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Impact of agricultural development on karstic groundwater of Saïda Mountains in Algeria

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***Abstract*:** The Saïda Mountains are composed of carbonate massifs (limestone-dolomite rocks) of Early to Middle Jurassic age. The Saïda Mountains aquifer is fed by precipitation and by a relatively dense temporary hydrographic system. The mountains represent an important water reservoir for northwestern Algeria. Anthropogenic impacts have continuously modified the physico-chemical characteristics of the water in this fragile aquifer. Concentrations of anthropogenic parameters [NO^-_3 (62 mg/l), SO^{2-}_4 (173 mg /l), Cl^- (123 mg/l)] at water points represent critical values that pose risks to the population. Interpretation of graphs of anthropogenic water parameters shows that the primary source of pollution is agricultural activity, which has increased significantly in the study area. However, our investigations and interviews with water resource managers show that great difficulties persist in the implementation of recommended protective actions.

***Keywords*:** karstic aquifers, anthropogenic pollution, agricultural livestock, Saïda Mountains, Nitrate pollution, physico-chemical characteristics.

1.Introduction

Numerous authors have studied the nitrate problem with particular attention to its origin and behavior in groundwater Didon-Lescot and al (1998)[1]; Guglielmi and al (1994)[2]; Louche and al (1998)[3]. Numerous authors in various regions of the Middle East have reported pesticide pollution of groundwater. To evaluate the vulnerability of groundwater, it is necessary to use chemical data for elements other than nitrates. In (1997) Djidi [4] used chemical measurement of water sampled from Saïda groundwater for his interpretations on the double role of water, as chemical and transport agent, through an aquifer.

The karstic groundwater of the Saïda Mountains represents a vital resource throughout northwestern Algeria, because of its geographical position and because of the natural wealth (agriculture and mineral waters) it provides. This groundwater is monitored qualitatively and quantitatively at the outlets of the primary springs. The groundwater currently suffers from considerable degradation incurred by the over-exploitation of water and excessive use of agricultural fertilizers. Establishment of protection for this resource should include an evaluation of vulnerable zones and installation of protection zones. Measures to protect the resource in question require a broad awareness on the part of concerned parties.

The purpose of this study is to characterize and provide details on the karstic Saïda Mountains, to analyze the manner in which the degradation affects the water, to specify causes that may lead to this degradation, and to propose adequate strategies to protect the water. The approach is based on three components:

The first consists of characterizing the physical context of the Saïda Mountains karstic system and evaluating anthropogenic impacts; The second involves the use of hydrochemical methods to evaluate the anthropogenic effects on groundwater; and the third relates to the awareness of interested parties in the field of agriculture. Jean-Joel. Gril, N. Carluer et G. Le Hénaff., (2011) [5] ; A. Berne., (2014) [6] ; S. Fass et J.-C. Block., (2014) [7]

2. Natural Specificities

The ecological diversity of the Saïda Mountains has created a territory rich in waters of varied physico-chemical and chemical composition. This area benefits from abundant mineral water reserves and several thermal springs. Geographically speaking, the Saïda region is characterized by two distinct compartments, namely: a steppe region in the south and a forested mountain region in the north.

2.1. Geographical location and climate

The Saïda Mountains are part of the Algerian north-western high plateaus, bounded to the south by the Oranaise High and to the north by the Sidi Kada and the Mina Mountains, to the west by the Daïa Mountains and to the east by the Frenda Mountains. (Fig.1)

The dominant climate in the region is continental, of semi-arid to arid type. Average rainfall is 400 mm. The annual precipitation is characterized by an extreme irregularity and a low number of rainy days. The average annual temperatures are 23°C with minima of 0°C and maxima of 35°C.

