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Physicochemical characterization of synclinal spring water of Taoura, region of Souk Ahras – North East Algeria

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Abstract: The springs of the Taoura region flow from a syncline shaped structure. All resources in the region were mobilized as a result of increased demand. However, the development of anthropic activities and population growth in the area pose risk for groundwater. Analytical results obtained from a series of samplings in November 2017–April 2018, express the quality of water suitable for the irrigation of agricultural land. The highest values are recorded in April 2018 at 20.5 to 21.6°C and pH of 8.0 to 8.2.

The study recorded high electrical conductivity from 1390 to 1495 µS·cm^{-1} and *TDS* from 1270 to 1500 mg·dm^{-3} in November 2017, which shows important mineralization that characterizes spring water. Physical parameters were measured *in situ* using a HORIBA multi-parameter probe.

Chemical analyses were carried out using NFT 90-005 titration, and nitrogen parameters by DIN 38405-D92 spectrophotometry. Maximum levels of nitrates and phosphates were recorded at 228 and 18.4 mg·dm^{-3} respectively. The principal component analysis (PCA) showed a good correlation of the November 2017 period with mineralization parameters. Moreover, there is a strong correlation between the wet period and pollution factors. The two methods of analysis has allowed to distinguish three groups of geochemical water types: a bicarbonate calcium group typical for waters having transited in carbonate horizons. A second chloride calcium group shows basic exchange between water and clay levels, and the third chloride bicarbonate calcium group reveals an enrichment in calcium and chloride, which reflects water circulation with an exchange of the carbonated and evaporitic sedimentary rock matrix.

Keywords: chemistry, principal component analysis (PCA), pollution, springs, Taoura, water quality

INTRODUCTION

Freshwater scarcity is becoming a threat to the sustainable development of the society. It has become evident in the face of a steadily increasing demand. The growing world population, improving living standards, changing consumption patterns, and the expansion of irrigated agriculture are the main driving forces behind the rising global demand for water [ERCIN, HOEKSTRA 2014; VOROSMARTY *et al*. 2000]. Synchronously, the aquatic environment is facing severe pressure and security issues related to drinking water sources are increasingly prominent [PAHL-WOSTL *et al*. 2013; WANG *et al*. 2020; WHEATER, GOBER 2015].

In the last decade, due to unavailability or inadequate quality of surface water, demand for groundwater resources has increased for drinking purposes globally, especially in arid and semi-arid areas. About one-third of the world's population use groundwater for drinking [MISHRA, SINGH 2010; NICKSON *et al*. 2005; TALLAKSEN, VAN LANEN (eds.) 2004; WILHITE 2000]. A simultaneous decline in quality exacerbates the availability problem. Public, industrial, and agricultural users all contribute to the problem either directly, through waste generation, or indirectly, by altering physicochemical and bacteriological properties of water.

The quality of surface water and groundwater in a geographical region can be affected by anthropogenic activities [TRAN *et al*. 2015], by the proliferation of different sources of pollution (fertilizers and pesticides, untreated wastewater discharge, uncontrolled solid waste discharge, urbanization, etc.) constitutes

a threat [Nouayti et al. 2015]. The lack of public awareness about the need to protect the environment leads to an imbalance of the ecosystem, and generates pollution [Brahimi, Chafi 2014]. Many types of wastewater entering the aquatic environment contain plant nutrients: various organic materials and nutrients, mainly nitrates and phosphates [Lacaze 1996]. Many organic substances are readily biodegradable and can be broken down and eliminated through natural self-purification capacity of aquatic environments. However, when in excess, their decomposition may lead to asphyxia of the aquifer; water quality control requires a good knowledge of the origins of pollution and the effects pollution has on the environment [Audoin 1991].

Numerous studies have assessed the quality of spring water in the world, which concluded that the hydrochemical analyses provide better understanding of possible changes in quality (i.e., Varol and Davraz [2015], White et al. [2016], Yang et al. [2016], Rao et al. [2017], Selvakumar et al. [2017]).

The subsoil of the Taoura Region has important hydric potential, especially from a qualitative point of view. It is made up of a network of springs used mainly for drinking, domestic use and irrigation of land. However, the development of the village and the increase in water needs may cause the degradation of water quality. The present study aims to evaluate the physicochemical characteristics and to apply the principal component analysis (PCA) to the spring water of the Taoura Region. People living in the area are entirely dependent on the groundwater resources to meet their needs. The study visualises and analysis existing correlations between different variables through their structuring and orientation, and identifies the main factors responsible for the quality of water.

MATERIAL AND METHODS

STUDY AREA

The region of Taoura is located 28 km south of the city of Souk Ahras, in the north surrounded by the Tell Mountains forming part of the southern slope of the Upper Medjerda mountains, by Jebel Ouenza in the south, and by the Commune of Merahna in the east and the Daïra of M'daourouch in the west (Fig. 1). The relief in the region is uneven, with more or less humid temperate climate, rainfall of 845 mm·y^{-1} measured at the Souk Ahras station (2003–2018), and an average annual temperature of about 16°C. The utilized agricultural area of 141 871 ha, which represents 86% of the total agricultural area of the wilaya, 62% are occupied by herbaceous crops [Djaba 2010]. These crops comprise as follows: 87% are cereals, 10% are fodder crops, 2% are market gardening and 1% pulses. These crops are generally treated with fertilizers and pesticides, especially nitrogen and phosphates.

In Taoura, Karst region, the limestones of the lower Maestrichian are very fissured and contain an important aquifer. The aquifer has been determined by drilling (Dréa and Taoura) and its capacity is about 10 to 110 dm³·s^{-1}. Cracks can reach the size of real caverns. These springs are located exclusively in the north of the syncline [Benabbas 2006; Djaba 2010].

The Taoura syncline has a more or less symmetrical structure (Obert and Leiken [1974] in Chadi [2004]). The axis of the syncline is oriented SW–NE. The stratigraphic succession of the Upper Cretaceous from the Emscherian through the Eocene creates the syncline's flanks. This orogen was eroded before Miocene sedimentation.

