Impact of treated wastewater on groundwater quality in the region of Tiznit (Morocco)

Mounir El Heloui, Rachida Mimouni and Fatima Hamadi

ABSTRACT

The Tiznit region has an arid to semi-arid climate. Rainfall is scarce and the reuse of wastewater for crop irrigation is common, and consequently groundwater can be contaminated by chemical and biological pollutants. A wastewater treatment plant is constructed with the aim of producing water suitable for reuse in agriculture and reducing groundwater pollution. The aim of this study is to assess the impact of factors that may influence groundwater quality, namely wastewater reuse and fertilizer use in the region. Groundwater was collected monthly over 1 year from five shallow wells (P1–P5) and analysed for a range of physicochemical and microbiological parameters. Concentrations frequently exceeded the WHO standards for potable water. The average concentration of nitrate was 98 mg/L. Conductivity varied from 1,930 to 2,500 μS/cm over four of the wells but was 11,703 in P3, which was close to the treatment plant. Bacteriological contamination was also found, with total coliforms varying from 0 at P1 to 9,000 cfu/100 mL at P4 and fecal coliforms (FC) 0 in P1, P2, P3 and P5 but up to 250 FC/100 mL at P4. Fecal streptococci (FS) varied from 0 to 3,500 FS/100 mL at P4. These values widely exceeded the limit for bacteria in water (0 units/100 mL).

Key words | bacteriological quality, groundwater, Morocco, physicochemical quality, Tiznit, wastewater reuse

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INTRODUCTION

Water resources in Morocco are under pressure due to low and irregularly distributed rainfall, high temperatures, wind, and low humidity, which often results in the occurrence of drought. As water needs for human population increase over time, the recourse to new water resources is necessary. Agricultural reuse of treated wastewater can be a real solution for better management of water resources, given that the volume of wastewater treated in different treatment stations is an available and regular resource. In addition, the use of treated wastewater has many advantages in terms of rationalization in water management, and the use of this water is also beneficial to farmers because it contains minerals and nutrients, and it is cheap as well (Abouelouafa *et al.* 2010). Therefore, there are a variety of factors driving wastewater use in agriculture. Such factors are physical, economic, social and political (Mateo-Sagasta & Burke 2008).

However, this practice imposes constraints on the quality of treated water, and assessing its subsequent impact requires groundwater quality monitoring. In Tiznit province, the wastewater treatment works is located on the left bank of Sidi Abderrahmene River, and the wastewater is discharged into this river. The wastewater treatment works is 800 m away from the residential area in Doutarga and 1,900 m away from the urban area of Tiznit. The treatment, which involves a series of lagoons, is designed to limit the amount of organic matter and inorganic pollutants discharged into the environment. Many micropollutants are not removed by this level of treatment, and they are detected in irrigated fields. The impact on groundwater is not known.

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Groundwater quality in a region is largely determined by both natural processes (dissolution and precipitation of minerals, groundwater velocity, quality of recharge waters and interaction with other types of water aquifers) and anthropogenic activities (Gordana *et al.* 2014). The concentrations of nitrate increase notably as a result of the large amount of chemical fertilizers used in agriculture (Compton & Boone 2000; Jiang *et al.* 2008).

Groundwater quality was studied in several areas of Morocco (Aghzar *et al.* 2002; Laftouhi *et al.* 2003; Hassoune *et al.* 2006; Bricha *et al.* 2007; Fetouani *et al.* 2008; Tagma *et al.* 2009; Benmoussa *et al.* 2012; Belghiti *et al.* 2013; Benabbou *et al.* 2013; Re *et al.* 2013). Some of these works (Tagma *et al.* 2009) studied the effect of nitrate on the groundwater quality, and they reported that the concentration of nitrate in groundwater exceed the Morrocan Norms (Norm 1997). Others works (Bricha *et al.* 2007) have evaluated the impact of the intensification of agricultural activity and discharges of untreated wastewater on the physicochemical and bacteriological quality of M'nasra groundwater. These authors found that the concentration of nitrate exceeded the recommended norm. Also, they reported that M'nasra groundwater presents high bacteriological pollution. However, according to our knowledge, no study had been conducted in the Tiznit region. The aim of this study is to evaluate groundwater quality in the region, particularly in the area of the wastewater treatment station, and to assess this against possible pollutant sources such as wastewater reuse or use of fertilizers.

