



# Controlling water supply quality: case study of Souk Ahras City in Algeria

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## Abstract

The treated drinking water produced by water treatment plants and transported via the water supply network to users is never sterile. This is why we refer to the disinfection rather than the sterilization of public water supplies. Microorganisms have the opportunity to contaminate the water at various points in the network, such as at reservoirs, where the water is in contact with the air and poorly protected openings can allow contamination from dust or insects. Network interventions (repairs, connections), leaks (in the case of depression), and accidents such as backflows or breaks can also result in the introduction of microorganisms into the network. To facilitate the monitoring and control of waterborne diseases, a sampling-based study was carried out during the spring and summer periods of 2017 and 2018 in Faubourg, Souk Ahras City, Algeria. A precise inventory of the physicochemical and bacteriological quality of the water in the network in Faubourg was established for different areas of this urban neighborhood. The results show that the development of a fast strategy is inevitable.

**Keywords** Water quality · Water supply · Waterborne disease · Souk Ahras City · Algeria

## Introduction

Ensuring high water quality is a universal health problem. Water is essential for life, but it can transmit diseases. Indeed, according to the World Health Organization, there are an estimated 4 billion cases of diarrhea and 2.2 million deaths from gastrointestinal infections annually (WHO 2008), while 1.1 billion people lack access to safe drinking water (Bensoltane 2010). To further place the issue of unsafe water into perspective, while half a million people are killed by war each year, ten times that number die from waterborne diseases (Koliyai 2000). Directly or indirectly,

water has become the leading cause of illness and death worldwide.

A recent estimate of the water resources in Algeria is 17 billion m<sup>3</sup>, of which 10 billion m<sup>3</sup> is surface water and 7 billion m<sup>3</sup> is groundwater (mainly in the Sahara). Water availability is 600 cubic meters per capita per year, which places Algeria well below the threshold for water poverty, 1000 cubic meters per capita per year, set by the World Bank. The water availability for Algeria is also expected to decline to 430 cubic meters per capita per year in the next 10 years, and a value of less than 500 cubic meters per capita per year is generally considered to indicate a water crisis (Drouiche et al. 2012; Anon 2014; Taikan and Rose 2020).

Water can be affected by various forms of pollution. Water quality, neglected for a long time, is now attracting considerable attention. A billion m<sup>3</sup> of wastewater are estimated to be generated by urban areas per year (Karrou et al. 2011), and about 200 million m<sup>3</sup> of untreated industrial wastewater are discharged into the environment annually. Water is polluted through uncontrolled and improperly monitored leaching practices as well as agricultural drainage, which includes nitrates and phosphorus from fertilizers. Pesticide residues can also be detected in some surface waters (Drouiche et al. 2020).

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On 23 August 2018, the Algerian Ministry of Health announced an outbreak of cholera in northern parts of the country, in and around the capital province of Algiers. The outbreak developed rapidly, with 41 confirmed cases reported between 7 and 23 August 2018 and an average of four cases reported daily from 24 to 30 August 2018 (WHO 2018). From 7 August to 6 September 2018, 217 cases with cholera-like symptoms were hospitalized; two of those patients died. Cases were reported from seven provinces. The Institut Pasteur Algiers found that 83 of the cases were caused by the *Vibrio cholerae* serogroup. Blida Province registered the highest number of cases (more than half), followed by Algiers, Tipaza, Bouira, Médéa, and Ain Defla. A total of 21 water sources (including three private sources) in the affected areas were tested for bacterial contamination, and 10 contained water deemed inappropriate for human consumption. One of the water sources tested positive for *V. cholerae* and was condemned. Before the 2018 outbreak, the last confirmed case of *V. cholerae* infection in Algeria occurred in 1996.

The parameters that control the evolution of water quality in the network are complex and have been the subject of extensive research (WHO 2004; Powell et al. 2004; Speight et al. 2009; Parus 2007; Nilufar et al. 2016, 2017; Guebail et al. 2017; Bensoltane et al. 2018). Fecal pollution originating from human sewage or animal sources can lead to health problems because of the presence of infectious microorganisms. The contamination of water with fecal material and domestic and industrial waste can lead to an increased risk of disease transmission to individuals who use those waters (Radha et al. 2007).

