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Assessment of physicochemical and bacteriological groundwater quality in irrigated Triffa Plain, North-East of Morocco

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Abstract

The physicochemical and bacteriological quality of groundwater was assessed to show the impact of the agriculture and human activities in the Triffa Plain located in North-East of Morocco. The current levels of contamination of the groundwater were estimated by analysing electrical conductivity, nitrate, nitrite, ammonia, orthophosphate, and indicators of faecal pollution content.

Water samples from 55 locations were collected during two period of time, the wet and the dry season of the year 2016. Result obtained indicated that most samples are highly contaminated. The electrical conductivity varied from 800 to 9 100 $\mu S \cdot cm^{-1}$. Nitrate levels ranged from 25 to 216 $mg \cdot dm^{-3}$, with 78% of samples exceeding the critical level value set at 50 $mg \cdot dm^{-3}$. Nitrate concentrations are slightly higher during the wet period in 73% of studied cases. Nitrite rarely exceeded the normal rate fixed by World Health Organization and reached 0.90 $mg \cdot dm^{-3}$. Ammonia and orthophosphate contents do not exceed these norms.

The study revealed a wide contamination of groundwater by microbial agents such as, total coliforms, faecal coliforms and faecal streptococci, with content ranged from 0 to 14 000, 0 to 5 000 and 0 to 5 000 $CFU \cdot (100\ cm^3)^{-1}$ respectively, confirming the impact of septic tanks, wastewater discharge into rivers without treatment, and the use of animal waste on the ground water vulnerability.

Samplings and measurements were carried out according to the international standard ISO 13395, ISO 11732 and ISO 15681-2 for chemical compounds and ISO 9308-1 and ISO 7899-2 for microbiological numerations.

Key words: *agriculture, bacteriological quality, groundwater, physicochemical quality, Triffa Plain, wastewater*

INTRODUCTION

In Morocco, the surface water resources are estimated to ac. $19 \cdot 10^9\ m^3$ per year, while for groundwater resources, with nearly 80 identified underground aquifers, the volume is estimated at ca. $4 \cdot 10^9\ m^3$ per year [BZIOUI 2004]. Morocco is classified among water-stressed countries with large drought period. The national averaged available water resources are estimated to be 750 m^3 per inhabitant per year. Add to that the qualitative degradation is threatening furthermore these resources [MEMEE 2014] and destroy the hydraulic heritage of the country [MATEE 2001], which constitutes the water privileged resources for drinking water.

Irrigated agriculture is responsible for 93% of the total consumed water in Morocco. It is also the principal driver for ensuring food security and economic development [EL HAMMOUMI *et al.* 2013]. Yet, intensive agriculture in irrigated areas is responsible for the release of pollutants to the groundwater [LAFTOUHI *et al*. 2003]. Indeed, the fiscal benefits granted to farmers since 1985, encourages strongly agricultural intensification. The irrigated areas, which represent only 12% of the useful agricultural area of the country, consume more than 50% of fertilizer inputs at the national level [FETOUANI *et al*. 2008].

Water is essential for life. However, it can also be a source of diseases [EL HAISSOUFI *et al.* 2011], because it can play the role of vector of potentially harmful agents, such as pathogenic microorganisms and chemical compounds [HASSOUNE *et al.* 2010; KELMENDI *et al.* 2018]. The daily absorption of large quantities of nitrate contained in the drinking water, may cause public health problems such as the appearance of certain cancers [WEYER *et al.* 2001], or infant methemoglobinemia [AVERY 2001; FREISHTAT *et al*. 2005; VENKATESWARI *et al*. 2007]. In Morocco, the use of groundwater from unprotected public or private wells, with the insufficiency of the sewage network and ignorance in the sense of hygienic rules facilitates the rise of certain diseases such as hepatitis and typhoid [HASSOUNE *et al.* 2006; MELLOUL *et al.* 2002]. In the Triffa Plain located in the North-East of Morocco, the pressures, and the practices of intensive irrigated agriculture, and the discharge of wastewater into rivers, have negative impacts on groundwater quality [BENKADDOUR 1997; FEKKOUL *et al*. 2013; FETOUANI *et al*. 2008; YAHYA *et al*. 2015]. Here, we report the assessment of groundwater quality using physicochemical and bacteriological analysis. We show the current levels of groundwater contamination with salinity, nitrates, nitrites, ammonium, and orthophosphates. These compounds are in direct relation with agricultural practices. Also we determine the degree of microbiological pollution caused by septic tanks.

MATERIAL AND METHODS

STUDY AREA

The Triffa Plain is the most productive irrigated agricultural area in north-eastern Morocco with an area of ca. 750 km^2 (Fig. 1A). It is limited in the North toward the Mediterranean Sea by Ouled Mansour hills, in the South by Beni Snassen Mountains, in the West by the Moulouya River and its affluent the Cheraa River, and in the East by the Kiss River, along the Moroccan-Algerian border. In Triffa Plain there are two aquifers (Fig. 1B), a shallow aquifer of the secondary and quaternary formations, and a deep aquifer of the Liassic formations [BOUGHRIBA, JILALI 2018]. The Triffa syncline is developed during secondary and quaternary geological formations. The quaternary formations cover almost the whole surface of the plain. The upper aquifer is unconfined, heterogeneous and composed of many lithological facies: sandstone, limestone, silt, clay, conglomerates and calcareous sandstone [FETOUANI *et al*. 2008]. The flow direction is from South-East to North-West [EL MANDOUR 1998].

The region's climate is Mediterranean, semi-arid with long dry periods with an average annual rainfall of ca. 300 mm and the average annual evapotranspiration of ca. 300 mm per year [FEKKOUL *et al*. 2013].

