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E – manuscript preparation
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Groundwater's physicochemical and bacteriological assessment: Case study of well water in the region of Sedrata, North-East of Algeria

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Abstract

Drinking water is a possible source of humans' illness when it contains chemicals and microorganisms especially from anthropogenic activities. The water supply from groundwater remains very important in Algeria. To assess the quality of groundwater in the region of Sedrata, analyses were carried out on 26 wells belonging to two neighbouring areas: one urban and the other rural. A study of physicochemical parameters has focused on the measurement of *in situ* temperature, electrical conductivity, pH and turbidity. Then the following parameters were analysed: hardness, and the elements: Ca^{2+}, Mg^{2+}, SO_4^{2-}, PO_4^{3-}, Cl^-, NO_2^-, NO_3^-, NH_4^+ as well as metal trace elements Fe^{2+}, Mn^{2+}, Al^{3+}. The samples taken for the bacteriological study were filtered and introduced into growth medium for the research and enumeration of total germs, faecal coliforms, faecal streptococci and sulphite reducing *Clostridium*. As a result, the contamination of the studied waters is almost general. Some of the most important obtained values are ranging from 4.8 to 76 $mg\cdot dm^{-3}$ for nitrates, the recorded values for mesophilic germs vary from 1 to 1100 $CFUs\cdot cm^{-3}$. Agricultural activity and livestock products on the one hand and the use of fertilizers on the other hand are the main sources of physicochemical and bacteriological pollution. Contaminated wells should be treated as soon as possible to limit contamination before spreading in the deep aquifers. In the future, it will be necessary not only to assess the health risks related to the level of contamination of these waters, but also to proceed with their treatment before supplying them to consumers.

Key words: *bacteriology, groundwater, physicochemistry, Sedrata, water quality*

INTRODUCTION

Safe drinking water should not expose the consumer to health hazards, and can be used for different household purposes including personal hygiene. Water could become a source of diseases after contamination caused mainly by the impact of different man activities [WHO 2008]. Human pressure encompasses the consequences of all agricultural and industrial activities, as well as sanitation procedures (wastewater, organic or chemical household wastes). Agricultural pollution which results not only from the use of mineral and organic fertilizers, pesticides for crop protection but also from farm animal wastes is one of the most difficult to limit because of its dispersal into the soil and its infiltration into groundwater [MIODUSZEWSKI 2015]. Nitrates are the most important elements in agricultural pollution and are dangerous for human health; these contaminants can cause methemoglobinemia, which is characterized by difficulty in transporting vital oxygen through the body, and the consequences can be extremely serious in newborns, even to the point of death. Water can also transmit infectious diseases, which result from the infiltration of pathogenic germs; they present a danger to the consumer ranging from simple diarrhoeas to much more serious diseases such as meningitis [WHO 2008].

Non-permanent supply of drinking water via the national distribution network has led people to resort to groundwater which are exploited for various uses including drinking. This study, which consists of the qualitative evaluation of well water used by inhabitants of Sedrata region, was conducted with the ultimate aim of identifying the problematic parameters of their potability and of estimating the importance of pollution and its potential origins then proposing measurements to be taken to remedy this.

MATERIALS AND METHODS

STUDY AREA

Two areas make up the Sedrata region; one urban and the other rural. They are located between the longitude 7°26’85” and 7°40’13” East, and the latitude 36°3’27” and 36°14’6” North. Sedrata is located in northeastern Algeria and western the city of Souk-Ahras (Fig. 1). The study area is 811 meters high (Fig. 2) and it has a surface area of 23 766 ha with population of 66 617, the average temperature in Sedrata is 13.5°C and the mean annual rainfall of the region is around 500 mm.

According to the Sedrata geological map drawn at 1:50 000, designed and published by the Army Geographical Service (Fr. Le service géographique de l'armée en 1977) in 1977, the study area includes two water tables; a phreatic aquifer (Miocene) which consists of detrital formations that extend over the entire plain of the Sedrata urban area, and a deep Eocene/Maestrichian aquifer located in the rural area named Khemissa consisting mainly of cracked carbonates formations, and which comes in two aspects; a captive karstic aquifer where the clay formations underlying the Miocene ensure its recharge and constituting the substratum of the phreatic aquifer and a free water table at the limestone outcrops in the northern part of Khemissa.

SAMPLING

The studied wells are located in the region of Sedrata: 7 in the urban area and 19 in the rural one (Fig. 2). Table 1 represents the location of the studied wells, they are classified according to their geographical co-ordinates from the West to the East of the area of Sedrata. Water samples collected for physicochemical analysis were stored at 4°C in disposable plastic vials and analysed within 24 h. For microbiological analysis, samples were taken at a depth of 50 cm in glass bottles previously sterilized in Pasteur oven (170°C) for 1 h, then transported in coolers at temperature ranging between 4 and 6°C. Analyses were made in times not exceeding 8 h [RODIER *et al*. 2009].

ANALYZES

To manage the risks associated with water consumption, priority should be given to those elements that pose a risk to human health or have a significant impact on the acceptability of water. Unlike chemicals that impact human health after long-term consumption, microbial contamination can cause major epidemics of water-borne diseases [WHO 2008].