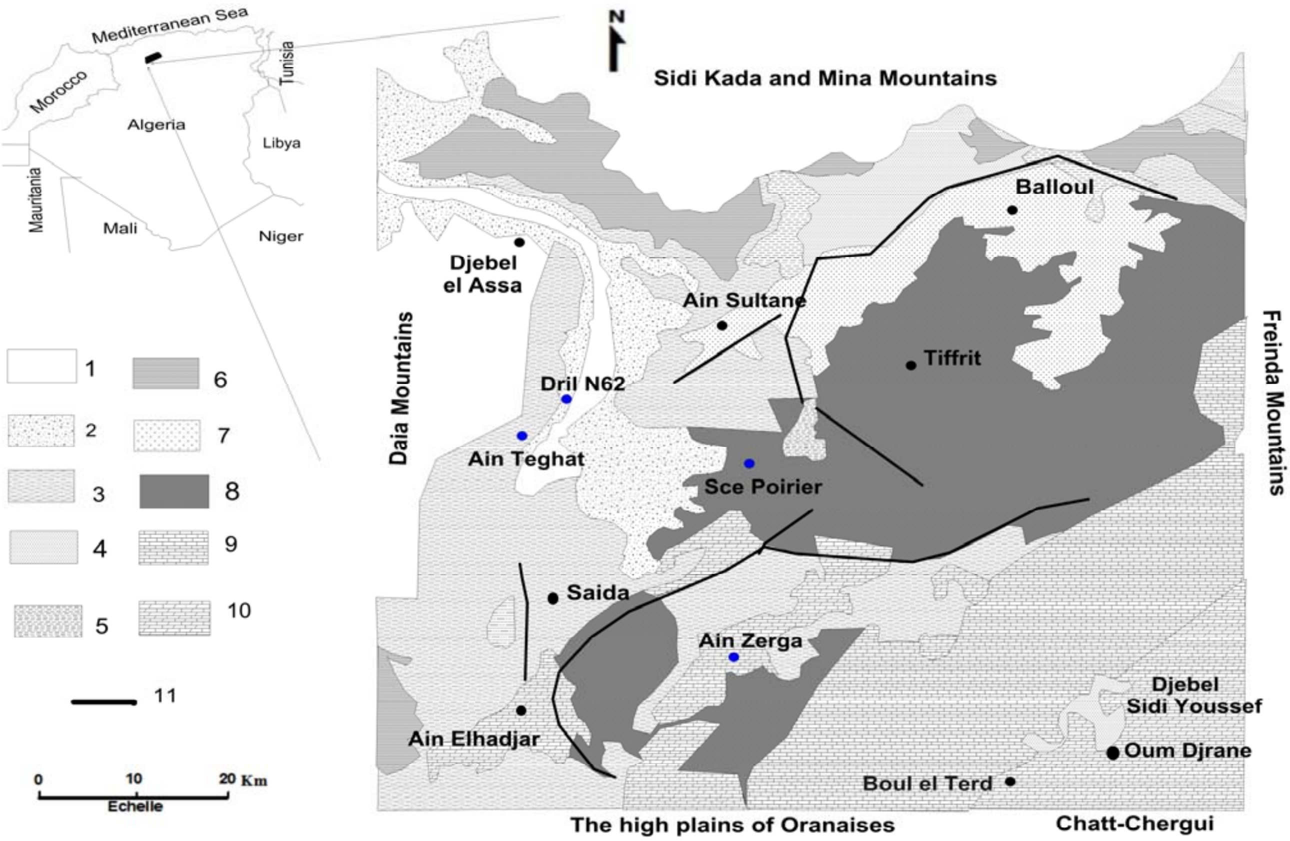

Fig.1: Geographical and geological location of the Saïda Mountains (Pitaud. G 1973)
1 Quaternary Alluvium, piedmont, *2* Plio Quaternary: Conglomerates, Sandstones, *3* Pliocene, Conglomerates "Highlands", *4* Mio-Pliocene, Conglomerates, Blue Marne, *5* Callovo-Oxfordien: Clayey Sandstone, *6* Lusitano: Solid Sandstone of Franchetti, *7* Silurian: Metamorfic and Eriptique, Bajo-Bathonien (*8* Crystalline Dolomite and Limestone, *9* White Limestone, *10* Dolomitic limestone), *11* Faile, Dril: Drilling, Sce: Source.

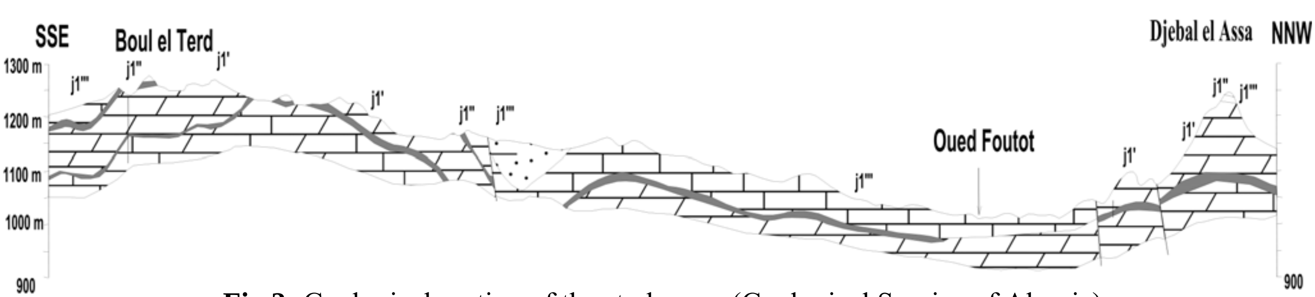

Fig.2: Geological section of the study area (Geological Service of Algeria)