MATERIALS AND METHODS

Study area

The Tiznit province belongs to the region of Souss-Massa-Drâa. It is located between 29 and 30 ° north in latitude. Its area is 6,960 km², with 1,150 km² of plains. In past decades, the city expanded onto the neighbouring rural areas so that it currently includes the localities of Atbane and Doutarga. In this province, the main economic activities are agriculture, livestock, and trade. Farming is carried out in small irrigated zones, either from water sources (900 acres), or by spreading running water or treated wastewater (3,650 acres). The perimeter of the present study is located around the wastewater treatment plant in the northwest of Tiznit (Figure 1). The wells are selected due to their proximity (upstream and downstream) to the wastewater treatment plant and to the area irrigated with the treated wastewater (Figure 1).

Figure 1 shows the location of the treatment plant (WWTP), wells (1–5), the area irrigated by treated wastewater (the green area located to the northeast of the wastewater treatment plant) and the direction of flow of streams (blue arrows).

Water samples and analytical techniques

The plain of Tiznit contains two kinds of aquifer. Both are used for drinking and irrigation:

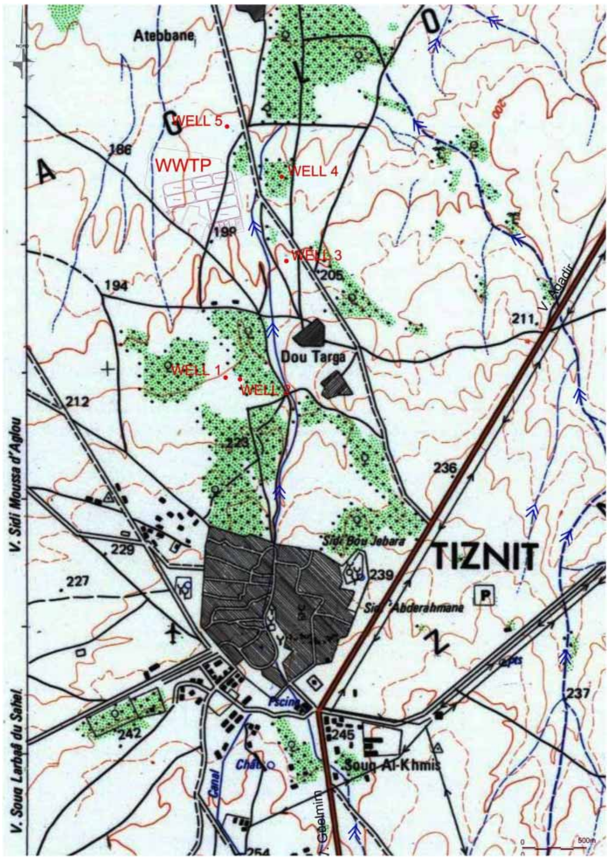

Figure 1 | Location of the well relative to the wastewater treatment station and the regions provided for reuse. The full colour version of this figure is available in the online version of this paper: http://dx.doi.org/10.2166/wrd.2015.061.

- widespread table in gréso-shale formations beneath the Plio-quaternaires deposits;
- a discontinuous table concentrated in karst channels that have developed in lacustrine limestone plioquaternaire.

The water of Tiznit's aquifer has two sources: either by direct infiltration of rainwater and flood (estimated at 8 million m^3), or by passing through the underground soil (estimated at 5.7 million m^3) (Ministry of Energy Mines Water and Environment of Morocco (MEMWE) 2015). The Georgian deep aquifers that are under shales are discontinuous and at great depth, which negatively affects the quality in terms of salinity and temperature (Ministry of Energy Mines Water and Environment of Morocco (MEMWE) 2015).

