# Physicochemical and isotopical characterization of groundwater in the basin of Guelma, North-East of Algeria

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## Abstract

Water quality is an important criterion for evaluating the suitability of water for drinking and domestic purpose. The main objective of this study was to investigate the physicochemical characterization of groundwater for drinking water consumption. Ten captured sources were selected from three aquifers including the Guelma Mio-Plio-Quaternary alluvial basin; the Senonian Heliopolis Neritic limestone aquifer, and the Eocene limestones of Ras El Agba-Sellaoua aquifer. The analyses concerned the periods of high water in May 2017 and low water in August 2017. Twelve parameters were determined for the water samples: pH, $T$ (°C), $EC$, $Ca^{2+}$, $Mg^{2+}$, $Na^+$, $K^+$, $Cl^-$, $HCO_3^-$, $SO_4^{2-}$, $NO_3^-$, $TH$ (hydrotimetric degree), $TAT$ (total alkalinity titration). The interpretation of the various analytical results allowed the determination of the chemical facies and the classification of the groundwater aquifers as follows: (*i*) in the alluvial layer, the gypsiferous marl substratum and the clays of the three terraces (high, medium and low) have given the water a chlorinated calcium chemical facies in the east part of the study area and travertines feeding partly alluvial layer, and have given a bicarbonated calcium water facies in the west, (*ii*) in the Senonian of Heliopolis limestone and Eocene carbonate formations of Ras El Agba-Sellaoua, the chemical facies are calcium bicarbonate. Water isotopes ($\delta^{18}O$ and $\delta D$) helped to determine the origin of groundwater. Overall, the groundwater in the area is hard and has significant to excessive mineralization. It is progressively degraded in the direction of flow, especially in the Guelma alluvial aquifer.

**Key words:** *drinking water, groundwater, physicochemical parameters, spring, water quality*

## INTRODUCTION

Water is the most essential supporting element for the survival of human life, gives full support in the movement, circulation and cycling of nutrients [BANO 2017; DAHOUA *et al.* 2017; HAMAD *et al.* 2018b]. In the last few decades, there has been a tremendous increase in the demand for fresh water due to rapid growth of population, unplanned urbanization, industrialization and too much use of fertilizers and pesticides in agriculture [BAHROUN, CHAIB 2017; BESSER *et al.* 2018; HAMED *et al.* 2018; JOARDER *et al.* 2008]. Meanwhile sufficient potable quality of water is deteriorating and its pollution level is going up at a fast rate. Increase in human population has exerted an enor-mous pressure on the provision of safe drinking water especially in developing countries [DEMDOUM *et al.* 2015; MOKADEM *et al.* 2016; SINGH 2010]. Most of the fresh water bodies all over the world are getting polluted, thus decreasing the potability of water [ETIM *et al.* 2013; HADJI *et al.* 2014; ROUABHIA *et al.* 2012]. In general, the quality of water is important as the quantity.

Contamination of groundwater by domestic, industrial effluents and agricultural activity is a serious problem faced by developing countries [BANO 2017; BENRABAH *et al.* 2016; DARAPU *et al.* 2011; HAMAD *et al.* 2018a; ZAHRI *et al.* 2016]. Over exploitation of ground water through the bore well and their improper handling resulted in very low ground water levels besides contamination of even bore

waters at some places [HAMED *et al.* 2017a, b; KELMENDI *et al.* 2018; LEELAVATHI *et al.* 2016; MOUICI *et al.* 2017]. There is also the addition of various kinds of pollutants and nutrients through the agency sewage, industrial effluents, agricultural runoff, etc.

The chemical composition of groundwater is very varied. In a water table, water can be affected by several factors (concentration, base exchange, reduction), which are capable of partially modifying its chemical characteristics [CHAVAN, ZAMBARE 2014; JAIN *et al.* 2005]. In the same layer almost always there are variations from upstream to downstream. The water circulates by leaching the lands crossed and there may be an increase in the total concentration of dissolved salts [HAMED *et al.* 2014; IYASELE, IDIATA 2015]. Their reconstitution can tell us about the origin of the waters [DETAY 1997]. The impacts of the long-term usage of such water on groundwater, hence the fate of irrigated agriculture and drinking water supply which depends on affected groundwater, have not yet been less studied and evaluated [MOHAMMAD *et al.* 2017].

This study focused particularly on the physicochemical and isotopic characterization of groundwater in the Guelma region. In this approach, ten (10) captured springs representing three different aquifers were selected. The analysis through surveys concerned the determination of major elements for the study of chemical parameters and the determination of physical parameters during periods of high and low water periods.

## STUDY AREA

The study area is located in the northeastern of Algeria, at 60 km South of the Mediterranean Sea and Annaba metropolis between 36°21' and 36°32' N in latitude, and 7° and 8°E in longitude (Fig. 1). Being part of the eastern Algeria Maghrebides chain, and the Seybouse watershed, it is drained from west to east by the Seybouse Wadi [ABH-CSM 2005; DJABRI 1996; Sogreah 2005; VILA

1980]. The altitude varies between 300 m at the alluvial plain, to 600 m at the Senonian limestone of Heliopolis and 740 m at the Eocene limestone of Ras El Agba-Sellaoua.

The alluvial layer or alluvial plain of Guelma (NAG) is arranged in tiers on the right bank of Seybouse Wadi and formed from Plio-Quaternary alluvium resting on a marl-gypsiferous bedrock of Miocene age. This alluvial plain is represented by 5 sampling springs (Rosfa, Hamia, Zouaniz, O. Maiz, Guergour). In high water period, it is fed by rainwater and partly by the travertine layer located upstream at an average altitude of 300 m. At low water period, it is fed by irrigation water from Seybouse Wadi, taking into account the agricultural activities practiced on its soil. It is surrounded by various hills and mountains that have been undergoing orogenic and geologic evolution such as: Mahouna (1411 m) in the South, Haouara (1292 m) in the North and Debagh (1060 m) in the North-West [LAHONDERE 1987; RAOULT 1975; VILA *et al.* 1968]. The reliefs consist of allochthonous lands belonging essentially to the Tellian domain composed of Meso-Cenozoic marls and carbonates, and whose sedimentation, from the open sea, took place in the pelagic domain (Tellian units) [ALGEO 1997].

From the Tortonian, the region has experienced several tectonic deformations [VILA 1980]. These accidents have created a distinctive faulting network with NE-SW direction. The lineaments bordering the north of the Guelma's Mio-Pliocene basin of is well defined with east-west direction. Major faulting is intercepted perpendiculary by secondary ones.

