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Original Research Paper

# Groundwater Contamination by Wastewater in Figuig Oasis (Eastern High Atlas, Morocco)

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## ABSTRACT

The aquifer basin of Figuig is located at the eastern extremity of High Atlas of Morocco. It is a multi-layer aquifer system. The Triassic formation is characterized by clay and the Jurassic formation by the carbonate, while the Quaternary formation is formed by alluvial silts and sands. The present work focuses on the study of salinity and contamination of groundwater by discharges of wastewater into septic tanks in this region. The methodology used was to map the spatial and temporal variation of salinity and to define the spatial extent of the contamination. The results obtained for (1) salinity, (2) bacteriology (faecal and total coliforms), and (3) nitrates and (4) a simulation of contaminant transport using the MODPATH code indicate that the southern zone has high salinity and the south and southeast areas are contaminated by wastewater discharges. For this purpose, the quality of groundwater in the oasis of Figuig deteriorated over time. This work is expected to assist local authorities in developing plans and in reducing the pollution to acceptable levels.

## INTRODUCTION

Protection of groundwater resources or surface water in the developing countries has increased. But, in spite of these efforts, some areas are still in trouble, in particular in oases or small towns where there is no sewerage network. Wastewater is discharged into septic tanks (one well which occupies the centre of each house; the average depth varies from 6 to 10 m), which is the case for Figuig oasis. These releases are a great danger to groundwater resources and thus the population.

Economic development in arid and semi-arid regions (Figuig oasis), particularly the growth of agriculture, has meant that groundwater is increasingly demanded by farmers due to increase in agricultural land and homes, and has therefore, led to increase in water exploitation operations. This is partly due to the abandonment of the land where the water has high salinity (palm trees), as well as to lower levels of sources used for irrigation.

Determination of the spatial distribution and evolution of salinity, piezometry, and nitrates over time, the identification of bacteriological contamination, and simulations using a numerical model of transport are the goals of this study. Several researches of this kind have aimed to study the groundwater contamination, for example Datta et al. (2011), Douagui et al. (2012), El Yaouti et al. (2008), Lamrani Alaoui et al. (2008), Lockhart et al. (2013) and Saber et al. (2014). The WHO (WHO 2000) limit for nitrates is 50 mg/L for drinking water. Nitrates are related to diabetes as well as oesophageal and gastric cancer, because of the reaction of amines with nitrates in food to form carcinogenic nitrosamines. It is also well documented that faecal contamination of drinking water causes many epidemics because the risk of epidemics is correlated with the incidence of faecal contamination (Ohou et al. 2008, Tallon et al. 2005). Faecal bacteria are used as indicators of faecal contamination and therefore the presence of pathogenic organisms. Water chemistry, pH, salinity, soil and the nature of the hydrodynamic characteristics (porosity and hydraulic conductivity) of rock influence the concentration and spatial distribution of a contaminant. Therefore, a geologic site survey study (Jilali 2014a) and a study of the vulnerability of groundwater (Jilali et al. 2014) were recently performed.

The approach used in the present work provides a better understanding of the quality of groundwater in the oasis of Figuig by studying the piezometry, salinity, bacteriology, and nitrates and carrying out transport simulations of a contaminant using a numerical model. The presence of contamination in the area is indubitable. Possible sources of nitrates in groundwater in decreasing order of importance are: (1) domestic wastewater, (2) agriculture (nitrogen fertilizer), (3) livestock excrement, and (4) cemeteries.

