Impact of Agriculture Upon the Chemical Quality of Groundwaters within the Saharian Atlas Steppe

El-Meita (Khenchela-Algeria)

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The El-Meita plateau is situated in the south of the city of Khenchela and it is delimited by the Saharan Atlas to the north and Chott Melghir to the south. The agricultural importance and the high productivity of this region are provided by the aggressive use of chemical fertilizers. For this reason, we have decided to conduct this study, considering that all water bodies – superficial waters and groundwaters – record significant amounts of NO_3^-, NO_2^-, NH_4^-, heavy metals (Pb, Cd, Cu, Zn and Hg) and other major chemical elements. The campaign of collecting the 30 water samples took place in the month of May 2016. The chemical analyses were conducted in the Lacip ain-Mlila laboratory in Algeria. Findings show a contamination of groundwater by nitrates and lead; values exceed the maximum limits approved by World Health Organization (WHO). TDS were also found in high concentrations, which limit the use of water for some agricultural cultures, but which can be admissible for certain salinity-resistant species.

Keywords: Aridity, Irrigations, Heavy metals, Nitrates, Pollution

Water represents the most resource of humankind. For this reason, studies concerning water quality are extremely numerous [1-5]. From this perspective, it is worth noting the works regarding: chemism [2-10], pollution [11-20], mineralization [3, 21-25], temperature [15, 26], irrigations [27-29], heavy metals [14, 16, 30, 31], piezometric level [12, 32], etc. Unfortunately, industrialization and agricultural development have entailed a high degree of pollution for all categories of water. Pollution in general affects the developing countries and the highly developed countries, though the latter benefit from means of defence. The most affected regions are the arid areas, with a hydric deficit. In these areas, the concentration of pollutants is higher in waters with a shorter period of regeneration [9].

Groundwaters in the south of Algeria represent the only drinking, industrial and mostly agricultural water supply source of the El-Meita plateau. The area studied here has an agricultural destination (culture of plants and pasturing). Grains represent the most important income source for local population, and the Algerian State takes into account the development of this activity, should the oil price drop dramatically. The need for irrigation water determines a permanent monitoring of groundwater quality, because surface resources are extremely scarce in this arid climate. At regional level, numerous problems regarding the pollution of groundwaters have been revealed [9, 19, 21]. Nitrates are listed among the most significant chemical pollutants of groundwater [18]. Nitrates represent, at the same time, the elements necessary for the development of plants. However, their massive presence within waters may lead to health problems for organisms, mostly for human beings. Consequently, nitrates are slightly lixiviant pollutants and they touch the water body without suffering any alterations [17].

Each year, a significant amount of chemical fertilizers is used in the El-Meita area: 16,000 quintals of TSP (46%) and 20,000 quintals of urea (46%) on an irrigated surface of 70,500 ha. Furthermore, 30-70% of azotized fertilizers are lost as ammonia (NH_3) and nitrous oxide (N_2O) in the atmosphere [16] or as nitrate (NO_3^-) at the surface of the soil or in groundwaters [13, 19, 21]. Hence, water table is highly vulnerable to pollution because the sandy texture facilitates the penetration of surface waters, (rainfall; return of irrigation waters; or through wadis).

Heavy metals – especially lead, zinc and copper – belong to the category of high polluters. Heavy metals may migrate in groundwaters; they accumulate in the food chain and they entail major risks for human health [31]. Anthropic sources of metal substance emission are due to the intensification of urban, agricultural or industrial activities [30]. High concentrations of heavy metals and organic soil pollution may be taken over by the human body, thus producing cancer, (this study underscores the major influences of heavy metals induced by chemical fertilizers used in agriculture). Therefore, the present study analyzes the physical-chemical quality of waters within the water table of the El-Meita region and it points out the degree of pollution in terms of nitrates and heavy metals; it also assesses the extent to which these waters may be used in agriculture.