The Guelma basin has experienced several basin filling cycles related to regional tectonics. It can be noted that the thermo-mineral springs are located along the directional faults (NE–SW and N–S). In the first direction, it is a placement of layers provoked by tectonics, in the second orientation (N–S), it is the tectonic of readjustment of the creation and birth of the current relief (Fig. 2).
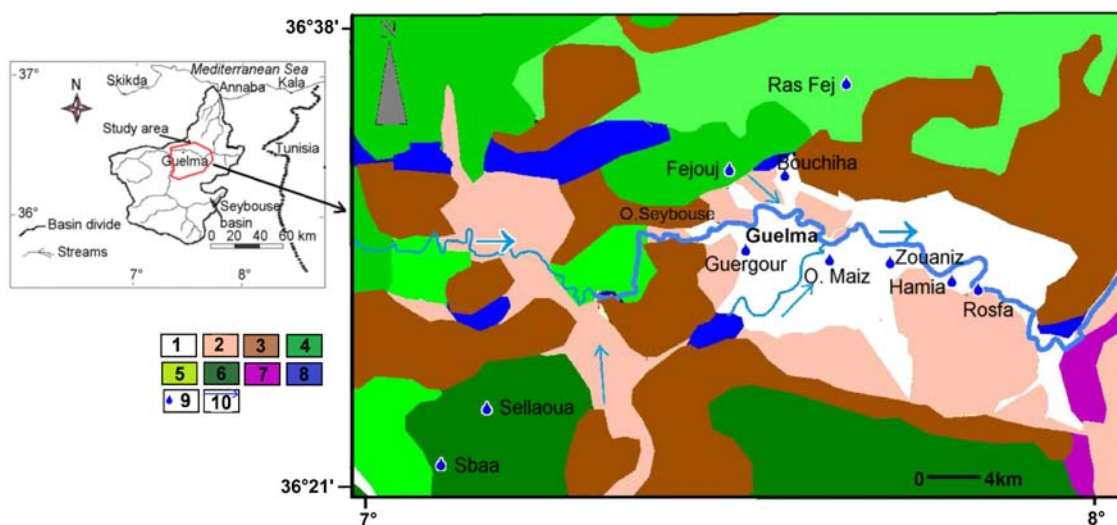


Fig. 1. Location of springs and geological description of the study area; *1* = Quaternary formations (sands, clays and gravels), *2* = Mio-Pliocene (clays, conglomerate and lacustrine limestone), *3* = Numidian sandstone, *4* = Mauritanian flysch, *5* = Neocomian to upper Lutetian (marly limestone), *6* = Ypresian (limestone), *7* = Trias (clays, gypsium and dolomitic limestone), *8* = Senonian (marls and marly limestone), *9* = spring, *10* = direction of flow; source: own elaboration

Fig. 2. Study area: A: Neocomian alluvial aquifer of Guelma (NAG) and Senonian limestone aquifer; B: plaine of NAG aquifer; source: own elaboration

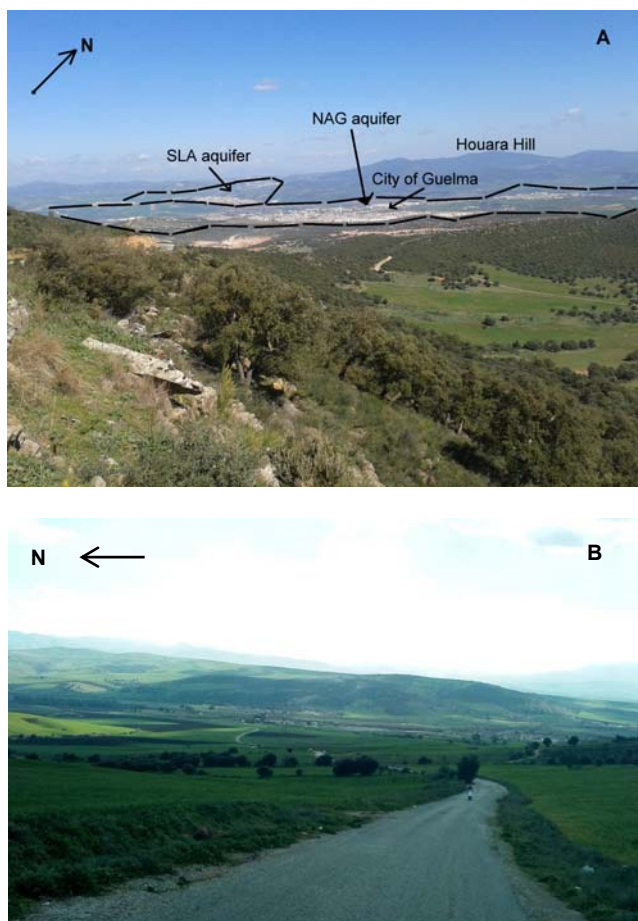Previous studies [Sogréah 2005] and exploitation of drilling holes, carried out by the Algerian Water Resources Agency (Fr. Agence Nationale des Ressources Hydrauliques – ANRH), have shown that the high terrace in the study area consists of two superposed aquifers, a free aquifer between 0 and 50 m formed of Quaternary pebbles, sand and gravel, and a semi-captive aquifer between 70 and 100 m formed of Pliocene coarse alluvium. The two aquifers are separated by a clay layer of 10 to 20 m in thickness. In the free water table, the transmissivities vary between $10^{-3}$ and $10^{-2}$ $m^2 \cdot s^{-1}$ and the porosities between 4 and 10%. In the semi-captive aquifer, they are equal $10^{-3}$ $m^2 \cdot s^{-1}$ and 1% respectively.

The perched aquifer forms the second aquifer and is represented by Senonian limestones (SLA) defined by marly limestones of Campanian to Maastrichtian age [LAHONDÈRE 1987] – Figure 2a. Meanwhile, the sampling springs of Ras Fej, Bouchiha and Fejouj are emerging from the marly limestone formations (Senonian age). From west to east these formations constitute the substratum of the Guelma Tellian beds. Groundwater that flows from north to south has given rise to springs of contact such as Ras Fej and Fejouj (calcareous marl and marl layers).

The Eocene limestone aquifer (ELA) consists of marly limestone bars resting on a marly layer. At this geologic formation, two sampling springs have been chosen, which

are: Sbaa and Sellaoua. The limestone formations belong to the series of the Tellian Paleogene. The survey and exploitation of drillings carried out in the study area has made it possible to distinguish from top to down alternating deposits of: gray marls of Lutetian age, massive limestones of Ypresian age and black marls of Paleocene age. The Sbaa spring located in the west part, whose flow varies between 0.4 $dm^3 \cdot s^{-1}$ and 2 $dm^3 \cdot s^{-1}$, and other springs of less importance indicate the existence of a perched aquifer with low hydrologic potentialities.

Geothermal energy comes from the heat within the earth. It takes advantage of this fact using water heated by the tectonic activity. The study area has shown the existence of six (6) thermal springs distributed from West to East, whose emergence temperatures are gradually decreasing from 100°C to 37°C towards the east, probably because of mixture with cold waters. Their origin assumes a classic hydrothermal cycle, affirming an absence of ancient volcanic activity but the presence of faulted areas. The main spring is represented by its miraculous waterfall of twenty meters high with water discharges of 100 $dm^3 \cdot s^{-1}$ irrationally exploited. With its temperature, this waterfall flows, as a geyser, is it ranked as a second in the world after Iceland ones. This energetic water potential, beneficial for renewable and environmentally resources, deserves to be of interest to scientists and policy makers in research and investment.