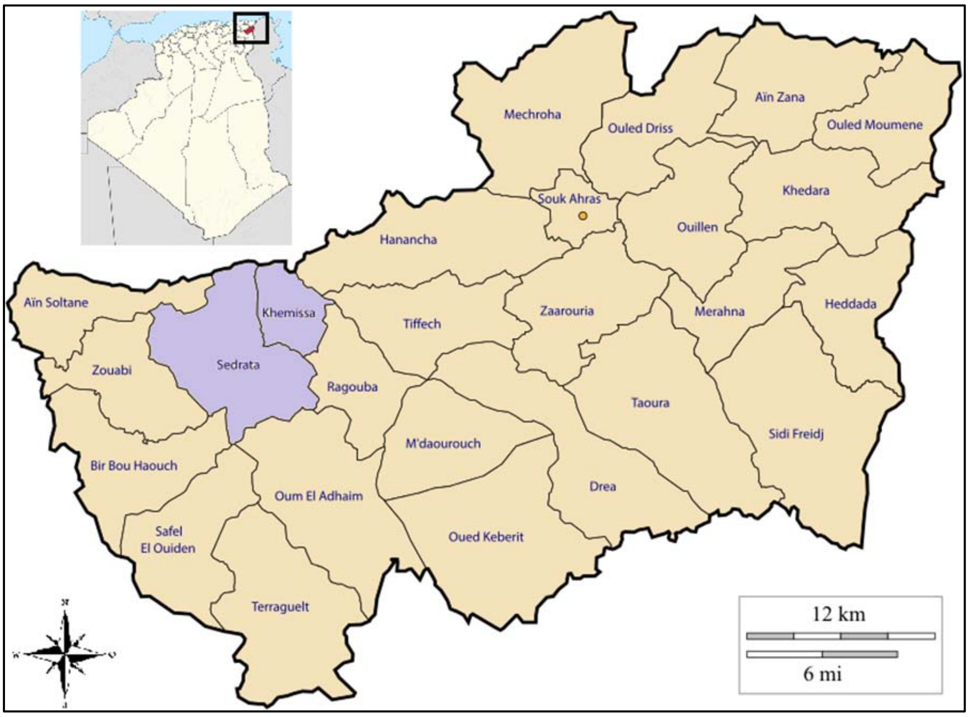

Fig. 1. Location of the region of Sedrata; the district of Sedrata is divided on two communes; Sedrata is the urban area and Khemissa is the rural one; source: own elaboration

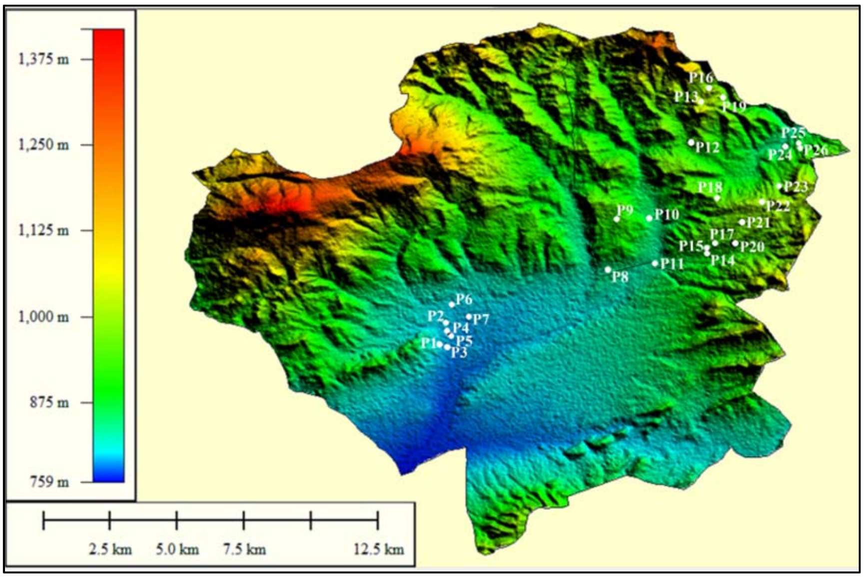

Fig. 2. Altitude of the region of Sedrata and location of the studied wells; wells' names as in Table 1; source: Digital Elevation Model, SRTM data and 1 arc second resolution

Table 1. Geographic coordinates of the studied wells

Well	Name	Geographic coordinate	
		longitude	latitude
P1	08 Mai 1945	7°31'59.2"	36°07'39.1"
P2	Rokaz	7°32'06.9"	36°08'06.4"
P3	Cité 20 Août	7°32'07.9"	36°07'56.0"
P4	Batiments des gendarmes	7°32'08.0"	36°07'36.8"
P5	Ben Smail	7°32'09.5"	36°07'52.0"
P6	Gendarmerie	7°32'13.9"	36°08'27.8"
P7	Sortie Aoulab	7°32'33.6"	36°08'13.4"
P8	Sidi Belghit	7°35'14.1"	36°10'49.2"
P9	Rhahlia Mekki	7°35'32.7"	36°10'10.2"
P10	Khemissa 1	7°36'04.2"	36°10'56.2"
P11	Mraihia Salah	7°36'14.5"	36°10'05.7"
P12	Rouabhia Hadj Rabeh	7°36'18.7"	36°09'17.0"
P13	Houaichia Hamid	7°37'02.3"	36°11'42.8"
P14	Braikia	7°37'11.7"	36°12'46.2"
P15	Keblouti	7°37'19.5"	36°09'39.2"
P16	Ain Mesdou Graana	7°37'21.6"	36°09'29.1"
P17	Bousseha Lekhmissi	7°37'31.4"	36°09'41.2"
P18	Sbaihia Mouha	7°37'34.7"	36°10'35.7"
P19	Ain Gatair	7°37'42.1"	36°12'36.7"
P20	Ghannam Amor	7°37'56.1"	36°09'41.0"
P21	Saaidia Jabou	7°38'03.6"	36°10'07.3"
P22	Elarbi	7°38'28.9"	36°10'31.1"
P23	Djlailia	7°38'48.7"	36°10'50.4"
P24	Djlailia Amor	7°38'56.4"	36°11'37.7"
P25	CEM Bouchagour Allaoua	7°39'13.6"	36°11'41.5"
P26	Ain Messousset APC	7°39'14.3"	36°11'36.6"

Source: own elaboration.

To carry out this work, a monthly follow-up was carried out over a period of three months (from January 2015 to March 2015).

