive agriculture in the region allows spreading irrational fertilizer rich in nitrates, phosphates and potassium-threatening deterioration of the physico-chemical quality of water from the alluvial aquifer. The areas most affected in the region are the central area and the area in the east mainly because of the shallow groundwater level.

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