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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 aquifers located in the alluvium of Mio-Plio-Quaternary. This study aims to determine the critical impact of natural and anthropogenic pollution on the physico-chemical properties of 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 agricultural activities 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 sources of pollution of aquifers in the region of Tadjenanet-Chelghoum Laid [1]. The pollution risk is accentuated further by the lack of protective cover, causing pollutants to enter 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 misuse of fertilizers in agriculture, the decomposition of plant materials or animal manure, domestic wastewater and industrial applications [3]. Through piezometric and hydrochemical studies in the unconfined aquifer, and from the results of physico-chemical analysis, the data necessary to define the risk caused by the phenomenon of pollution have been provided.

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 nitrates, due to their high solubility and low affinity for ion exchange [3,4]. Nitrates are the most oxygenated and soluble form of

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nitrogen; they are the result of the nitrogen cycle, and are essential nutrients to plants. 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].

2. Materials and methods

2.1. Geological and hydrogeological settings

The region of Tadjenanet-Chelghoum Laid covers an area of 1,130 km^2. It is a 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 mountains 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 northwest and southeast. This morphology is monotonous and is 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 in 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 Hammam Grouz in the northeast. The average annual rainfall reaches 372 mm estimated over a period of 16 years (1988/1989—2003/2004) at the station of Grouz Hammam. Establishment of water balance using Thornthwaite and relationships of Tixeron-Berkaloff shows that the ETR is of the order of 343 mm, and contrary infiltration does not exceed 6 mm, while the runoff can reach 24 mm.

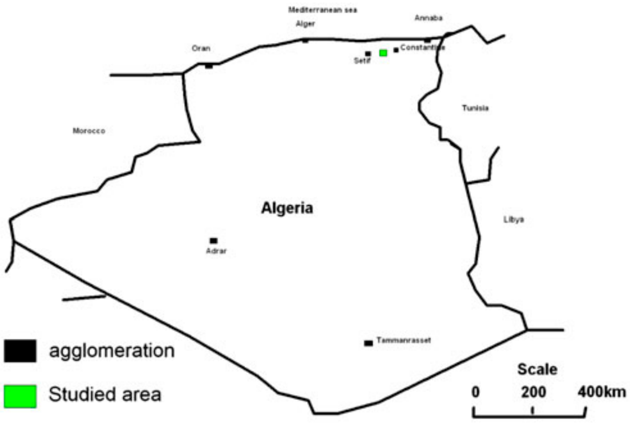

Fig. 1. Location of the studied area.

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 [1,6,8,11].
- A shallow aquifer in the Quaternary alluvium developed at Oued Rhumel which is in destocking phase.
- A continuous aquifer formation in the fluvio-lacustrine Mio-Pliocene age.

The first part covers the entire northeastern region in the Cretaceous carbonate massif of Djebel Grouz. The second aquifer is thin and closely linked to waterways. In times of low water availability, 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 have high mineralization following an intense evaporation [1]. Its groundwater level is relatively close to the surface, from 0 to 3 m [9], and is of 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 deposits, usually with quite pronounced reddish coloration. These formations crop out much more on the periphery of the watershed, and consist of lacustrine limestone, red marl, silt, and sand red (Fig. 3).

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

- A limit to inflow from the massive carbonate that surrounds the plain in the north, southwest, and north.
- A limit to outflow to the northeast 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 value confused with the bowl of the dam.