In order to assess the physicochemical quality of samples; we have been interested in:

1) physical properties of water as; temperature, conductivity, and turbidity;
2) indicators affecting organoleptic properties: chlorides, phosphates, sulphates, iron, manganese, hardness (calcium and magnesium);
3) pollution indicators affecting the health of consumers: nitrogen products and aluminium;

analyses were carried out according to the following methods: the temperature in situ with a thermometer, the electrical conductivity and the pH using a conductivity meter and a pH-meter; turbidity with a turbidimeter, chlorides and hardness were analysed with the Mohr method [RODIER *et al.* 2009]; the elements:

- Ca^{2+} and Mg^{2+} were measured using flame atomic adsorption spectrometry with respective detection limits of 0.1 $mg·dm^{-3}$ and 5 $µg·dm^{-3}$ [RODIER *et al.* 2009],
- SO_4^{2-} and PO_4^{3-} were determined with molecular adsorption spectrometry at respective wavelengths of 650 nm and 800 nm [RODIER *et al.* 2009],
- NO_2^-, NO_3^- and NH_4^+ were measured using molecular adsorption spectrometry at respective wavelengths of 415 nm, 543 nm and 630 nm [RODIER *et al.* 2009],
- Fe^{2+}, Mn^{2+} and Al^{3+} were quantified with flame atomic adsorption spectrometry with respective detection limits of 20 $µg·dm^{-3}$, 10 $µg·dm^{-3}$ and 50 $µg·dm^{-3}$ [RODIER *et al.* 2009].

For the microbiological study, we have been interested in a group of pollution indicators and therefore a very likely presence of pathogens [WHO 2008]. The total germs were counted following the filtration of the water to be analysed using membranes with a porosity of 0.45 µm before they were introduced onto the solid growth medium and incubated at 37°C and 22°C for 24 h. For total coliforms, faecal coliforms and faecal streptococci, their search and enumeration were performed following the incorporation in selective agar plates of a quantity of 1 cm^3 of the water samples diluted in distilled water. For sulphite-reducing *Clostridium*, the water samples were heated to 80°C and then 20 cm^3 were incorporated into the liver meat agar and incubated at 37°C for 24 h [RODIER *et al.* 2009].

RESULTS AND DISCUSSION

TEMPERATURE

Temperature is an important parameter for the study of well water as it provides insight into the depth of studied wells. Temperature intervenes in the chemical and microbiological transformations in the waters [BENRABAH *et al.* 2016]. The collected data show that the values of the temperature vary from 12.6°C to 17.9°C (Fig. 3). These values, not exceeding the world standards, are influenced by the ambient temperature which testifies the shallowness of these waters [BENRABAH *et al.* 2016].

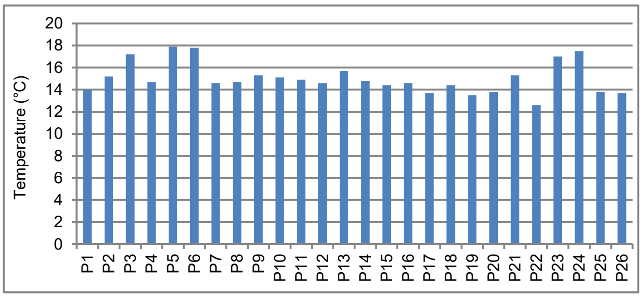

Fig. 3. Temperature variations in the studied well-water; P1–P26 = study wells as in Fig. 2 and Tab. 1; source: own study

HYDROGEN POTENTIAL (PH)

The pH is influenced by the origin of water and the nature of the crossed terrain. It plays an important role in the physicochemical balance of water [BELGHITI *et al.* 2013b] and varies according to the minerals' dissolution and precipitation [BENRABAH *et al.* 2016]. The pH values of the studied wells fall within the range of the potability standard [WHO 2008], and ranged from 6.8 to 7.65 (Fig. 4).

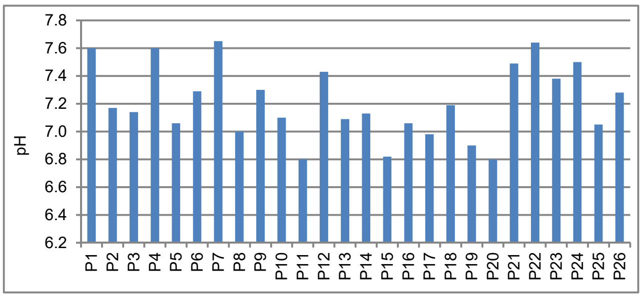

Fig. 4. pH variations in the studied well-water; P1–P26 = study wells as in Fig. 2 and Tab. 1; source: own study

CONDUCTIVITY

The conductivity reflects the water mineralization; it varies according to the concentration of dissolved salts and is often influenced by temperature because it acts on the dissolution of salts in water [BENRABAH *et al.* 2016]. The wells: P1, P4, P6, P19, P20, P24 and P25 exceed the WHO standards set at 2500 µS·cm^{-1}, and this may be due to the natural salinity of the waters in this region, or, according to NOUAYTI *et al.* [2015], this seems to result from the leaching of the rock reservoir where the water remained (Fig. 5).

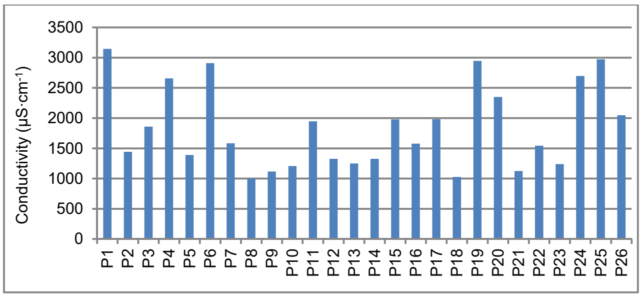

Fig. 5. Variations of electrical conductivity in the studied well-water; P1–P26 = study wells as in Fig. 2 and Tab. 1; source: own study

CHLORIDES

Chlorides are important inorganic anions present in varying concentrations in natural waters and constitute an indicator of pollution [MAKHOUKH *et al.* 2011]. Their presence in groundwater may indicate anthropogenic contamination because of their existence in the urine as well as in the maintenance products [MATINI *et al.* 2009]. Well-waters in the region of Sedrata range from 23.9 to 370.64 mg·dm^{-3} and does not exceed the maximum limits imposed by international standards of 600 mg·dm^{-3} (Fig. 6).