Multiple orogenic phases affected the region. The general tectonics is very simple, regular folds in SW–NE directions with rare longitudinal faults but many transverse strikes in the Turonian and Senonian limestone bars.

The study area is characterized by the presence of carbonate formations [Bousnoubra 2002], water activity and intense tectonic movements that occurred in this region and accelerated the process of karst genesis and the observed compartmentalization.

The dominant formations are mostly Maestrichtian limestones, constituting the syncline structure which is covered by formations of the Mio-Plio-Quaternary age. The limestones are fissured and karstified, supporting the accumulation of groundwater. Examination of the lithostratigraphic columns of boreholes drilled in the area, coupled with the interpretation of geological data, allows to determine various groundwater tables.

The study area is essentially characterized by two main aquifers superimposed as follows:

The Mio-Plio-Quaternary nappe (free nappe). The nappe is contained in heterogeneous formations, such as marls, conglomerates, sands, gravels and sandy silts; the same formations are dated from the Miocene to the Quaternary. The works capturing this nappe are imperfect, so its range (vertical and horizontal) cannot be precisely defined, which results in the scarce knowledge about the nappe and its potential.

The Maestrichtian limestone tablecloth (captive tablecloth). This tablecloth outcrops towards the two flanks of the syncline (North and South). It goes through springs and plunges deep under the Mio-Plio-Quaternary filling, giving the structural form of the area. At the centre of the structure, the depth can reach about 600 m.

The extension of the water table is horizontal. It is subdivided into two superimposed aquifers separated by a thin layer of marl. Layers of clay and marl formation limit the top of the water table. The substratum is marly in its origin. It should be noted that this tablecloth is considered the main water reservoir in the area, consisting of marls and fissured limestone belonging to the Lower Maestrichtian and Middle Campanian periods. The Lower Maestrichtian limestones are very fissured and contain an important aquifer. The cracks may have cavern dimensions confirmed by borehole T1, which reached a cavern at a depth of 103 m [Friane 2000].

Limestone is particularly present in the centre of the captive Taoura aquifer, but as we go towards north-east, we can see a thinning of the layer which at the foothills of the reliefs does not exceed 110 m.

The karst regions are very heterogeneous and anisotropic; the unsaturated zone, consisting of soil, epikarst, a transmission zone, and the saturated zone are characterized by a duality of permeability – open conduits, cracks, and pits on the one hand, and low permeability rock volumes on the other. This results in groundwater flow of different types and storage capacity.

Despite their significant contribution to the freshwater supply, karst aquifers are particularly vulnerable to contamination due to their hydrogeological characteristics. These contaminants can then be rapidly transported into the saturated zone through the conduit networks of karst systems.

The chemical composition of water in the karst aquifer is related to many factors such as land use, recharge processes
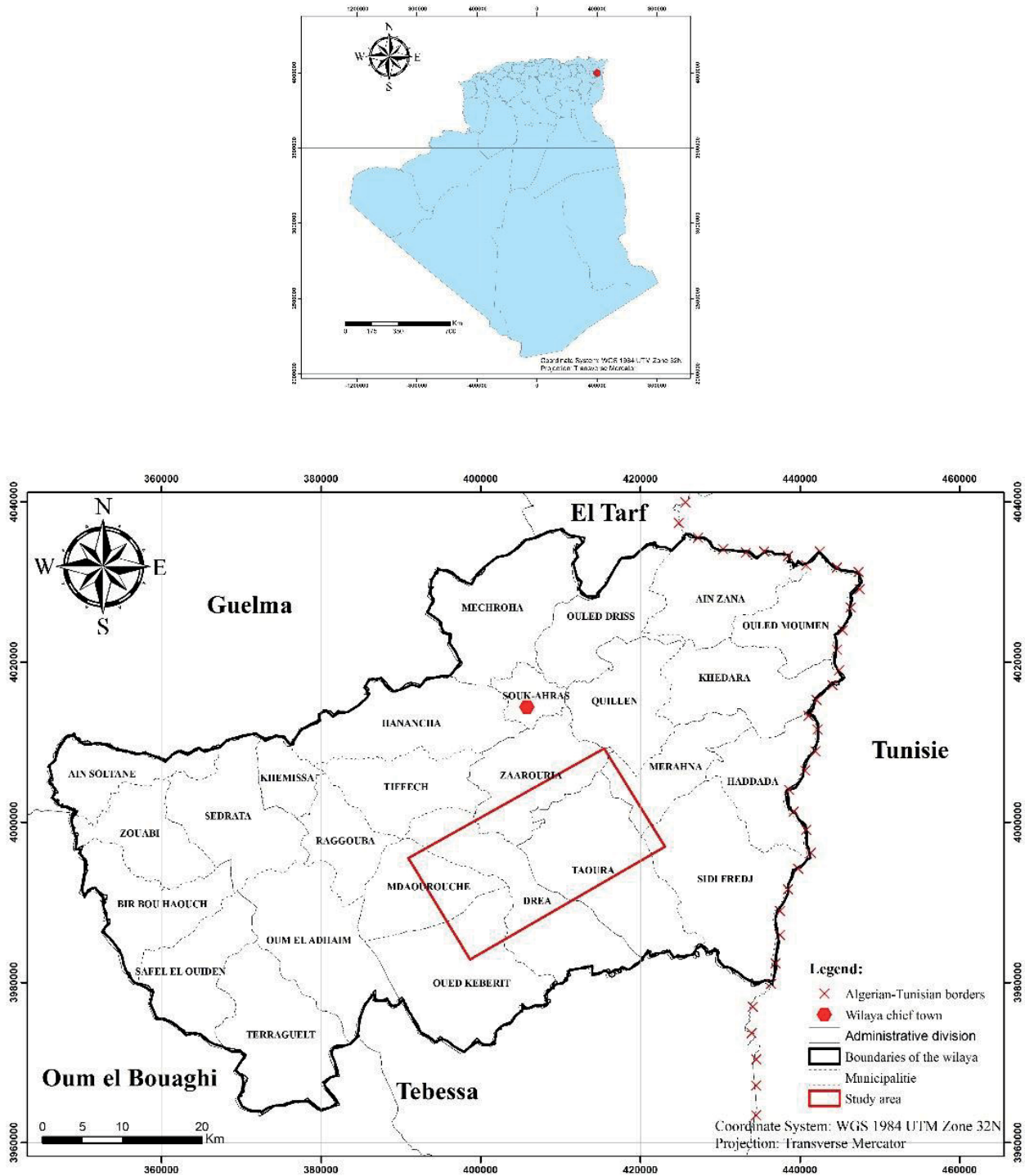
Fig. 1. The geographical location of the study area; source: own elaboration

(diffuse or concentrated, climatic conditions, lithology of the reservoir and infiltration zone, and flow conditions/transit time in a micro-fractured matrix, cavities or conduits). It also varies within the same system according to spatial criteria (e.g. depending on sampling location, source or manhole in flooded zone), as well as according to temporal criteria. Indeed, we observe time-bias variations in water chemical composition at the same observation point and different hydrological conditions that inform us about processes in the system.