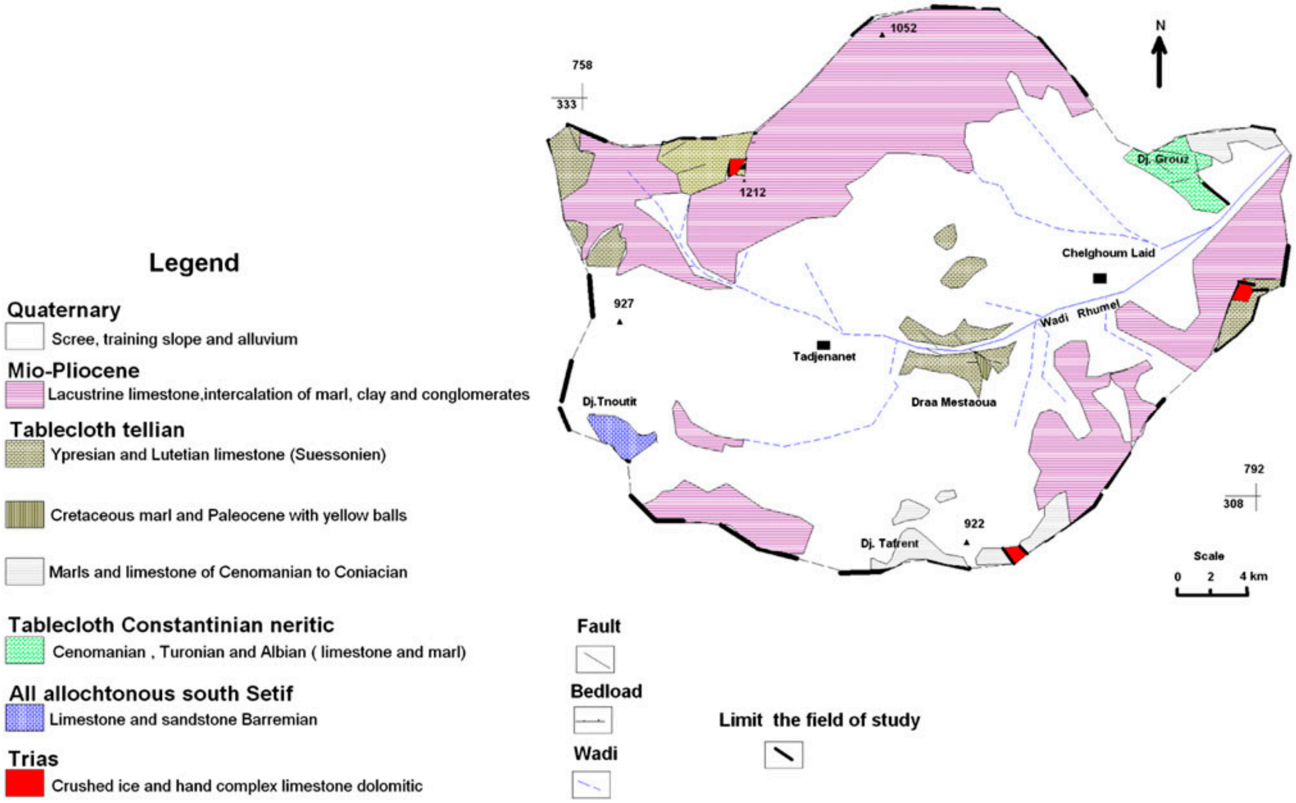

Fig. 2. Geological map of the sub-basin of Tadjenanet-Chelghoum Laid (according to J.M.Vila-1977).