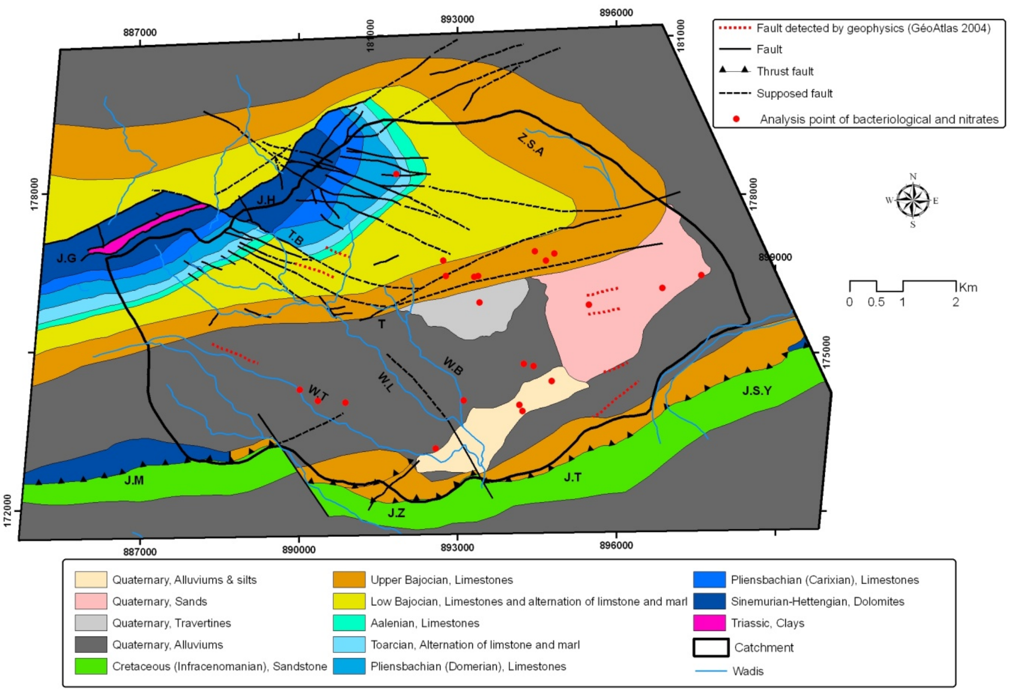


Fig. 1: Geographic and geology of the study area. J. G: Jbel Grouz; J. H: Jbel el Haïmeur; Z.S.A: Zrigat Sidi Abdelkader; T.B: Tiniet el Bida; T: Tachroumt; W.B: Wadi Bouchalikane; W.L: Wadi Lakbir; W.T: Wadi Tazoukart; J.M: Jbel Mélias; J.Z: Jbel Zenaga; J.T: Jbel Tarhla; J.S.Y: Jbel Sidi Youssef (Jilali et al. 2015, Jilali & Zarhloule 2014).

## MATERIALS AND METHODS

### Study Area

Figuig oasis is located at the eastern extremity of High Atlas. In the geological and hydrogeological setting, the dominant formations are Jurassic carbonates occupying the mountains (anticlines) and Quaternary alluvium in the plains (synclinal) of Figuig (Fig. 1). Recently, a more detailed geologic study was performed (Jilali 2014a). The highly fractured geological formations in the region play an important role in the circulation of groundwater (Jilali 2014a, 2014b).

Climatic conditions are arid, with an annual average rainfall calculated over a period of 76 years (1935-2011) of 120 mm. The distribution of rainfall from year to year is very variable; it never rains the same amount in the same month. The average temperature can vary between 3°C and 45°C or even 48°C. The evaporation of rainwater is very high, and can reach 80% of the total rainfall (Jilali 2014a, Jilali 2014b).

### Sampling of Groundwater and Data Collection

**Piezometry and salinity:** The correlation between salinity and electrical conductivity has been established by several authors (Lu et al. 2004, Richards 1954). Historical measures of salinity (mg/L) and electric conductivity for two years (2010-2011) were used to calculate a coefficient of correlation between them. The data of the electrical conductivity and hydraulic head for 1995 and 2004 originate from different organizations (ABHM 2004, Assou 1996). Four measurement campaigns were carried out: (1) the July 2008 campaign only concerned the piezometry, (2) the June 2010 campaign involved measurement of hydraulic head and salinity, and (3) the November 2011 and February 2012 campaigns involved measurement of salinity. The IDW geostatistical modelling method allowed the different maps of salinity to be traced.

**Bacteriology and nitrates:** A measurement campaign was performed in December 1995 for a physico-chemical analysis of groundwater in the oasis of Figuig (Assou 1996). Recently, two measurement campaigns at 22 points (7 sources, 6 wells, 9 boreholes) were completed in November 2011 and February 2012. Parameters measured *in situ* were the pH, temperature (°C), salinity (mg/L), electrical conductivity (µS/cm), turbidity (NTU), and dissolved oxygen (mg/L). The samples were collected over two days in sterile bottles stored at 4°C in cold boxes until they arrived at the laboratory, and analyses were performed on the same day. Further details of the sampling method adopted are as follows:

1. The choice of sampling points was fixed according to the main directions of groundwater flow, taking into ac-

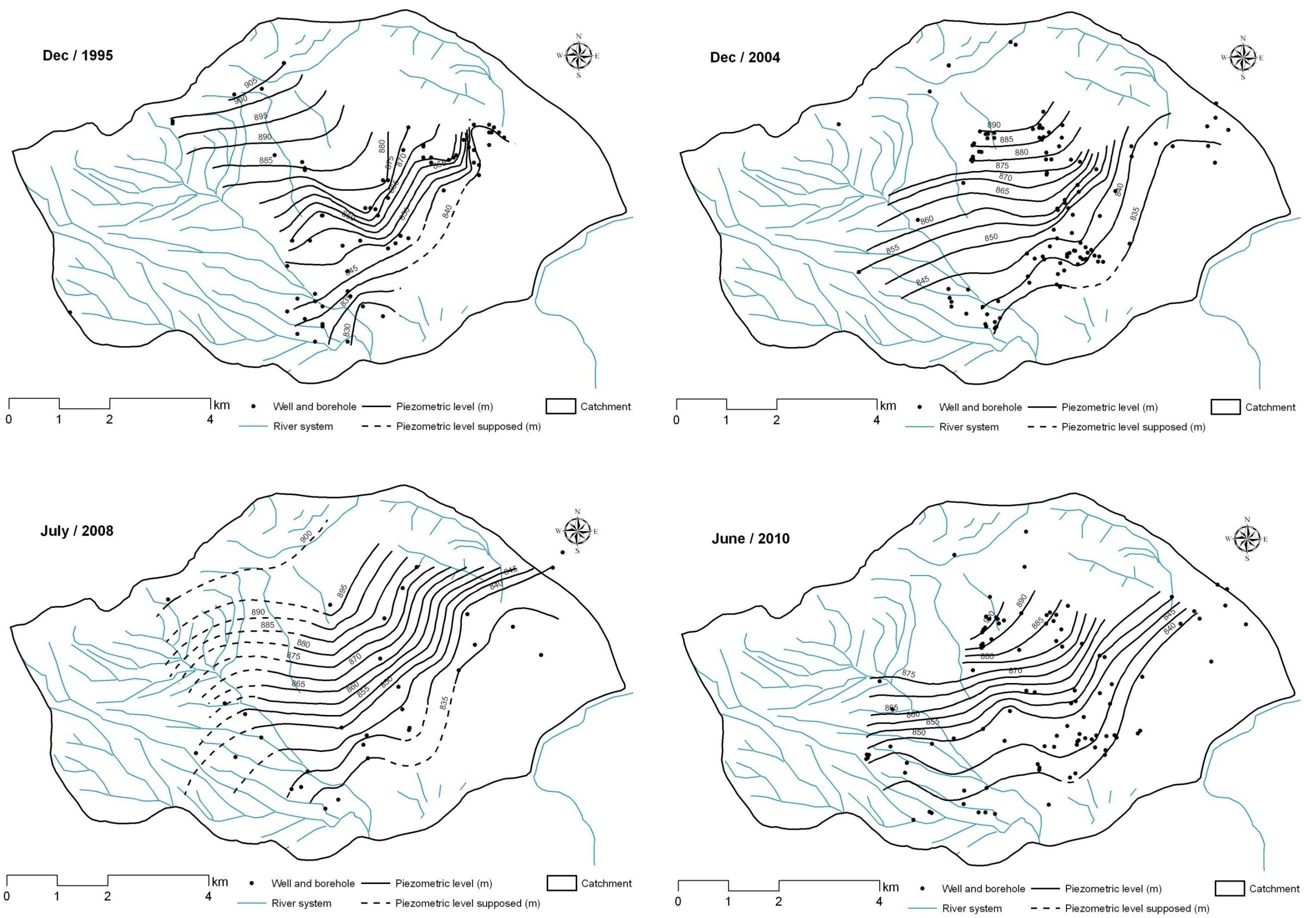


Fig. 2: Piezometric maps for 1995, 2004, 2008 and 2010.

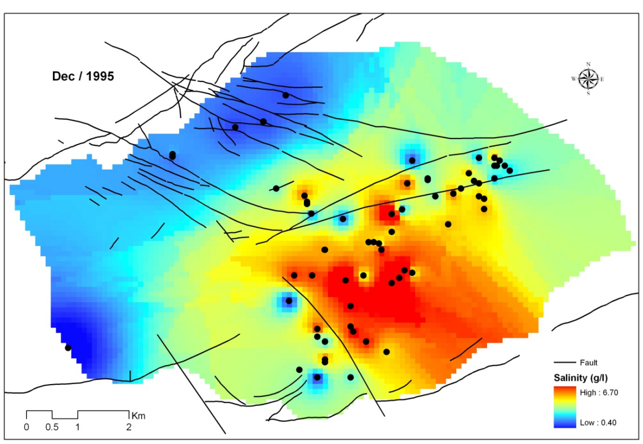


Fig. 3: Salinity in December 1995 (black point: borehole).

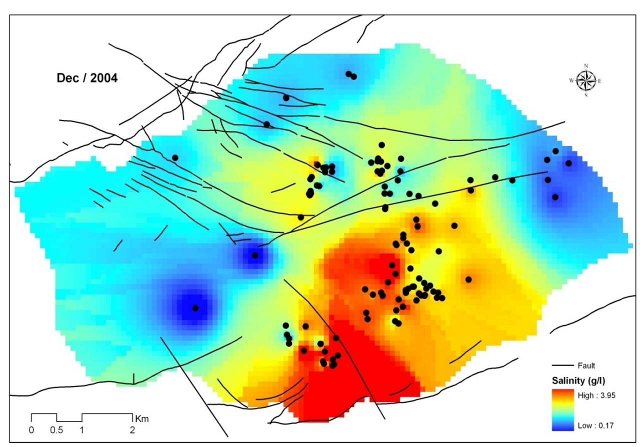


Fig. 4: Salinity in December 2004 (black point: borehole).

count, of course, the positions of agglomerations and agricultural areas.