2.2. Geological and Hydrogeological Context

Two hydrogeological studies have been conducted in the Saïda Mountains, by Pitaud 1973 [8] and the ANRH (Agence Nationale des Ressources Hydrauliques) (National Agency of Hydraulic Resources) (1982)[9] . These two studies involved the collection of numerous geological and hydrogeological data, which now require updating.

According to Clair (1952) [10] and Pitaud (1973) [11] , the Saïda Mountains are composed of a vast anticline of secondary Mesozoic age, mainly represented by formations of the Lower and Middle Jurassic dolomite pinching out the Triassic on the Tiffrit-Ain Soltane Paleozoic mole. Brittle tectonics has affected these carbonate formations and resulted in the very specific characteristic structures of the karstic regions. According to Bakalowicz, (2005) [12] , the karstic aquifers have characteristics that distinguish them from other formations.

These four characteristics are: Strong heterogeneity with greater of various dimensions, empty very large, flow speeds reaching some hundreds of meters per hour, and spring flow that can reach several dozen m^3/s Bakalowicz, 2005, P.148[13] .

The Saïda Mountains contain karstic aquifers of geological interest; they are represented by carbonate rocks of Aalenian-Bajocian-Bathonian age with a water potential ranging from 38 to 50 hm^3 a year. The groundwater of this aquifer is unconfined at the level of plateau and confined under the Saïda valley. (See Figs. 1 and 2)

2.3. Economic resources

The Saïda Mountains have relatively high economic potential, based mainly on agriculture and livestock. Pastoralism is of primary importance, and transhumance movements are increasing. The area is home to about 805585 head of sheep and 136517 hect of agricultural land are in production.

2.3.1 Livestock

Livestock is being raised throughout the Saïda Mountains. The number of livestock increased from 615160 to 866090 between 1997 and 2014 (Table 1).

2.3.2 Agricultural crops:

During the 2001-2005 period, the region recorded a sharp increase in areas planted in fruit trees, from 3276 hect in 2001 to 9500 hect in 2005. At the same time, the surface area occupied by cereals decreased sharply, from 127030 hect in 2001 to 105000 hect in 2005. According to The Ministry of Agriculture says it has committed a large amount of money for agricultural development programs. (Table 2).

Table. 1: Change in the livestock population (DSA, Directorate of Agricultural Services) of Saïda for the years [1991 to 2014].

Year	Total head	Year	Total head	Year	Total head
1991	811341	2001	355035	2009	677148
1992	788019	2002	420540	2010	704178
1993	726200	2003	443202	2011	722494
1994	703600	2004	620216	2012	749933
1995	761700	2005	591220	2013	892972
1996	610100	2006	656920	2014	866090
1997	615060	2007	622113	/	/
2000	443570	2008	507120	/	/

Table. 2: Change in agricultural land acreage for the period: 2000-2015 (DSA)

Year	Total Area	Year	Total Area
2000	132946	2008	109277
2001	128806	2009	128722
2002	121513	2010	129655
2003	116599	2011	130650
2004	120848	2012	131821
2005	124153	2013	133582
2006	122371	2014	135137
2007	122673	2015	130453

2.3.3 Industry

Given the agro-pastoral vocation of the Saïda Mountains region, the area used for industry is relatively minor. The industrial sector is represented by a few businesses with a relatively mild pollution effects, including a cement and plaster factory (El-Hassasna), two brickyards (Sidi Aïssa), agri-food industries in the Saïda industrial zone (dairy production, mineral water, semolina, mills), as well as various industries (textiles in Rebahia and paper bags in Ain El Hadjar).