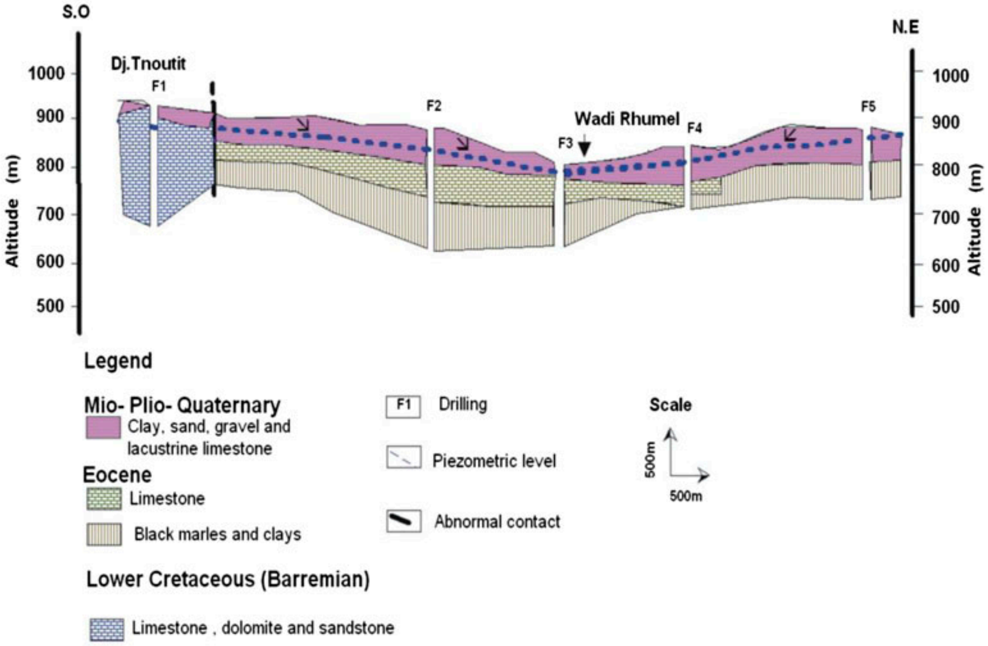

Fig. 3. Hydrogeological section.

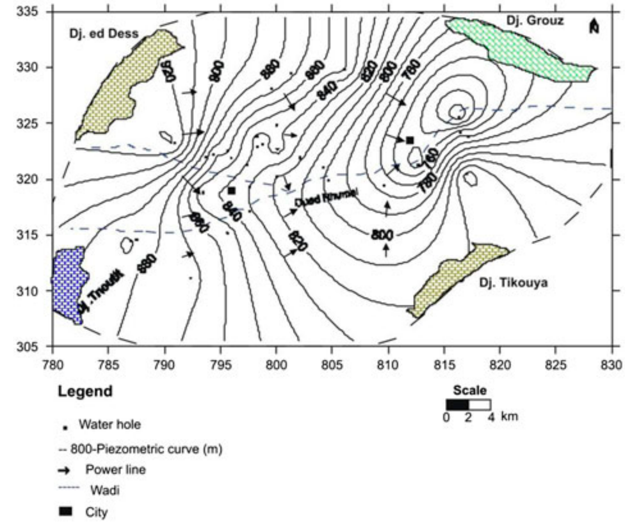

Fig. 4. Piezometric map.

The change in transmissivity (Fig. 5) was analyzed using nine pumping tests conducted at constant flow in small-diameter wells distributed over the majority of the region 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 from the variation in hydrodynamic parameters of $2.5.10^{-4}$ -1.10^{-4} m^2/s [1].

2.2. Sample collection

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

- To have an idea about the physico-chemical identity of the 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.

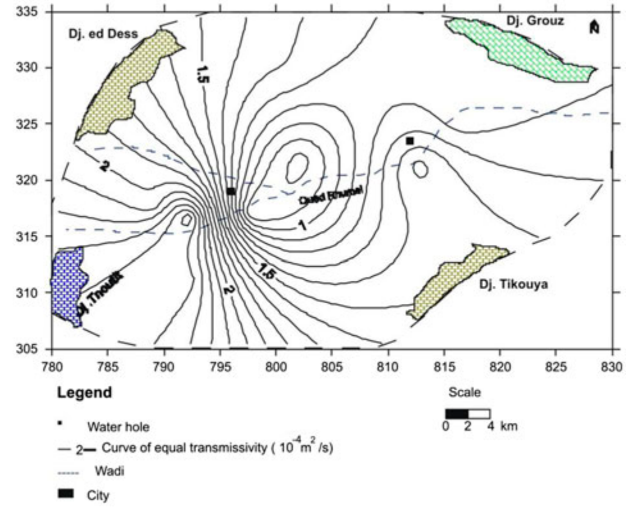

Fig. 5. Map of transmissivity in 10^{-4} m^2/s.