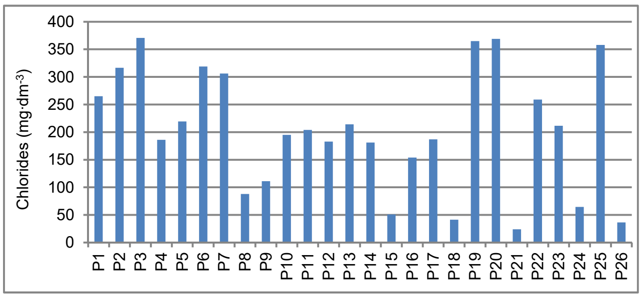

Fig. 6. Variations of chloride concentrations in the studied well-water; P1–P26 = study wells as in Fig. 2 and Tab. 1; source: own study

STUDY OF THE RELATIONSHIP BETWEEN CONDUCTIVITY AND CHLORIDE CONCENTRATION

The linear correlation analysis, showed that the conductivity is moderately related to the chloride concentration, which explains the high values of conductivity encountered (Fig. 7).

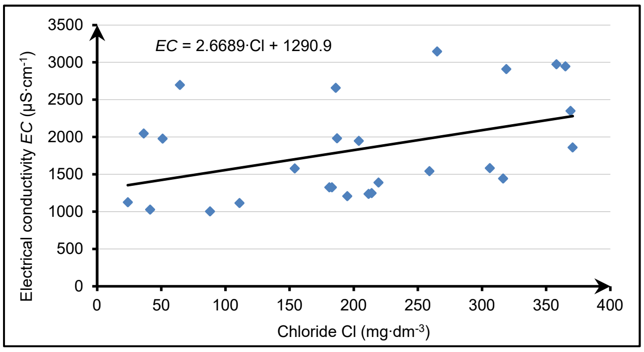

Fig. 7. Relationship between conductivity and chloride concentration (linear correlation) analysis; source: own study

TURBIDITY

Highly turbid waters cause a decrease in free residual chlorine and therefore a high demand for chlorination for their treatment and prevention of contamination. This could lead to the production of organohalogenous substances such as chloroform in the case of high organic turbidity [Guergazi *et al*. 2006]. Studies proved that the consumption of these toxic compounds causes liver, thyroid, dermal and ocular diseases and also many alterations on immunological and reproductive systems [Kodavanti *et al*. 2017].

Wells P1 and P17 have higher turbidity than the limit set by the international standards at 5 NTU, and this is probably due to a high concentration of suspended matter that could be organic or inorganic because of their lack of coverage. The remained wells have a turbidity ranging from 0.2 to 4.9 NTU and not exceeding the limit value for the potability of the water (Fig. 8).

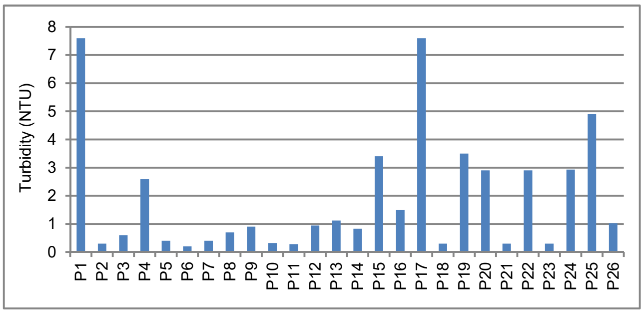

Fig. 8. Variations of the turbidity in the studied well-water; P1–P26 = study wells as in Fig. 2 and Tab. 1; source: own study

CALCIUM

The calcium content in the groundwater varies according to the crossed land; in fact, the waters that cross the carbonate rocks contain the most [Hassoune *et al*. 2006; Kahoul *et al*. 2014]. Calcium can come from the hydrolysis of silicate minerals and contribute to the hardness, and thus influencing the organoleptic quality of water [Kahoul *et al*. 2014; Matini *et al*. 2009]. The well-waters of the region of Sedrata are lower in calcium content than the value limited by the world standards at 200 mg·dm^{-3}, except p1 and P24 in which calcium contents are higher (Fig. 9).

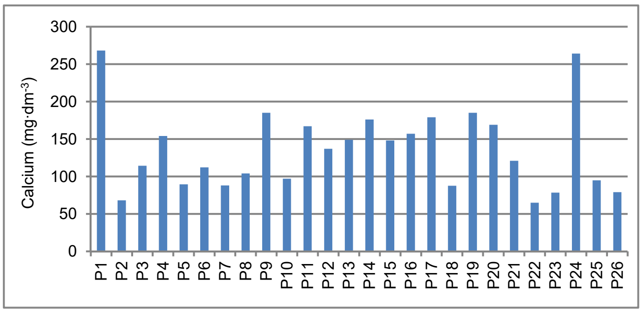

Fig. 9. Variations of calcium concentrations in the studied well-water; P1–P26 = study wells as in Fig. 2 and Tab. 1; source: own study

MAGNESIUM

The rainwater can solubilize Mg^{2+} from dolomitic rocks. 50% of the studied well-waters have magnesium contents higher than the value limited by the WHO which is 50 mg·dm^{-3} (Fig. 10). As for calcium, the concentration of magnesium varies according to the traversed terrain during the infiltration [Belghiti *et al*. 2013a; Hassoune *et al*. 2006]. Water rich in magnesium is beneficial for the consumer and has important intakes especially in cardiac and vascular function; it acts on cardiac excitability and vascular tone, contractility, reactivity and growth [WHO 2009].

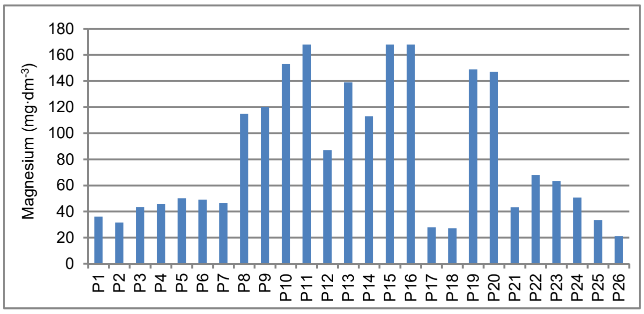

Fig. 10. Changes of magnesium concentrations in the studied well-waters; P1–P26 = study wells as in Fig. 2 and Tab. 1; source: own study

HARDNESS

The total hardness of the water represents the concentration of calcium and magnesium [Matini *et al*. 2009]. Consumption of hard water can bring the daily needs of calcium and magnesium. However, the use of hard water in irrigation can increase the pH of the soil affecting plants that grow under acidic conditions [Moyo 2013]. The obtained values vary from 249 to 704 mg·dm^{-3}, about 50% of wells exceed the WHO standard of 500 mg·dm^{-3}and which constitute no health risk (Fig. 11).