Water samples were collected monthly from five wells (P1–P5) over 1 year (February 2011–January 2012). The Lambert coordinates of these wells were 29° 43′ 47″ N, 9° 43′ 52″ W (the P1 well/24 m); 29° 43′ 0″ N, 9° 43′ 52″ W (P2/22 m); 29° 43′ 0″ N, 9° 43′ 48″ W (P3/26 m); 29° 43′ 38″ N, 9° 43′ 41″ W (P4/23 m); and 29° 44′ 4″ N, 9° 43′ 54″ W (P5/24 m) (Table 1). In choosing these five sites, the frequency of water use by their owners and their geographical distribution around the wastewater treatment plant was considered (Figure 1). For each sample, before starting sampling, the pump spout was heated with a gas torch, and then the pump was left to run to obtain a true sample of the well water. Each sample was placed in a 500 mL sterile bottle according to the Moroccan standards (Norm 1997). Immediately after sampling, the bottles were labeled (date, number of the well, type of analysis) and placed in the dark in an icebox at 4–6 °C before being transported to the laboratory for analysis on the same day.

Physicochemical parameters studied in the field were air and water temperatures (Mercury thermometer), water pH (pH meter, Mark: WTW, Model number: 7491106) and electrical conductivity (Condictivimeter, Mark: CONSORT, Model number: 60328). They were measured on site using portable calibrated equipment according to techniques by Rodier *et al.* (1996). In the laboratory, the concentrations of nitrates were determined via a colorimetric method (Rodier *et al.* 1996) with a spectrophotometer (Mark: HACH, Model number: 1423584). The correlation between the air and water temperature were determined by using the statistics software STATISTICA. Data were analyzed by one-way analysis of variance (ANOVA) (STATISTICA software ver. 6 StatSoft, 2001, France). Mean separations were performed by Newman and Keuls test, at $P < 0.05$.

The bacteriological parameters determined in this study were the enumeration of total coliforms (TC) and the estimation of fecal contamination bacteria by counting fecal coliforms (FC) and streptococci (FS). The counts of these bacteria were made by means of the statistical method of the most probable number (MPN) of Mac-Grady (AFNOR 1997). A series of five tubes containing specific medium cultures were inoculated by groundwater dilutions. Coliforms were counted after 24–48 h incubation at 37 °C in the lauryl-sulfate-Tryptose Broth medium (presumptive test). Positive tubes (with bacteria growth and gas production) were submitted to a confirmation test: (i) with Brilliant Green Bile Broth incubated for 24 h at 37 °C (confirmation of TC); and (ii) with EC Broth incubated for 24 h at 44 °C

Table 1 | Characteristics of the studied wells

Well	Groundwater levels	Type of well	Lambert coordinates	Location/Treatment plant	Type of use
P1	24	Dug well	29° 43′ 47″ N 9° 43′ 52″ W	Upstream	Consumption, irrigation
P2	22	Dug well	29° 43′ 0″ N 9° 43′ 52″ W	Upstream	Consumption, irrigation
P3	26	Dug well	29°° 43′ 0″ N 9° 43′ 48″ W	Upstream	Irrigation
P4	23	Dug well	29° 43′ 38″ N 9° 43′ 41″ W	Downstream	Irrigation
P5	24	Dug well	29° 44′ 4″ N 9° 43′ 54″ W	Downstream	Irrigation

(confirmation of FC). If bacteria growth and gas production occurred on the media, they indicated the presence of TC and FC, respectively. FS were counted after water incubation in the Azide Dextrose Broth (Rothe broth) for 48 h at 37 °C (presumptive test), and the inoculums of positive tubes were placed in the Litsky medium with a further incubation at 37 °C for 24 h (confirmation test). The results of such counts were expressed under the form of the most probable numbers of germs per 100 mL (MPN/100 mL) according to the statistical table of Mac-Grady (AFNOR 1997).

Every trimester during the period study (March, June, September, December 2011), we examined the quality of treated wastewater at its exit, so as to deduce if there was a correlation between the quality of water in the wells and the treated wastewater. The studied parameters were as follows: nitrates, electrical conductivity and FC.