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

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

The physico-chemical parameters (T°C, pH, and conductivity) are measured *in situ* using a pH meter and a conductivity type WTW. 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 gave paranitosalicylate sodium of yellow color (415 nm) [10].

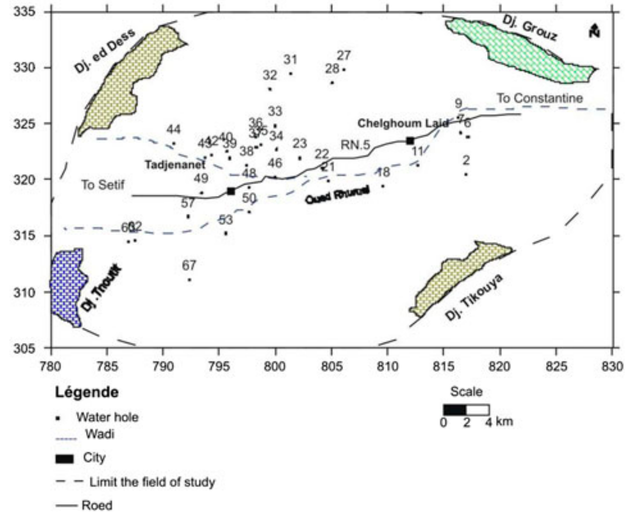

Fig. 6. Inventory map of water points have been the subject of physico-chemical analysis.

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

No. of 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

3. Results and discussion

Water chemistry of the alluvial aquifer is characterized by wide variation in the concentrations of chemical elements: Na^{+-} (51–143 mg/l) and Cl^- (88–339 mg/l), SO_4^-, (30–1,100 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^-, NH_4^+, PO_4^-(0.01–2.2 mg/l) (Table 1).

The origin of these chemicals is linked to the geological nature of the land to come in to contact with water by dissolution of gypsum in the Triassic and Quaternary formations and dissolution of limestone and dolomite, which is characteristic of the Cretaceous formations at the periphery of the study area. Only nitrogen compounds have a different origin, which is related to the use of fertilizers (chemical and/or organic) in 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 one, with 51% of water samples analyzed. This group has very high hardness (>30 F), providing water of average quality, resulting in 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, and Cond. Several significant correlations between different chemical elements was observed, with a strong correlation ($r > 0.6$) 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.

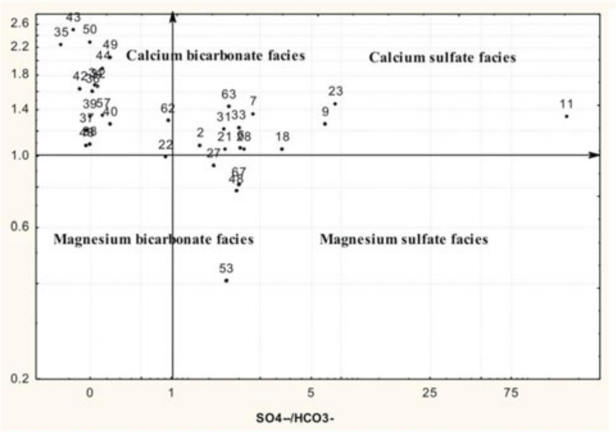

Fig. 7. Distribution of facies chemical water points.