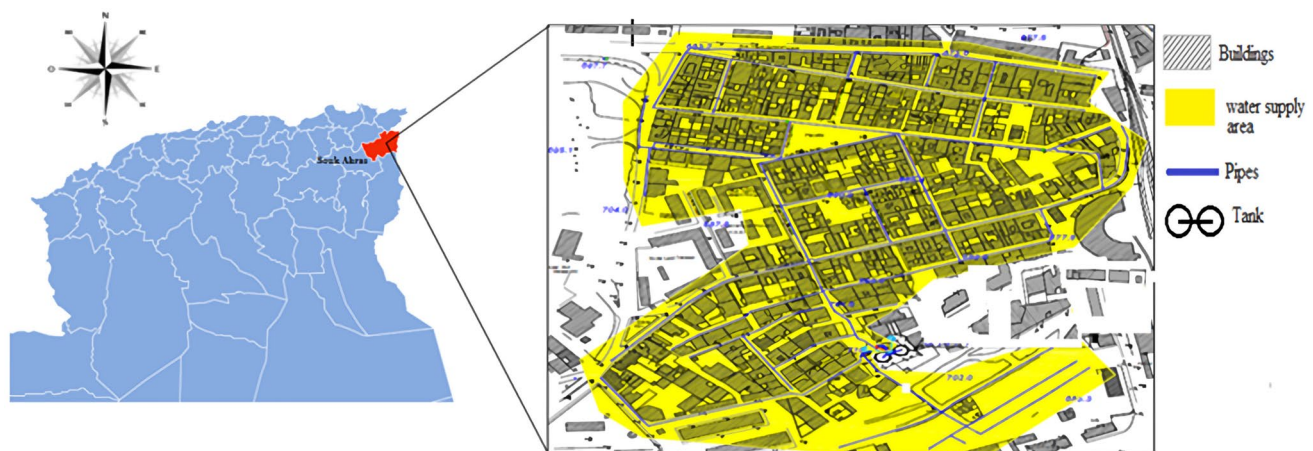
It is impractical to continuously perform extensive, comprehensive analyses of the microbiology of drinking water samples directly, given the wide range of pathogens that could be present in them. Instead, we look for the presence of particular types of bacteria which indicate that, despite

the precautions taken, the water may not be of the usual high standard. These bacteria, which are generally *E. coli* and fecal streptococci, are known as “indicator bacteria.” *E. coli* can survive for a considerable time in water, making it a good indicator of the presence of other pathogenic bacteria. Thus, the detection of *E. coli* in drinking water supplies provides clear evidence of fecal contamination (Mara and Horan 2003). Fecal streptococci are the fecal pollution indicator species most commonly used as an alternative or adjunct to coliform bacteria such as *E. coli* (Sinton et al. 1993). These bacteria are not considered to be the causative agents of illnesses in swimmers, but they do behave similarly to the actual fecal pathogens (Prüss 1998). Fecal streptococci are generally more resistant to the natural water environment and to purification processes than other indicator organisms, and are often the only sign of the fecal nature of the pollution at points distant from the original source of pollution (Cohen and Shuval 1973).

In the Algerian city of Souk Ahras, the principal source of water pollution is industrial development (new industry or the expansion of an existing industry), which leads to the generation of increased amounts of industrial effluents and agricultural and residential wastes (sometimes illegally drained). The aim of the work summarized in this paper was to identify the pollutant levels in treated (potable) water at different points in the water distribution network in a neighborhood of Souk Ahras.

## Study area

The case study was carried out in an urban neighborhood—Faubourg—in Souk Ahras City, northeastern Algeria, as shown in Fig. 1. The study area corresponded to the latitudes 36.2772–36.2844°N and longitudes 7.9452–7.9524°E. The Faubourg sector is supplied by two water tanks, each



**Fig. 1** Study area: the Faubourg neighborhood in Souk Ahras City, Algeria

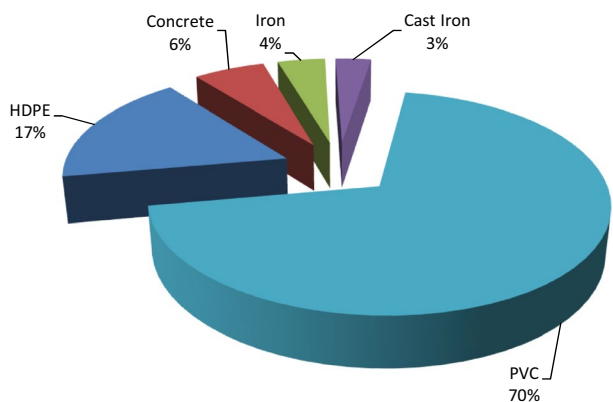
with a capacity of 400 m<sup>3</sup>. This is an old urban area that has reached saturation. This area is small, and included 398 domestic subscribers, 15 government buildings, and 34 small businesses according to the Algeria Water Company (ADE) during the first three quarters of 2018.

The water network in this area consists mainly of PVC pipes 63–160 mm in diameter, as shown in Fig. 2 (Zeghadnia 2007).

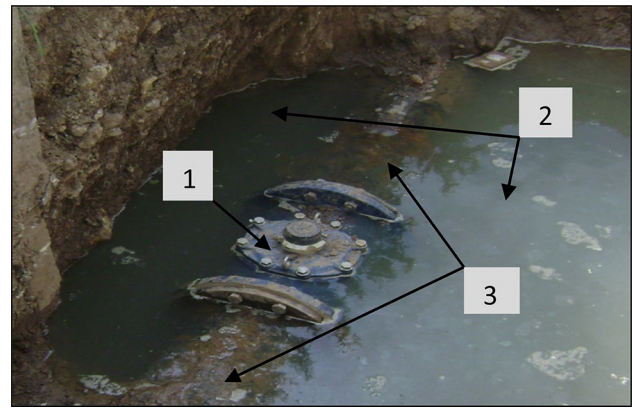
### Problems with the water network in the Faubourg neighborhood