RESULTS AND DISCUSSION

Physicochemical parameters

Figure 2 indicates water temperatures in the five wells from February 2011 to January 2012. These values were close to the mean temperature (22.4 °C) with a minimum of 18 °C (P1 well water in March) and a maximum of 26.6 °C (P4 well water in August). Air temperature shows significant variation (average, 24.4 °C) (Figure 3), although we noted a positive correlation between air and water thermal variations ($r = 0.87$) (Figure 4).

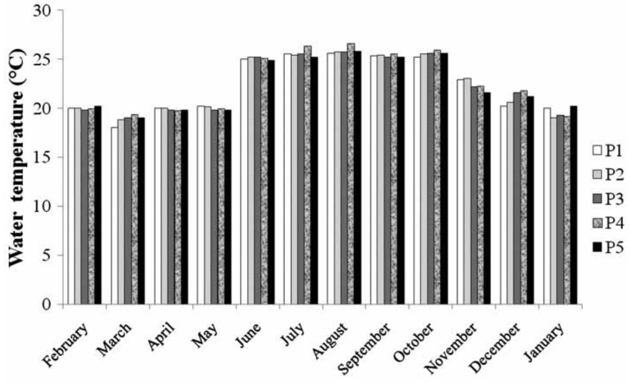

Figure 2 | Monthly variations of air temperature in the province of Tiznit from February 2011 to January 2012.

This correlation can be explained by the influence of air temperature on water temperature, because the studied wells were shallow in depth (Makoutode *et al.* 1999; Rutkoviene *et al.* 2005).

The pH values (Figure 5) did not show large variations between all wells, as they remain near the mean value (7.06) with a minimum of 6.8 (P1 in December) and a maximum of 7.3 (P5 in March 2011). These values do not exceed the norms regarding drinking water and irrigation. These values, which range between the scale of minimum and maximum limits (pH, 6 and 8.5, respectively), comply with Moroccan standards concerning drinking water. The pH value usually ranges between 6 and 8.5 in natural water (Chapman & Kimstach 1996).

Water samples collected from the five wells were highly mineralized, with electric conductivity (Figure 6) ranging from 1,930 μs/cm (P1/July 2011) to 13,900 μS/cm (P3/August 2011). A high conductivity indicates strong mineralization of water (Rodier *et al.* 1996). According to the Moroccan standards, groundwater is divided into five classes ranging from high class to very bad class (Table 2). The P1, P2, P4 and P5 well waters were classified in the middle class (1,300–2,700 μS/cm), taking into account that 2,500 μS/cm is the value accepted by European standards (Hassoune *et al.* 2006; WHO 2006; Ranjitsinh & Dipak 2014), whereas P3 was classified in the very bad class. According to local farmers of Attebane, water wells in the region are known for their high salinity. Given that the perimeter studied was only 8 km from the Atlantic coast, it appears that groundwater was contaminated by the intrusion of sea water (Hsissou *et al.* 2001).

Very intense nitrate pollution (Figure 7) was also detected in water samples. The mean value was approximately 98 mg/L, with a minimum of 58 mg/L (P1 well in June) and a maximum of 130 mg/L (P4 in August). All these concentrations exceeded the value of 50 mg/L according to both the Moroccan and WHO standards. Similar concentrations were found in water collected from Essaouira basin wells (Laftouhi *et al.* 2003) and in water collected from Settat wells (Hassoune *et al.* 2010). As the nitrate concentration rarely exceeded 0.45 mg/L in the natural environment, higher values indicated the presence of