ANALYSIS PROTOCOL

The data acquired through our research and monitoring cover two years (November and April 2017–2018). The evolution of physicochemical characteristics of spring waters in the region has been determined by an analysis of a series of samples. Each of the ten springs listed was sampled twice (2017–2018). Data were processed by the principal component analysis (PCA) to study mechanisms that control spatial and temporal evolution of the quality of the Taoura groundwater.

Physical parameters (hydrogen potential, electric conductivity, temperature, and dissolved oxygen) were measured in situ using a HORIBA multi-parameter probe. Chemical analyses were carried out on the main elements responsible for water mineralization, cations (calcium, magnesium, sodium, and potassium) and anions (chlorides, sulphates, and bicarbonates) by NFT 90-005 titration, nitrogen parameters: nitrites, nitrates, ammonium and phosphates were evaluated by DIN 38405-D92 spectrophotometry.

Two sampling campaigns (2017–2018), for a total of 10 samples, were carried out to study the quality of spring water, origin of salinity, and its spatial-temporal evolution during both periods of the year.

The ten selected springs are perennial, accessible, and cover the most inhabitable areas: Taoura town and its surroundings (Fig. 2). Coordinates are recorded with a GARMIN GPS.
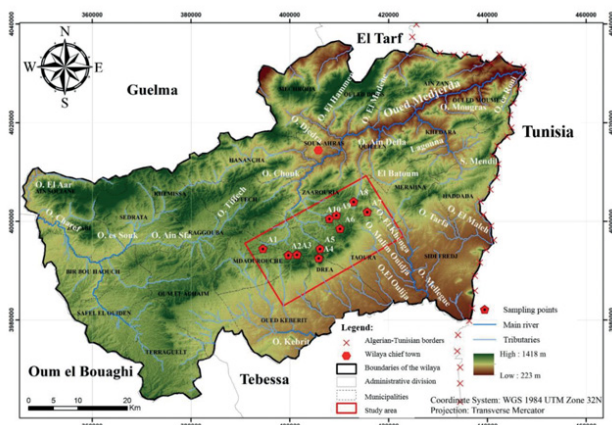

Fig. 2. Location of the sampling points; source: own elaboration

RESULTS AND DISCUSSION

PHYSICOCHEMICAL EVOLUTION

TEMPERATURE

Temperature plays an essential role in increasing chemical and bacterial activity. It varies depending on ambient temperature, seasons, geological nature, and the depth of the water level in relation to the ground surface. It is one of the most important characteristics of an aquatic system that affects dissolved oxygen levels [RAJENDRAN, MANSIYA 2015]. Temperature ranges from 15.1 to 21.6°C. The lowest temperature of 15°C was recorded in November 2017 (A1, A5, A6). All the values recorded do not exceed potability standards (12–25°C). Freshwater is generally more acceptable than hot water. High water temperature increases the proliferation of microorganisms and problems related to taste, odour, colour, and corrosion [WHO 2011]. The ten sources are classified according to Schoeller's classification of cold springs [SCHOELLER 1962] – Figure 3.

HYDROGEN POTENTIAL

The pH (hydrogen potential) measures the concentration of H^+ ions in the water. This parameter characterizes a large number of physicochemical equilibria and depends on multiple factors, including the origin of water, geological nature of the substrate,
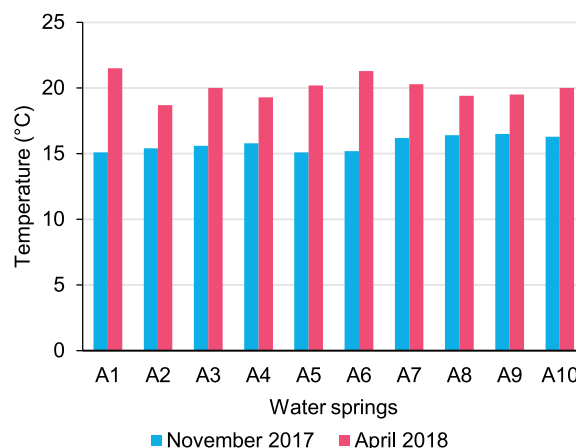

Fig. 3. Temperature values during two campaigns (November 2017, April 2018); source: own study

and the watershed crossed. Spring waters have a relatively alkaline pH both in November 2017 and April 2018 period, which varies between 7.4 and 8.2 (Fig. 4). This is probably related to the bicarbonate ion (HCO_3^-), (Ca^{2+}), which reflects the presence of limestone rocks ($CaCO_3$) and dolomites ($CaMg(CO_3)_2$). When these rocks are present, the risk of acidification is low. Source waters can be considered acceptable according to WHO standards.
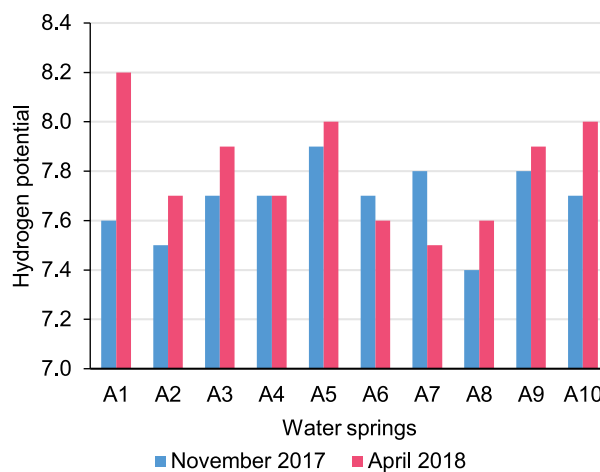