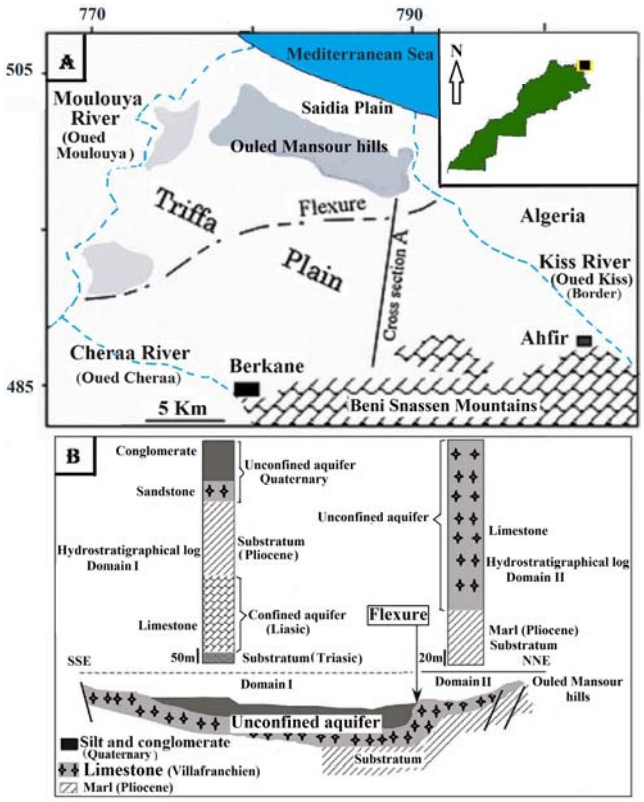

Fig. 1. Study area: A) location, B) the North-South hydrogeological cross-section of Triffa Plain; source: FEKKOUL *et al.* [2013], modified

SAMPLING STRATEGY AND WATER ANALYSIS

Fifty-five ground water samples (51 wells and 4 springs: Titilila (S8), Ain-Beida (S17), Ain-Zerga (S18), Ain-Zebda (S21)) spread over the study area (Fig. 2). All wells were dug manually and are fed from the unconfined

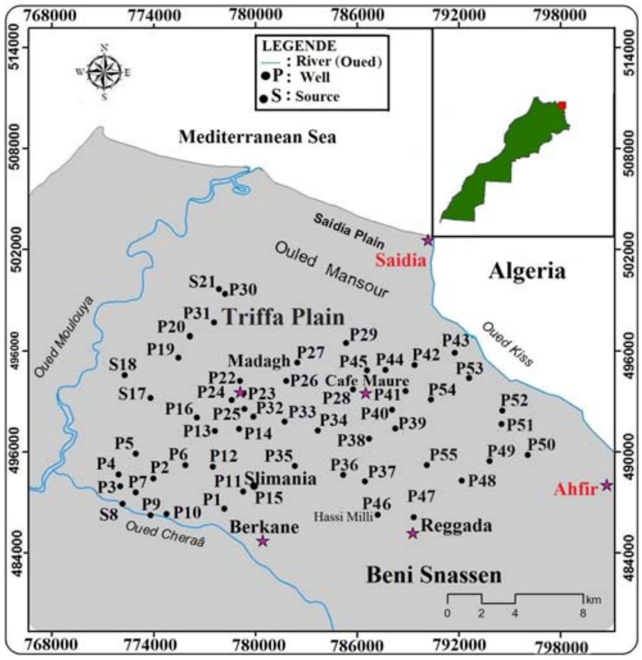

Fig. 2. Sampling locations in Triffa Plain; source: own elaboration

aquifer. Their depth to water level varies between 2 m (in centre part of plain (Madagh)) and 65 m below ground surface (in South of the plain).

Water salinity of wells P30, P35 and spring S21 are high, and could increase dramatically during a drought. Consequently their water is not used as drinking water or for irrigation, whereas P13 is used only for irrigation for salt tolerant crops and forage plants. It is worth to note that from time to time, local health authorities carry out awareness campaigns to inform the public about the treatment of well water prior to its use as drinking water. And most people declare boiling water prior to consumption, but this is effective for eliminating bacterial contaminations and not for other chemical contaminants. Two main sampling campaigns were conducted, the first one during the wet period, March–April 2016 and the second during the dry period, July–August 2016. In the field, the temperature, the pH were measured using pH-meter portable (VWR), the electrical conductivity (*EC*) was measured with a portable conductivity meter (COND 330i / SET), and a piezometric levels by piezometric probe. Two samples has been collected from the same place, one collected for bacteriological analysis in sterile glass bottles, and the second one for chemical analysis in 500 cm^3 polyethylene bottles, which were well washed in laboratory with the distilled water, and cleaned several times by the pumped water before sampling. All water samples were immediately cooled to 4°C in portable icebox and transferred to the laboratories. The chemical analysis for major ions were performed by protocols described as follows:

– the nitrate and nitrite (NO_3^- and NO_2^-) were determined colorimetrically by continuous flow analysis (Skalar method) [ISO 13395];
– the ammoniacal nitrogen ($NH4^+$) was determined colorimetrically by continuous flow analysis (Skalar method) [ISO 11732];
– the orthophosphate ($H_2PO_4^-$) was determined by continuous flow analysis (CFA) cited in AFNOR [ISO 15681-2].

The bacteriological analysis was performed immediately after sampling in the provincial laboratory of envi ronmental hygiene of Berkane. The analysis includes: total coliforms (TC), faecal coliforms (FC) and faecal streptococci (FS) according to norms ISO 9308-1, ISO 9308-1 and ISO 7899-2 respectively:

– enumeration of total coliform bacteria per 100 cm^3, using the membrane filtration (0.45 μm) and culture on Tergitol agar TTC 7 agar 24 h at 37°C;
– enumeration of faecal coliform bacteria per 100 cm^3, using membrane filtration (0.45 μm) and culture on Tergitol agar TTC 7 agar 24 h at 44°C;
– enumeration of faecal streptococci bacteria per 100 cm^3, using membrane filtration (0.45 μm) and culture on Slanetz Bartley agar 24–48 h at 37°C.

Some results are presented by thematic maps, using geographical information system (GIS). Mapping of the piezometric levels was performed by Surfer v14 software. It is worth to note that during the field surveys, we noticed that many rural areas were not supplied with drinking water and others did not have accessibility to any sewer network. Thus, the wastewater was discharged into ground via septic tanks and in some cases was discharged to the soil surface which may results in serious public health concerns.

RESULTS AND DISCUSSION

PHYSICAL AND CHEMICAL PARAMETERS

Electrical conductivity (*EC*)

The current levels of the groundwater salinity of Triffa Plain, and their intra-annual variability during the year 2016 were assessed by measuring the *EC* which provides information on the degree of mineralization of the waters. The *EC* values ranged between 800 and 8 940 $\mu S \cdot cm^{-1}$ during the wet period (Fig. 3a) and between 900 and 9 100 $\mu S \cdot cm^{-1}$ during the dry period (Fig. 3b).