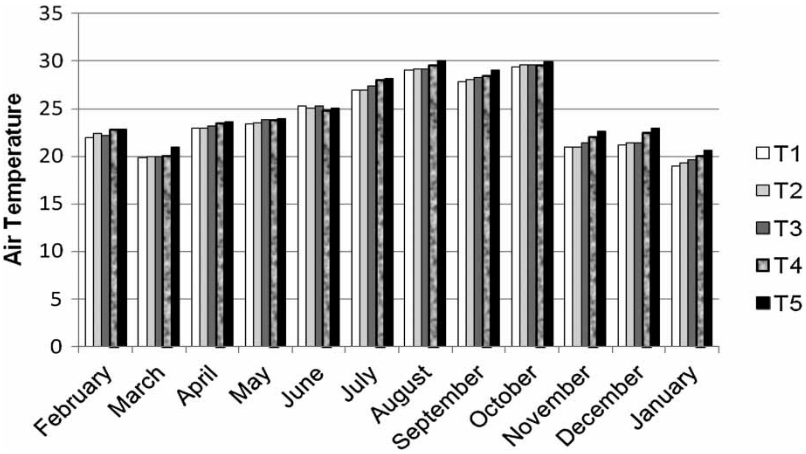

Figure 3 | Monthly variations of water temperature in the five wells (P1–P5).

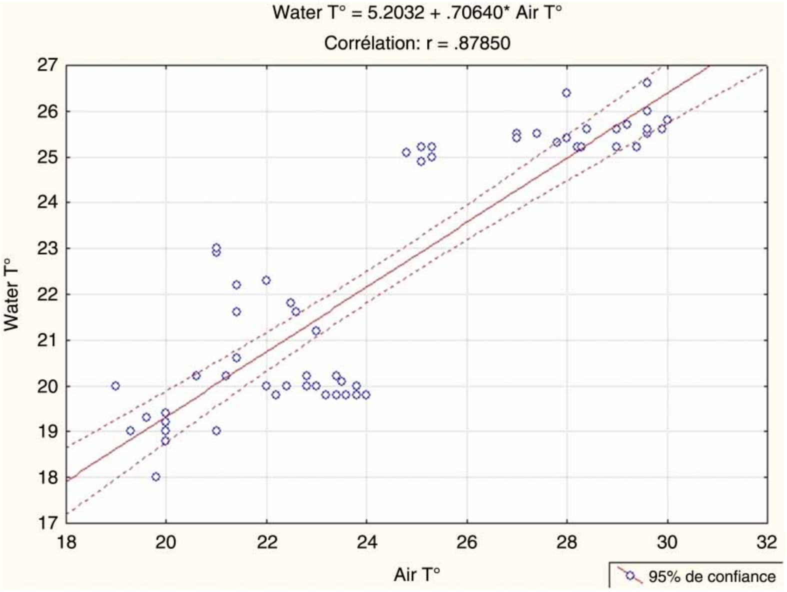

Figure 4 | Correlation between the water temperature and air temperature.

wastewater in surface and groundwater and particularly the wastewater, and/or the excessive use of fertilizers (Chapman & Kimstach 1996; Derwich *et al.* 2010). This alteration of groundwater quality by nitrates may be attributed to nitrate leaching due to excessive use of fertilizers for agricultural products, namely mint and other vegetable crops, in the studied perimeter (Levallois & Phaneuf 1994; Wick *et al.* 2012). Other factors also contributing to this contamination were: (i) superficial aquifers facilitating the contact between nitrate leaching and groundwater (Turin 1991; Aghzar *et al.* 2002; Hassoune *et al.* 2010; Marouane *et al.* 2014) and/or (ii) permeable geological formations which led to high nitrate concentrations in underlying groundwater (Zeraouli 1993; Pitt *et al.* 1999; Bricha *et al.* 2007).

At the output of the wastewater treatement plant, the values of nitrates varied from 0.84 to 4.85 mg/L, conductivity varied from 1,670 to 2,000 µs/cm. (Table 3). These results indicate that the quality of the treated effluent is good and does not exceed the discharge standard in the natural environment.

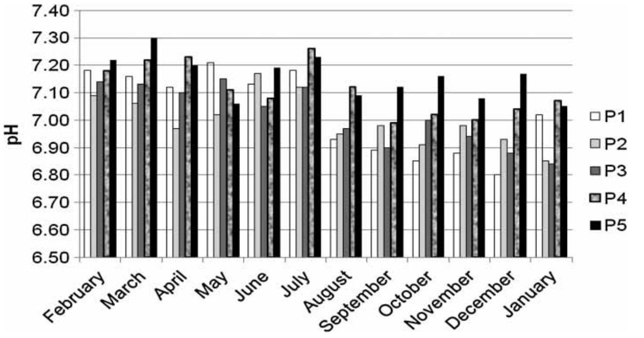

Figure 5 | Monthly variations of water pH in the five wells (P1–P5) studied in the province of Tiznit from February 2011 to January 2012.