Fig. 4. Hydrogen potential values in water springs (November 2017, April 2018); source: own study

ELECTRICAL CONDUCTIVITY

Conductivity measures the ability of water to conduct current between two electrodes. Most dissolved substances in water are in the form of electrically charged ions. Therefore, conductivity measurement allows to determine the amount of salts dissolved in water. It also depends on water temperature: it is higher as the temperature rises. The results of measurements allowed to observe the variation in conductivity. The conductivity varied between 469 and 1495 $\mu S \cdot cm^{-1}$ during the two periods considered (Fig. 5). Low values of 469 $\mu S \cdot cm^{-1}$ are recorded for A7, moderate for A4, A5, A9 and high values for A1, A2, and A6. The origin of mineralization is attributed a priori to the rather high content of mineral salts.
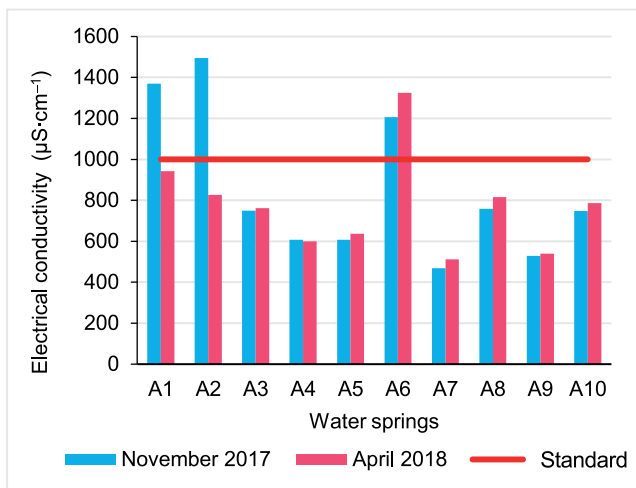
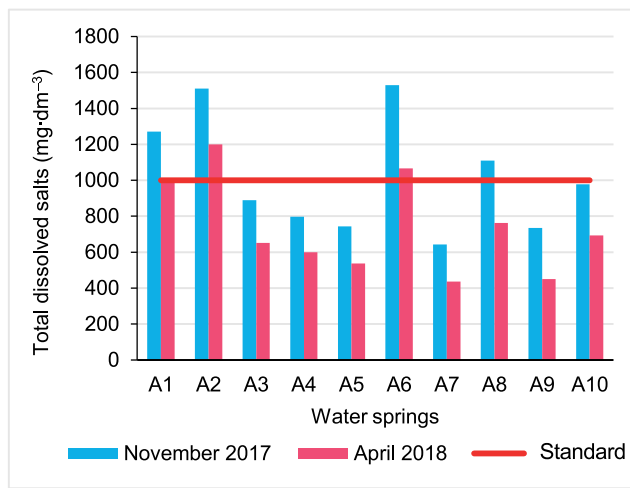Fig. 5. Electrical conductivity measured in the study area (November 2017, April 2018); source: own study

Fig. 6. Evolution of total dissolved salts in the water springs (November 2017, April 2018); source: own study

Sources A1, A2, and A6 represent values exceeding the WHO standard of 1000 $\mu S \cdot cm^{-1}$, which may be due to the leaching of fertilizers with irrigation water, or these sources drain highly saline soils linked to the Triassic period in the region.

TOTAL DISSOLVED SALTS

Total dissolved salts (*TDS*) represent the total concentration of dissolved substances in water. These minerals can originate from several natural sources as well as human activity (Tab. 1).

Table 1. Evaluation grid for total dissolved salts (*TDS*) in water

TDS (mg·dm^{-3})	Evaluation	Water springs	
		April 2018	November 2017
<300	excellent	–	–
300–600	good	A5, A7, A9	–
600–900	passable	A3, A4, A8, A10	A3, A4, A5, A7, A9
900–1200	low	A1, A2, A6	A8, A10
>1200	unacceptable	–	A1, A2, A6

Source: own study.

TDS results show that the high values are located at points A1, A2, A6 (November 2017 period) with contents of 1270 to 1500 mg·dm^{-3}, respectively (Fig. 6). The rest of the points and for the majority of the points are of low to decent quality. Points A5, A7, and A9, show good quality during the April 2018 period, ranging from 300 to 600 mg·dm^{-3}.

DISSOLVED OXYGEN

Dissolved oxygen (*DO*) is a parameter that provides information on the state of water, promoted growth of microorganisms, and the development of pathogenic germs. Dissolved oxygen in spring water ranges from 6.86 to 8.99 mg·dm^{-3} (Fig. 7). These values are in the range 4–18 mg·dm^{-3}, which indicates the absence of significant pollution (Tab. 2).
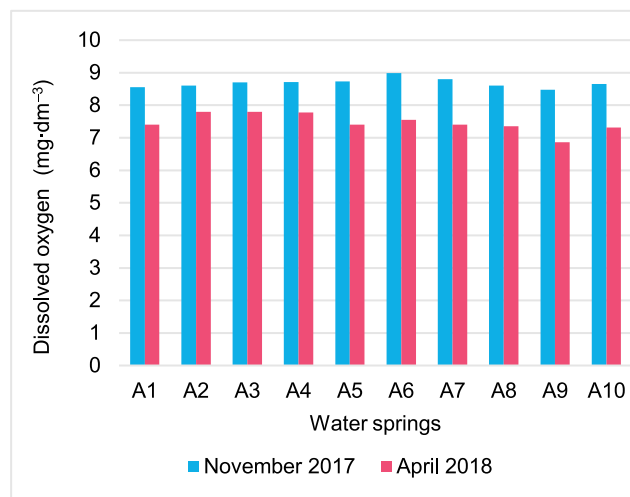

Fig. 7. Dissolved oxygen values in Taoura water springs (November 2017, April 2018); source: own study

Table 2. Grid used for groundwater oxygen assessment

Element	Class I good	Class II medium	Class III bad	Class IV very bad
O$_2$ (mg·dm^{-3})	4–18	2.4–4	1.2–2.4	0–1.2

Source: own study.