The high mineralization rates are related to the lithological nature of the reservoir which is strengthened by the effect of intensive irrigation in several areas of the plain, on both sides of the Hassi-Smia flexure [FEKKOUL *et al.* 2013]. The highest levels of *EC* were recorded near the Ouled Mansour hills, as in the spring water of Ain-Zebda (S21) and the well (P30) with an *EC* recorded of ca. 8 300 $\mu S \cdot cm^{-1}$and 9 100 $\mu S \cdot cm^{-1}$ respectively during the dry period. The well (P35), representing the zone situated to the North-East of Berkane measured 7 590 $\mu S \cdot cm^{-1}$during the same period. In Slimania, Madagh, and going towards outlet sources of Ain-Beida (S17) and Ain-Zerga (S18), situated in the North-West of the plain, and in the area in the North of Café Maure, the *EC* ranged from 3 000 to 5 700 $\mu S \cdot cm^{-1}$.

In contrast, the *EC* below 2 700 $\mu S \cdot cm^{-1}$ were recorded in the area parallel to the Cheraa River, Café Maure, the area located at North-West of Ahfir and in the Reggada zone (P37) with an *EC* ranging from 800 $\mu S \cdot cm^{-1}$ to 900 $\mu S \cdot cm^{-1}$ which represented the lowest salinity recorded in the study.

Nitrate, nitrite, ammonium and orthophosphate concentrations

Phosphorus and nitrogen are macronutrient that plays an important role in improving agricultural production. World consumption of fertilizers is estimated at ca. 85 mln t of nitrogen and 15 mln t of phosphorus [ROY *et al*. 2006]. By 2020, the consumption of mineral fertilizers will reach 114 mln t of nitrogen fertilisers and 21 mln t of phosphorus per year [BUMB, BAANANTE 1996]. It is worth to note that Moroccan consumption of nitrogen fertilizers is estimated at ca. 51 $kg \cdot ha^{-1}$ [WANZALA 2007].

Triffa Plain is one of the most important and productive agricultural areas in Morocco. This region is well known by intensive agricultural systems, producing citrus, industrial crops such as sugar beet, conventional crops such as cereals, vegetables and forage crops. Farmers use different fertilizers such as ammonium nitrate 33.5%, mono ammonium phosphate (MAP), ammonium sulphate, super triple phosphate, potassium sulphate, NPK (18, 46, 0 kg) and Solupotasse. Such use of fertilizers has led to the

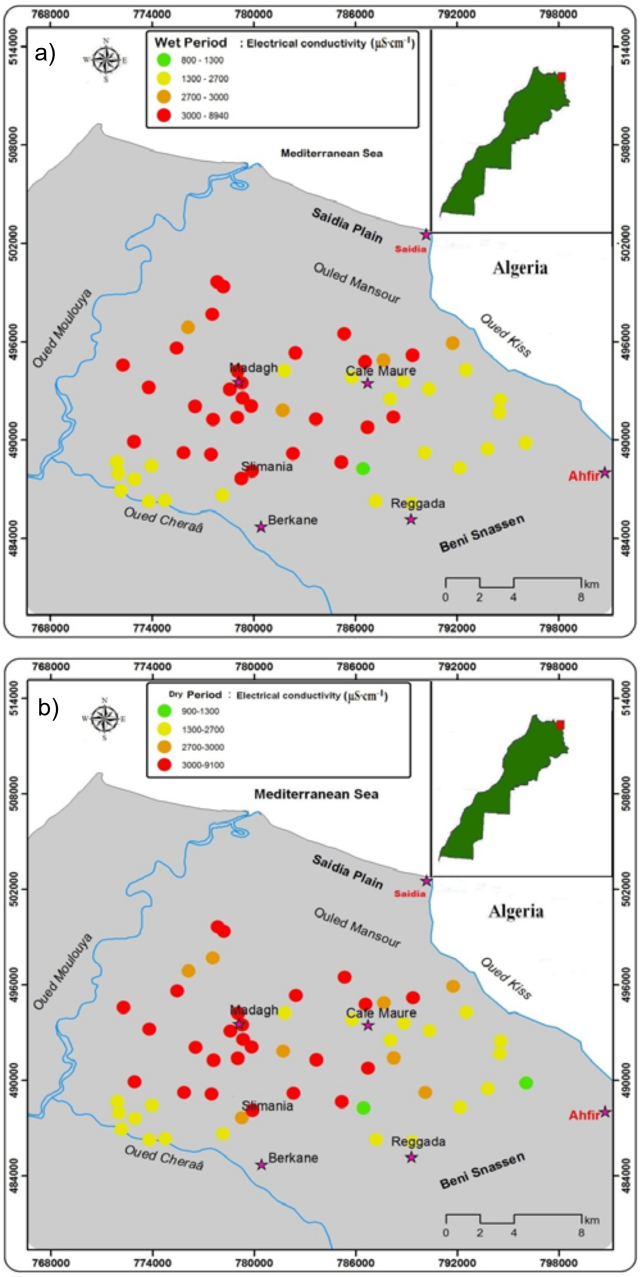

Fig. 3. Spatial variation of electrical conductivity (μS·cm^{-1}) in groundwater of Triffa Plain during: a) the wet period 2016, b) the dry period 2016; source: own study