Experimental part

Study area

The study area is situated south from Wilaya de Khenchela, between 34°30’-35°00’ N latitude and 6°78’-7°30’ E longitude. The El-Meita plateau covers a surface of 2.350 km² and the altitudinal gap ranges between 1.248 m and 12 m (fig. 1).

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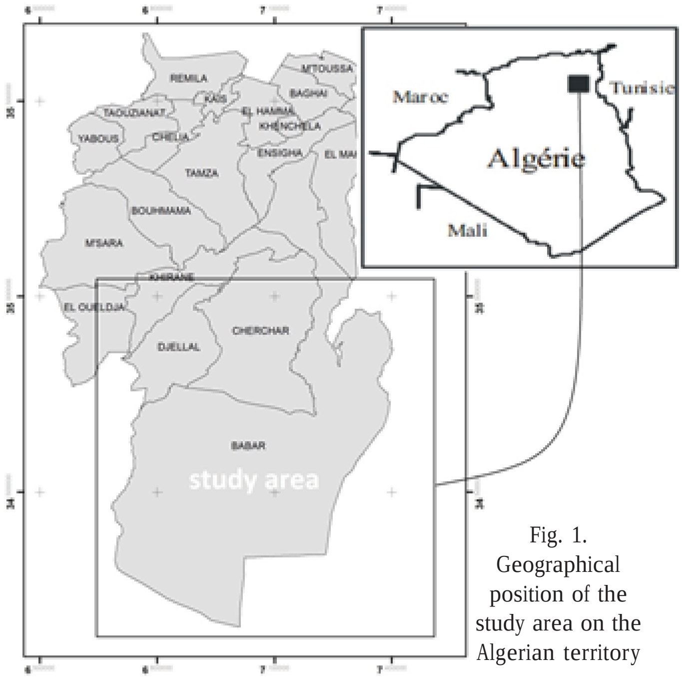

Fig. 1. Geographical position of the study area on the Algerian territory

The climate is arid and semiarid, with maximal temperatures recorded between the months of May and October and minimal temperatures during the winter (5°C). The annual average is 22°C. Mean annual precipitations range between 200 mm (semiarid climate) in the north and 60 mm (arid climate) in the south.

The main dry valleys (wadis) that dredge the plateau are as follows: Mehane, Ouzzern and Elmeita. They spring from the north and they disappear in the endorheic depression of Chott Melghir in the south. The relatively even topographic surface favours the development of agriculture, mostly the cultures of wheat and barley. In order to increase productivity, irrigations based on groundwaters are used, especially the phreatic ones. Drills that capture groundwater are as deep as 30-200 m and they are implanted in the Pliocene-Quaternary water table. This geological layer comprises gravels, sands and clays up to 525 m thick (fig. 2). This represents the first layer, situated on top of an impermeable marl substrate. The Miocene-Pliocene depth layer is captive and it represents the second water body of the terminal complex.

Methodology

For a precise mapping of the area and for the localization of sampling points, several field campaigns were conducted between September 2015 and January 2016. The sampling took place in the period March-April 2016; 30 samples were taken, (4 sources and 26 drills). Some parameters were measured in situ using the Consort C931 multiparameter, version 2.4 (temperature, *p*H, TDS and electric conductivity) [24]. The other chemical analyses (major elements and heavy metals) were evaluated in the Lacip –Ain-Mlila Laboratory in Algeria (accredited at national level). The calculation of ionic balance resulted, in most cases, in values below 5% [7].

Results and discussions

Groundwater quality in the El-Meita area is relatively good for irrigations and for the supply of human settlements, which suffer from acute lack of water. However, it risks an alarming endangerment, considering that surface waters keep on transporting the chemical products within the fertilizers used in agriculture. The data obtained are related to the values provided by WHO (World Health Organization) (table 1).

The temperatures measured in situ were distributed into two groups. The first group is represented by P21, P22, S31, S32, S33 and S34 drills, which values range between 16.9°C and 21.5°C (low values due to the high altitude of sampling points, because they are situated in the sub-mountainous sector). The second group encompasses the rest of drills, where temperatures range between 22.1°C and 27.9°C (points situated in lower altitudinal areas).