NITROGEN PARAMETERS

Nitrates NO$_3^-$. Nitrate contamination in groundwater is one of major problems found by water quality studies [ALAM *et al.* 2012]. Nitrate is the most oxygenated form of nitrogen and is highly soluble. The presence of nitrates in groundwater is linked to the intensive use of chemical fertilizers [LARABA *et al.* 2013].

Nitrate concentration vary during the two periods, with standard values in April 2018 between 32 mg·dm^{-3} and 50 mg·dm^{-3}, except for point A6 where the value is 62 mg·dm^{-3} which exceeds the 50 mg·dm^{-3} limit (Fig. 8). In November 2017, the values are significantly higher; between 41 (A8 and A9) and 44 mg·dm^{-3} (A7) which remain within the standard, whereas in the other sources, the limit has been significantly exceeded and varied between 53 mg·dm^{-3} (A4 and A5) and 228 mg·dm^{-3} (A6).

Nitrates do not produce colour or odour in water and can cause cancer in humans when consumed over a long period [ALAM et al. 2012]. The high concentration of nitrate in drinking water is toxic and prompts the blue baby syndrome (methaemoglobinaemia) in children and gastric carcinoma [COMLY 1945; GILLY et al. 1984].
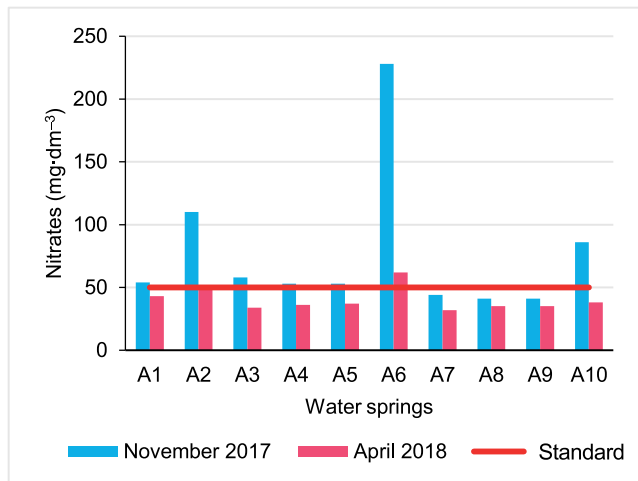

Fig. 8. Nitrate concentrations in Taoura water springs (November 2017, April 2018); source: own study

Nitrites NO_2^-. Nitrites represent a less oxygenated and less stable form in the nitrogen cycle; they represent the passage between nitrates and ammonium; it is a toxic form originating from agriculture or urban and industrial discharges [KHADRI 2009]. Values of this parameter in spring waters are very low and in the November 2017 period varied between 0.01 and 0.03 mg·dm^{-3}. This remains within the standard (0.1 mg·dm^{-3}) (Fig. 9). In contrast, the values of nitrites in the April 2018 period were between 0.1 (A5) and 0.19 mg·dm^{-3} (A9) and exceeded the standard.
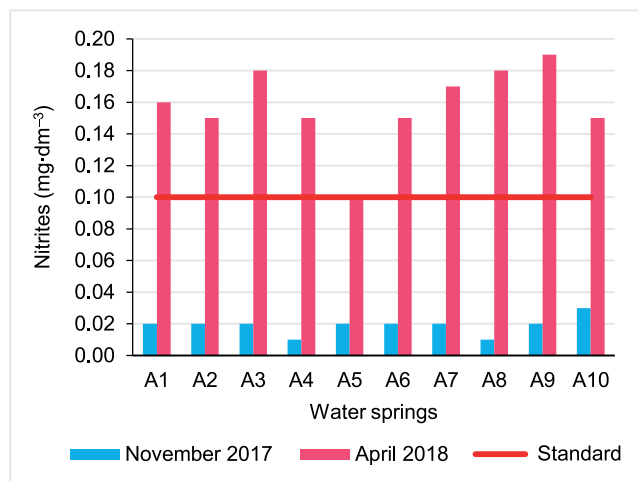

Fig. 9. Nitrite concentrations in Taoura water springs (November 2017, April 2018); source: own study

Ammonium NH_4^+. The ammonium ion is the main form of nitrogen in nature [CHAHBOUNE et al. 2014; DERWICH et al. 2013]. The ions result from anaerobic processes in ecosystems [CHAPMAN (ed.) 1996]. Ammonium comes from human activities, agricultural discharges (especially manure) or industrial discharges and wastes. The variations in ammonium levels fluctuate from 0.16 to 0.41 mg·dm^{-3} and from 0.28 to 0.35 mg·dm^{-3}, in April and in

November respectively (Fig. 10). The rainy period has the highest ammonium level compared to November 2017. This reflects leaching from the agricultural land surrounding the Taoura region, which remains below the WHO acceptable standard (0.5 mg·dm^{-3}).
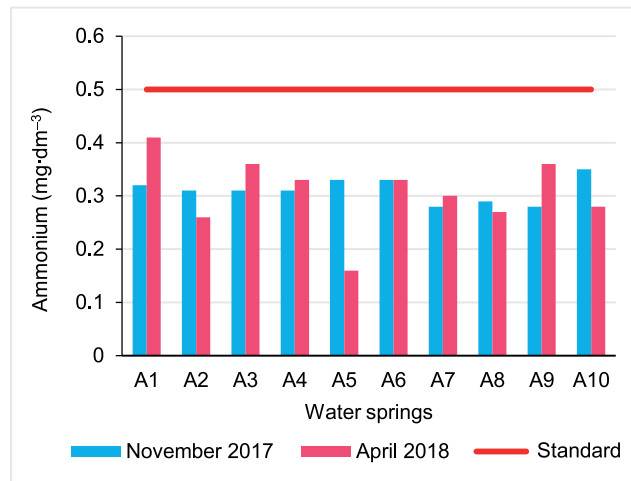