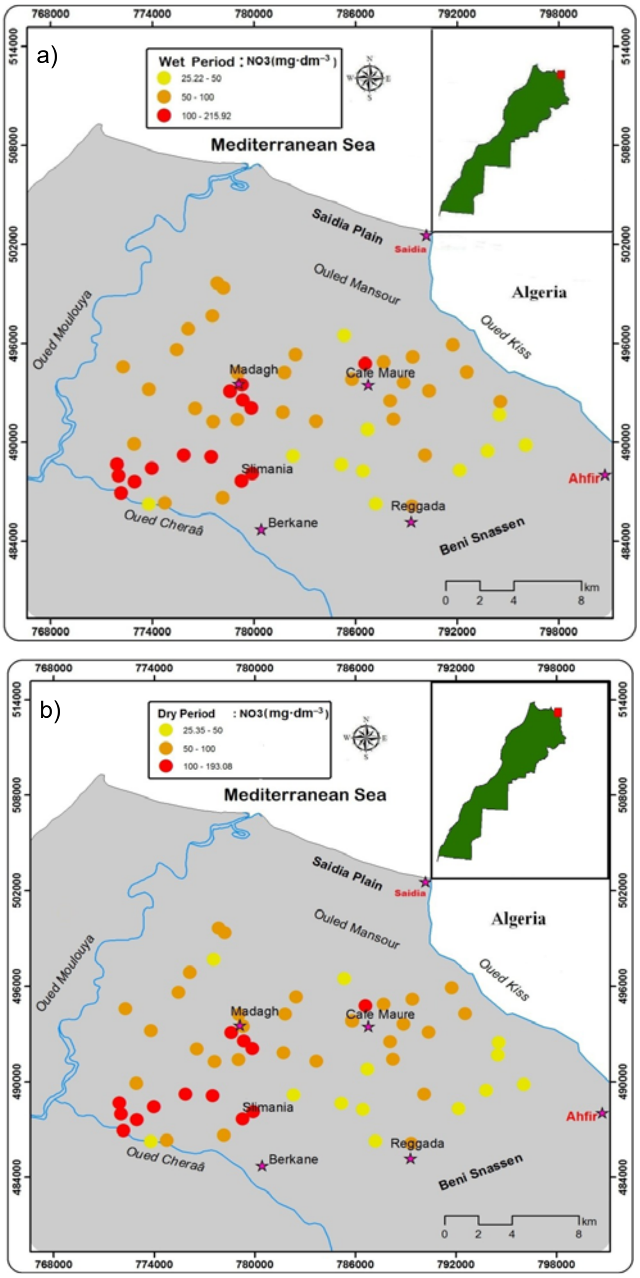

Fig. 4. Spatial variation of nitrate (mg·dm^{-3}) in groundwater of Triffa Plain during: a) the wet period 2016, b) the dry period 2016; source: own study

pollution of the groundwater in this region. This study evaluates the nitrate level and assesses its impact on the quality of the groundwater taking into consideration time and space.

Nitrate. The nitrate levels in the unconfined aquifer varied from 25 (well P48) to 216 mg·dm^{-3} (well P11) during wet period 2016 (Fig. 4a) and from 25 (well P48) to 193 mg·dm^{-3} (well P11) during dry period 2016 (Fig. 4b). In 78% of the samples, the registered values exceeded the critical level of 50 mg·dm^{-3} as fixed by standards of the World Health Organization (WHO) for drinking water.

The spatial variation maps of nitrate in groundwater of Triffa Plain (Fig. 4) showed that the highest levels of nitrates contamination of the groundwater were observed for the study area in south-western part of Slimania and bordering areas of the Cheraa River, for the springs in the north-western area (Ain-Beida S17, Ain-Zerga S18, and Ain-Zebda S21), in the north-eastern area (Café Maure), and in the centre part of the aquifer (Madagh). In all other areas, in the South of the plain with the wells: P35, P38, P36, P37 and P46, and in south-eastern part of the plain, in the zone situated between Reggada and Ahfir, the concentrations of nitrate recorded ranged between 25 and 45 mg·dm^{-3}.

During the year 2016, 24.5% of samples showed nitrate concentrations superior to 100 mg·dm^{-3}, 53.6% of samples had concentrations ranging from 50 to 100 mg·dm^{-3}, and in 21.8% of samples the concentrations were below 50 mg·dm^{-3}.

By comparing the spatial distribution map of nitrate with that of piezometric levels (wet period 2016) – (Fig. 5), it will be noted that the zones of high contamination by nitrates, are generally either with shallow water depths, or with more permeable soil.

The nitrate concentrations of groundwater in each sampling point, either well or spring water, varied generally dependent on the wet or the dry period (Fig. 6). They decreased in 73% of samples (40 wells or springs) during the dry period 2016, by values ranging from 0.5 to 35 mg·dm^{-3}, while they increased in 27% of cases (15 samples) by values ranging from 0.13 to 13 mg·dm^{-3} except for the well P53 where this value reached 43.9 mg·dm^{-3}. The rise of nitrate concentration in groundwater can be explained by the fact that due to precipitations during the wet period, the nitrate is highly leached into the deeper layers of soil and then to groundwater in one hand and as consequence to the use of mineral and organic fertilizers during this period.