3. Agricultural Pollution

The main crops grown in the area are cereals (wheat, barley), which occupy a surface of about 57423 hect; vegetable production that covers a surface approaching 3686 hect; and orchards occupying a surface area of about 136517 hect. Consequently, the various products (phosphates, nitrogen and potash and phytosanitary products) used to increase agricultural output, both qualitative and quantitative, lead to important pollution risks for groundwater. Fertilizers used to amend the soil easily infiltrate towards the groundwater, thereby risking contamination of this water. The primary fertilizers used in this area are ammo-nitrate 33% (NH_4^+ NO_3^-), potash sulfite and calcium nitrate $Ca(NO_3^-)_2$. The quantities of fertilizers used are shown in the table below, (Table 3).

Table. 3: Use of fertilizers by type of dominant speculation in quintals (DSA, 2005)

fertilizer (quintals) / culture	nitrogen	phosphore	potassium
tree crops	6608	3304	3304
viticul	553	474	316
cereal crops	81500	48900	48900
vegetab-gardening	1764	1372	1372
total	90425	54050	53892

4. Materials And Methods

For this project, we sampled four main representative karst systems of the Saïda Mountains, namely: Ain Zerga spring, Drilling N62, Ain Teghat spring, and Poirier spring. These water points were sampled quarterly during the period: 2004-2007 and monthly during the year 2014. The physical parameters (electric conductivity, temperature and pH) were measured in situ. Other parameters and elements (Turbidity, RS, Ca^{2+}, Mg^{2+}, Na^+, K^+, NH_4^+, HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-, PO_4^{2+}) were analyzed at the ANRH Oran laboratory using the following methods:

- Volumetric dosing for: Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-.
- Spectrophotometer for: SO_4^{2-} and NO_3^-.
- Flame spectrophotometer for: Na^+, K^+.

5. Results

The karstic formations of the Saïda Mountains are covered by a relatively thin layer of soil, which facilitates the transmission of fertilizer towards subterranean waters through the unsaturated zone Chakravarty and al (1989) [14] ; Banton and al (1995) [15] ; S. G.D. Smith and al (1999) [16] . This karstification allows direct contact between the atmosphere and groundwater, and any temperature change automatically influences the variability of groundwater temperature (14 to 23°C). The pH is slightly basic (7,1 to 8,1) and conductivity ranges from 550 to 995 μscm^{-1}, indicating increasing mineralization.

Interpretation of Piper diagram results (Fig. 3) indicates that the water facies of the Saïda Mountains are generally calcium bicarbonate to magnesium, with a tendency towards nitrate, sulfate, and chloride. This tendency is linked to anthropogenic agricultural pollution.

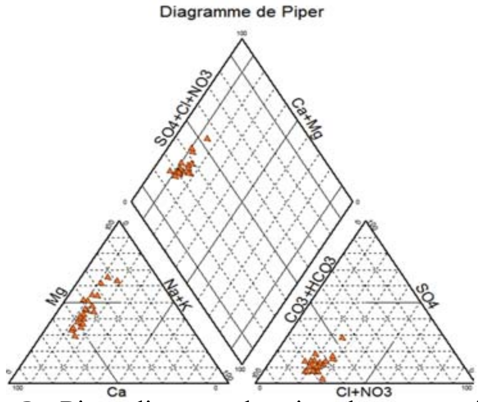

Fig.3: Piper diagram showing the composition of the Saïda Mountain aquifer water.

The chemical composition of drinking water must meet certain norms of physico-chemical character. The pH indicates that the Saïda Mountains aquifer water is slightly basic, with values between 7,6 and 8,1. Average annual temperatures at the groundwater table range between 14°C and 23°C with an average of 19,2°C.

The water ranges from average to highly mineralized. The average of Total Dissolved Solids is about 6,9 mg/l. Electric conductivity values range between 551 and 993 μScm^{-1}. The increase in electrical conductivity shows a salt contribution from soil leaching during rainfall infiltration and remobilization of salt stored in sediments. This phenomenon thus promotes sulfate, chloride, and nitrate contamination of the aquifer. Nitrates generally come from the mineralization of organic waste Schenck (1991) [17] and artificial fertilizers. Organic matter is mineralized through the biological oxidation of ammonium (NH_4^-) to NO_3^-; in Canter, (1997) [18]. The successive transformations made by chemoautotrophic bacteria are the following:

- $NH_4^+ + 3/2\ O_2 \rightarrow NO_2^- + 2H^+ + H_2O$ (by bacteria of the Nitrosomonas family)
- $NO_2^- + ½\ O_2 \rightarrow NO_3^-$ (by bacteria of the Nitrobacter family).