Fig. 10. Ammonium concentrations during the two campaigns (November 2017, April 2018); source: own study

Phosphates PO_4^{3-}. Phosphate levels in waters studied are very high for both periods (November 2017 and April 2018) and range from 4.2 to 7.2 mg·dm^{-3} for April 2018, and from 7.4 to 18.4 mg·dm^{-3} for November 2017, with a tendency to increase in the dry period (Fig. 11). The origin of phosphates in water could be linked to urban discharges or the dissolution of chemical fertilizers (NPK).
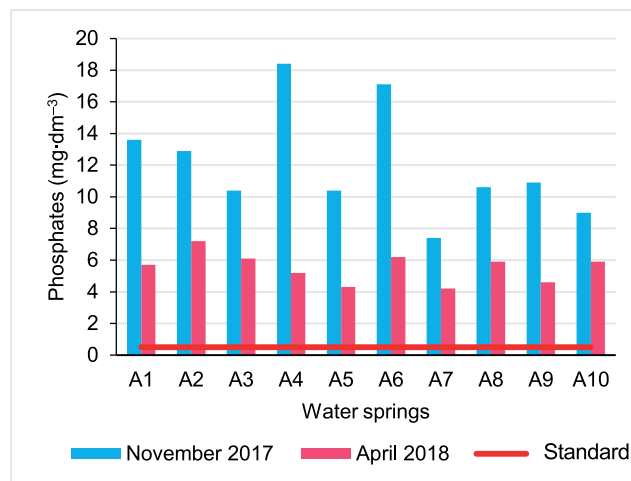

Fig. 11. Phosphates concentrations during the two campaigns (November 2017, April 2018); source: own study

Results of analyses show that phosphate values are above the WHO standard (0.5 mg·dm^{-3}) at all the points sampled as a result of the pollution of groundwater caused by agricultural practices in the study area (excessive use of phosphates in the form of chemical fertilizers or pesticides).

• **Chemical facies determination**

Results of chemical analyses were processed using the Piper diagram, which represents the chemical facies of a set of water

samples. Results obtained from the different campaigns are summarized in Table 3.

Table 3. Representation of the hydrochemical facies of spring waters according to periods

Campaign	Chemical facies	Number of sources	Percentage
November 2017	calcium chloride	2	20
	bicarbonate calcium	8	80
April 2018	calcium chloride	3	30
	bicarbonate calcium	6	60
	calcium chloride bicarbonate	1	10

Source: own study.

The majority, 80% of the source samples collected have a bicarbonate calcium facies: sources (A3, A4, A5, A6, A7, A8, A9, and A10), and 20% of the sources have a chloride calcium facies: sources (A1, A2) (Fig. 12).
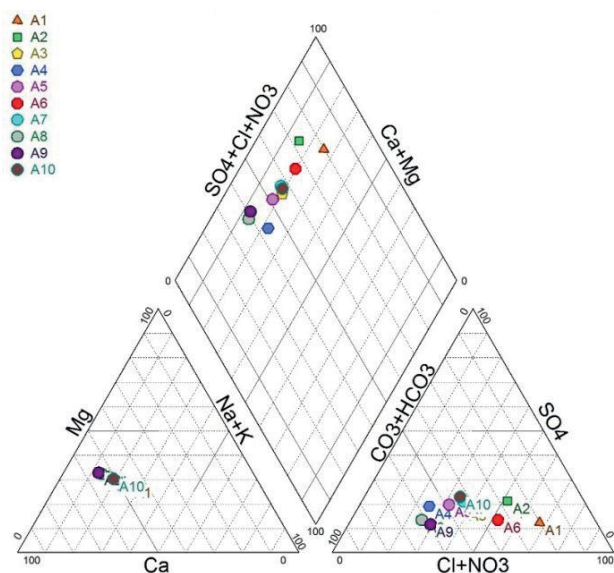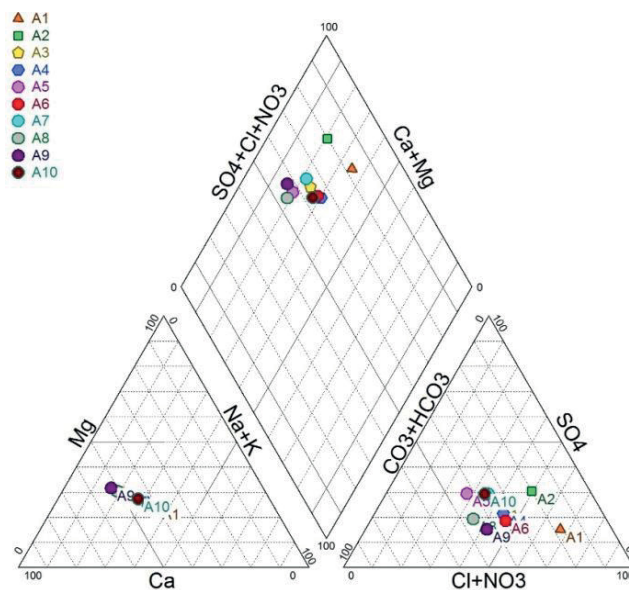

Fig. 12. Graphic representation of water springs chemical facies on Piper diagram (November 2017); source: own study

This diagram shows that 60% of the source samples collected have a calcium bicarbonate facies: sources (A3, A5, A7, A8, A9, and A10), 30% of the sources have a calcium chloride facies: sources (A1, A2, A6) and 10% have a calcium chloride bicarbonate facies (Fig. 13).

The analysis of the two diagrams shows a good correlation between HCO_3^- and Ca^{2+} ions ($R = 0.65$), which confirms the same origin of these two elements. This could be the dissolution of carbonate (limestone) formations during the transition of water through the aquifer formation.

PRINCIPAL COMPONENT ANALYSIS (PCA)

The PCA allows an analysis of the relationships between the numerous variables, thus providing information on the evolution of water chemistry and the determination of the dominant

Fig. 13. Graphic representation of the water springs chemical facies on Piper diagram (April 2018); source: own study

characteristics in the environment. This method is widely used to interpret hydrochemical data [ABRID 2015; TOUMI *et al.* 2016].