The *p*H value is situated around neutralization: 7.2-7.77. The value of electric conductivity increases on the north-south direction, namely of superficial waters and groundwaters runoff. In this case, the dissolution of salts throughout runoff leads to increased conductivity, (it records a maximum value in P16). The value of TDS increases similarly: it reaches the maximum value in P16, namely 3097 mg/L.

The Piper Diagram – also known as the triangle diagram – identifies the chemical features of ionic analyses [22, 28] (fig. 3). Concerning cations, we have noted a calcic dominance for all samples, (calcium sand substrate and calcareous rocks). Magnesium records low values. Anions are grouped in the centre of the triangle, with slight

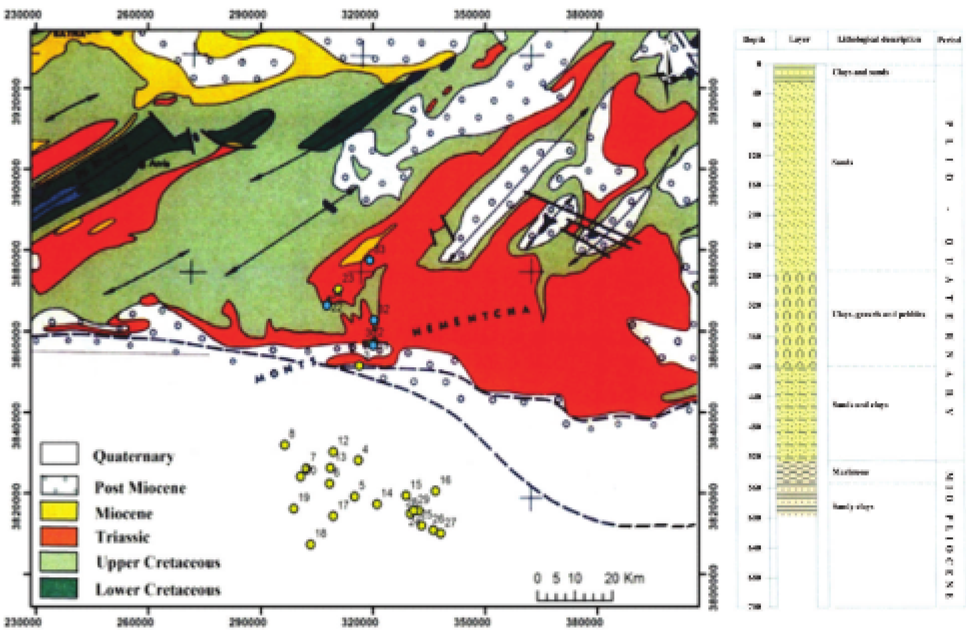

Fig. 2. Geological map of the region and distribution of the sampling points

Parameters	Units	Minimum	Maximum	Mean	SD (écart type)	WHO for drinking water
EC	(µs/cm)	1502	4173	2324	725	2500
pH	-	7.2	7.77	7.48	0,17	6.5-9.5
TDS	mg/L	1134	3097	1758	544	1000
K^+	mg/L	3	18.8	5.89	3.7	-
Ca^{2+}	mg/L	221,61	623.5	380.1	123.4	200
Mg^{2+}	mg/L	14.76	34.12	21.61	7.42	150
Na^+	mg/L	55.9	186.2	89.3	26.6	200
HCO_3^-	mg/L	297.21	897.55	464.47	169.45	-
Cl^-	mg/L	67.9	532.5	255.8	131.4	250
SO_4^{2-}	mg/L	57.7	688	403.5	128.5	500
NO_3^-	mg/L	42.66	103.53	68.3	12.93	50
NO_2^-	mg/L	0.005	0.917	0.05	0.166	3
NH_4^+	mg/L	0.013	0.099	0.049	0.023	0.20
Pb^{2+}	(µg/L)	8.68	32.57	15.87	4.99	10
Zn^{2+}	(µg/L)	19.23	70.71	49.97	13.13	$3x10^3$
Cd^{2+}	(µg/L)	ND	0.21	0.15	0.04	3
Cu^{2+}	(µg/L)	12,59	102,21	62.15	21.5	$2x10^3$
Hg^{2+}	(µg/L)	ND	0,06	0.033	0.015	1