The study area is subject to a temperate semi-arid climate. The climatic rhythm indicates that the region is characterized by two distinct seasons: one rainy and cold with relatively high rainfall (600 mm) and low temperatures from October to May; the other dry and less rainy with high temperatures (42°C) recorded in August [DERRADJI *et al*. 2004]. The water balance established according to the formula of Thorntwaite [REMINIERAS 1993] brings out for an average precipitation of 574 mm, a potential evapotranspiration of 900 mm, a real transpiration of 440 mm, a water deficiency (*D*) of 470 mm, 80 mm of runoff (*R*) and infiltrated water of (*I*) 60 mm. The location of the selected springs is shown in Figure 1.

## MATERIALS AND METHODS

The water samples were done through field survey and a primary source of data was obtained from a comprehensive survey conducted, using polyethylene flasks, in high-water (May 2017) and low-water (August 2017) periods. Before using these flasks, they were previously washed with distilled water and then rinsed with water to be analysed and were then transported at low temperature to the Algerian Waters Laboratory, ADE (Fr. Laboratoire Algérien des Eaux). In total, twenty samples were taken representing all springs. The characteristics of the physicochemical parameters of groundwater quality have been determined according to the usual methods of analysis [RODIER 2009] and which were as follow:
– the conductivity (*EC*), measured at 25°C, the hydrogen potential (pH) and the temperature *T* in °C were determined by means of a multimeter device of the INOLAB.WTW type;

– calcium and magnesium ions were determined by titration complexometry with the disodium salt of EDTA (ethylenediaminetetraacetic acid);
– alkalinity was based on the neutralization of a certain volume of the sample by sulfuric acid ($H_2SO_4$, 0.02N);
– the chlorides were determined by the Mohr's method (argentimetry);
– the sulphates were determined by precipitation with barium chloride; this was the turbidimetric measurement on the disorder obtained at $\lambda = 435$ nm, using a spectrometer of the type: SE 120 Karl Kolb;
– nitrates were obtained by cadmium reduction method; the reading was automatic on Skalar self-analyser device at $\lambda = 540$ nm;
– the sodium and the potassium were determined by flame spectrophotometer on device of type: JENWAY.PFP7;
– for the isotope analysis, the ten samples were taken in polyethylene tubes of about 10 ml ($10\ cm^3$), filled to the brim and sealed to eliminate air bubbles; the isotopic analyses of $^{18}O$ and $^2H$ were performed using a mass spectrometer; for the analysis of $^{18}O$; $1\ cm^3$ of water was heated at high temperature to obtain a vapor (gas) which would be injected through the mass spectrometer for analysis; the same technique was undertaken for the $^2H$ from $mm^3$ of water.

## RESULTS AND DISCUSSION

The results of the physicochemical parameters for water samples are presented in Tables 1 and 2.

## PHYSICOCHEMICAL CHARACTERIZATION

The water temperature varied between 9 and 21.1°C during high water and low water period. These temperatures were close to ambient temperature and therefore indicated a shallow origin of the studied waters. All the sampled waters have a pH between 6.3 and 8.5. In the alluvial layer, it varied from east to west, from slightly acid to slightly alkaline. In the aquifers of Heliopolis and Ras El Agba, the pH was neutral to alkaline. The conductivity was essentially related to the presence of ionic species in solution and allowed an estimation of the total mineralization of water. In the Guelma alluvial aquifer (NAG), the water generally has conductivity greater than 1000 µS·cm$^{-1}$. During both periods, the electrical conductivity of water has tended to increase in the direction of flow from upstream to downstream. The solution of the mineral elements from the upstream travertine layer has contributed significantly to the increase of this parameter downstream of the aquifer (NAG).

In the Senonian neritic limestones of Heliopolis (SLA), observed in the springs of Bouchiha, Ras Fej and Fejouj, the conductivity has increased from the north (Ras Fej) to the south (Bouchiha) and varied between 646 and 1127 µS·cm$^{-1}$ at high water and 695–1158 µS·cm$^{-1}$ at low water periods in the direction of the groundwater flow. It is noted that the significant mineralization upstream became excessive downstream. The slow flow in the aquifer has acted in favour of dissolution proportional to the time of contact with the rock.

**Table 1.** Results of chemical analyses (in mg·dm$^{-3}$) of groundwater (May 2017)

| Spring | Ca$^{2+}$ | Mg$^{2+}$ | TH (°F) | Na$^+$ | K$^+$ | SO$_4^{2-}$ | Cl$^-$ | HCO$_3^-$ | TAT | NO$_3^-$ | EC (µS·cm$^{-1}$) | pH | T (°C) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rosfa | 121.3 | 44.3 | 53 | 65.7 | 5.3 | 100.5 | 247 | 238.4 | 38 | 30 | 2 030 | 7.2 | 11.0 |
| Hamia | 200 | 90 | 49 | 126 | 5.0 | 230 | 354 | 448 | 37 | 90 | 2 180 | 7.2 | 18.0 |
| Zoaniz | 140 | 32 | 52 | 90 | 2.0 | 160 | 150 | 280 | 28 | 71 | 1 850 | 7.3 | 9.6 |
| O. Maiz | 140 | 52 | 87 | 92 | 1.0 | 200 | 160 | 336 | 28 | 33 | 1 500 | 7.2 | 9.0 |
| Guergour | 92.3 | 34.1 | 75 | 98.1 | 2.3 | 98 | 105.9 | 281.2 | 35 | 117 | 1 613 | 6.3 | 13.0 |
| Bouchiha | 68 | 25 | 28 | 57 | 1.4 | 65 | 114 | 209 | 27 | 26 | 1 127 | 7.2 | 11.0 |
| Ras Fej | 69 | 23.1 | 21 | 24 | 0.5 | 20 | 56.8 | 288 | 27 | 1 | 646 | 7.3 | 13.1 |
| Fejouj | 76 | 26.7 | 39 | 48.8 | 2.7 | 52 | 63.9 | 297.6 | 23 | 57 | 806 | 7.5 | 20.0 |
| Sellaoua | 65 | 21 | 28 | 23 | 0.3 | 53 | 43 | 212 | 26 | 7 | 740 | 7.6 | 15.0 |
| Sbaa | 47 | 20 | 30 | 13.4 | 0.8 | 12 | 22 | 217.2 | 25 | 8.1 | 559 | 7.3 | 13.1 |

Explanations: *TH* = hydrotimetric degree, *EC* = electrical conductivity, *TAT* = total alkalinity titration.
Source: own study.