- **Campaign November 2017**

This analysis was carried out on a data table of 10 individual factors and 17 variables during the two periods (November and April periods): temperature (T), pH, electrical conductivity (EC), dissolved oxygen (O_2), cations (Ca^{2+}, Mg^{2+}, Na^+, K^+), anions (Cl^-, HCO_3^-, SO_4^{2-}), nitrogen compounds (NO_3^-, NO_2^- and NH_4^+), phosphate (PO_4^{3-}) and heavy metals (Fe and Zn) – Table 4.

Table 4. Eigenvalues of correlation matrix, and related statistics (November 2017); active variables only

Factor	Eigenvalue	Total – variance %	Cumulative – Eigenvalue	Cumulative %
F1	6.693	39.370	6.693	39.370
F2	2.985	17.558	9.678	56.928
F3	2.812	16.543	12.490	73.472

Source: own study.

Variables that are well correlated with each other are shown in bold. They probably indicate the common origin of these elements or their similar evolution (Tab. 5).

The correlation circle F1–F2 totals 56.93% of the cumulative variance (Fig. 14a).

In its negative part, factor F1 representing 39.37% of the total variance shows Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-}, *CE* and opposes them to the pH and temperature. It probably explains the influence of the latter on the mineralization of water, so the F1 axis groups together the elements responsible for chemical facies of spring waters, such as calcium bicarbonate and calcium chloride. We can thus say that the F1 axis is the mineralization axis.

Factor F2, representing 17.56% of the total variance, includes in its negative part nitrogen compounds (NO_3^-, NO_2^-, NH_4^+), PO_4^{2-}, Zn and Fe and opposes them to HCO_3^-. We can therefore say that the F2 axis is the pollution axis.

**Table 5.** Factor coordinates for variables, based on correlations (November 2017)

Parameter	F1	F2	F3
Ca^{2+}	**−0.923**	0.220	0.093
Mg^{2+}	**−0.923**	0.221	0.095
Na^+	**−0.946**	−0.043	−0.138
K^+	−0.486	−0.319	**0.756**
Cl^-	**−0.717**	0.100	−0.468
HCO_3^-	−0.130	0.467	**0.591**
SO_4^{2-}	**−0.733**	0.117	−0.441
NO_3^-	**−0.784**	−0.345	0.325
NO_2^-	−0.123	−0.292	**−0.627**
NH_4^+	−0.466	**−0.528**	−0.229
PO_4^-	**−0.528**	−0.282	0.520
Fe^{2+}	0.270	**−0.673**	0.245
Zn^{2+}	0.170	−0.478	−0.447
EC	**−0.930**	0.116	−0.269
pH	0.515	**−0.795**	−0.109
O_2	−0.306	**−0.565**	0.472
T	**0.581**	0.576	0.232

Explanations: variables that are well correlated with each other are shown in bold. They probably indicate the common origin of these elements or their similar evolution, EC = electrical conductivity, T = temperature.
Source: own study.

The F1 axis groups A1 and A2 with calcium chloride chemical facies of high chloride content, opposing them to point clouds A3, A4, A5, A7, A9, and A10 with a calcium bicarbonate facies. Therefore, the F1 axis is the mineralization axis (Fig. 14B). The F2 axis is the pollution axis because it characterizes sources of high nitrogenous matter and metallic trace elements content.
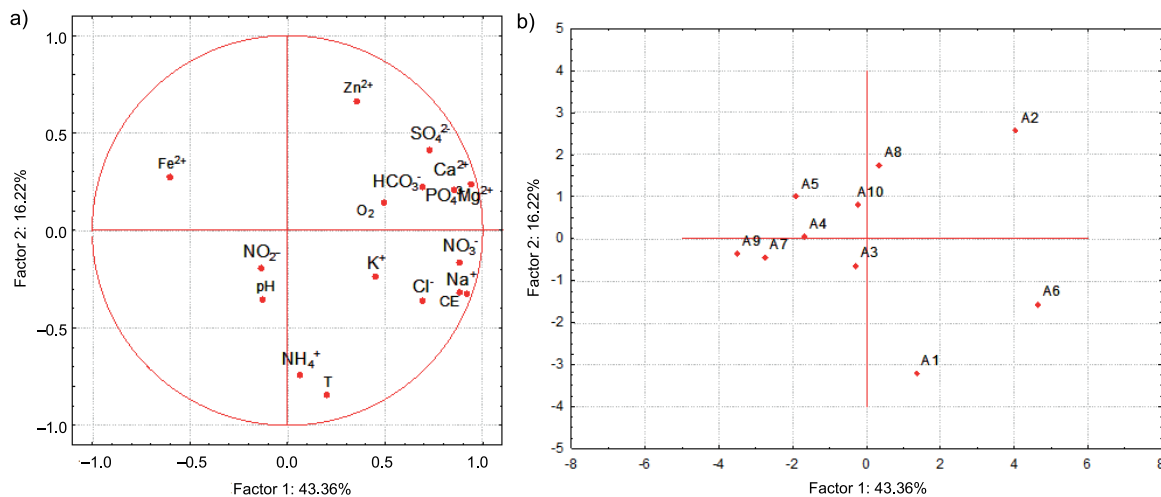
- **April 2018 Campaign**

In April 2018, the F1–F2 correlation circle represents 59.58% of the cumulative variance (Tab. 6, Fig. 15A).

Table 6. Eigenvalues of correlation matrix, and related statistics (April 2018); active variables only

Factor	Eigenvalue	Total – variance %	Cumulative – eigenvalue	Cumulative %
F1	7.370	43.355	7.370	43.355
F2	2.757	16.216	10.127	59.572
F3	2.009	11.819	12.136	71.390

Source: own study.

Variables that are well correlated with each other are shown in bold (Tab. 7).

Factor F1 representing 43.36% of the total variance includes in its positive part, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-}, HCO_3^-, CE. This axis groups together the elements responsible for the chemical facies of spring waters, which are calcium chloride – calcium bicarbonate and calcium chloride bicarbonate.

We can say that the F1 axis is the mineralization axis, as long as it includes all elements responsible for the mineralization of spring water.