2. The targeted items were operational (water is pumped every week).
3. Sampling was performed after stabilization of the parameters measured *in situ* for a minimum duration of 20 minutes.
4. Bacteriological and nitrate analyses were performed after 4 hours of sampling.
5. Three samples were taken and analysed for each water

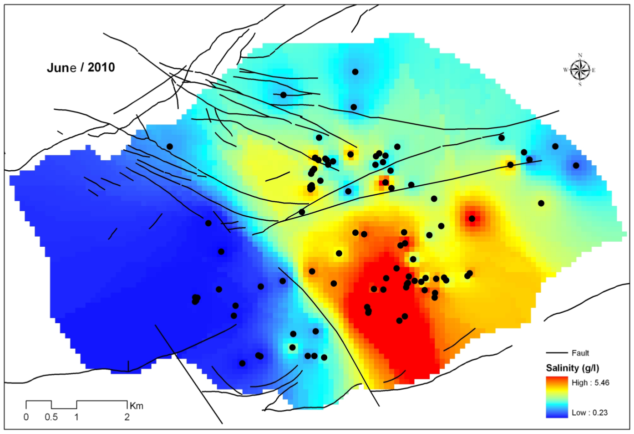


Fig. 5: Salinityin June 2010 (black point: borehole).

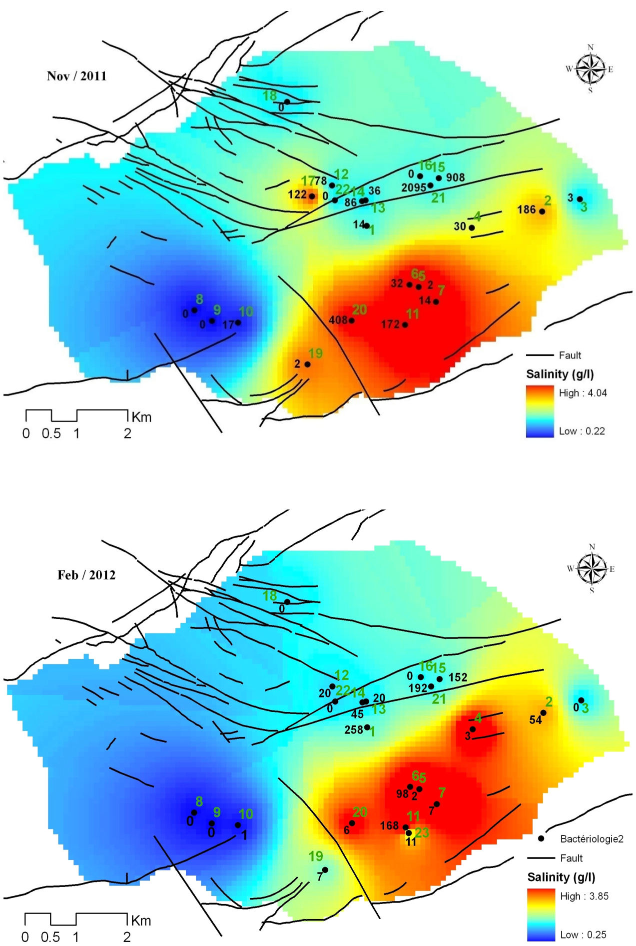


Fig. 6: Salinity and bacteriology in November 2011 and February 2012 (black point: borehole and spring).

point for the identification of faecal (FC) and total coliforms (TC), and a single sample was taken for the analysis of nitrate.

The technique used for the identification of bacterial contamination was based on FC (*E. coli*). A membrane of 45µm was used to filter 100 mL of water. The culture medium was the FC DifcoTM Broth Base. Incubation was performed at 42.5°C for 24 hours. The number of bacteria was determined by colony in 100 mL (CFU/100 mL). For nitrates, the method used was that described by Rodier (Rodier 1984).

**Simulation of transport:** The exploitation of the hydrodynamic model (Jilali 2009, Jilali 2014a, 2014b) made it possible to follow the evolution of the contaminant over time. Different simulations of contaminant transport were performed, considering advective transport (MODPATH). The movement of the particles (contaminant) has the same effective speed as the groundwater. Therefore, the concentration of the dissolved substances is conservative and is simply conveyed along the flow lines according to the following equation:

$$Ve = q/n_e$$

Where,

Ve: effective velocity (m/s)

q: specific flow (m/s)

$n_e$: effective porosity

Particles were injected into the water table, and the porosity selected was 5%. The simulations are for agglomerations (sources of contamination), of which the oldest was built in 1980.