**Table 2.** Results of chemical analyses (in mg·dm$^{-3}$) of groundwater (August 2017)

| Springs | Ca$^{2+}$ | Mg$^{2+}$ | TH (°F) | Na$^+$ | K$^+$ | SO$_4^{2-}$ | Cl$^-$ | HCO$_3^-$ | TAT | NO$_3^-$ | EC (µS·cm$^{-1}$) | pH | T (°C) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rosfa | 156 | 38 | 70 | 102 | 5.0 | 85 | 270 | 354 | 40 | 31 | 2 020 | 7.4 | 19.0 |
| Hamia | 120 | 75 | 67 | 90 | 3.0 | 200 | 200 | 330 | 35 | 80 | 2 160 | 7.1 | 19.9 |
| Zoaniz | 150 | 72 | 48 | 60 | 4.0 | 166 | 180 | 305 | 26 | 80 | 1 750 | 7.3 | 19.0 |
| O. Maiz | 133 | 36 | 61 | 156 | 2.0 | 98 | 250 | 366 | 26 | 89 | 1 163 | 7.2 | 19.3 |
| Guergour | 150 | 80 | 55 | 80 | 7.0 | 180 | 200 | 340 | 33 | 120 | 1 594 | 7.0 | 19.7 |
| Bouchiha | 150 | 80 | 30 | 104 | 1.2 | 160 | 282 | 293 | 26 | 65 | 1 158 | 7.6 | 21.1 |
| Ras Fej | 75 | 23 | 24 | 18 | 0.3 | 32 | 42 | 292 | 26 | 6 | 695 | 7.1 | 18.0 |
| Fejouj | 76 | 27 | 20 | 48 | 2.5 | 53 | 65 | 292 | 24 | 53 | 950 | 7.4 | 18.3 |
| Sellaoua | 52 | 26 | 70 | 25 | 1.0 | 26 | 30 | 252 | 24 | 23 | 695 | 7.5 | 16.4 |
| Sbaa | 51 | 18 | 28 | 17 | 1.0 | 16 | 29 | 235 | 25 | 13 | 950 | 8.5 | 16.4 |

Explanations as in Tab. 1.
Source: own study.

In the Eocene limestone aquifer of Ras El Agba--Sellaoua (ELA), in Sellaoua and Sbaa, the conductivity varied between 559 and 740 µS·cm$^{-1}$ in high water and between 573 and 667 µS·cm$^{-1}$ in low water periods. In this aquifer, the feeding zone and the emergence were very close, so the water-rock contact time was very short and did not allow a significant dissolution of the mineral elements contained in the rock.

According to WHO standards [2005], the hydrotimetric degree (*TH*) or water hardness of the Guelma alluvial water table (NAG) has increased in the direction of a general flow from south to north and from west to east. The element *TH* varied between 32 and 54°F. The water has changed from hard upstream to very hard downstream. Senonian neritic limestones from Heliopolis (SLA) flow was from north to south, the *TH* which has a value of 22°F upstream has reached 32°F downstream. According to Durfor and Becker's classification [DURFOR, BECKER 1964], the groundwater analysed was medium at Eocene limestones of Ras El Agba-Sellaoua (ELA). Waters were considered hard to the extent that the hydrotimetric degree was between 32 and 54°F.

In the Guelma alluvial aquifer (NAG), alkalinity was influenced by the direction of flow and the nature of the crossed lands. It is noted that in the southern part, the aquifer of travertines which partly could feed the main aquifer was at the origin of the values of the alkalinity, which oscillated between 35 and 40°F. On the other hand, in the east, the basement gypsum marls have given the waters an alkalinity varying between 19 and 29°F. In the Senonian Heliopolis (SLA) neritic limestone table, the neritic limestones have given the waters an alkalinity that oscillated between 24 and 30°F during the analysis period. Related to the Eocene limestones of Ras El Agba – Sellaoua (ELA), the Eocene carbonate formations were at the origin of the values of the alkalinity, which varied between 24 and 30°F.

Nitrate ions ($NO_3^-$) were present in nature where they were part of the nitrogen cycle. They represented the most soluble form of nitrogen. Mainly used as inorganic fertilizers for plant growth and the synthesis of organic nitrogen compounds, excess nitrates could be found quickly in groundwater [ODW 1987]. Waste containing organic nitrogen was also a source of nitrates obtained from different biochemical processes (ammonification and nitrification). Nitrate concentrations in the analysed waters ranged from 1 mg·dm$^{-3}$ to 117 mg·dm$^{-3}$ in high water period and from 6 mg·dm$^{-3}$ to 120 mg·dm$^{-3}$ in low water period. The concentration of $NO_3^-$, downstream of the aquifer exceeding the standard of potability (50 mg·dm$^{-3}$), might assume contamination of the water. Indeed, the presence of agricultural activities at the (NAG) level could explain this high concentration of nitrates in water, especially downstream. The source of Guergour is located downstream of an agglomeration, so the nitrate levels of 117–120 mg·dm$^{-3}$ recorded in the waters of the springs were of domestic origin. The remaining water points showed nitrate concentrations below 50 mg·dm$^{-3}$ and as such their origin was natural.

## CHEMICAL FACIES

The determination of the hydrochemical facies of water was based on a decreasing classification of concentrations in milli-equivalents per dm$^3$ of anions and then cations. The facies was given by the dominant anion and cation [DETAY 1997]. The graphical representation of the groundwater chemical facies of the three aquifers in the two analysis areas was illustrated in Figure 3.

Globally, the hydrochemical facies was calcium bicarbonate upstream of the Guelma alluvial layer, calcium chlorinated downstream, and calcium bicarbonate in the other two aquifers. The appearance of intermediate secondary poles during the vertical fluctuations of the piezometric level following the rains has been notified.

## ISOTOPIC CHARACTERIZATION

It is known that groundwater exploitation is always accompanied by several studies for the estimation of reserves and the understanding of aquifer behaviour over time [DU *et al.* 2016; HÉLÈNE *et al.* 2001]. In the study region, all the
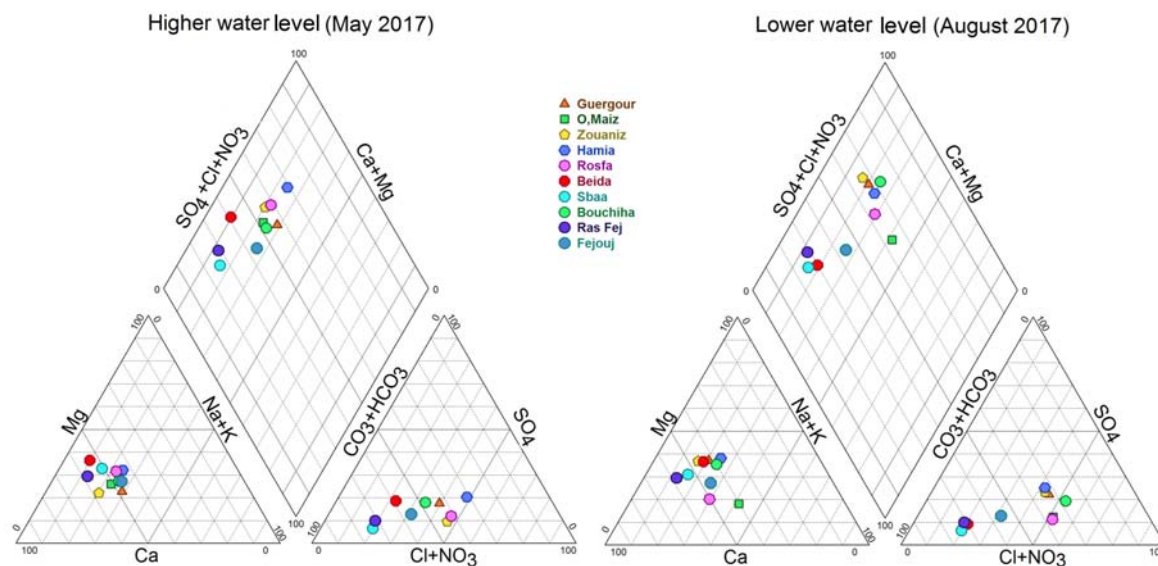
Fig. 3. Hydrochemical facies of groundwater in the study area during high water and low water periods; source: own study