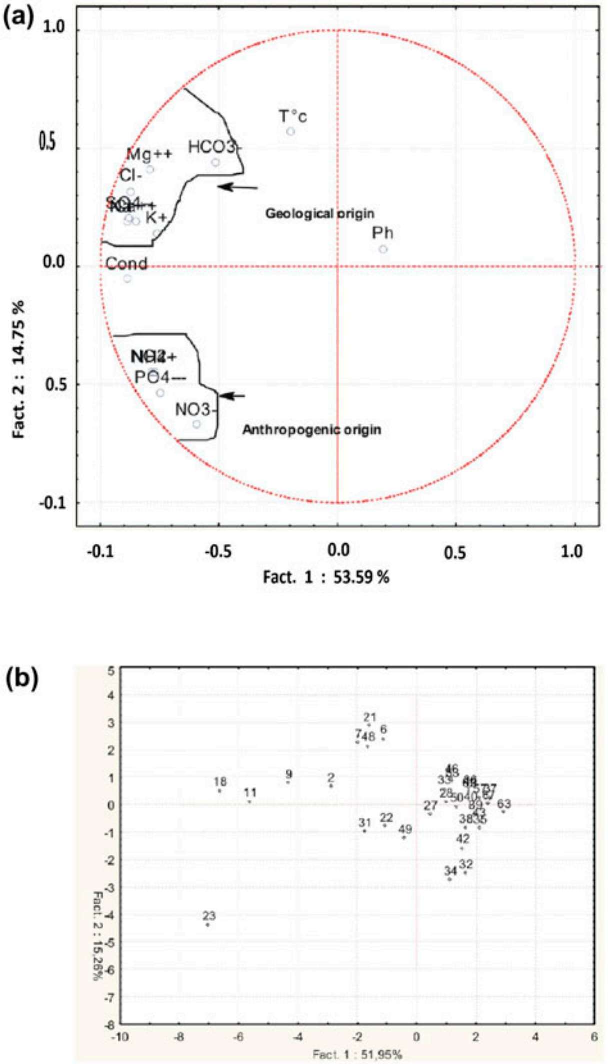

Fig. 8. ACP graphical representation of chemical data May 2007. (a) Projections of variables on the factorial (1 × 2). (b) Projected individuals on the factorial (1 × 2).

Negative correlations were observed between pH and Ca^{++}, Mg^{++}, SO_4^-, Cl^-, NO_3^-, NO_2^-, NH_4^+, and PO_4^-, indicating the role of pH in the dissolution of evaporite formations above. The analysis was carried to two factors and only 68% of the total variance could be cast (Fig. 8(a)).

- The horizontal axis expresses F1 53% of 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 areas most vulnerable to nitrate pollution are 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 southwestern 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

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.

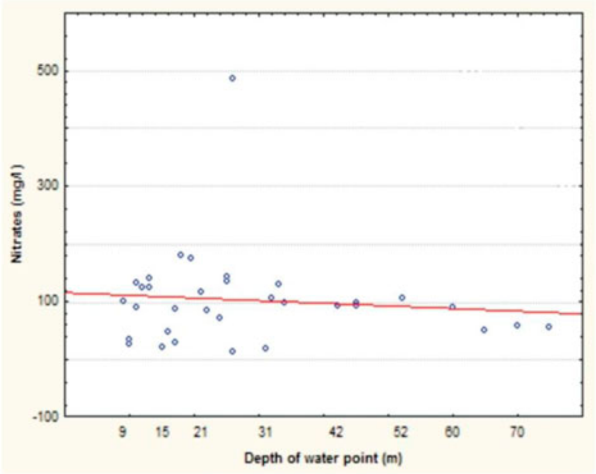

Fig. 10. Relation nitrate—depth of the water point.

3.2.2. Relationships of nitrate–nitrite and ammonium–nitrate

The other two nitrogen forms (nitrite and ammonium) appear from a certain concentration limit

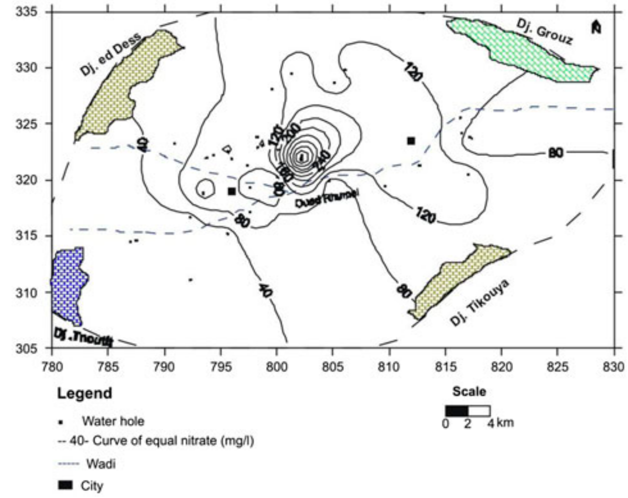

Fig. 9. Variation of the nitrate concentrations in alluvial groundwater.