## RESULTS AND DISCUSSION

**Piezometry and salinity:** The study of the hydraulic head of the water of Figuig aimed to monitor changes in the water table from 1995 to 2010 (Fig. 2). The results of tracing the four piezometric maps show a generalized groundwater flow from north to south and northwest to southeast. The change in the shape of piezometric curves is not very significant from one year to the next. The most important pumping is done by three wells located in the carbonate formations of Lias at Jbel El Haimeur and springs (Khattarat) in the Bajocian formations (Fig. 1). Of these, one borehole and the sources are used for irrigation and the other two boreholes are used for supplying drinking water in the region.

The temperature, pH, dissolved oxygen and turbidity are in the range of 19.6-31°C, 6.84-7.7, 0.12-6.93 NTU and 0.96-4.12 mg/L, respectively. The correlation between the electrical conductivity and salinity deduced from the measurement history of the two years is 0.51 according to the fol-

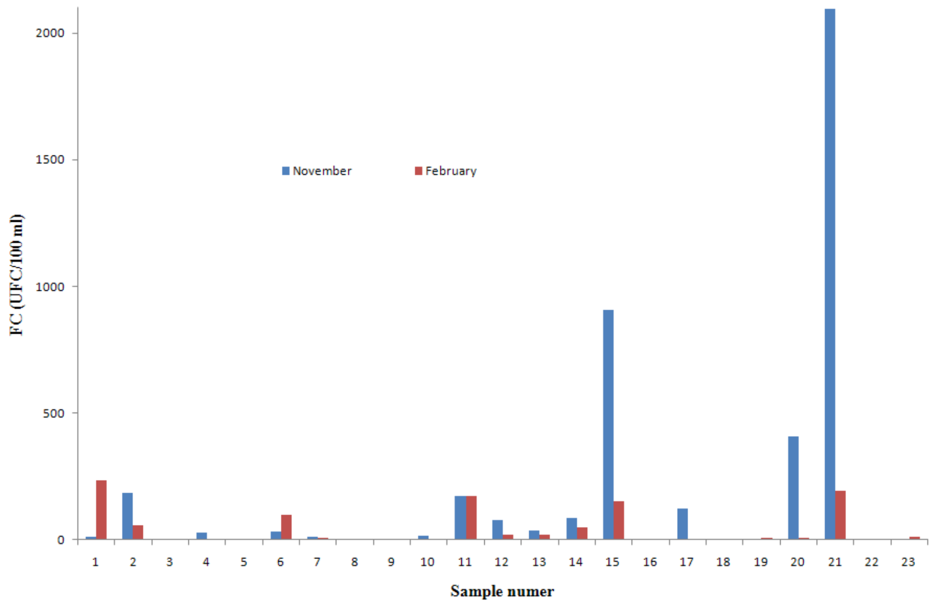


Fig. 7: Abundance of FC in groundwater sampled in November and February.

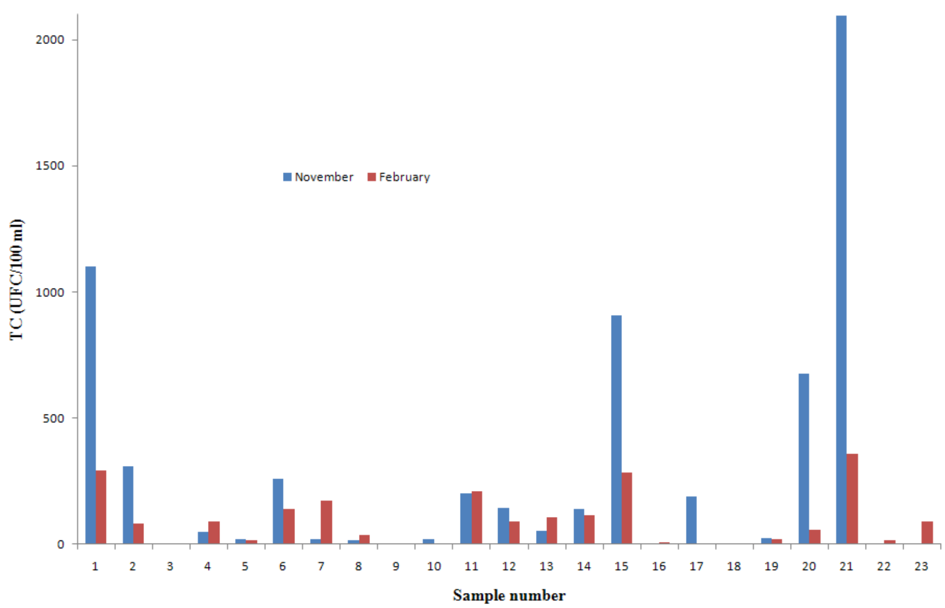


Fig. 8: Abundance of TC in groundwater sampled in November and February.

lowing equation:

Salinity (mg/L) = 0.51 × electric conductivity (µS/cm)

Measurements of the static levels of groundwater as well as salinity were performed in different periods (Figs. 3 to 6). In the years 1995 and 2010, measurements were made after torrential rains, while in the years 2004 and 2011 they were carried forward.