The infrastructure of the water network in the Faubourg neighborhood is dilapidated, and the lack of segmentation which reflects the deficiency in the management of drinking water causing the users to be dissatisfied. The reasons for this situation are well known: a high number of leaks due to the general poor condition of the network (see Fig. 3); major financial and supply issues and pressure losses due to these leaks; and contaminant intrusion events caused by substantial leaks, which can lead to detrimental or fatal water-quality episodes (Boulos et al. 2008). Despite major efforts to protect water quality (Majzoub 2000; Abuzeid and Abdel-Meguid 2007), several studies from various countries—Algeria (Abdelbaki et al. 2012; Ramdani et al. 2012; Achour and Chabbi 2014; Rahmani and Brahim 2017), Tunisia (Ayari and Ayari 2017), Morocco (Kadaoui et al. 2019), Egypt (Wagida 2003; Donia 2007), and Saudi Arabia (Al-Zarah 2014; Al-Omran et al. 2015)—have reported that the problems mentioned above are the main challenges involved in keeping drinking water safe.

The average volume produced in the Faubourg neighborhood per day in during 2017 was estimated at 35,000 m<sup>3</sup>; although there was a lack of continuous service. It should be noted that the distribution system operates in an intermittent fashion (it is active for less than 10 h), which promotes the



**Fig. 2** Types of pipes used to supply water to the Faubourg neighborhood



**Fig. 3** Leaks in the water distribution system in Souk Ahras (1 rotatable flanged fittings, 2 water leak, 3 cast iron pipe)

degradation of pipes on the one hand and the penetration of depression into the distribution network on the other; the latter phenomenon leads to stagnant suspended pipes, causing water quality degradation.

Water loss from a water supply network is often categorized into either a background leakage or a burst (Puust et al. 2010). The former typically includes flow from deficient joints and small defects in the pipe walls, while the latter includes outflows from larger (usually detectable) holes and cracks. Pressure management is considered to be among the most efficient methods of controlling leaks, especially background leakages (Gomes et al. 2012; Vicente et al. 2016; Ahopelto and Vahala 2020).

Corrosion is one of the main problems affecting domestic water supplies. Figure 4 highlights the different types of corrosion damage caused by electrochemical phenomena, starting at the inner walls, where and a biofilm can develop (i.e., free biomass in the system adheres to the walls of the pipe). The resulting environment can lead to the degradation of drinking water quality.

Biofilms form on many submerged surfaces, regardless of whether the surface material is biological in nature. The inner surfaces of drinking water pipes are invariably colonized by biofilms, even in the presence of a residual disinfectant. In addition to their potential to cause corrosion and to change the taste and odor of the water, these biofilms control the microbiological content of the distributed water and contain pathogens (Flemming et al. 2002; Percival and Walker 1999; September et al. 2007; Szewzyk et al. 2000; WHO 2011; Wingender and Flemming 2011). Protozoa are also commonly found within drinking water system biofilms, and these protozoa have been associated with pathogen persistence and invasiveness (Tyn-dall and Domingue 1982; Thomas and Ashbolt 2011). Biofilms are suspected to be the primary source of microorganisms in drinking water systems that are fed with treated water and have no pipeline breaches, and are of particular concern in



**Fig. 4** Internal corrosion and contamination of cast iron water mains in the Faubourg neighborhood: **a** an old water main encrusted with deposits; **b** an old, heavily corroded pipe; **c** a flange containing dark mud (1 deposits, 2 buildup of corrosion, 3 flange, 4 black mud)

older drinking water systems (LeChevallier et al. 1987; Wingender and Flemming 2011).

## Methods and materials

### Sampling and methods of analysis

In order to obtain a better understanding of the factors that affect water quality, samples were collected from different locations in the Faubourg neighborhood of Souk Ahras and then analyzed. The analysis, including the collection and storage of samples, was carried out according to Algerian standards (General Secretariat of the Algerian

Government 2011). Some of the samples were taken from a reservoir (water tank), and the other samples were taken from the middle and end of the main network supplied by the same tank. These samples, taken during summer/autumn 2017 and winter/spring 2018, were analyzed in laboratories of the Algerian Water Company (ADE) to evaluate their physicochemical quality and in the laboratory of the Health Department of Souk Ahras to determine their bacteriological quality.

Seventy-two water samples were collected, with each point in the network sampled twice during the sampling periods. The samples were taken using sterile glass bottles with a capacity of one liter. The bottles were numbered, labeled, and transported at 4 °C to the laboratories (ISO 1986), where

their turbidity was measured with a nephelometer, pH was determined using a pH meter, organic matter was analyzed using potassium permanganate ( $\text{KMnO}_4$ ) in an acid medium, residual chlorine was examined using visual spectrometry, temperature was measured using a mercury thermometer, and nitrite, nitrate, and ammonium levels were determined by a colorimetric method using a UV/visible spectrometer. Bacteriological characteristics were determined using the multiple-tube most probable number (MPN) technique (Csuros et al. 1999; Bezuidenhout et al. 2002).