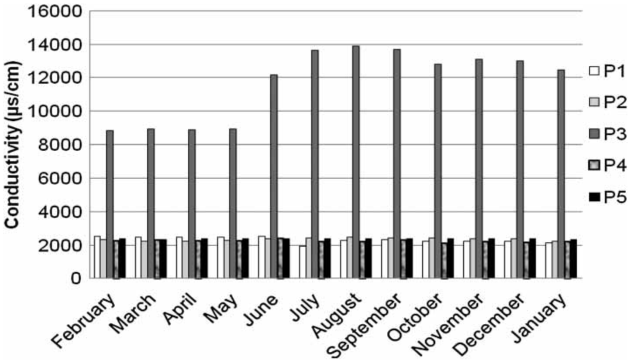

Figure 6 | Monthly variations of electric conductivity in the water sampled in five wells (P1–P5) studied in the province of Tiznit from February 2011 to January 2012.

Bacteriological parameters

Human activities on the land surface may cause groundwater contamination by bacterial pathogens. In general, the microbiological quality of groundwater should be better than that of surface water, since pathogens are filtered by the soil and subsoil during the recharge process. Leaking waste water evacuation systems, leaking septic tanks, slurry and organic waste deposits, buried biomass, including animal remains, may be responsible for pathogen contamination of groundwater (Fetouani *et al.* 2008).

Total coliform concentration (Figure 8) varied from 0 (P1) to 9.10^3 TC/100 mL (P4) with an average in the range of 263 TC/100 mL. Except for a value of 0 recorded in P1 in the month of March 2011, all the others values exceeded the European, French and WHO, as well as the Moroccan, standards (0 TC/100 mL). High TC values in all wells were probably due to fecal pollution. Similar results were obtained by other authors who studied the impact of wastewater on groundwater in Marrakech (Lyakhloufi *et al.* 1999; Lamrani *et al.* 2008), Settat (Hassoune *et al.* 2010) and Abidjan (Douagui *et al.* 2012). Except for P1, P2, P3 (upstream of the wastewater treatment station) and P5 (downstream of the wastewater treatment station), the well P4 (downstream of the wastewater treatment station) showed a high concentration of FC ranging between 0 and 210 FC/100 mL (Figure 9). The presence of FC in the ground water causes a public health risk. In the literature (Geldreich 1999; Barwick *et al.* 2000; El Haissoufi *et al.* 2011), it is known that FC such as *Escherichia coli* and/or *Klebsiella pneumoniae* can cause respiratory, genito-urinary and digestive infections, or even sepsis.

The highest FS concentrations (Figure 10) were noted in the P4 well water (August 2011), with $3.5\ 10^3$ FS/100 mL and $1.1\ 10^3$ FS/100 mL. These values exceeded Moroccan and international standards (0 FS/100 mL). When streptococci were detected in water wells, fecal contamination by pathogenic microorganisms must be seriously suspected (Simmons *et al.* 2001). Edberg *et al.* (2000) suggested that well water (groundwater) in which streptococci were identified must not be consumed.

Our results are similar to those of other authors, such as as Makoutode *et al.* (1999), who studied the qualities of wells located near the population in rural areas of Benin; and Bricha *et al.* (2007), who studied the quality of groundwater of M'nasra (Morocco), located in an agricultural area, and in addition releases of untreated sewage. These studies found streptococci rates exceeding 10^3 FS/100 mL in water wells.