previous studies developed have never used isotopic techniques. In many cases and in the absence of reliable hydrodynamic data, the isotopic techniques made it possible to understand the operation of the aquifers, the origin of the water and thus facilitated the management of the resource.

In this context, we have tried to give an isotopic characterization of the groundwater of the study area. For this purpose, isotopic analyses of the waters of ten (10) springs were carried out in low water period (August 2017) to study the isotopic variations of the stable isotopes of water such as $\delta^{18}O$ and $\delta D$ (Tab. 3, Fig. 4).

**Table 3.** Results of isotopic analyses (‰) of groundwater in the region of Guelma (August 2017).

| Samples | $X$ (m) | $Y$ (m) | $Z$ (m) | $\delta D$ | $\delta^{18}O$ |
|---|---|---|---|---|---|
| KBO5 ARD (Rosfa) | 935300 | 360300 | 170 | –16.1 | –6.3 |
| KBO5 AH BA (Hamia) | 934500 | 361150 | 165 | –52.7 | –5.1 |
| KBO5 AZ BA (Zouaniz) | 931300 | 362200 | 190 | –14.8 | –5.5 |
| KBO5 OM B (O. Maiz) | 927300 | 362100 | 200 | –35.7 | –4.8 |
| KBO5 AG G (Guergour) | 922200 | 362400 | 300 | –40.1 | –6.0 |
| KBO5 AB H (Bouchiha) | 924400 | 365700 | 270 | –3.4 | –4.7 |
| KBO5 RFGBS (Ras Fej) | 928200 | 372800 | 400 | –31.6 | –7.0 |
| KBO5 AA EF (Fejouj) | 921100 | 367500 | 315 | –33.6 | –5.4 |
| KBO5 AB SA (Sellaoua) | 907000 | 352200 | 705 | –42.6 | –7.2 |
| KB5 AS REA (Sbaa) | 904400 | 348500 | 745 | –34.2 | –6.8 |

Source: own study.

The spatio-temporal variations in stable isotope contents ($^{18}O$, $^{2}H$) can provide information on the origin of groundwater. These variations are due to the fractionation that occurs during phase changes and chemical reactions. In order to understand the process of isotopic phenomena, a brief discussion has to be undertaken. Thus, during the fractionation process, the vapour is still depleted in heavy isotopes relative to the remaining liquid (or the condensate is always enriched in heavy isotopes with respect to the original vapour). Due to the fractionation which depends on the temperature [DANSGAARD 1964; SIEGENTHALER, OESCHGER 1980], the isotope contents vary according to several parameters [LEDESMA-RUIZA, MAHLKNECHTA 2017; PLATA 1994; ROZANSKI et al. 1992], such as evapo-

ration, elevation, latitude, the effect of continentality [HÉLÈNE et al. 2001] and the lithology of the surrounding land.

Isotopic variations in water ($H_2O$) from rain, snow, ice, wadis, lakes and most low-temperature groundwater are extremely systematic. To a great approximation, all the meteoric waters on earth obey to the following equation [CRAIG 1961]:

$$\delta D\ (‰) = 8\delta^{18}O + 10\ (‰) \tag{1}$$

The linear relationship between $\delta^{18}O$ and $\delta D$ is due to the fact that evaporation and $H_2O$ condensation in the atmosphere and hydrosphere define an equilibrium process which is determined by the ratio of equilibrium exchange equilibrium constants. D/H and $^{18}O/^{16}O$ between the liquid and the stream waters. For example: at equilibrium and at ambient temperatures, $H_2O$ vapour will be depleted in deuterium by about 70‰ and in $^{18}O$ by about 9‰ with respect to liquid water. The fractionation of D/H and $^{18}O/^{16}O$ increases proportionally with the decrease in temperature; hence, the factor 8 of the slope of the meteoric water line (GMWL). We know that air masses escape from the oceans and always go across the continents due to different pressures. This leads to very significant geographical and topographic isotopic effects in the rains water and snow.

The values of $\delta D$ and $\delta^{18}O$ of meteoric waters are therefore lower at higher elevations. The average annual isotopic composition correlates linearly with the local mean temperature which is in turn correlated with latitude and elevation. This correlation with temperature is directly related to the fact that hot air contains a significant amount of water than cold air and therefore the atmospheric temperature is the main factor that determines the fraction of water vapour that comes from the mass of the air since leaving the ocean reservoir.

The zero (0) value of $\delta^{18}O$ of ocean water is intermediate between the $\delta^{18}O$ values of most rocks (typically between +4 and +35‰) and the values of all meteoric waters between 0 and –25‰. On the contrary, the $\delta D$ value for all terrestrial materials is negative. It should also be noted that the $\delta^{18}O$ values of water in high salinity and high evaporation regions (Red Sea) can reach +11‰. It is important to point out that the isotopic composition of the ocean waters controls all meteoric waters.
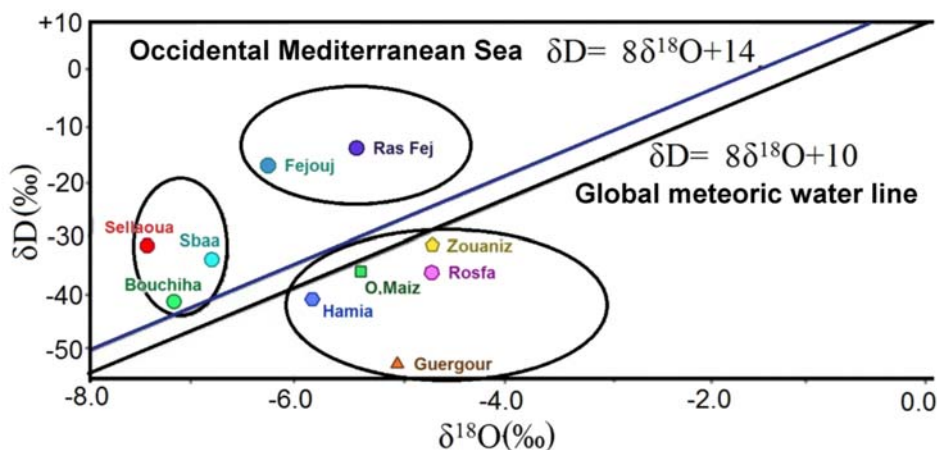