Initially, four types of measurements were carried out on 4–5 June 2018: the tank level and outlet flow were evaluated, the pressure in the lower part of the network was gauged, and the free residual chlorine level was determined at different points. Thus, the measurement campaign aimed to establish a precise, documented inventory of the network conditions by determining the characteristic indicators of distribution service in different areas of the city, such as loss rates, network performance, pressure, and residual chlorine levels, as shown in Fig. 5.

## Results

### Physicochemical analysis

Remarkable temporal variations in certain parameters were recorded; the maximum values recorded for the water samples are shown in Fig. 6. Mean values with standard deviations were: organic matter  $1.42 \pm 0.34$  mg/l, residual chlorine  $0.35 \pm 0.2$  mg/l, temperature  $20 \pm 1$  °C, nitrate  $0.01 \pm 0.006$  mg/l, and ammonium  $0.05 \pm 0.005$  mg/l. A slight increase in nitrate levels was sometimes recorded, but the level remained insignificant throughout the sampling periods. The ammonium most likely originated from sewage seepage (Zeghadnia 2014), and the ammonium level is accentuated by the low level of free chlorine; according to Algerian standards (General Secretariat of the Algerian Government 2011), the chlorine concentration is below the maximum permissible level (0.2–0.5 mg/l).

Figure 6 shows that the residual chlorine concentration decreases as the distance from the injection point (often the treatment plant) increases, meaning that the growth rate of pathogenic bacteria increases with distance from the injection point. The nitrates may have entered the water due to poor agricultural practices. The results

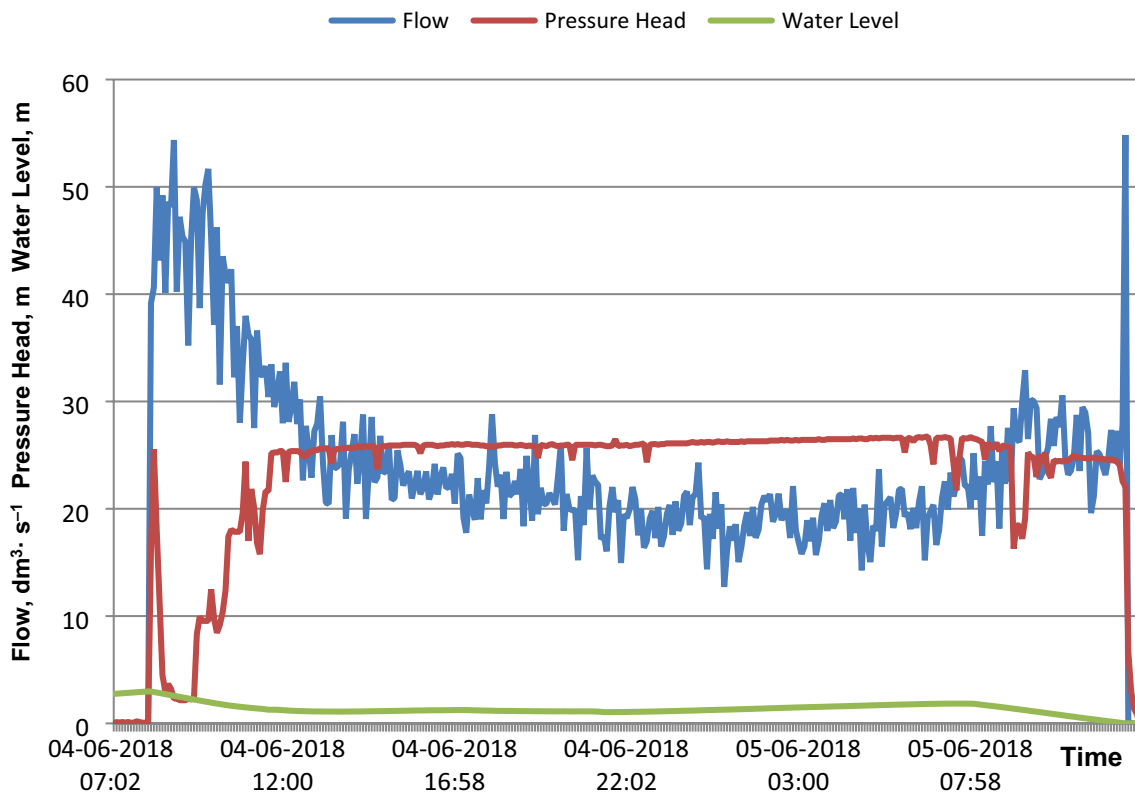
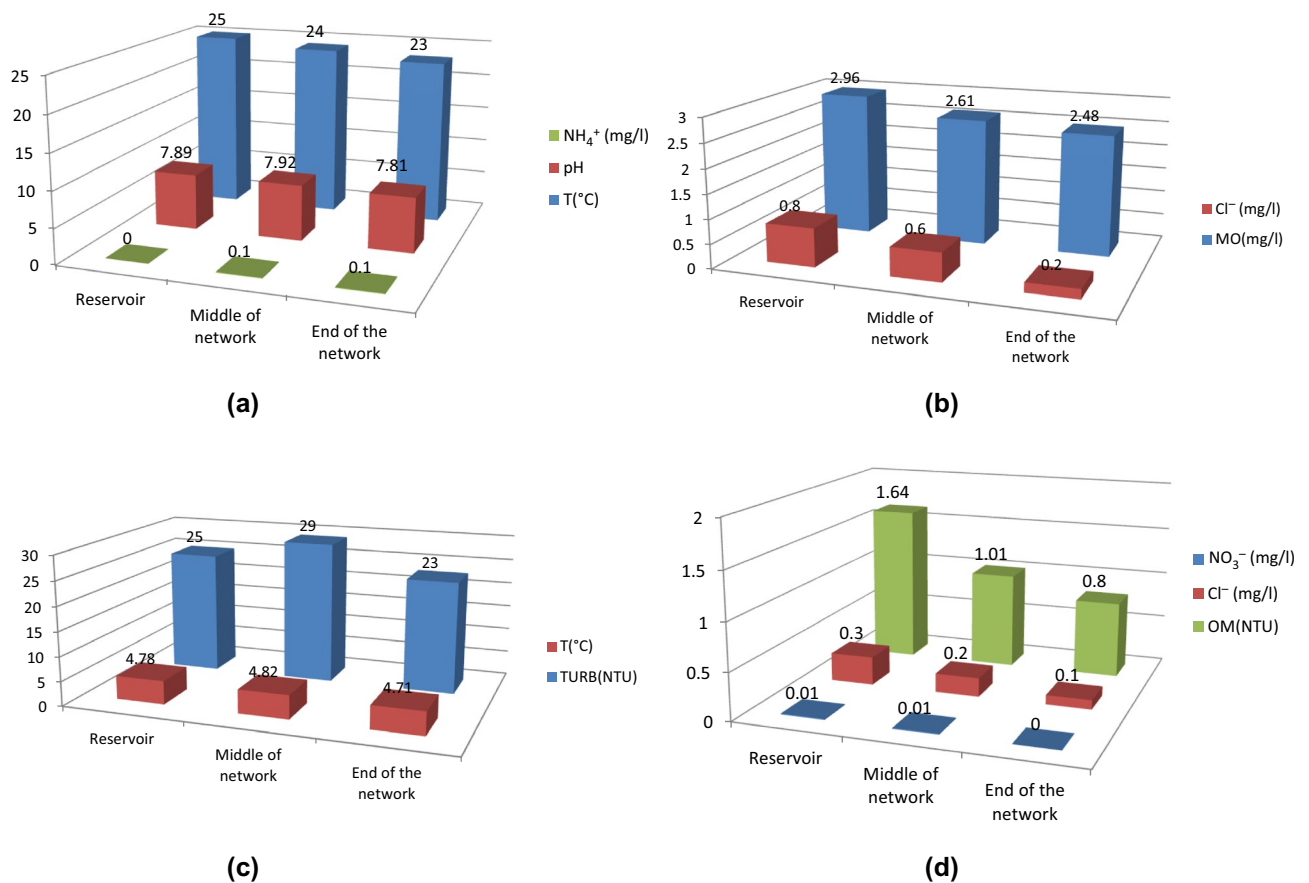