In general, the results show that the highest salinity was recorded in the area of the palm trees (in the south). The spatial extension of salinity is controlled by the rise or descent of the groundwater level. During periods of rise we recorded the highest levels of salinity, i.e. 6.7 and 5.54 g/L in 1995 and 2010 respectively. Thus, we found that the concentration became higher towards the east of the oasis. This is practically related to groundwater flows from west to east, while during periods when we recorded a lowering of the groundwater level, the salinity showed a decrease which

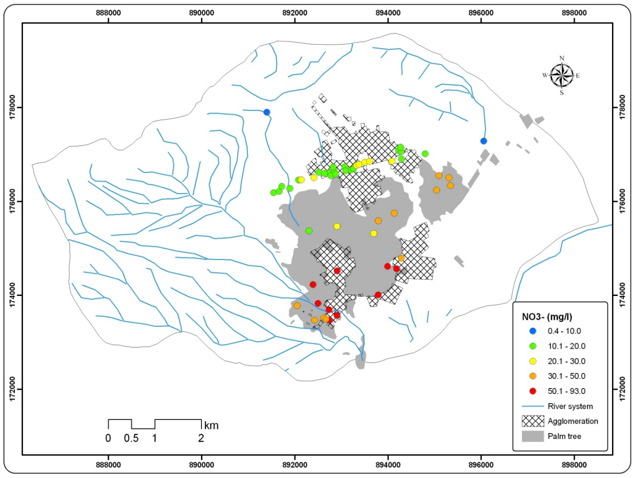


Fig. 9: Concentration of nitrate in 1995.

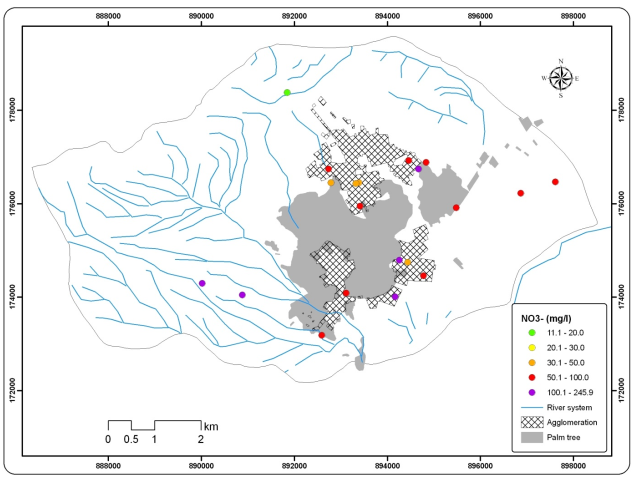


Fig. 10: Concentration of nitrate in 2012.

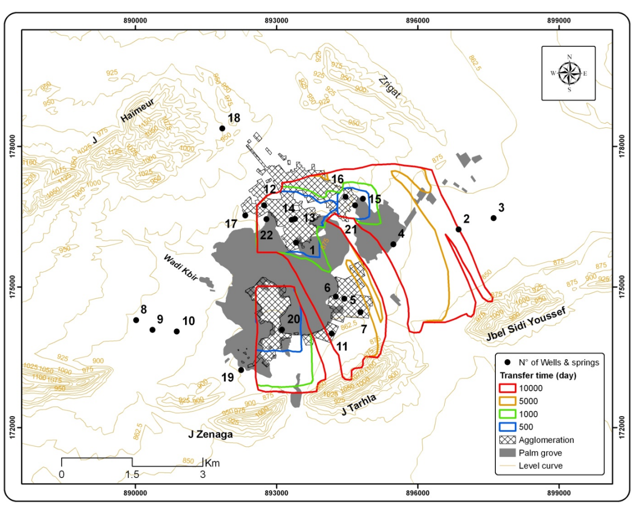


Fig. 11: Perimeter time (day) transfer of particles.

spread out to the west (2004 and 2011).

The superposition of the structural map (Jilali 2014a) on the different maps of salinity shows that it is controlled by faults. This is most evident during periods of high groundwater level. The origin of the salinity is still questionable. A few possible causes can be mentioned: (1) accumulation and concentration of salts from water sources at the time of the formation of travertine, (2) soil leaching due to irrigation, and (3) Triassic clay formations.