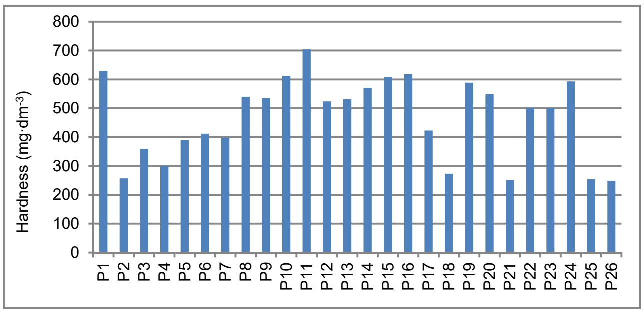

Fig. 11. Variations of the hardness in the studied well-water; P1–P26 = study wells as in Fig. 2 and Tab. 1; source: own study

SULPHATE

Sulphate is the ionic form of sulphur after its combination with oxygen. Thanks to the sulphur cycle; it could exist in soil and rocks in organic or mineral forms [Derwich *et al*. 2010]. Their presence in groundwater may be due to the infiltration of rainwater loaded with agricultural products [Fehdi *et al*. 2009]. Sulphate and chlorides affect the taste of water, cause corrosion of pipes, and reduce the effectiveness of chlorination [GUERGAZI, ACHOUR 2005]. The sulphate level of well-water in the region of Sedrata does not exceed 400 mg·dm^{-3}; the value limited by the WHO standards, while P13, P16 and P24 are of a considerable concentrations (Fig. 12).

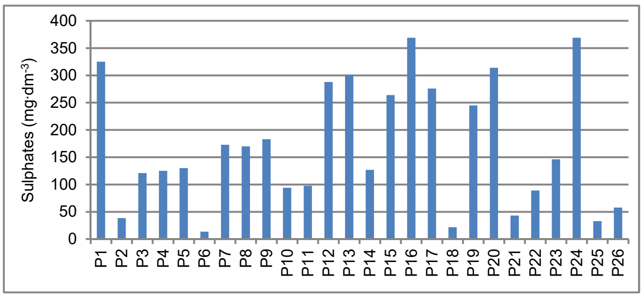

Fig. 12. Variations of sulphate concentrations in the studied well-water; P1–P26 = study wells as in Fig. 2 and Tab. 1; source: own study

PHOSPHATES

The presence of high phosphate concentrations is an index of pollution that affects the quality of drinking waters. They could have been originated from industrial and domestic discharges or agricultural products through the use of fertilizers and pesticides [RODIER *et al.* 2009]. The phosphate level of Sedrata's well-waters is below the WHO standard of 5 mg·dm^{-3} (Fig. 13).

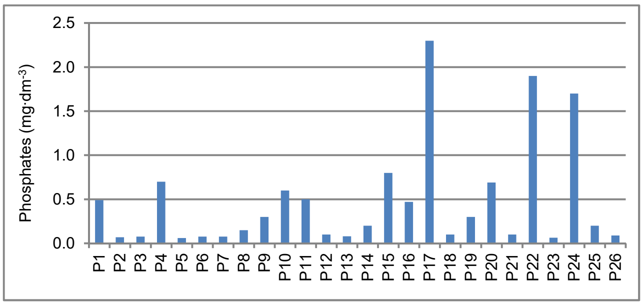

Fig. 13. Changes of phosphate concentrations in the studied well-water; P1–P26 = study wells as in Fig. 2 and Tab. 1; source: own study

NITRATE

Nitrate is an oxidized form of nitrogen which is a very present element in the soil and is essential for the growth of plants. Nitrogen exists in the soil in different forms; reduced (NH_4) oxidized (nitrate, nitrite) or organic (proteins, amino acids). With regard to groundwater contamination; the nitrates that infiltrate are the most problematic and originate the natural cycle of nitrogen in the soil (decomposition of organic matter, nitrifying bacterial activity, etc.), farming using fertilizer as well as natural or synthetic fertilizers, and sewage contamination [BENRABAH *et al.* 2016; DERWICH *et al.* 2010]. The results of the analysis showed that the nitrate concentrations vary from 4.8 to 76.0 mg·dm^{-3}. Except in the wells P22, P24 and P25, the values are lower than the WHO standard of 50 mg·dm^{-3} and given their geographical position, this could be due to the agricultural activity of the rural area (Fig. 14).

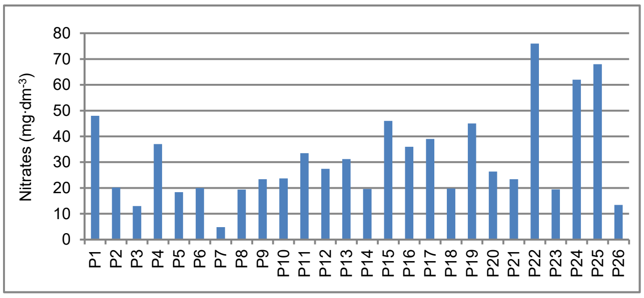

Fig. 14. Variations of nitrate concentrations in the studied well-water; P1–P26 = study wells as in Fig. 2 and Tab. 1; source: own study

NITRITES

Nitrites are less present than nitrates; they originate from the degradation of organic matter, the reduction of nitrates and the oxidation of ammonia. Their excessive presence in drinking water presents a health hazard because of their toxic oxidizing power [BELGHITI *et al.* 2013b]. The well P4 located in the urban area contains a higher nitrite concentration than the Algerian standard set at 0.1 mg·dm^{-3}. It may be contaminated by the infiltration of wastewaters. However, analyses of the wells P8, P10, P11, P14, P17, P20, P22 and P25 located in the rural area show nitrite levels exceeding the standards (Fig. 15). This pollution is probably due to animal wastes, manure spreading or chemical fertilizers used in agriculture [AYAD *et al.* 2016].