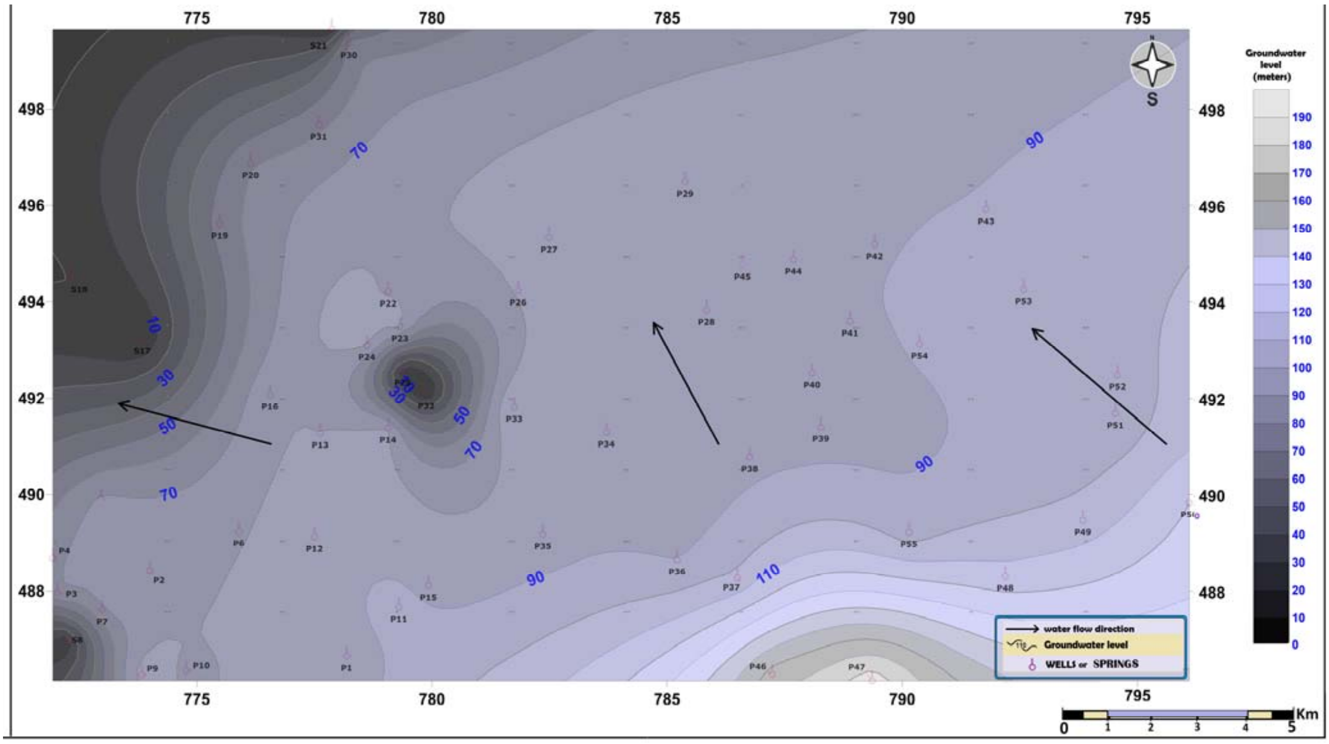

Fig. 5. Map of piezometric levels (in m above the average sea level) and flow vectors, Triffa Plain, wet period 2016; source: own study

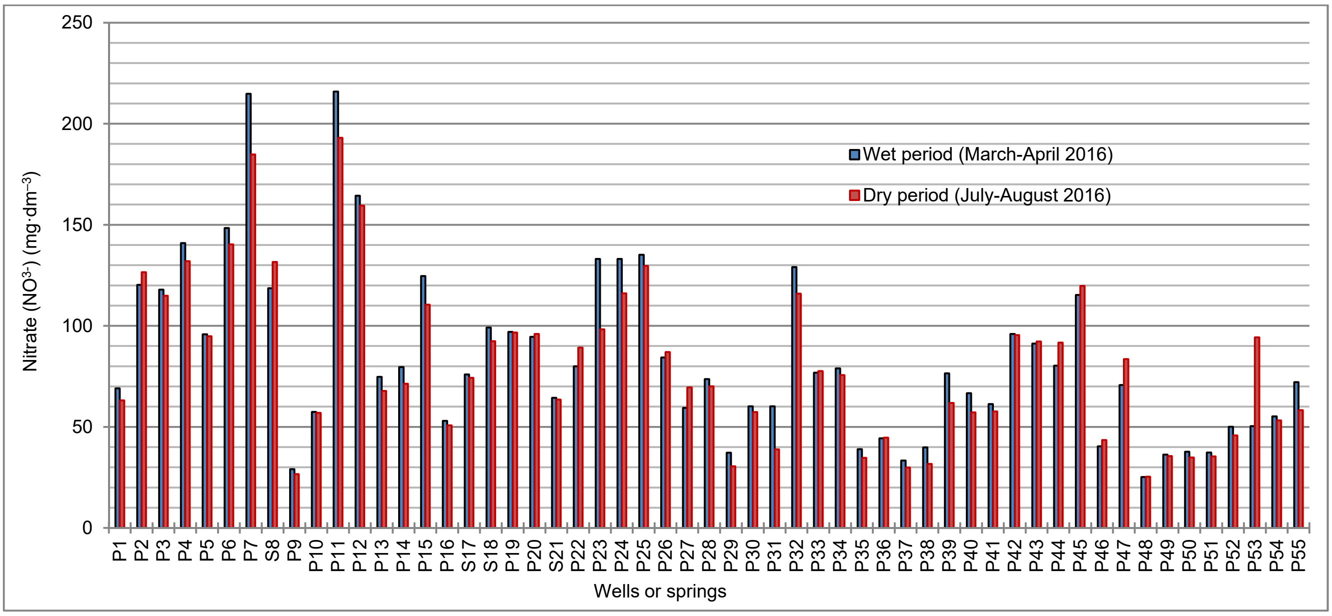

Fig. 6. Variation of nitrate concentration in groundwater sampled during wet and dry periods 2016; P1–P55 = sampling points as in Fig. 2; source: own study

However in dry period, in areas where the water table is near to the soil surface or where the soil is more permeable, and the irrigation is gravitational and intense as in the case of some abundant late vegetable cultures which receive high quantities of nitrogen fertilizers, the leaching of nitrates is also important as in the case of wet period. This might be one of the reasons for the slight augmentation of their concentrations recorded in 27% of samples.

The result reported herein shows that nitrate concentration levels in Triffa Plain groundwater rose continuously from 1997 up today as reported by BENKADDOUR [1997], FETOUANI *et al*. [2008], FEKKOUL *et al*. [2013] and YAHYA *et al*. [2015].

This increasing nitrate pollution is most probably due to the increase in the quantities of nitrogen fertilizers and manure used to increase the agricultural productivity to meet the need of the growing population. Indeed, from the year 2000 until 2016, the surfaces of citrus fruits have passed from 11 205 ha to 17 229 ha, the vegetable crops surfaces rose from 5 548 ha to 6 296 ha and the surface of industrial crops of which sugar beet roses from 1 003 ha to 1 645 ha [ORMVAM 2016].

Nitrite. Nitrite is the ionic intermediate state between nitrate and ammonia nitrogen, which explains their low quantities encountered in the aquatic environment. Nitrites result from an incomplete oxidation of organic matter.Their high levels are due to agricultural runoff, refuse dump runoff or contamination with human or animal wastes where the nitrate is reduced to give nitrite by sulphite-reducing anaerobic bacteria. They can also be related to the bacterial oxidation of ammonia [BENGOUMI *et al.* 2004]. In this study, we report that nitrites content of groundwater samples from Triffa Plain area during the wet period did not exceed the normal rate set at 0.1 $mg \cdot dm^{-3}$ by WHO for drinking water, except for the wells P6, P20 and P55 where values were 0.14, 0.27 and 0.9 $mg \cdot dm^{-3}$ respectively. During the dry period, the nitrite concentrations observed were below 0.04 $mg \cdot dm^{-3}$ for all samples except for the well P35 where concentration was 0.24 $mg \cdot dm^{-3}$. The nitrite concentration reported herein were generally slightly higher than those reported by FETOUANI *et al.* [2008] concerning the groundwater of the Triffa Plain where nitrite concentrations ranged from 0.0009 and 0.13 $mg \cdot dm^{-3}$.