Anthropogenic groundwater pollution varies according to agricultural activity and according to weather conditions. The monitoring over time of anthropogenic elements within the four karst systems during the 2004-2014 period has shown the following relatively high concentrations: sulfates (173 mg/l), nitrates (58 mg/l) and chlorides (123 mg/l).

5.1. Nitrate pollution

The nitrate concentration present in aquifer water suggests a large pollution source. Nitrate concentrations increased agricultural and livestock activity increased Avgoustinos Avgoustis and all 2013 [19], 2012 [20] . In 2004, the annual nitrate average reached 22,5 mg/l; during that year agricultural surface area was estimated at 120,599 hect and the livestock population was of the order of 620,216 head. In 2014, the nitrate average had increased to 41 mg/l. The nitrate increase is related to agricultural development (135000 hect) and the increase in the number of livestock (866,090 head). (Table. 4)

Table. 4: Nitrate concentrations variations (mg/l) period 2004-2014

dates	drilling N62	sce Ain Zerga	sce Poirier	sce Ain Teghat
24/08/04	21	24	/	/
21/12/04	21	24	/	/
21/03/05	15	22	/	/
20/06/05	20	21	/	/
25/09/05	26	25	/	/
18/12/05	20	30	/	/
19/03/06	25	16	/	/
20/06/06	25	41	/	/
31/10/06	23	38	/	/
26/12/06	30	32	/	/
20/02/07	26	29	/	/
28/01/14	37	37	58	35
04/03/14	33	25	27	53
30/03/14	33	41	35	55
07/05/14	35	39	35	59
12/06/14	33	38	36	58
16/07/14	36	40	37	59
19/08/14	36	39	36	60
24/09/14	35	37	33	58
17/11/14	38	34	35	57
20/12/14	39	35	35	59
28/01/15	38	30	34	62

Nitrate concentrations increased in the early 2000s. This increase resulted from agricultural development in the region. We see a good correlation between the rise in nitrate content t and the increases in agricultural surface area and the livestock population (Fig.4).

In the part of our study area where the climate is semi-arid, the variation of agricultural activity is influenced by rainfall. The average nitrate content in the irrigated perimeters areas reached relatively high concentrations (56 mg/l), whereas, in non-irrigated perimeters the average was 36 mg/l (see Figs. 5and 6).

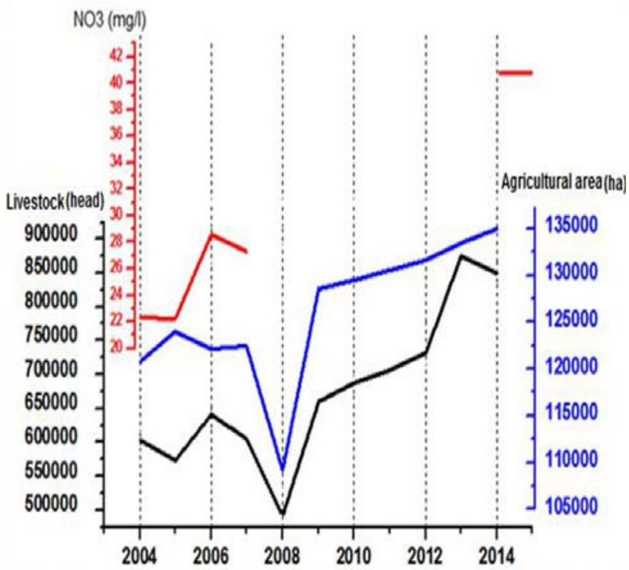

Fig.4: The relationship between nitrate variations and agricultural activity (2004 – 2014).

Fig.5: Monthly change in nitrate concentrations (2014).