High contamination of water wells (with the presence of FC, TC and FS) might be attributed to animal fecal pollution, or human-induced pollution (septic tanks, livestock farming, poultry feces, and use of animal waste as fertilizer on farmland adjacent to wells), or lack of hygiene rules (open pits, use of contaminated buckets). The ratio of FC/FS in the P4 water well during the study period was <4. This explains

Table 2 | Classification of groundwater quality according to the conductivity

Quality class	Excellent	Good	Medium	Bad	Very bad
Conductivity (µs/cm)	<400	400–1,300	1,300–2,700	2,700–3,000	>3,000

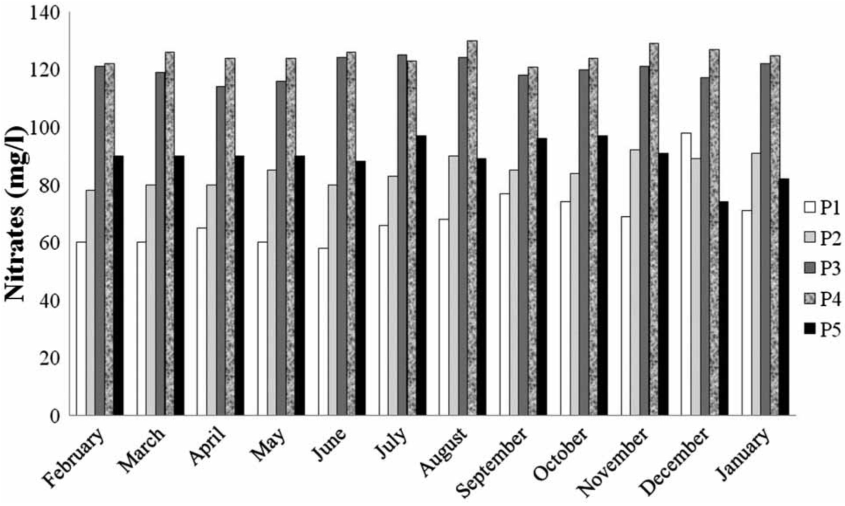

Figure 7 | Monthly variations of nitrate concentrations in the water sampled in five wells (P1–P5) studied in the province of Tiznit from February 2011 to January 2012.

Table 3 | Quality variations of treated wastewater in Tiznit from March to September 2011

	Nitrates (mg/L)	Conductivity (μs/cm)	Fecal coliform (FC/100 mL)
March	1.16	1,670	400
June	0.84	2,000	800
September	4.85	1,685	400
December	0.98	1,702	200

the origin of the contamination, which is strictly animal, as the area is known to have high numbers of poultry around P4. These results confirm the observations of Jagals *et al.* (1995) who noted a high ratio of FC/FS (>4). Such a high ratio is considered as a good pollution indicator of human origin, while a low ratio shows animal pollution. Similar results for well pollution were reported in several areas of Fez (El Haissoufi *et al.* 2011).

At the output of the wastewater treatment plant, the values of FC varied from 200 to 800 FC/100 mL.

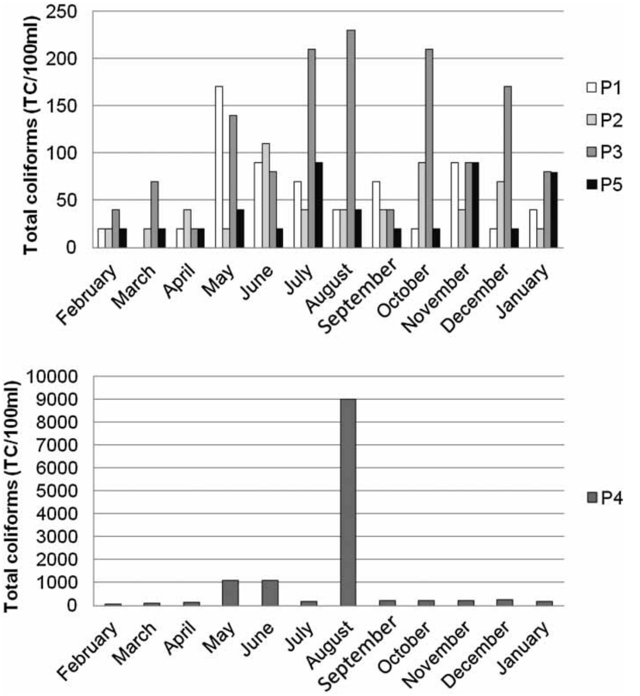

Figure 8 | Monthly variations of TC in the water sampled in the P1, P2, P3 and P5 wells (5A) and in the P4 (5B) in the province of Tiznit from February 2011 to January 2012.