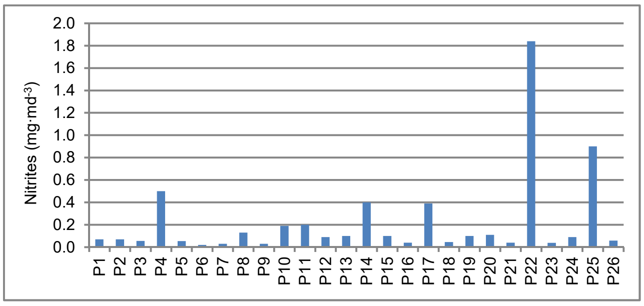

Fig. 15. Variations of nitrate concentrations in the studied well-water; P1–P26 = study wells as in Fig. 2 and Tab. 1; source: own study

AMMONIUM

Ammonium is the most reduced form of nitrogen and constitutes the end product of the degradation of organic and inorganic matter in soil and aquatic environments [KABOUR *et al.* 2012]. The presence of ammonium in percolation groundwater indicates anthropogenic contamination. Moreover, this element also originates from bacterial activity of the soil, agriculture and industrial wastes [KABOUR *et al.* 2012]. Wells P1, P16, P17, P19, P20 and P22 have higher levels than the WHO standard of 0.5 mg·dm^{-3}, taking into account the geographical position of the well P1; its high concentration in ammonium may be due to an infiltration of wastewater coming from a probable crack in the conduct of these polluted waters located not far from the P1 (Fig. 16).

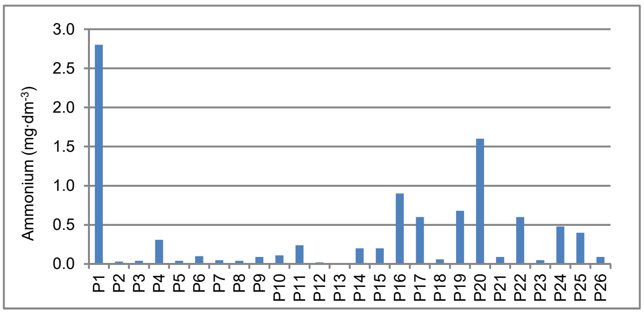

Fig. 16. Variations of ammonium concentrations in the studied well-water; P1–P26 = study wells as in Fig. 2 and Tab. 1; source: own study

METALLIC TRACE ELEMENTS

Iron and manganese. Mn and Fe are metallic trace elements that could exist in the water, exceeding the standards at which they could infect the organoleptic aspect of the water. They do not present a health hazard but they could enter in reaction and thus cause an antagonistic effect on the process of chlorination. They could also damage plumbing fixtures [GUERGAZI *et al.* 2006; MOYO 2013]. The waters from wells P1, P8, P9, P10, P11, P12, P13, P14, P18, P25 and P26 have higher iron and manganese contents than the values limited by the world standards at 0.3 mg·dm^{-3} for iron and 0.5 mg·dm^{-3} for manganese. In addition, three other wells contain iron concentrations exceeding the standards; this may be due to the composition of the internal walls of the wells which are generally made of steel (Fig. 17, 18).

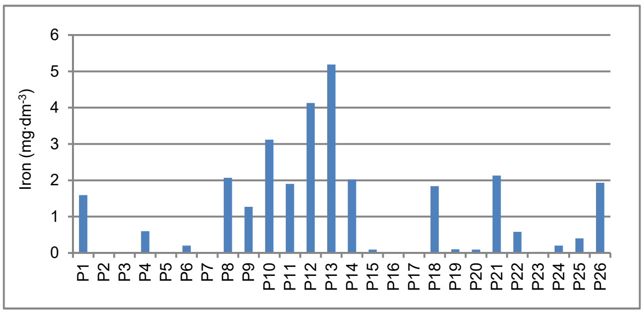

Fig. 17. Variations of iron concentrations in the studied well-water; P1–P26 = study wells as in Fig. 2 and Tab. 1; source: own study

Aluminium. Al is the most abundant metal element in the environment. Its presence in water could be due to the composition of the crossed terrestrial layers, and its long-term consumption could have serious consequences on human health [BATAYNEH 2012]. Wells P2, P4, P10, P11, P20, P24 and P25 have aluminium contents above 0.2 mg·dm^{-3}; the standard set by the WHO (Fig. 19). Based on the technique of the US Environmental Protection Agency [US EPA 2002], A. T. Batayneh calculated the risk of consuming water with aluminium concentrations ranging from 0.007 to 0.365 mg·dm^{-3} (values lower than those found during the analysis of Sedrata well-water and which ranges from 0.01 to 1.7 mg·dm^{-3}). It has been estimated that 4 of 10,000 people are in danger of developing oncological diseases.

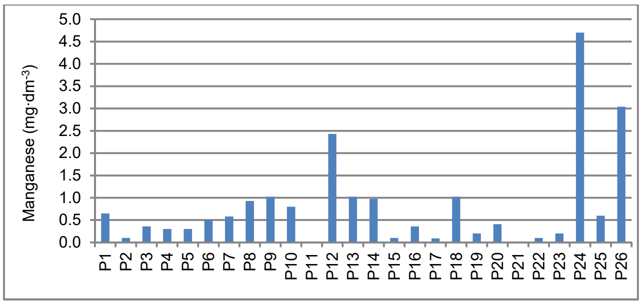

Fig. 18. Variations of manganese concentrations in the studied well-water; P1–P26 = study wells as in Fig. 2 and Tab. 1; source: own study

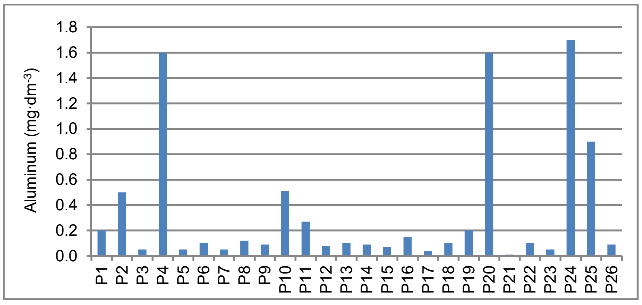

Fig. 19. Variations of aluminum concentrations in the studied well-water; P1–P26 = study wells as in Fig. 2 and Tab. 1; source: own study