Fig. 5 Measured data for the examined distribution network (Bensoltane et al. 2018)



**Fig. 6** Parameter measurements throughout the Faubourg water distribution network: **a** temperature ( $T$ ), pH, and ammonium ( $\text{NH}_4^+$ ) during the summer period; **b** free chlorine ( $\text{Cl}^-$ ) and organic matter

( $\text{OM}$ ) during the summer period; **c** turbidity ( $\text{TURB}$ ) and temperature ( $T$ ) during the spring period; **d** nitrate ( $\text{NO}_3^-$ ), free chlorine ( $\text{Cl}^-$ ), and organic matter ( $\text{OM}$ ) during the spring period

indicate that the water presents a serious risk to consumers, especially given that residual chlorine levels are often negligible (or even zero) at several points (especially at the end of the network)—a phenomenon often noted by consumers. Indeed, the latter parameter was significantly reduced during the summer period, which can be a major factor in bacterial proliferation.

The maximum turbidity recorded was 29 NTU, which is far higher than the limit set by Algerian standards (5 NTU). The mean turbidity was 12 NTU, with a standard deviation of 0.65. In a water supply network, high turbidity can point to potential problems; for example:

- The precipitation of iron, aluminum, and manganese due to oxidation in the network. Increasing the oxidized iron and manganese concentrations drives up the turbidity levels. Hence, both iron and manganese showed high positive correlations with aluminum, a probable consequence of residual amounts of aluminum entering the

water distribution network after the raw water has been treated (Prasada and Danso-Amoako 2014).

- Significant corrosion. Parameters such as pH and dissolved oxygen have been found to influence the concentration of iron in the water distribution network. Stumm (1960) found that, in general, increasing the pH in the distribution network from pH 7 to pH 9 increased pipe weight loss and the corrosion rate.
- Precipitates formed following flocculation in the network degrade the organoleptic quality of the water and encourage the proliferation of microorganisms.