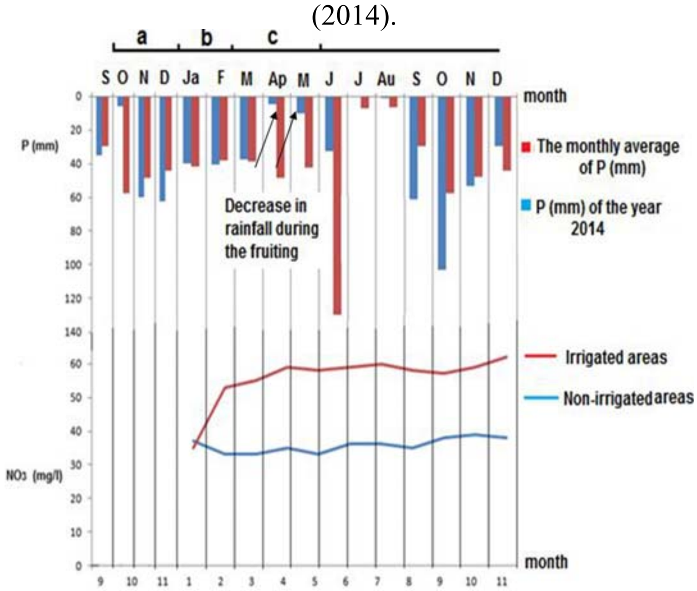

Fig.6: The relationship between the nitrate concentrations and rainfall (2013-2014)
a (sowing time). b (application period of chemical and organic fertilizers). c (phytosanitary period of treatment during fructification of the plant)

This increase in the nitrate concentrations suggests that groundwater pollution is relatively recent. Nitrate concentrations during (2004-2007) ranged from 15 to 41 mg/l; however, in 2014 the average of this element reached 41mg/l. Between 2007 and 2014 nitrates increased about 2,14 mg/l per year.

The nitrate average of Tehgat Spring reached 56 mg/l in 2014 due to relatively high levels of agricultural activity and animal breeding. Nitrate pollution can cause pathologies in animals and human beings, particularly methemoglobinemia in babies and cancer in adults, Olson and al (1972) [21] ; Blood and Henderson (1971) [22] ; Davison and al (1964) [23] -(1965) [24] ; Bennet and al (1968) [25] , Colmy (1945) [26.

5.1.1Origin of the nitrate pollution

To determine whether agricultural or breeding activities had more impact on increased nitrate concentrations, we the years between 1992 and 2014, and we notice that the years 1992 and 2014 had similar numbers of livestock (788,019 and 866,090 head);

- Agricultural crops increased from a small area (less than 5000 hect) in 1992 to 135,137 hect in 2014; and- Nitrate concentrations increased from 5 mg/l in 1992 to 41 mg/l in 2014.

We conclude that the agricultural crops had a greater influence than livestock breeding on increased nitrate concentrations in the karstic aquifer.

In 1992, nitrate concentrations ranged between 5 and 8 mg/l (ANRH) at a time when livestock numbered 788019 head, and agricultural production was low.

Since the year 2000, when the state began to subsidize agricultural development, nitrate concentrations have increased to relatively high values (22,5 mg/l in 2004) (28,8 mg/l in 2006) and (41mg/l in 2014) as the agricultural area increased. At the same time, the livestock population remained similar to those of the 1990s. (Table. 5)

Table. 5: Changes in nitrate levels, Livestock and agricultural area

				The State subsidy Period for The Agricultural Development						
Dates	1992	1993	1994	2000	2001	2004	2005	2006	2007	2014	2015
NO_3^- (mg/l)	**5-8**					**22.5**	22.4	28.8	27.5	**41.02**	41
Livestock (head))	788019	726200	703600	443570	355035	620216	591220	656920	622113	866090	
agricultural surface area (hect)	Low agricultural cultivation			Start of subsidized agriculture		120848	124153	122673	122673	135137	130453

5.2. Sulfate pollution (See Table. 6 and Fig.7)

Sulfate is generally released from phytosanitary products. The use of sulfur for the protection of vineyards and for some vegetable crops, such as to protect tomatoes from mildew, and the use of potash slag and phosphates as fertilizer can generate high quantities of sulfates. The average concentration of this constituent reached relatively high values during the years 2004-2007 (84,1 mg/l). In 2014 sulfate concentrations decreased by half (43 mg/l).

The drop in sulfates in that year may be explained by the reduction in fruit production due to the lack of rain, particularly for the months of April (5 mm) and May (10 mm), which is the fruit production period. Even so, sulfate concentrations in irrigated zones (Ain Teghat) remained high (61 mg/l). The variations in sulfate contents show that sulfate pollution is linked to agricultural activity.