CONCLUSIONS

According to the results of the quarterly analysis carried out in 2011 on the treated wastewater in Tiznit, we found that the values of the measured elements were different from those measured in well waters (nitrates varied from 0.84 to 4.85 mg/L, conductivity varied from 1,670 to 2,000 μs/cm and FC varied from 200 to 800 FC/100 mL). They all meet the standards for discharge into the natural environment. So, we cannot attribute well contamination to the treatment plant effluent. The high values of nitrate pollution can be related to the excessive use of fertilizers; the electrical

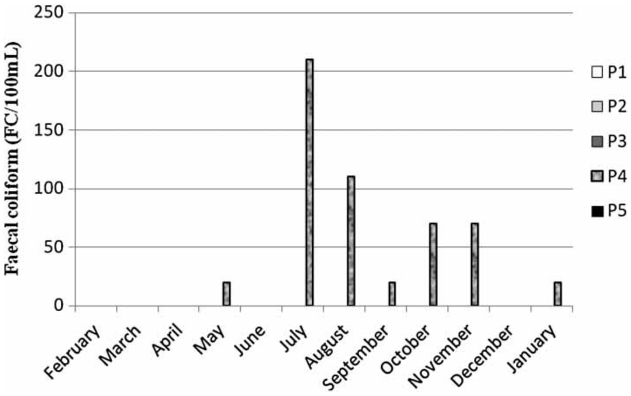

Figure 9 | Monthly variations of FC in the water sampled in five wells (P1–P5) studied in the province of Tiznit from February 2011 to January 2012.

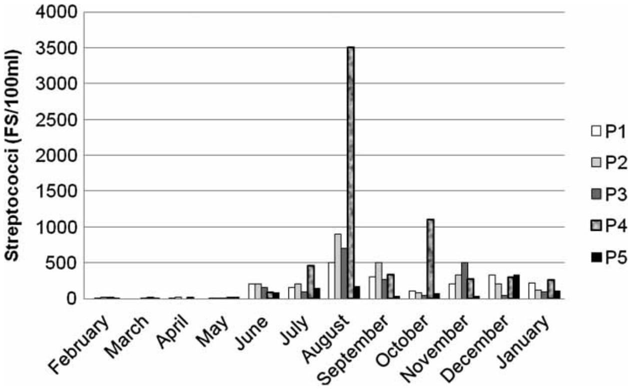

Figure 10 | Monthly variations of FS in the water sampled in five wells (P1–P5) studied in the province of Tiznit from February 2011 to January 2012.

conductivity of the groundwater can be related to the intrusion of sea water; and the bacteriological contamination can be related to animal or human pollution.

In conclusion, the contamination of the five wells studied exceeded Moroccan standards regarding well water which is used as drinking water, irrigation water and other uses. In fact, the physico-chemical properties of these water wells did not allow their recommendation for human consumption because nitrates exceeded the Moroccan standards (50 mg/L); electrical conductivity in the P1, P2, P4 and P5 water wells was medium, whereas a high value of conductivity was noted in the P3 well water, indicating saline water. In addition, bacterial pollution was high and permanent in all the wells, with high contamination by FC and FS especially in the P4 well water. As the ratio of FC/FS was less than 4, we confirm that the origin of this contamination is animal. To summarize, most analyses revealed that Tiznit groundwater quality (in Atteban and Douterga localities) did not comply with the European, Moroccan and WHO standards. To address this situation we recommend the following:

- Treated water must maintain the same quality from the wastewater treatment plant to the fields for irrigation.
- Farmers must consider rational fertilization, taking into account the charge of treated water in some fertilizers (nitratres).
- Respect for good irrigation practices in the case of reuse of treated water.
- The application of guidance programs by users of well waters.

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