Several samples had temperatures that were greater than 15 °C. Above this temperature, unpleasant tastes or odors can occur in the water. However, water services have little influence on the temperature of the water. Efforts must therefore focus on other parameters that change with the temperature. The sample pH varied between 7.81 to 7.92 (mean:  $7.87 \pm 0.06$ ), indicating that the pH values were within the limits prescribed by Algerian standards.

**Table 1** Proportion of the samples that contained bacterial pollution

Year	Bacterial pollution rate (%)	Weak presence of germs (%)	Strong presence of germs (%)
2017–2018	8	85	15

## Bacteriological analysis

Bacteriological analysis of drinking water is essential to ensure that the water does not contain germs or bacteria that pose a risk to the health of consumers (Festy et al. 2003; WHO 2004; Razzolini et al. 2011; Habimana et al. 2014; Ouahchia et al. 2014). Bacteriological data from the Health Agency of Souk Ahras were used to determine the bacterial pollution in the water distribution network (Table 1).

The results show that the bacteriological parameter is strongly related to that kind of pollution. Generally, the presence of bacteria in water samples is due to the infiltration of wastewater into the drinking water distribution network.

The maximum acceptable concentration of pathogenic bacteria (mostly fecal coliform or *E. coli*) in potable water is zero detectable coliforms per 100 ml of water (EPA 2003), although in villages and small towns, a maximum of 5 cfu/100 ml is reportedly allowed for 90% of the samples analyzed over the course of a year (Ezeugwunne et al. 2009).

Accordingly, the count for many samples were exceedingly high the maximum contamination level for bacteria in drinking water (EPA 2003; WHO 2004; General Secretariat of the Algerian Government 2011). The results of analyses performed on water samples are presented in Table 1; 8% of the water samples yielded presumptively positive results, exceeding 1 cfu/100 ml; none of the 8% of the water samples are in compliance with Algerian standards (General Secretariat of the Algerian Government 2011; EPA 2002), where 85% among them were characterized by a insignificant presence of germs, with counts > 11 cfu/100 ml, while 15% have a strong presence of pathogenic bacteria in water ranged from 20 to 210 cfu/100 ml.

The high concentrations of germs in the samples may indicate that the water sources are fecally contaminated (EPA 2003; Osuinde and Eneuzie 1999). These pathogens were probably transferred to the samples from the environment; likely through sewage or other unhygienic sources (EPA 2002; Ezeugwunne et al. 2009).

## Conclusions

Contamination of drinking water is common and often occurs when the water is transported from the storage tank to the consumer. Continuous monitoring of the water flowing through the distribution network is imperative to preserve

public health. The most important actions to implement to control the growth of bacteria in distribution systems are maintaining a sufficient level of disinfecting chlorine throughout the network and limiting the concentration of organic matter. The existence of accidental pollution in the study area was probably due to the inadvertent mixing of wastewater with the drinking water network as a result of incorrectly designed pipelines and issues with old components of the network (e.g., corrosion). Since some of the samples in this study had concentrations of germs that were far above zero and the residual chlorine concentration was very low when it reached consumers, an emergency plan and strategy are required to evaluate the water supply system and correct the deficiencies in water quality.

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## Compliance with ethical standards

**Conflict of interest** The authors declare no conflict of interest.

## References

- Abdelbaki C, Touaibia B, Allal MA, Kara SF (2012) Applied systemic approach to water supply network the case of an urban cluster of Tlemcen—Algeria. *Proc Eng* 33:30–37
- Abuzeid K, Abdel-Meguid A (2007) Water conflicts and conflict management mechanisms in the Middle East and North Africa Region. Center for Environment and Development for the Arab Region and Europe (CEDARE), Cairo
- Achour S, Chabbi F (2014) Disinfection of drinking water—constraints and optimization perspectives in Algeria. *Larhyss J* 19:193–212
- Ahopelto S, Vahala R (2020) Cost-benefit analysis of leakage reduction methods in water supply networks. *Water* 12:1–15
- Al-Omran A, Al-Barakah F, Altuquq A, Anwar A, Nadeem M (2015) Drinking water quality assessment and water quality index of Riyadh, Saudi Arabia. *Water Qual Res J Can* 50:287–296
- Al-Zarah AI (2014) Evaluation of household drinking water quality in Al-Ahsa City, Saudi Arabia. *Res J Environ Sci* 8:62–77
- Anon (2014) Drought Management Strategy in Algeria. Regional workshop for the Near East and North Africa, Cairo, Egypt, 17–20 Nov 2014. [https://www.ais.unwater.org/ais/pluginfile.php/605/mod\\_page/content/23/Algeria\\_2.pdf](https://www.ais.unwater.org/ais/pluginfile.php/605/mod_page/content/23/Algeria_2.pdf)
- Ayari K, Ayari A (2017) For better governance of drinking water in Tunisian rural areas. *Larhyss J* 29:7–21
- Bensoltane MA (2010) Dégradation de la qualité d'eau potable dans les réseaux de distribution/Cas de la ville de Souk-Ahras. Thèse Magister. Département de génie civil, Université de Souk Ahras, Souk Ahras
- Bensoltane MA, Zeghadnia L, Djemili L, Gheid A, Djebbar Y (2018) Enhancement of the free residual chlorine concentration at the ends of the water supply network: case study of Souk Ahras City—Algeria. *J Water Land Dev* 38:3–9
- Bezuidenhout CC, Mthembu N, Puckree T, Lin J (2002) Microbiological evaluation of the Mhlathuze River, Kwazulu-Natal (RSA). *Water SA* 28:281–286

