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: Ca2+, Mg2+, SO4^{2–}, PO4^{3–}, Cl–, NO2–, NO3–, NH4+ as well as metal trace elements Fe2+, Mn2+, Al3+. 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∙dm–3 for nitrates, the recorded values for mesophilic germs vary from 1 to 1100 CFUs∙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 [MIOUSZEWSKI 2015]. Nitrates are the most important elements in agricultural pollution and are dangerous for human health; these contaminants can cause methemoglobinemia, which is character-
ized 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].
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

EC = 2.6689 ∙ Cl + 1290.9
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).

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].

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).

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).

**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).

**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 (NH₄) 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).

**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].

**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).

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).

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.

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 HAISOUFI 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...
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.

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.

**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

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**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

**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

**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

**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 to 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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**Okresy:** fizykochemiczna i bakteriologiczna wód podziemnych:
**Służbom:** Studium przypadku wody studziennych 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 temperatury, przewodnictwa elektrolitycznego, pH i mętności wody. Analizowano także twardość, stężenie Ca$^{2+}$, Mg$^{2+}$, SO$_4^{2-}$, PO$_4^{3-}$, CI$^-$, NO$_3^-$, NO$_2^-$, NH$_4^+$ i metali śladowych Fe$^{2+}$, Mn$^{2+}$, Al$^{3+}$. Próbki do badań bakteriologicznych sączono wody, parametry fizykochemiczne, Sedrata, wody podziemne

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