Fig. 4. Relationship between $\delta D$ and $\delta^{18}O$ in groundwater of the Guelma region (August 2017); source: own study

The intercept (+10) of the MWL must deviate to a higher value in the low humidity regions. For example, in the eastern Mediterranean where the intercepts can be worth +22 [YURTSEVER, GAT 1981] and the value of +14 in the western Mediterranean. Indeed our study area has responded geographically to the conditions of the western Mediterranean area. The isotope values of $H_2O$, ($\delta D$ and $\delta^{18}O$), will be compared and interpreted with respect to the western Mediterranean line using the Equation (2) [HÉLÈNE *et al*. 2001] and GMWL [CRAIG 1961] – Figure 4 as:

$$\delta D = 8\delta^{18}O + 14 \qquad (2)$$

The graphical representation of the pairs of values, according to the relation $\delta D$ and $\delta^{18}O$, has revealed two large classes of springs, one located to the right of the MWL and has contained the springs of the alluvial aquifer (NAG); the other located at the left of the western Mediterranean line and has carried the rest of the springs of the other two aquifers (SLA and ELA).

Therefore, the first class was distinguished by the waters of the springs from (1 to 5), where the pairs of isotopic values gave points to the right of the MWL. These waters were rich in $\delta^{18}O$ with values ranging from –6.3 to –4.8‰ and low values in $\delta D$ ranging from –52.7 to –14.8‰ (Tab. 3). This $\delta^{18}O$ enrichment would be caused by evaporation during the summer season [CRISS 1999]. The second class was represented by the waters of the springs of 6 to 10. In this case, the points were located to the left of the line of the western Mediterranean area. These waters were enriched in $\delta^{18}O$ and in $\delta D$ with $\delta^{18}O$ values between –7.2 and –4.7‰ and values of $\delta D$ between –42.6 and –3.4‰.

## CONCLUSIONS

The survey done in the present study has concerned the groundwater in three aquifers of different lithologies and ages in the region of Guelma. The different analytical methods were used for the determination of the mineral elements. It has been possible to study the evolution of the main physicochemical parameters both from a geographical and geological point of view.

Mineral water load was the final result of a complex set of processes that occurred along the water path from the upstream feeding zone to the downstream. The major reactions recognized as responsible for enrichment or depletion of the elements in groundwater were the $Ca^{2+}$ – $Mg^{2+}$ exchange due to the interaction between water and carbonate rocks, $Na^+ – Ca^{2+}$ or $Na^+ – Mg^{2+}$ base exchange.

The temperature of the groundwater in the alluvial layer and the groundwater of the Senonian limestones were close to ambient temperature. In the Eocene limestone aquifer, the temperature was remarkably low, which could indicate a deeper origin or a more important cover. The pH of the waters varied from slightly acidic in the alluvial layer because of a possible agricultural pollution to alkaline. This alkalinity would come from the dissolution of the minerals present in the country. The conductivities were variable according to the considered aquifer and increased in the flow direction from upstream to downstream. Groundwater had a medium mineralization and was therefore pure and good for drinking and domestic use. It was generally chlorinated and containing bicarbonate calcium and magnesium. Chloride, bicarbonate, calcium, sodium and magnesium ions were responsible for the chemical facies during high and low water periods.

In general, the mineral characteristics of the groundwater in the study area appeared to be generally within the permissible limits and evolve poorly downstream of the flow.

The isotopic values have made this study possible to classify the division of groundwater into two classes according to the enrichment or the depletion of oxygen and hydrogen, and thus indicating their origin.

Finally, the contribution of a geophysical study is essential to define the extensions and limits of aquifers. Drilling will reinforce the geophysical results for the identification of the productive formations. Moreover, the addition of isotopes as natural tracers would help to know the origin and age of the waters. The creation of protection perimeters around catchments would preserve the quality of the waters and therefore, protect the health of the populations. An interest could also be done on focusing on the hydrotherapy, very pronounced in the study area, by the existence of promising thermal springs that could be beneficial to the national economy such as tourism.

## REFERENCES

ABH-CSM 2005. Qualité des eaux souterraines dans le bassin de la Seybouse [Groundwater quality in the Seybouse Basin]. Agence de Bassin Hydrographique Constantinois-Seybouse-Mellegue. Internal Report pp. 46.

ALGEO 1997. Etude géophysique de la plaine alluvionnaire de Guelma [Geophysical study of the alluvial plain of Guelma]. Internal Report pp. 35.

BAHROUN S., CHAIB W. 2017. The quality of surface waters of the dam reservoir Mexa, Northeast of Algeria. Journal of Water and Land Development. Vol. 34 (VII–IX) p. 11–19. DOI 10.1515/jwld-2017-0034.

BANO N. 2017. Assessment of physicochemical characteristics of groundwater quality used for drinking water supply of Firozabad City, India using index method. Journal of Applied Science and Environmental Management. Vol. 21. Iss. 4 p. 728–731.

BENRABAH S., ATTOUI B., HANNOUCHE M. 2016. Characterization of groundwater quality destined for drinking water supply of Khenchela City (eastern Algeria). Journal of Water and Land Development. Vol. 30 (VII–IX) p. 13–20. DOI 10.1515/jwld-2016-0016.

BESSER H., MOKADEM N., REDHAOUNIA B., HADJI R., HAMAD A., HAMED Y. 2018. Groundwater mixing and geochemical assessment of low-enthalpy resources in the geothermal field of southwestern Tunisia. Euro-Mediterranean Journal for Environmental Integration. Vol. 3. Iss. 16. DOI 10.1007/s41207-018-0055-z.

CHAVAN B.L., ZAMBARE N.S. 2014. Physicochemical analysis of groundwater samples in Solapur City, Maharashtra, India. International Journal of Research in Civil Engineering Architecture and Design. Vol. 2. Iss. 3 p. 7–12.

CRAIG H. 1961. Isotopic variations in meteoric waters. Sciences. Vol. 133 p. 1702–1703.

CRISS R.E. 1999. Principles of stable isotope distribution. New York. Oxford University Press. ISBN 0195117751 pp. 254.

DAHOUA L., SAVENKO S.V., HADJI R. 2017. GIS-based technic for roadside-slope stability assessment: An bivariate approach for A1 East-West highway, North Algeria. Mining Science. Vol. 24 p. 81–91.

DANSGRAAD W. 1964. Stable isotopes in precipitation. Tellus. Vol. 16 p. 436–468.

DARAPU S.S.K., SUDHAKAR E.B., KRISHNA K.S.R., RAO P.V., SHEKHAR M.C. 2011. Determining water quality index for the evaluation of water quality of river. International Journal of Engineering Research and applications. Vol. 1. Iss. 2 p. 174–182.