- Boulos P, Schade T, Baxter CW (2008) Locating leaks in water distribution systems using network modeling. *J Water Manag Model* R228–21
- Cohen J, Shuval HI (1973) Coliforms, fecal coliforms, and fecal streptococci as indicators of water pollution. *Water Air Soil Pollut* 2:85–95
- Csuros M, Csuros C, Ver K (1999) Microbiological examination of water and wastewater. Lewis, New York
- Donia N (2007) Survey of potable water quality problems in Egypt. In: 11th Int Water Technol Conf (IWTC11), Sharm El-Sheikh, Egypt, 15–18 March 2007
- Drouiche N, Ghaffour N, Naceur MW, Lounici H, Drouiche M (2012) Towards sustainable water management in Algeria. *Desalin Water Treat* 50:272–284
- Drouiche N, Khacheba R, Soni R (2020) Water policy in Algeria. In: Zekri S (eds) Water policies in MENA countries. *Global Issues in Water Policy* 23. Springer, Cham
- Environmental Protection Agency (EPA) (2002) Safe Drinking Water Act amendment. EPA, Washington, DC. <http://www.epa.gov/safewater/mcl>
- Environmental Protection Agency (EPA) (2003) Safe Drinking Water Act (EPA 816-F-03-016). EPA, Washington, DC
- Ezeugwunne IP, Agbakoba NR, Nnamah NK, Anahalu IC (2009) The prevalence of bacteria in packaged sachets water sold in Nnewi, South East, Nigeria. *World J Dairy Food Sci* 4:19–21
- Festy B, Hartement P, Ledrans M, Levallois P, Payment P, Tricard D (2003) Qualité de l'eau (Chap. 13). In: Gérin M, Gosselin P, Cordier S, Viau C, Quénel P, Dewailly É (eds) *Environnement et santé publique—fondements et pratiques*. Éditions Tec&Doc, Paris, pp 333–368
- Flemming HC, Percival S, Walker J (2002) Contamination potential of biofilms in water distribution systems. *Water Supply* 2:271–280
- General Secretariat of the Algerian Government (2011) Executive decree No. 11-125 of 17 Rabie Ethani 1432 corresponding to 22 March 2011 defining the humane drinking water quality. *Official Journal of the Democratic and Popular Algerian Republic (JORA)* No. 18
- Gomes R, Marques SA, Sousa J (2012) Identification of the optimal entry points at District Metered Areas and implementation of pressure management. *Urban Water J* 9:365–384
- Guebail A, Bouzian T, Zeghadnia L, Djebbar Y, Bouranene S (2017) Rainwater harvesting in Algeria: utilization and assessment of the physico-chemical quality. Case study of Souk-Ahras region. *Rev Courrier Sav* 23:85–94
- Habimana O, Nesse LL, Møretrø T, Berg K, Heir E, Vestby LK, Langsrud S (2014) The persistence of *Salmonella* following desiccation under feed processing environmental conditions: a subject of relevance. *Lett Appl Microbiol* 59:464–470
- ISO (1986) Qualité de l'eau: dosage du cobalt, nickel, cuivre, zinc, cadmium et plomb, méthodes par spectrométrie d'absorption atomique [Water quality: determination of cobalt, nickel, copper, zinc, cadmium and lead: atomic absorption spectrometry methods]. ISO 8288. ISO, Geneva
- Kadaoui M, Bouali A, Arabi M (2019) Assessment of physicochemical and bacteriological groundwater quality in irrigated Triffa Plain, North-East of Morocco. *J Water Land Dev* 42:100–109
- Karrou M, Oweis T, Bahri A (2011) Improving water and land productivities in rainfed systems. Community-based optimization of the management of scarce water resources in agriculture in CWANA. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo
- Koliai D (2000) Assainissement et réutilisation des eaux usées épurées [Sewerage and reuse of purified waste water]. In: *Int Conf on Integrated Water Management*, Oran, Algiers, 2–3 May 2000
- LeChevallier MW, Babcock TM, Lee RG (1987) Examination and characterization of distribution system biofilms. *Appl Environ Microbiol* 53:2714–2724
- Majzoub T (2000) International legal norms governing the management of shared surface water resources (International and Regional Perspectives). In: ESCWA/CEDARE Expert Group Meeting on the Legal Aspects of the Management of Shared Water Resources, Sharm El-Sheikh, Egypt, 8–11 June 2000
- Mara D, Horan N (2003) Handbook of water and wastewater microbiology. Elsevier, New York, ISBN 978-0-12-470100-7
- Nilufar I, Rehan S, Manuel JR, Christelle L (2016) Assessment of water quality in distribution networks through the lens of disinfection by-product rules. *Water SA* 4:337–349
- Nilufar I, Manuel JR, Farahat A, Rehan S (2017) Minimizing the impacts of contaminant intrusion in small water distribution networks through booster chlorination optimization. *Stoch Environ Res Risk Assess* 31:1759–1775
- Osuinde MI, Enezie NR (1999) Bacteriological analysis of ground water. *Nigeria J Microbiol* 13:47–54
- Ouahchia C, Hamaidi-Chergui F, Hamaidi MS, Saidi F (2014) Preliminary investigation for consumer perceptions of drinking water quality in Tipaza (Algeria). *Int J Innov Appl Stud* 9:1675–1686
- Parus P (2007) Urban water quality evaluation using multivariate analysis. *Acta Montan Slovaca* 12:150–158
- Percival SL, Walker JT (1999) Potable water and biofilms: a review of the public health implications. *Biofouling* 42:99–115
- Powell JC, Clement J, Brandt M (2004) Predictive models for water quality in distribution systems. IWA, London, p 106. ISBN 184339913X
- Prasad TD, Danso-Amoako E (2014) Influence of chemical and biological parameters on iron and manganese accumulation in water distribution networks. *Proc Eng* 70:1353–1361
- Prüss A (1998) A review of epidemiological studies from exposure to recreational water. *Int J Epidemiol* 27:1–9
- Puust R, Kapelan Z, Savic DA, Koppel TA (2010) Review of methods for leakage management in pipe networks. *Urban Water J* 7:25–45
- Radha KR, Dharmaraj K, Ranjitha KBD (2007) A comparative study on the physicochemical and bacterial analysis of drinking, borewell and sewage water in the three different places of Sivakasi. *J Environ Biol* 28:105–108
- Rahmani ASE, Brahim C (2017) Water supply prediction for the next 10 years in Algeria: risks and challenges. *Irrig Drain Systel Eng* 6:197
- Ramdani A, Djellouli H, Aït Yala N, Taleb S, Benghalem A, Mahi C, Khadraoui A (2012) Physico-chemical water quality in some regions of Southern Algeria and pretreatment prediction. *Proc Eng* 33:335–339
- Razzolini MTP, Günther WMR, Martone-Rocha S, Bastos VK, Thaís Fd, Cardoso MRA (2011) Quality of water sources used as drinking water in a Brazilian peri-urban area. *Braz J Microbiol* 42:560–566
- September SM, Els FA, Venter SN, Brözel VS (2007) Prevalence of bacterial pathogens in biofilms of drinking water distribution systems. *J Water Health* 5:219–227
- Sinton LW, Donnison AM, Hastie CM (1993) Faecal streptococci as faecal pollution indicators: a review. Part I: taxonomy and enumeration. *N Z J Mar Freshw Res* 27:101–115
- Speight V, Uber J, Grayman W, Martel K, Friedman M, Singer P, Digiano FA (2009) Probabilistic modeling framework for assessing water quality sampling programs. Water Research Foundation, Denver
- Stumm W (1960) Investigation of the corrosive behavior of waters. *J ASCE Sanit Eng Div* 86:27–46
- Szewzyk U, Szewzyk R, Manz W, Schleifer KH (2000) Microbiological safety of drinking water. *Annu Rev Microbiol* 54:81–127