Ammonium. Most ammonium concentrations were below 0.02 $mg \cdot dm^{-3}$ during the wet period except for the wells P52, P53, P47, P35, P50, P54, P48, P51 where the concentrations were higher, but did not exceed the limit set by WHO for drinking water, with values of 0.06, 0.09, 0.10, 0.14, 0.16, 0.20, 0.25, 0.32 $mg \cdot dm^{-3}$ respectively. The content of ammonium recorded in this study was slightly higher than those reported by FETOUANI *et al.* [2008] about the same region. During the dry period all wells showed ammonium concentrations below 0.02 $mg \cdot dm^{-3}$. The absence of ammonia nitrogen usually reflects a process of high level of biodegradability by using biological processes like the nitrification-denitrification process [GRADY *et al.* 2011; SKRZYPIEC, GAJEWSKA 2017; WEF 2005] which leads to ammonia nitrogen removal. It has to be noted as well that the ammonium may be partially fixed in the soil and does not contaminate groundwater [ERSKINE 2000].

Orthophosphates. The orthophosphate concentrations found in wells and spring waters samples were below 0.02 $mg \cdot dm^{-3}$, except for the well P55 where the concentration was 0.24 $mg \cdot dm^{-3}$ during the wet period and the well P30 where the concentration was 0.19 $mg \cdot dm^{-3}$ during the dry period.

These values, below the maximum allowable value by WHO for drinking water, can be explained by the fact that orthophosphates are easily fixed by the soil, mainly by iron oxides and aluminium [HALIM *et al*. 2009].

RESULTS OF BACTERIOLOGICAL ANALYSIS

The most frequent type of groundwater contamination in rural areas is faecal pollution. The latter is due to livestock, inadequate human waste disposal systems [BARNES, GORDON 2004; CONBOY, GOSS 2001] and to various other sources [MAHLER *et al.* 2000]. It is important to evaluate this faecal contamination, especially if this groundwater is used for domestic purpose without any treatment systems [ATHERHOLT *et al*. 2003].

In addition to its agricultural wealth, the Triffa Plain is habitat for a large rural population represented by inhabitants scattered along the boundaries of farms or grouped in small villages or towns. Despite the efforts of the state to provide this population with drinking water during the last decade, there are still many homes without access to this source of life. This forces a large part of rural population to rely on raw groundwater (springs or wells) for its drinking and domestic water supply.

The lack of sewage networks, even in some towns, forces the population to install septic tanks. The latter are sometime located too close to a drinking water well and thus bacteriological, viral and parasitic contaminants from the wastewater can end up in drinking water that put the public's health at risk. In the rural commune of Madagh, which is constituted by 13 locations of 12 096 inhabitants spread over an area of 120 km^2, only 19% of the population and 8% of locations are connected to the sewage system. Whereas in the town Café Maure of a surface of 109 km^2 and 11 765 inhabitants, and in the other areas of the Triffa Plain, as Slimania and bordering areas of the Cheraa River, the wastewater facilities are absent [PCD 2012–2016]. Thus, it was important to study the Triffa groundwater microbiology.

Apart few exceptions, the faecal pollution indicators are not hazardous, but their presence in groundwater is a sign of probable contamination by dangerous pathogenic bacteria for human health. Indeed, the presence of faecal coliforms may indicate the presence of enteropathogenic microorganisms, such as Salmonella and Norwalk virus [CRAUN *et al.* 2002]. In Morocco, waterborne diseases are one of the leading causes of death among children, particularly in rural areas (45% of total population) [LAHBABI, ANOUAR 2010]. Thus, it is necessary to assess the rate of contamination and to evaluate the importance of different factors of pollution.

In regard to faecal pollution indicators, the results of bacteriological study of selected groundwater samples (55 wells and springs) sampled in wet and dry period are presented by GIS maps.

Total coliforms (TC). Almost all sampled wells and springs were contaminated with TC. Their quantities differed between wells and water springs, and depended on the sampling period, wet or dry. We noticed that the rate of TC increased during the dry period. During the wet period of 2016, TC values varied from 0 CFU·(100 cm^3)$^{-1}$ in wells and spring waters (S17, S18, P37 and P54) and 9 000 CFU·(100 cm^3)$^{-1}$ (P50) – (Fig. 7a), with an average of 708.5 CFU·(100 cm^3)$^{-1}$, whereas during the dry period of the same year, the TC values varied from 0 CFU·(100 cm^3)$^{-1}$(P55) and 14 000 CFU·(100 cm^3)$^{-1}$ (P36) – (Fig. 7b) with an average of 1 500 CFU·(100 cm^3)$^{-1}$.

Faecal coliforms (FC). FC are indicators of faecal contamination and are also present in almost all sampled wells and springs. Their rates were higher during the dry period and in general, their quantities are less when compared to the TC.

During the wet period, FC values ranged between 0 CFU·(100 cm^3)$^{-1}$ in springs and the wells (P6, P12, S17, S18,P25, P37, P39, P48, P54) and 3 550 CFU·(100 cm^3)$^{-1}$– (P35) (Fig. 8a), with an average of 270 CFU·(100 cm^3)$^{-1}$, whereas during the dry period the FC values ranged between 0 CFU·(100 cm^3)$^{-1}$ – (P55) and 5 000 CFU·(100 cm^3)$^{-1}$ – (P11 and P36) (Fig. 8b), with an average of 637.5 CFU·(100 cm^3)$^{-1}$.

Faecal streptococci (FS). FS are indicators of faecal contamination and are also present in almost all wells and water springs, but generally with smaller rates than FC. In wet period, FS values ranged between 0 CFU·(100 cm^3)$^{-1}$ – (P12, P14, S17, S18, P25, P37 and P44) and 5 000 CFU·(100 cm^3)$^{-1}$ – (P35) (Fig. 9a), with an average of 216.9 CFU·(100 cm^3)$^{-1}$. In dry period, the FS values varied between 0 CFU·(100 cm^3)$^{-1}$ – (P6, S17, S18, P25, P31, P38, and P55) and 2 000 CFU·(100 cm^3)$^{-1}$ – (P36) (Fig. 9b), with an average of 146.2 CFU·(100 cm^3)$^{-1}$.