**Bacteriology and nitrates:** The region of Figuig has no sewerage network. However, many homes have wastewater filtration systems. These systems are similar to lagooning basins. There may be one or two basins for filtering wastewater, with a maximum volume of 3 $m^3$. This system reduces the concentration of waste. The static level of the water table of Figuig varies between 8 and 20 m. Specifically, regions that represent the minimum depth of the water table coincide with the agglomerations. This implies that groundwater is in direct contact with the wastewater.

The results from the bacteriological analysis (Table 1, Figs. 7 and 8) show that for November 2011 and February 2012 the numbers of FC and TC vary between 0 and 2049 CFU/100mL and 0 and 237 CFU/100mL respectively. The largest number of FC was recorded in November and the highest number of contaminated items was recorded in the same month. Borehole No. 18 (IRE 189/50) is used to supply drinking water and showed no contamination during the two measurement campaigns. The residential area is contaminated and migration of the contaminant could reach the southeast towards the river Zouzfana. This is facilitated by the direction of groundwater flow. In contrast, it is difficult to explain the origin of the contamination in the western zone (borehole No. 10).

According to WHO, the concentration of nitrates should not exceed 50 mg/L (WHO 2000) so that the water is potable. Comparison of the nitrate concentrations between the two measurement campaigns of 1995 and 2012 (Figs. 9 and 10) shows a remarkable increase in nitrates. Nitrate concentrations measured in 2012 in the southern and southeastern parts of the plain of Figuig (agglomeration and palm trees) exceed the limit for potability (50.16 to 113.04 mg/L). North of the palm trees, concentrations range from 30.3 to 115.04 mg/L, with the highest values being related to direct contact with sewage. Moreover, boreholes No. 8 and No. 10 have the highest concentration in the study area, i.e. 234.93 and 245.94 mg/L respectively. The origin of these high concentrations is unknown, but it may be natural because the flow direction is to the south and southeast, so it is difficult to explain the migration of the contaminant in the opposite direction to the flow and its high concentra-

Table 1: Parameters measured *in situ*: FC, TC and nitrates in November (Nov) and February (Feb).