DEMDOUM A., HAMED Y., FEKI M., HADJI R., DJEBBAR M. 2015. Multi-tracer investigation of groundwater in El Eulma Basin (Northwestern Algeria), North Africa. Arabian Journal of Geosciences. Vol. 8. Iss. 5 p. 3321–3333.

DERRADJI F., KHERICI N., ROMEO M., CARUBA R. 2004. Aptitude des eaux de la vallée de la Seybouse à l'irrigation (Nord-Est algérien) [Suitability of the waters of the Seybouse Valley for irrigation (North-East of Algeria)]. Sécheresse. Vol. 15 p. 353–360.

DETAY M. 1997. La gestion active des aquifères [Active management of aquifers]. Paris. Masson. ISBN 2225856230 pp. 440.

DJABRI L. 1996. Mécanismes de la pollution et vulnérabilité des eaux de la Seybouse, Origines géologiques, industrielles, agricoles et urbaines [Mechanisms of pollution and vulnerability of Seybouse waters, geological, industrial, agricultural and urban origins]. PhD thesis. Es Sciences. Annaba, Algeria. University of Badji Mokhtar pp. 261.

DU M., ZAVATTEROA E., MAA Q., DELESTREB O., GOURBES-VILLEA P., FOUCHE O. 2016. 3D hydraulic modeling of a complex alluvial aquifer for groundwater resource management. Procedia Engineering. Vol. 154 p. 340–347.

DURFOR C.N., BECKER E. 1964. Public water supplies of the 100 largest cities in the US. US-Geological Survey Water Supply Paper. Vol. 1812 pp. 364.

ETIM E.E., ODOH R., ITODO A.U., UMOH S.D., LAWAL U. 2013. Water quality index for the assessment of water quality from different sources in the Niger Delta Region of Nigeria. Frontiers in Science. Vol. 3. Iss. 3 p. 89–95.

HADJI R., LIMANI Y., BOUMAZBEUR A., DEMDOUM A., ZIGHMI K., ZAHRI F., CHOUABI A. 2014. Climate change and their influence on shrinkage – swelling clays susceptibility in a semiarid zone: A case study of Souk Ahras municipality, NE-Algeria. Desalination and Water Treatment. Vol. 52. Iss. 12 p. 2057–2072.

HAMAD A., BAALI F., HADJI R., ZERROUKI H., BESSER H., MOKADEM N., HAMED Y. 2018b. Hydrogeochemical characterization of water mineralization in Tebessa-Kasserine karst system (Tuniso-Algerian Transboundry basin). Euro-Mediterranean Journal for Environmental Integration. Vol. 3. Iss. 1. DOI 10.1007/s41207-017-0045-6.

HAMAD A., HADJI R., BÂALI F., HOUDA B., REDHAOUNIA B., ZIGHMI K., HAMED Y. 2018a. Conceptual model for karstic aquifers by combined analysis of GIS, chemical, thermal, and isotopic tools in Tuniso-Algerian transboundary basin. Arabian Journal of Geosciences. Vol. 11. Iss. 15.

HAMED Y., AHMADI R., HADJI R., MOKADEM N., BEN DHIA H., ALI W. 2014. Groundwater evolution of the Continental Intercalaire aquifer of Southern Tunisia and a part of Southern Algeria: Use of geochemical and isotopic indicators. Desalination and Water Treatment. Vol. 25. Iss. 12 p. 1990–1996.

HAMED Y., HADJI R., REDHAOUNIA B., ZIGHMI K., BÂALI F., EL GAYAR A. 2018. Climate impact on surface and groundwater in North Africa: A global synthesis of findings and recommendations. Euro-Mediterranean Journal for Environmental Integration. Vol. 3. Iss. 1. DOI 10.1007/s41207-018-0067-8.

HAMED Y., REDHAOUNIA B., BEN SÂAD A., HADJI R., ZAHRI F., EL HIDOURI B. 2017a. Groundwater inrush caused by the fault reactivation and the climate impact in the mining Gafsa Basin (Southwestern Tunisia). Journal of Tethys. Vol. 5. Iss. 2 p. 154–164.

HAMED Y., REDHAOUNIA B., BEN SÂAD A., HADJI R., ZAHRI F., ZIGHMI K. 2017b. Hydrothermal waters from karst aquifer: Case study of the Trozza basin (Central Tunisia). Journal of Tethys. Vol. 5. Iss. 1 p. 33–44.

HÉLÈNE C.J., KAMEL Z., YVES T., ABDELKRIM D. 2001. Caractérisation isotopique des pluies en Tunisie. Essai de typologie dans la région de Sfax [Isotopic characterization of rainfall in Tunisia. Typology test in the region of Sfax]. Comptes Rendus de l'Académie des Sciences – Series IIA – Earth and Planetary Science. Elsevier. Vol. 333. Iss. 10 p. 625–631.

IYASELE J.U., IDIATA D.J. 2015. Investigation of the relationship between electrical conductivity and total dissolved solids for mono-valent, di-valent and tri-valent metal compounds. International Journal of Engineering Research and Reviews. Vol. 3. Iss. 1 p. 40–48.

JAIN P., SHARMA J.D., SOHU D., SHARMA P. 2005. Chemical analysis of drinking water of villages of Sanganer Tehsil, Jaipur District. International Journal of Environmental Science and Technology. Vol. 2. Iss. 4 p. 373–379.

JOARDER M.A., RAIHAN F., ALAM J.B., HASANUZZAMAN S. 2008. Regression analysis of ground water quality data of Sunamjang district, Bangladesh. International Journal of Environmental Research. Vol. 2 p. 291–296.

KELMENDI M., KADRIU S., SADIKU M., ALIU M., SADRIU E., HYSENI S.M. 2018. Assessment of drinking water quality of Kopiliq village in Skenderaj, Kosovo. Journal of Water and Land Development. Vol. 39 (X–XII) p. 61–65. DOI 10.2478/jwld-2018-0059.

LAHONDERE J.C. 1987. Les séries ultra telliennes d'Algérie nord orientale et les formations environnantes dans leur cadre structural [The ultra-tellian series of northeastern Algeria and the surrounding formations in their structural framework]. PhD thesis. Sciences. Toulouse, France. University of Paul Sabatier pp. 242.

LEDESMA-RUIZA R., MAHLKNECHTA J. 2017. Geochemical and isotopic characterization of groundwater in Tecate, Baja California, Mexico. Procedia Earth and Planetary Science. Vol. 17 p. 516–519.

LEELAVATHI C., SAINATH U.K., RABBANI A.K. 2016. Physicochemical characterization of ground water of Autonagar, Vijayawada, Krishna district. International Journal of Engineering Development and Research. Vol. 4. Iss. 2 p. 1324–1328.

MOHAMMAD A.H., ABDULLAT G., ALZUGHOUL K. 2017. Changes in total dissolved solids concentration during infiltration through soils (rain, fresh groundwater and treated wastewater). Journal of Environmental Protection. Vol. 8 p. 34–41.