Table 1
CHEMICAL PARAMETERS OF GROUNDWATERS WITHIN THE EL-MEITA FIELD (ALGERIA)

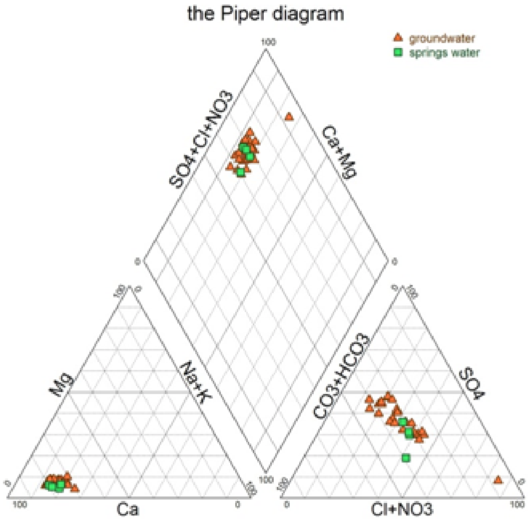

Fig. 3. The Piper diagram for all analyzed samples

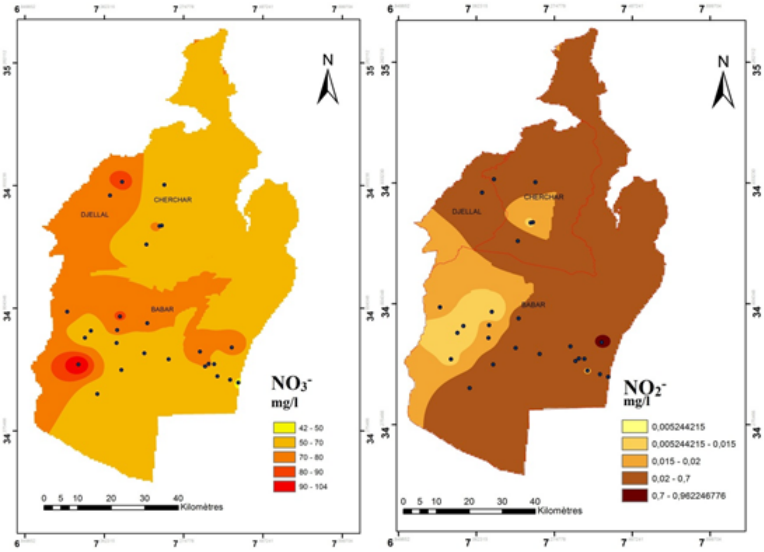

Fig. 4. Distribution of NO_3^- and NO_2^- concentrations

tendencies towards sulphates. The chemical features of the samples are similar to chlorinated-sulphated-calcic waters.

Nitrates emerge due to the excessive use of chemical fertilizers. The sandy nature of the soil favours their concentration on the north-south alignment, according to the direction of groundwater runoff. The maximum value is 103.53 mg/L. High concentrations – exceeding the European norms – have been recorded for the spring waters situated in the north of the area, at the foot of mountains. This contamination is due to swampy areas situated at high altitudes, where local inhabitants use both chemical fertilizers and natural fertilizers (manure) (fig. 4).

Nitrate ion may be present in groundwaters from sewerage or from corroded pipes. The values range between 0.005 and 0.041 mg/L, with an average of 0.019 mg/L. An abnormality was pointed out in P16, where the concentration is 0.917 mg/L; this may be caused by the corrosion within the tubes of the sewerage system. Ammonia presents low values, which do not exceed the concentrations recommended by WHO (0.2 mg/L): 0.013-0.099 mg/L.