BACTERIOLOGY

Total germs. The presence of total germs in drinking water is an indicator of pollution indicating a contamination possibly due to the infiltration of germs from faeces of animals or the non-coverage of wells [EL HAISSOUFI *et al.* 2011]. Nearly 65% of the wells are contaminated by total mesophilic germs. The recorded values vary from 1 to 1100 CFUs·cm^{-3} (Fig. 20). The total germs at 22°C were found in 50% of the wells ranging from 1 to 700 CFUs·cm^{-3} (Fig. 21). The total germs at 22°C represent the environment bacteria, while the total germs at 37°C represent

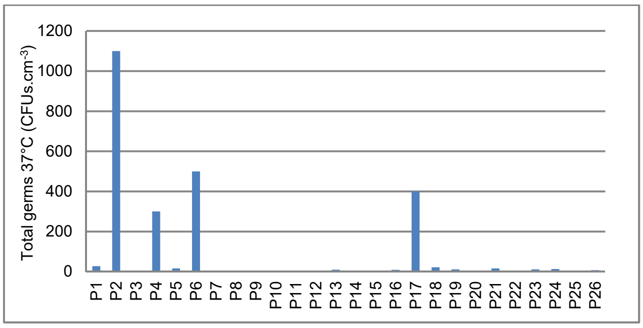

Fig. 20. Variations of total mesophilic germs of the studied well-water; P1–P26 = study wells as in Fig. 2 and Tab. 1; source: own study

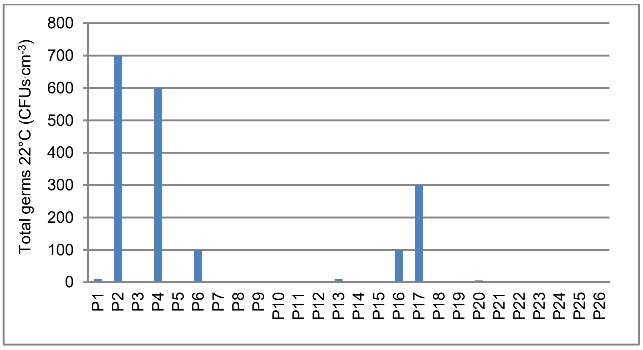

Fig. 21. Variations of the total germs at 22°C of the studied well-water; P1–P26 = study wells as in Fig. 2 and Tab. 1; source: own study

mainly the human or animal intestinal flora. The presence of total germs in drinking water is an indicator of pollution indicating a contamination possibly due to the infiltration of germs from faeces of animals or the non-coverage of wells [EL HAISSOUFI *et al*. 2011].

Total coliforms. Approximately 38% of the studied wells represent total coliform levels ranging from 13 to 900 CFUs·cm^{-3} and greater than the WHO standard set at 10 CFUs·cm^{-3} (Fig. 22). The intensity of groundwater pollution is influenced by soil type and pollutant doses [BRICHA *et al*. 2007]. The observed contamination is punctual and may be due to domestic or agricultural discharges containing animal wastes.

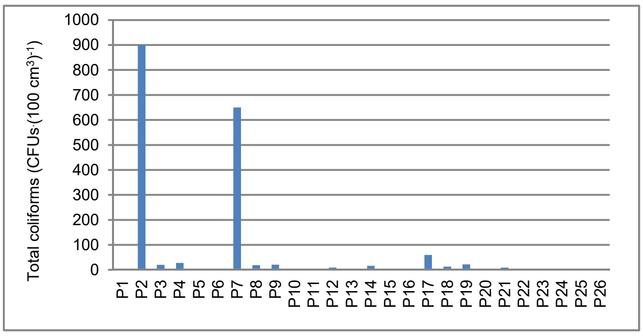

Fig. 22. Variations of total mesophilic coliforms in the studied well-water; P1–P26 = study wells as in Fig. 2 and Tab. 1; source: own study

Faecal coliforms. Except for P2 well-water, the search for faecal coliforms was negative, which confirms that pollution of the P2 well containing 2 CFUs·(100 cm^3)$^{-1}$ would be punctual (Fig. 23). The presence of these germs is a direct indicator of faecal contamination that could be of human or animal origin [AKA *et al*. 2013].

Faecal streptococci. Amongst the 26 studied wells, only P2 and P6 are contaminated with faecal streptococci containing respectively 5 and 2 CFUs·(100 cm^3)$^{-1}$ (Fig. 24). Using the method of BORREGO and ROMERO [1982] and KOFFI-NEVRY *et al*. [2012] was able to determine the origin of faecal contamination by calculating the ratio (R) faecal coliforms/faecal streptococci (FC:FS). If R is less than 0.7, the contamination is of animal origin, and if it is higher than 4, it is of human origin. If R is between 0.7 and 1.0, the contamination is mixed with predominantly animal origin; it is mixed and predominantly human if R ranges between 2 and 4. The origin is uncertain if R ranges between 1 and 2. R ratios calculated for the two wells (P2, P6) are 0.4 for the well P2 and 0 for the well P6. These two values are lower than 0.7, which shows that their faecal contamination is of animal origin [KOFFI-NEVRY *et al.* 2012]. Faecal bacteria are a major risk for gastroenteritis for consumers.