MOKADEM N., DEMDOUM A., HAMED Y., BOURI S., HADJI R., BOYCE A., LAOUAR R., SAAD A. 2016. Hydrogeochemical and stable isotope data of groundwater of a multi-aquifer system: Northern Gafsa basin – Central Tunisia. Journal of African Earth Sciences. Vol. 115 p. 174–191.

MOUICI R., BAALI F., HADJI R., BOUBAYA D., AUDRA P., FEHDI C.É., CAILHOL D., JAILLET S., ARFIB B. 2017. Geophysical, geotechnical, and speleologic assessment for karst-sinkhole collapse genesis in Cheria plateau (NE Algeria). Mining Science. Vol. 24 p. 59–71.

ODW 1987. Estimated national occurrence and exposure to nitrate and nitrite in public drinking water supplies. Office of Drinking Water. US Environmental Protection Agency pp. 156.

PLATA A. 1994. Composicion isotopic de las precipitaciones sub-terraneas de la Peninsula Iberica [Isotopic composition of the underground precipitations of the Iberian Peninsula]. Madrid, Spain. Centro de Estudios y Experimentacio de Obras Publica. Vol. 39. ISBN 84-7790-177-5 pp. 139.

RAOULT J.F. 1975. Evolution paléogéogrphique et structurale de la chaine alpine entre le golf de Skikda et Constantine (Algérie orientale) [Palaeogeographical and structural evolution of the Alpine chain between the Skikda golf course and Constantine (Eastern Algeria)]. Bulletin de la Societe Geologique de France. Ser. 7. Vol. XVII (3) p. 394–409.

REMENIERAS G. 1986. L'hydrologie de l'ingénieur [The hydrology of the engineer]. 2nd ed. Paris. Eyrolles. ISBN 978-2-212-05220-6 pp. 462.

RODIER J. 2009. L'analyse de l'eau; eaux naturelles, eaux rési-duelles, eaux de mer. Chimie, physico chimie, microbiologie, biologie, interprétation des résultats [Water analysis; natural waters, wastewater, seawater. chemistry, physico-chemistry, microbiology, biology, interpretation of results]. 8th ed. Paris. Dunod. pp. 1383.

ROUABHIA A., DJABRI L., HADJI R., BAALI F., FAHDI CH., HANNI A. 2012. Geochemical characterization of groundwater from shallow aquifer surrounding Fetzara Lake NE Algeria. Arabi-an Journal of Geosciences. Vol. 5. Iss. 1 p. 1–13.

ROZANSKI K., ARAGUAS L., GONFIANTINI R. 1992. Relation be-tween long-term trend of oxygen-18 isotope composition of precipitation and climate. Science. Vol. 258 p. 982–985.

SIEGENTHALER V., OESCHGER H. 1980. $^{18}O$ in precipitation: corre-lation with temperature and altitude on a regional scale. Na-ture. Vol. 285 p. 314–316.

SINGH L. 2010. Environmental geography. New Delhi. APH Publ. Corp. ISBN 978-8131306994 pp. 473.

Sogreah 2005. Etude hydrogéologique de la nappe alluvionnaire de Guelma [Hydrogeological study of the Guelma alluvial aquifer]. Internal report. Bagnolet. Société française d'ingé-nierie p. 318–333.

VILA J.M. 1980. La chaine alpine d'Algérie orientale et des confins Algéro-Tunisiens [The alpine chain of eastern Algeria and the Algerian-Tunisian borders]. PhD Thesis. Natural Sciences. Paris 3, France pp. 665.

VILA J.M., BUSNARDO R., DEVRIES A., MAGNE J., SIGAL J. 1968. Données stratigraphiques sur la série renversée et charriée du Djebel Bousbaa et étude de son cadre structural (région de Guelma, constantinois, Algérie) [Stratigraphic data on the reversed and carried series of Jebel Bousbaa and study of its structural framework (region of Guelma, Constantinois, Algeria)]. B.S.G. Paris France. Vol. 7. Iss. 10 p. 206–212.

WHO 2005. Célébration de la décennie internationale d'action l'eau, source de vie (2005–2015) [Celebrating the international decade of water action, source of life (2005–2015)]. World Health Organization. Guide of sensibilization pp. 34.

YURTSEVER Y., GAT J.R. 1981. Atmospheric waters in stable iso-tope hydrology: deuterium and oxygen$^{-18}$ in the water cycle. Technical Report Series. No. 210. Vienna. IAEA p. 103–142.

ZAHRI F., BOUKELLOUL M., HADJI R., TALHI K. 2016. Slope sta-bility analysis in open pit mines of Jebel Gustar career, NE Algeria – A multi-steps approach. Mining Science. Vol. 23 p. 137−146.

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**Fizyczna, chemiczna i izotopowa charakterystyka wód gruntowych w basenie Guelma w północnowschodniej Algierii**

STRESZCZENIE

Jakość wody jest ważnym kryterium oceny jej przydatności do picia i potrzeb domowych. Celem pracy było zbadanie fizycznych i chemicznych właściwości wody przeznaczonej do konsumpcji. Do badań wybrano dziesięć ujęć wody zloka-lizowanych w trzech poziomach wodonośnych: aluwialny basen mioceńsko-plioceńsko-czwartorzędowy Guelma, wapien-ny poziom z okresu późnej kredy i poziom eoceńskich wapieni w Ras El Agba-Sellaoua. Analizy prowadzono w okresie wysokiej wody w maju 2017 r. i niskiej wody w sierpniu 2017 r. W próbkach wody oznaczono 12 parametrów: pH, $T$ (°C), $EC$ (przewodnictwo), $Ca^{2+}$, $Mg^{2+}$, $Na^+$, $K^+$, $Cl^-$, $HCO_3^-$, $SO_4^{2-}$, $NO_3^-$, $TH$ (całkowita twardość), $TAC$ (całkowita alkalicz-ność). Interpretacja uzyskanych wyników umożliwiła wydzielenie grup chemicznych i klasyfikację poziomów wodonoś-nych w następujący sposób: (i) strefa aluwialna, gipsowo-wapienne podłoże i iły trzech tarasów (wysoki, średni i niski) – wody grupy chlorkowo-wapniowej we wschodniej części badanego obszaru i wody wodorowęglanowo-wapniowe w zachodniej części, (ii) wapienie późnej kredy i eoceńskie utwory węglanowe w Ras El Agba-Sellaoua – wody o charak-terze wodorowęglanowo-wapniowym. Analiza izotopowa ($\delta O^{18}$ i $\delta D$) pozwoliła ustalić pochodzenie wód gruntowych. Ge-neralnie wody gruntowe badanego obszaru są twarde i charakteryzują się wysoką bądź nadmierną mineralizacją. Wody ulegają stopniowej degradacji w kierunku przepływu, szczególnie w aluwialnym poziomie wodonośnym Guelma.

**Słowa kluczowe:** *jakość wody, parametry chemiczne, parametry fizyczne, woda pitna, wody podziemne, źródło*