The heavy metals analyzed are represented by Pb, Zn, Cd, Cu and Hg. Concentrations are distributed into two groups: the first is represented by Pb, which concentrations exceed the norms provided by WHO (10 µg/L) 8.68-32.57 µg/L (due to intensive use of chemical fertilizers). The second group encompasses Zn, Cd, Cu and Hg, which values of concentrations are below the norms of WHO (table 1).

The drills within the Pliocene-Quaternary water body ensure irrigations. Water salinization and alkalinization represent the main risks that may reduce agricultural use. The Richards Diagram [23] combines electric conductivity with SAR (Sodium Absorption Ratio) in order to assess the risk (fig. 5). SAR is calculated using the formula below:

$$SAR = Na^+/0.5\ [(Ca^{2+} + Mg^{2+})]^{½}$$

The results obtained in the Riverside and Wilcox Diagrams demonstrate that the waters within the El-Meita region are classified into two groups:

- C3S1: average quality waters, due to the high concentrations of polluting elements. They comprise the upstream waters used for the cultures that tolerate salts. They are used on well-dredged soils. Conductivity control must be permanent in the centre of the studied area and at the level of spring waters.

- C4S1: poor quality waters, situated in the downstream region (south) and at the northern limit of the plateau, where the values of electric conductivity are very high. Waters may be used in agriculture only for some species of plants, which tolerate high values of salts, and on very well dredged and washed soils.

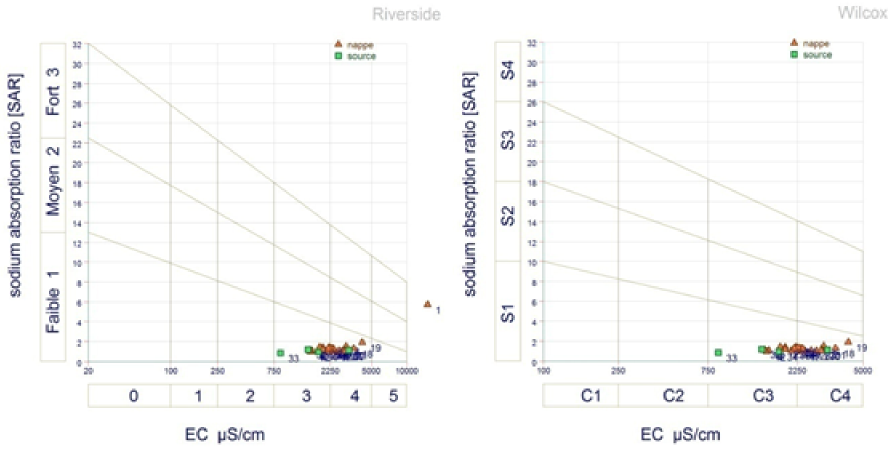

Fig. 5. Riverside Diagram (left) and Wilcox Diagram (right) for the waters of the El-Meita field (SAR)

Overall, the waters within the El-Meita region may be used only for plants that tolerate a relatively high degree of salts. For this reason, local population is specialized only in the culture of locally used plants.

Conclusions

The only water source for El-Meita is represented by the phreatic water body of the terminal complex of the Saharan Atlas. The analysis of all parameters that characterize the quality of waters has shown that chemical fertilizers, excessive irrigation and the sandy nature of the substrate facilitate the infiltration of pollutants towards groundwaters. Results demonstrate a contamination of water table with NO_3^- and Pb, from agricultural activities. For this reason, high values of electric conductivity were recorded for the entire area: 1502-4173 µs/cm (they exceed the irrigation threshold established by WHO because waters are highly mineralized).

Despite these parameters that lower water quality and mostly electric conductivity, the SAR (Sodium Absorption Ratio) calculation classifies the waters into two main groups: average quality and poor quality. Waters may be used only for plants that tolerate high degree of mineralization (e.g. wheat). It is recommended to monitor permanently the quality of groundwaters, particularly the use of chemical fertilizers that may lead to a dramatic decrease in water quality.

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