- Taikan O, Rose EQ (2020) Economically challenged and water scarce: identification of global populations most vulnerable to water crises. *Int J Water Resour Dev* 36:416–428
- Thomas JM, Ashbolt NJ (2011) Do free-living amoebae in treated drinking water systems present an emerging health risk? *Environ Sci Technol* 45:860–869
- Tyndall RL, Domingue EL (1982) Co-cultivation of *Legionella pneumophila* and free-living amoebas. *Appl Environ Microbiol* 44:954–959
- Vicente DJ, Garrote L, Sánchez R, Santillán D (2016) Pressure management in water distribution systems: current status, proposals, and future trends. *J Water Resour Plan Manag* 142:04015061
- Wagida AA (2003) Environmental health in Egypt. *Int J Hyg Environ Health* 206:339–350
- WHO (2004) Guidelines for drinking water quality, vol 1, 3rd edn. Recommendations. WHO, Geneva
- WHO (2008) World Health Organization report. WHO, Geneva
- WHO (2011) Guidelines for drinking water quality, 4th edn. WHO, Geneva
- WHO (2018) Disease outbreak news, cholera—Algeria. WHO, Geneva
- Wingender J, Flemming HC (2011) Biofilms in drinking water and their role as reservoir for pathogens. *Int J Hyg Environ Health* 214:417–423
- Zeghadnia L (2007) Computation of the pressurized turbulent flow in circular pipe. Magister thesis. Badji Mokhtar University, Annaba
- Zeghadnia L (2014) Contribution au dimensionnement d'un réseau d'assainissement en tenant compte de l'aspect stationnaire et non stationnaire de l'écoulement. PhD thesis. Badji Mokhtar University, Annaba