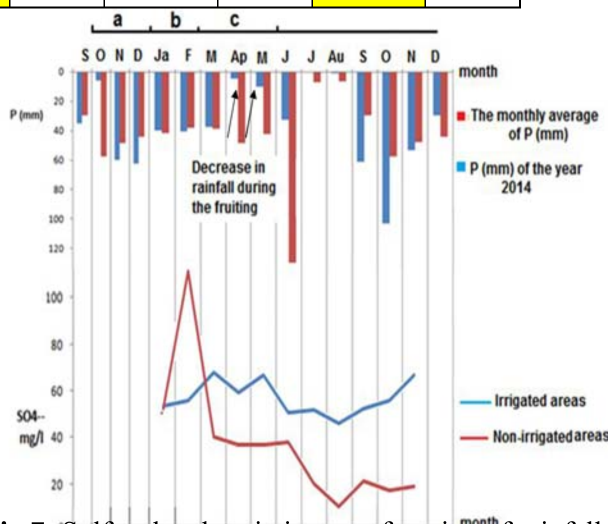

Fig.7: Sulfate level variation as a function of rainfall (2014)

Table. 6: Sulfate concentrations variations (mg/l) period 2004-2014

dates	drilling n62	sce ain zerga	sce poirier	sce ain teghat
24/08/04	72	68	/	/
21/12/04	72	12	/	/
21/03/05	96	76	/	/
20/06/05	75	72	/	/
25/09/05	173	62	/	/
18/12/05	67	93	/	/
19/03/06	12	66	/	/
20/06/06	35	50	/	/
31/10/06	90	55	/	/
26/12/06	89	50	/	/
20/02/07	144	46	/	/
28/01/14	31	27	57	58
04/03/14	44	53	110	60
30/03/14	48	57	46	71
07/05/14	46	43	43	63
12/06/14	61	40	43	70
16/07/14	38	29	44	55
19/08/14	40	31	28	56
24/09/14	40	30	19	51
17/11/14	40	30	29	57
20/12/14	40	32	25	60
28/01/15	45	34	27	70

5.3. Chlorine pollution

The excessive use of phytosanitary products in agriculture has caused severe groundwater pollution in recent years. (Table. 8) shows a rather high chlorine concentration (123 mg/l and 90 mg/l) for the period from 2004 to 2006) these concentrations decreased during 2014 (from 85 mg/l to 62 mg/l). Similar to the behavior of sulfates, the chloride concentrations followed the same pattern as sulfates, a pattern that is linked to the intensity of agricultural activity, as explained previously.

6. Commentary

The spatial distribution of NO_3^-, SO_4^{2-} and Cl^- pollution is closely linked to agricultural activity. Agricultural practices that can cause groundwater pollution fall into two groups: strictly agricultural practices (plowing, cultivation, fertilizer use, and chemical control of vegetable diseases) and water management practices, mainly regarding irrigation. Climatic factors such as temperature, precipitation, wind, and humidity have a relative influence on the behavior of fertilizers applied to the soil surface. In addition, the intensity and distribution of precipitation will modulate the quantity of water available to carry dissolved compounds through the karstic zone.

7. Recommendations

The rules resting on the laws regulating the use of fertilizers in zones identified as vulnerable such as our region, (where nitrate concentration in subterranean waters intended for drinkable water supply are over 50mg/l (threatening concentration)) are:

- The excessive use of fertilizer increases the expenses of the farmer on one hand, and increases the nitrate contents in the groundwater.
- The reduction of the dosage rate per hectare for fertilizers can minimize the expenses and decrease the contents in nitrate;
- Creation of pilot farms acting as a reference for farmers;
- Avoid standard irrigation systems (surface flooding and furrow irrigation), by introducing recent systems such as localized systems and sprinkler irrigation to control the rates of fertilizer use.
- After any cultivation, do not leave anymore farmlands without vegetation cover (fallow land). The permanent covering of the ground by vegetation, not requiring any fertilizer, or by crop residue is more effective on the lowering of nitrates.

8. Conclusion

The Saida Mountains have high agricultural potential, given their abundant water resources. As agricultural activity increases, anthropogenic impacts multiply, and they represent the primary source of groundwater degradation.

Analytical results showing concentration of nitrate (60 mg/l), chloride (123 mg/l), and sulfate (173 mg/l) highlight the extent of anthropogenic pollution of the karstic groundwater.

Fertilizers and phytosanitary products used in agriculture are the primary source of groundwater pollution, particularly when these substances are applied to the land (open land, fallow land) outside of the vegetation period

Sustainable protection of this groundwater is relatively difficult, but is still possible if we apply measures better adapted to the real dangers, if the protection engages all stakeholders involved in groundwater management, and if the protection program addresses environmental interactions.

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