Almost all groundwater of unconfined aquifer of Triffa Plain sampled in this study showed a bacteriological contamination during the wet and the dry periods, with seasonal variation in the concentration of bacteria indicators as result of faecal pollution except for the spring waters Ain-Beida (S17), Ain-Zerga (S18) and well (P37) during the wet period and well (P55) during the dry period, where no contamination was recorded. The presence of both FC and FS provided strong evidence of faecal contamination [ATHERHOLT *et al*. 2003] which was probably due to the infiltrations of wastewater produced by human and/or animal. These results indicated the deterioration of groundwater quality.

The growing population and the multiplication of slums along the rural areas, without any urban plan, generate a proliferation of septic tanks systems as the only sewage facilities what cause the increase of the contamination

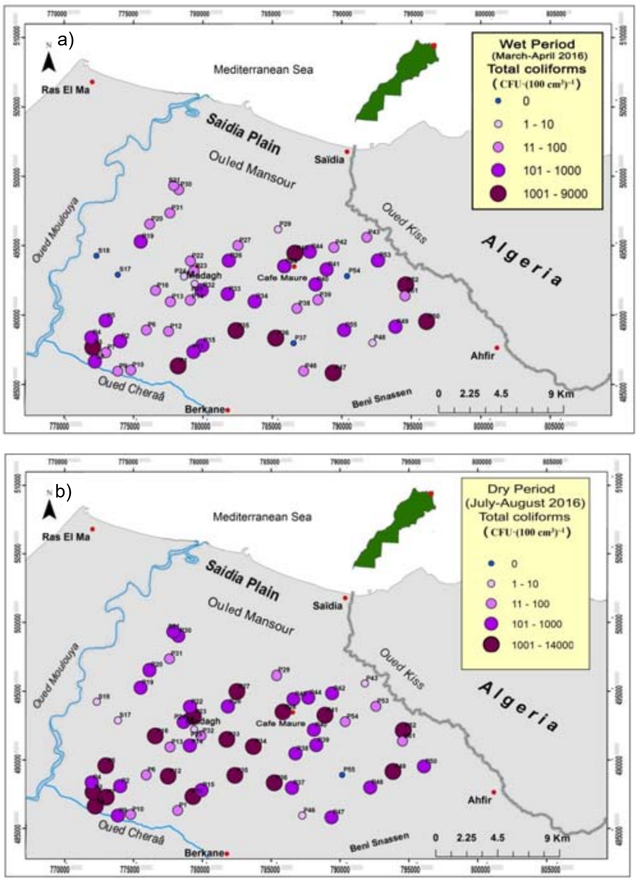

Fig. 7. Distribution of total coliforms concentrations (CFU·(100 cm^3)$^{-1}$) in groundwater of Triffa Plain sampled during: a) the wet period 2016, b) the dry period 2016; source: own study

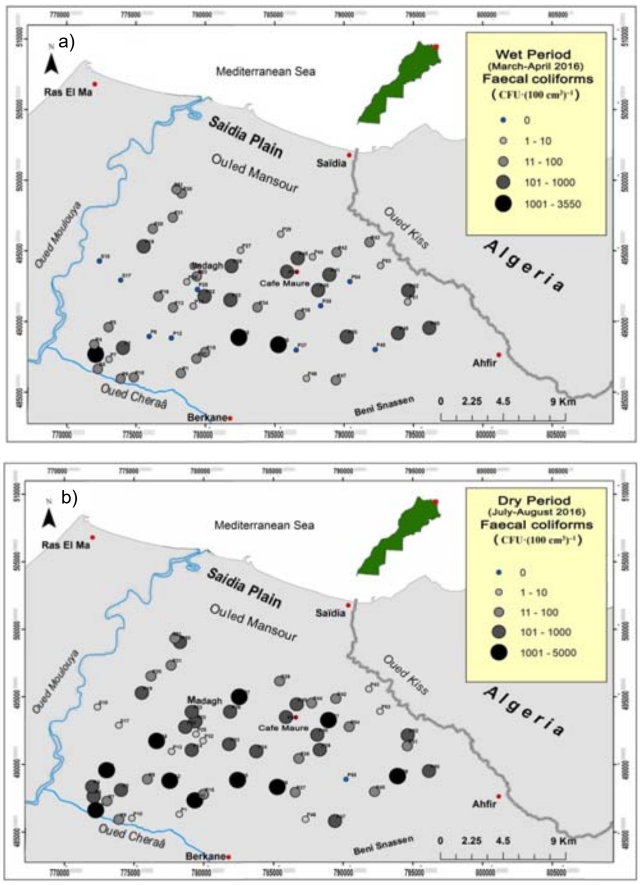

Fig. 8. Distribution of faecal coliforms concentrations (CFU·(100 cm^3)$^{-1}$) in groundwater of Triffa Plain sampled during: a) the wet period 2016, b) the dry period 2016; source: own study

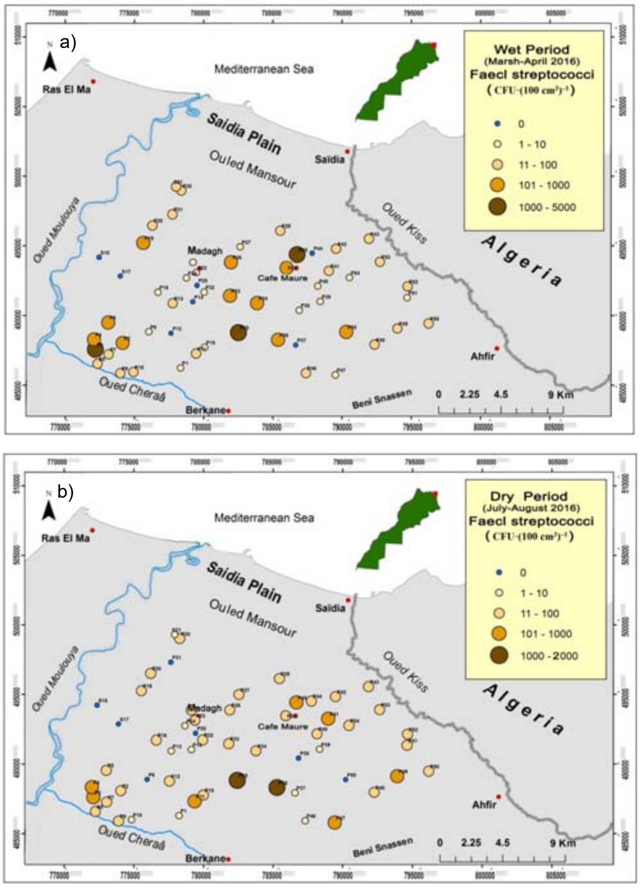

Fig. 9. Distribution of faecal streptococci concentrations (CFU·(100 cm^3)$^{-1}$) in groundwater of Triffa Plain sampled during: a) the wet period 2016, b) the dry period 2016; source: own study