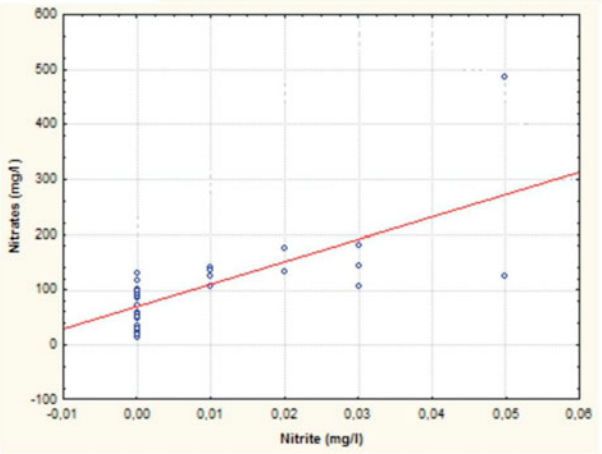

Fig. 11. Relation nitrate–nitrite.

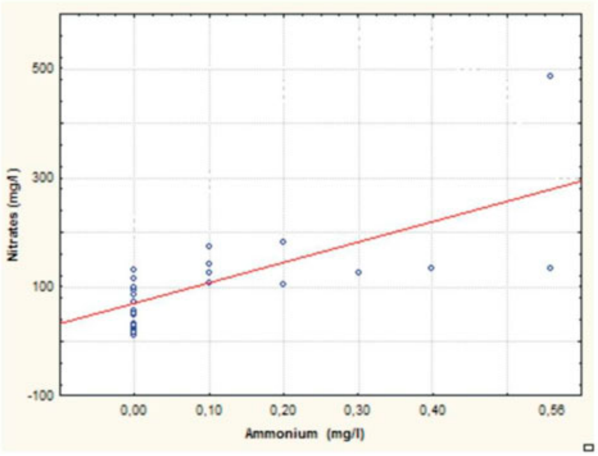

Fig. 12. Relation ammonium nitrate.

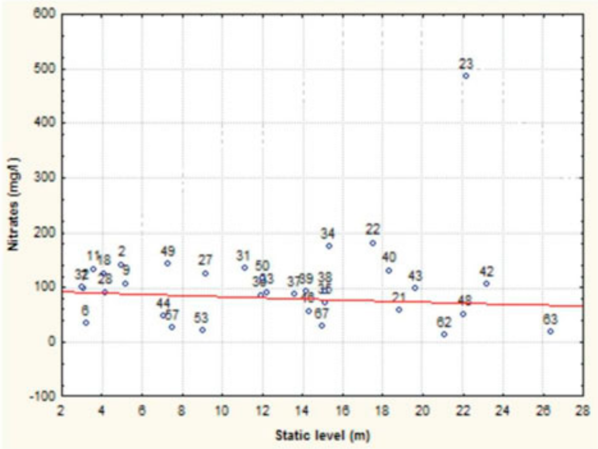

Fig. 13. Relation nitrate—static level (May 2007).

for nitrate (100 mg/l). They are mainly due to the reduction of the nitrate form. The pairing of these two forms happens 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 will play 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 content of nitrates due to the ease of ion nitrate to be transported by water through the unsaturated zone of small thickness. The water at the water points located in the central and eastern plains show a large hydraulic gradient and the intense pumping causes a leaching of agricultural land which is being abused by the use of chemical fertilizers (N, P, and K) in these locations.

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 in the east and west edge 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 carbonates formations surrounding the plain.

The water chemistry was used to assess the physical and chemical qualities 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 of Mio-Plio-Quaternary.

The practice of intensive agriculture in the region allows spreading of irrational fertilizers 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 east, mainly because of the shallow groundwater level.

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