Factor F2, representing 16.22% of the total variance, in its positive part includes Fe, Zn, PO_4^2. However, its negative part is characterized by NO_3^-, NO_2^-, NH_4^+.

Axis F2 includes NO_3^-, NO_2^-, NH_4^+, and opposes them to Fe, Zn, PO_4^{2-}. Therefore, we can say that it is the pollution axis. Pollution factors are present due to the proximity of a landfill (leachate infiltration) or domestic discharges.

In its positive part, the F1 axis groups A2 and A6 with calcium chloride facies and opposes them to the point cloud of A4, A5, A7, and A9 with calcium bicarbonate facies. Hence, we can say that the F1 axis is the mineralization axis (Fig. 15b).

In its positive part, axis F2 groups A8 and A10 which represent observed iron and zinc contents and opposes them to points A1 and A3 representing high content of NO_2^- and PO_4^{2-}. Thus, axis F2 is the pollution axis.

Fig. 14. Projection of variables and individuals on the factorial axis (F1–F2); source: own study
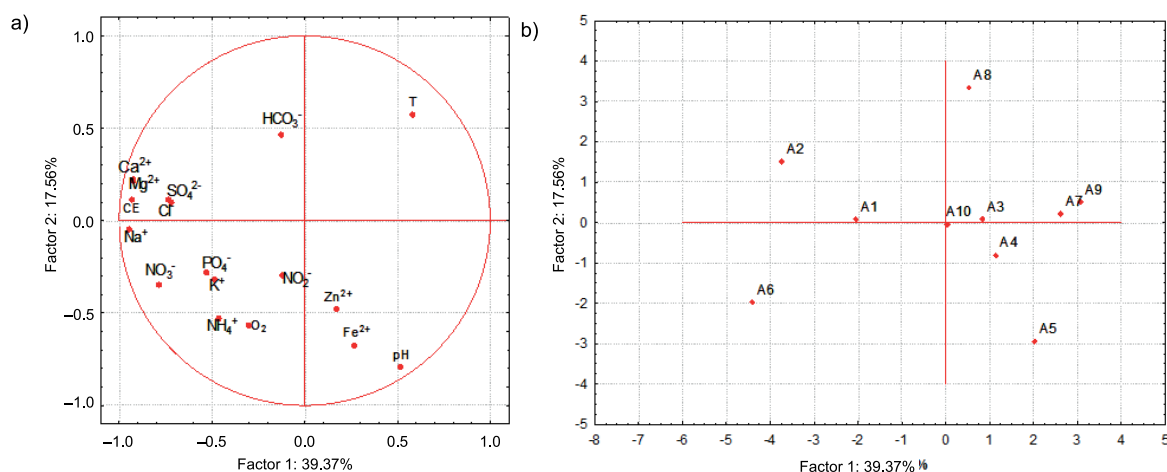
Fig. 15. Projection of variables and individual factors on the factorial axis (F1–F2); source: own study

Table 7. Factor coordinates of the variables, based on correlations (April 2018)

Parameter	F1	F2	F3
Ca^{2+}	**0.941**	0.237	0.007
Mg^{2+}	**0.940**	0.237	0.004
Na^+	**0.919**	−0.324	0.158
K^+	0.449	−0.239	**−0.789**
Cl^-	**0.688**	−0.360	0.505
HCO_3^-	**0.690**	0.225	−0.471
SO_4^{2-}	**0.725**	0.415	0.446
NO_3^-	**0.880**	−0.163	−0.206
NO_2^-	−0.137	−0.190	−0.111
NH_4^+	0.064	**−0.742**	0.074
PO_4^{3-}	**0.853**	0.211	0.190
Fe^{2+}	**−0.601**	0.273	−0.164
Zn^{2+}	0.354	**0.663**	0.067
EC	**0.879**	−0.314	−0.243
pH	−0.124	−0.353	**0.693**
O_2	0.490	0.140	0.097
T	0.202	**−0.846**	−0.093

Explanations: as in Tab. 5.
Source: own study.

CONCLUSIONS

Located in the Wilaya of Souk Ahras, the region of Taoura is part of the eastern zone of the Medjerda sub-basin in the east of Algeria. The dominant formations are mostly Maastrichtian limestone, constituting the synclinal structure covered by formations of the Mio-Plio-Quaternary age. The limestone is fissured and karstified promoting the accumulation of groundwater.

Results of the spring water quality analyses reveal significant mineralization of the Taoura water springs considering the high values of electrical conductivity 1495 µS·cm⁻¹ and *TDS* of 1500 mg·dm⁻³. The mineralization of these waters reflects two dominant facies: calcium bicarbonate and calcium chloride. The high contents of nitrates (228 mg·dm⁻³) and phosphates

(18.4 mg·dm⁻³) could be due to surface water infiltration from irrigation and the use of chemical fertilizers, which represents organic pollution.

The ten sources are classified according to Schoeller's classification (1962) as cold springs, with a relatively alkaline pH, which is related to the presence of calcareous rocks ($CaCO_3$) and dolomites ($CaMg(CO_3)_2$). Therefore, the risk of acidification is low.

It has been noted that according to the chemical composition, there are mainly two types of waters with different chemical facies: calcium bicarbonate waters (A3, A4, A5, A6, A7, A8, A9, A10) probably originating from the captive deep water table, and calcium chloride waters (A1, A2) probably originating from the free water table.

The interpretation of the results shows that the spring waters are contaminated with nutrients, such as nitrogen compounds (nitrates for low waters: 228 mg·dm⁻³, nitrites for high waters: 0.19 mg·dm⁻³) and phosphate contents are very high for both periods, due to excessive use of fertilizers.

The principal component analysis (PCA) identified elements responsible for the high mineralization and agricultural contamination. The pollution poses health risk to the rural population scattered in the region. Due to the development of rural areas and the growing demand for drinking water, effective pollution control and sustainable management of water resources are necessary to overcome water quality problems. Thus, it is necessary to provide regular monitoring for better understanding of the origin of the phenomena and protecting these suburban and rural settlements which, in most cases, continue to use water from springs without much consideration.

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