of the groundwater. This is the case of several locations of rural communes of Triffa Plain, such as Café Maure, Madagh and the South-West area of Triffa Plain where almost all wells and springs have high FC concentrations. The values varied from 11 to 3 550 CFU·(100 cm^3)$^{-1}$ during the wet period whereas in dry period the concentrations were greater and varied from 100 to 5 000 CFU·(100 cm^3)$^{-1}$. Also, the FS concentrations ranged from 11 to 5 000 CFU·(100 cm^3)$^{-1}$ in wet period and from 11 to 1 000 CFU·(100 cm^3)$^{-1}$ in dry period. These high levels of indicators of faecal contamination of groundwater in these areas were mainly due to domestic wastewater and to the use of manure by farmers. In addition, raw sewage is dumped untreated into the Cheraa River which may contaminate groundwater by infiltration in adjacent areas. Adding to this the shallow depths of the aquifer at these levels facilitate this contamination.

In deep wells situated far from towns (P35 and P36) as in the South and South-East of the plain, the high contamination can have other origins. Their high levels of contamination by FC and FS during the two periods of sampling were probably due to the fact that these wells were mainly exposed to direct contamination by the waste of livestock and avifauna through the mouth of the wells. The concentrations of TC and FC increased in the dry period as result of the rise in temperature and nutrients which promoted their multiplication, whereas the concentration of FS decreased during the same period. Persistence of bacteria in the aquatic environment depends on various parameters, such as nutrients and temperatures [LECLERC *et al*. 2002]. The prevalence of FS, with rapid die-off, showed either recent contamination by faecal material or high level of contamination possibly associated with organic matter [CONBOY *et al*. 2001].

CONCLUSIONS

Water quality is managed and assessed in terms of bacteria indicators levels and physico-chemical characteristics. The results obtained, showed that groundwater quality of Triffa aquifer becomes deteriorated. The contaminations of wells and spring waters by nitrates during the wet and the dry periods showed that their levels exceed the standard value fixed by WHO for drinking water in ac. 78% of samples. Furthermore, the nitrate contamination of groundwater increased during the wet period in 73% of cases as result of leaching by rainfall and irrigation during this period of high agricultural activity. The deterioration of the groundwater quality of Triffa Plain is also characterized by the salinization phenomena. Indeed, the monitoring of electrical conductivity showed that the groundwater was well mineralized.

The investigation showed also that almost all wells and springs were contaminated by bacteriological factors such as TC, FC or FS. We suspected that intensive irrigated agriculture was the main cause of the diffuse nitrate pollution as result of excessive and repeated application of chemical nitrogen fertilizers and manure, whereas, the groundwater contamination by faecal germs was the result of untreated sewage septic tanks or animal wastes. It should also be noted that the presence of stables of cattle, sheep and avifauna and the use of their waste as fertilizer can lead to contamination of groundwater, by nitrates and pathogenic bacteria, especially in areas with shallow groundwater.

Local authorities should monitor at regular intervals the level of contamination and point out any contaminated well or spring not fit for human ingestion and advise the local population on the risks associated with the consumption of such contaminated water. They also should secure drinking water supply for the population living in this area in order to avoid any health concerns.

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Fizyczna, chemiczna i bakteriologiczna ocena jakości wody gruntowej na nawadnianej Równinie Triffa w północnowschodnim Maroku

STRESZCZENIE

Przeprowadzono fizyczną, chemiczną i bakteriologiczną ocenę jakości wód gruntowych, aby wykazać wpływ rolnictwa i innych form działalności człowieka na Równinie Triffa w północnowschodnim Maroku. Poziom zanieczyszczeń oceniono przez analizę przewodnictwa elektrolitycznego, stężeń azotanów i azotynów, jonów amonowych, ortofosforanów oraz wskaźników zanieczyszczeń pochodzenia kałowego.

Próbki wody pobrano z 55 stanowisk dwukrotnie – w czasie pory suchej i deszczowej w 2016 r. Wyniki analiz wskazują, że większość próbek wody była silnie zanieczyszczona. Przewodność elektrolityczna właściwa zmieniała się od 800 do 9 100 $\mu S \cdot cm^{-1}$. Stężenie azotanów (V) wynosiło od 25 do 216 $mg \cdot dm^{-3}$, a w 78% próbek stwierdzono stężenie większe niż wartość krytyczna równa 50 $mg \cdot dm^{-3}$. Stężenie azotanów (III) były nieco większe w porze deszczowej w 73% badanych przypadków. Stężenie azotanów (III) rzadko przekraczało normy ustalone przez WHO, osiągając maksymalnie 0,90 $mg \cdot dm^{-3}$. Stężenie jonów amonowych i ortofosforanów nie przekraczało wartości normatywnych.

Badania wykazały silne skażenie wód podziemnych mikroorganizmami, co przejawiało się dużym zagęszczeniem całkowitym bakterii coli (0–14 000 $jtk \cdot (100\ cm^3)^{-1}$), bakterii coli pochodzenia kałowego (0–5 000 $jtk \cdot (100\ cm^3)^{-1}$) i kałowych streptokoków (0–5 000 $jtk \cdot (100\ cm^3)^{-1}$). Wyniki te potwierdzają wpływ osadników gnilnych, dopływu nieoczyszczonych ścieków i stosowania nawozów naturalnych na jakość wód gruntowych.

Słowa kluczowe: *czynniki bakteriologiczne, czynniki chemiczne, czynniki fizyczne, jakość wody, Równina Triffa, ścieki, woda gruntowa*