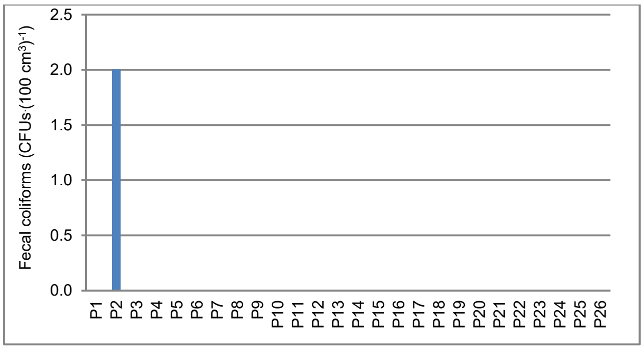

Fig. 23. Variations of mesophilic faecal coliforms in the studied well-water; P1–P26 = study wells as in Fig. 2 and Tab. 1; source: own study

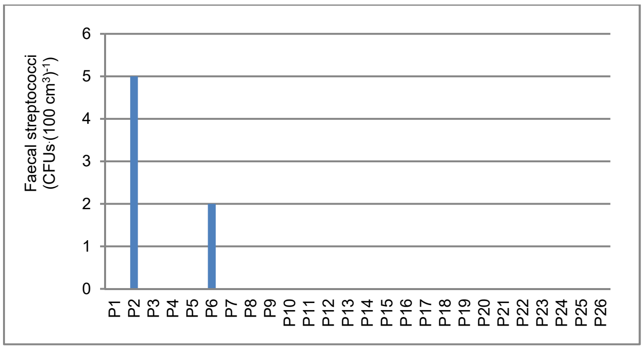

Fig. 24. Variations of mesophilic faecal streptococci in the studied well-water; P1–P26 = study wells as in Fig. 2 and Tab. 1; source: own study

Sulphite-reducing *Clostridium*. The search for sulphite-reducing *Clostridium* in the analysed well-water showed that about 35% are contaminated, containing values ranging from 1 to 3 CFUs·(20 cm^3)$^{-1}$ (Fig. 25). The contamination of P20 and P22 wells is probably old given the absence of coliform bacteria, which is not the case for

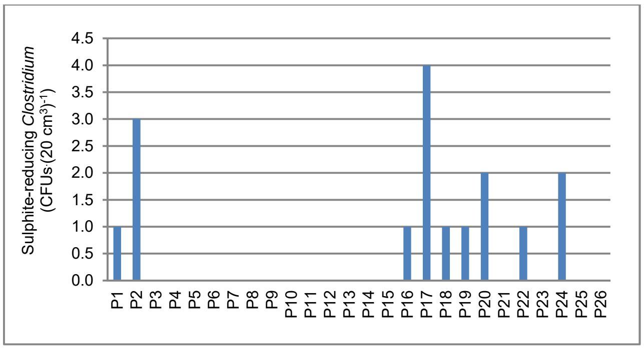

Fig. 25. Variations of the sulphite-reducing *Clostridium* in the studied well-water; P1–P26 = study wells as in Fig. 2 and Tab. 1; source: own study

the rest of the wells whose pollution is due to faecal contamination given the presence of coliform bacteria. Sulphite-reducing *Clostridium* spores are very persistent and show a sign of groundwater vulnerability [AYAD *et al.* 2016].

CONCLUSIONS

The results of physicochemical and bacteriological analyses have allowed us conclude that the contamination of the studied well-waters is almost general. In fact, the studied waters have properties that make them not recommended for human consumption. This is mainly due to the following parameters: electrical conductivity, hardness, nitrates, nitrites, ammonium, trace metals (Fe, Mn and Al), total germs and total coliforms. The chemical pollution (by nitrates, nitrites and ammonium) comes mainly from the excessive use of mineral fertilizers. While microbiologically the contamination comes from animal dung and livestock effluents. With regard to the research of faecal coliforms, faecal streptococci, and sulphite-reducing *Clostridium* spores, it appears that the contamination is punctual. Therefore, it is strongly recommended to treat the contaminated wells as quickly as possible in order to preserve groundwater, especially in depth of a possible pollution spread.

Compared with the literature evaluating groundwater quality at the national and continental levels, it has been found that well water in the region of Sedrata does not exceed Algerian or global standards excessively. However, some arrangements need to be made to limit the sources of contamination, including: household waste management, monitoring and renovation of sewage networks, monitoring the use of synthesized fertilizers in agriculture, and considering the rebuilding of the wells' internal walls lining to replace the steel responsible for the high rates of metallic trace elements.

In the future, it will be necessary not only to assess the health risks related to the level of contamination of these waters, but also to proceed with their treatment before supplying them to consumers.

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Ocena fizykochemiczna i bakteriologiczna wód podziemnych: Studium przypadku wody studziennej w regionie Sedrata (północno-wschodnia Algieria)

STRESZCZENIE

Woda pitna jest potencjalnym źródłem chorób, kiedy zawiera substancje chemiczne i mikroorganizmy pochodzące z działalności człowieka. Zaopatrzenie w wodę ze źródeł podziemnych odgrywa dużą rolę w Algierii. Aby ocenić jakość wód gruntowych w regionie Sedrata, przeprowadzono analizy w 26 studniach znajdujących się w dwóch sąsiadujących ze sobą obszarach – miejskim i wiejskim. Badania czynników fizycznych i chemicznych obejmowały pomiar *in situ* temperatury, przewodnictwa elektrolitycznego, pH i mętności wody. Analizowano także twardość, stężenie Ca^{2+}, Mg^{2+}, SO_4^{2-}, PO_4^{3-}, Cl^-, NO_2^-, NO_3^-, NH_4^+ i metali śladowych Fe^{2+}, Mn^{2+}, Al^{3+}. Próbki do badań bakteriologicznych sączono i wprowadzano na pożywkę w celu określenia stężenia całkowitej ilości mikroorganizmów, bakterii z grupy coli, fekalnych streptokoków i siarkowych bakterii *Clostridium*. Wyniki dowodzą, że zanieczyszczenie badanych wód jest powszechne. Spośród najbardziej znaczących wyników należy wymienić stężenie azotanów w zakresie od 4,8 do 76 $mg \cdot dm^{-3}$ i mezofilnych bakterii od 1 do 1100 $jtk \cdot cm^{-3}$. Rolnictwo, hodowla i chów zwierząt oraz stosowanie nawozów są głównymi źródłami fizycznego, chemicznego i bakteriologicznego zanieczyszczenia wód. Skażone studnie powinny być oczyszczane tak szybko, jak to możliwe, aby zapobiec rozprzestrzenianiu się zanieczyszczeń w całym poziomie wodonośnym. W przyszłości konieczna jest ocena ryzyka zdrowotnego w związku ze skażeniem wód, ale także ich uzdatnianie przed dostarczeniem tych wód do konsumentów.

Słowa kluczowe: *bakteriologia, jakość wody, parametry fizykochemiczne, Sedrata, wody podziemne*