| Nov. 2011 | Feb. 2012 | Number | Type | EC (µS/Cm) | | Salinity (g/L) | | Tp (°C) | | pH | | Turbidity (NTU) | | $O_2$ (mg/L) | | FC (UFC/ 100 mL) | | TC (UFC/ 100 mL) | | $NO_3$ (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Nov | Feb | Nov | Feb | Nov | Feb | Nov | Feb | Nov | Feb | Nov | Feb | Nov | Feb | Nov | Feb | Feb |
| 14.11.2011 | 09.02.2012 | 1 | Borehole | 2620 | 2820 | 1.33 | 1.44 | 25.7 | 24.7 | 7.25 | 7.13 | 28 | 6.93 | 2.91 | 3.03 | 14 | 237 | 1100 | 294 | 55.88 |
| 14.11.2011 | 08.02.2012 | 2 | Borehole | 5030 | 5050 | 2.60 | 2.63 | 22.5 | 21.5 | 7.07 | 7.09 | 1.24 | 1.33 | 3.34 | 3.35 | 186 | 57 | 309 | 82 | 57.88 |
| 14.11.2011 | 08.02.2012 | 3 | Borehole | 2310 | 2320 | 1.16 | 1.17 | 22.5 | 20.9 | 7.34 | 7.35 | 0.21 | 0.15 | 3.38 | 3.51 | 3 | 0 | 3 | 1 | 50.16 |
| 14.11.2011 | 08.02.2012 | 4 | Well | 7540 | 7280 | 4.01 | 3.86 | 21.3 | 20.5 | 7.09 | 7.15 | 2.37 | 1.92 | 3.33 | 3.65 | 30 | 3.5 | 49 | 90 | 55.59 |
| 14.11.2011 | 07.02.2012 | 5 | Borehole | 6880 | 7270 | 3.64 | 3.86 | 22.5 | 21.8 | 6.95 | 6.99 | 0.36 | 1.36 | 2.06 | 2.35 | 2 | 2 | 19 | 18 | 32.58 |
| 14.11.2011 | 07.02.2012 | 6 | Well | 6530 | 6640 | 3.44 | 3.50 | 21.2 | 20.4 | 6.99 | 7.03 | 0.12 | 0.4 | 2.94 | 3.19 | 32 | 97 | 260 | 142 | 104.18 |
| 14.11.2011 | 07.02.2012 | 7 | Well | 6540 | 7000 | 3.45 | 3.71 | 22 | 21.1 | 6.97 | 7.1 | 0.28 | 0.55 | 0.96 | 1.65 | 14 | 8 | 21 | 174 | 98.17 |
| 14.11.2011 | 09.02.2012 | 8 | Borehole | 452 | 529 | 0.22 | 0.26 | 25.2 | 24.7 | 7.5 | 7.45 | 0.38 | 1.47 | 3.82 | 4.05 | 0 | 0 | 17 | 37 | 234.93 |
| 14.11.2011 | 09.02.2012 | 9 | Borehole | 456 | 515 | 0.22 | 0.25 | 26.2 | 23.7 | 7.49 | 7.61 | 1.42 | 1.66 | 3.67 | 3.51 | 0 | 0 | 1 | 1 | - |
| 14.11.2011 | 08.02.2012 | 10 | Borehole | 571 | 560 | 0.28 | 0.27 | 24.7 | 24.6 | 7.4 | 7.5 | 0.83 | 0.32 | 3.78 | 4.12 | 17 | 2 | 21 | 5 | 245.94 |
| 14.11.2011 | 08.02.2012 | 11 | Well | 7620 | 7600 | 4.05 | 4.04 | 21.4 | 20.5 | 6.84 | 6.93 | 0.32 | 0.48 | 1.17 | 1.2 | 172 | 172 | 202 | 209 | 113.04 |
| 15.11.2011 | 07.02.2012 | 12 | Spring (Tighzert) | 2230 | 2180 | 1.12 | 1.10 | 29.3 | 28.3 | 7.28 | 7.53 | 0.31 | 0.54 | 2.18 | 2.32 | 78 | 20 | 144 | 90 | 68.88 |
| 15.11.2011 | 07.02.2012 | 13 | Spring (Maghni) | 2370 | 2220 | 1.20 | 1.12 | 28.6 | 29.4 | 7.38 | 7.43 | 0.48 | 0.73 | 2.55 | 2.58 | 36 | 20 | 55 | 106 | 36.87 |
| 15.11.2011 | 07.02.2012 | 14 | Spring (Tanoute) | 2380 | 2250 | 1.20 | 1.14 | 29 | 28.8 | 7.27 | 7.43 | 1.08 | 0.73 | 2.19 | 2.57 | 86 | 48 | 142 | 114 | 46.01 |
| 15.11.2011 | 07.02.2012 | 15 | Spring (Gaga) | 2610 | 2600 | 1.32 | 1.32 | 27 | 27.3 | 7.7 | 7.69 | 0.57 | 0.85 | 3.44 | 3.67 | 908 | 153 | 908 | 286 | 98.32 |
| 15.11.2011 | 07.02.2012 | 16 | Spring (Ifli Ajdid) | 2580 | 2460 | 1.31 | 1.24 | 30.4 | 31 | 7.3 | 7.34 | 0.46 | 0.49 | 2.94 | 2.73 | 0 | 0 | 2 | 7 | 67.88 |
| 15.11.2011 | - | 17 | Well | 5970 | - | 3.13 | - | 23.2 | - | 7.1 | - | 0.9 | - | 2.68 | - | 122 | - | 188 | - | - |
| 15.11.2011 | 09.02.2012 | 18 | Borehole (AEP) | 2290 | 2250 | 1.15 | 1.13 | 28 | 26.3 | 7.44 | 7.45 | 0.66 | 0.32 | 2.9 | 3.26 | 0 | 0 | 0 | 0 | 11.15 |
| 15.11.2011 | 08.02.2012 | 19 | Borehole | 5550 | 2950 | 2.90 | 1.50 | 23.2 | 20.9 | 6.99 | 7.21 | 6.59 | 0.94 | 3.16 | 4 | 2 | 7 | 25 | 21 | 87.74 |
| 15.11.2011 | 09.02.2012 | 20 | Borehole | 6390 | 6410 | 3.37 | 3.38 | 22.6 | 21.3 | 6.89 | 6.96 | 1.21 | 2.08 | 1.54 | 1.83 | 408 | 7 | 676 | 58 | 50.59 |
| 15.11.2011 | 07.02.2012 | 21 | Spring (Tajamalt) | 2510 | 2520 | 1.27 | 1.28 | 29.3 | 30.7 | 7.6 | 7.54 | 1.04 | 0.64 | 3.05 | 3.12 | 2095 | 194 | 2095 | 357 | 115.04 |
| 15.11.2011 | 07.02.2012 | 22 | Spring (Tzaderte) | 2250 | 2180 | 1.16 | 1.10 | 29.3 | 28.2 | 7.32 | 7.41 | 0.29 | 0.69 | 2.37 | 2.55 | 0 | 0 | 0 | 18 | 30.30 |
| - | 08.02.2012 | 23 | Well | - | 3520 | - | 1.81 | - | 19.6 | - | 7.34 | - | 3.43 | - | 4.12 | - | 13 | - | 90 | - |

tion. The supply of drinking water in the region is from borehole No. 18 (Fig. 6), which is north of the oasis at Jbel El Haimeur (Fig. 1). It has a low concentration of nitrates (11.15 mg/L).

The number of sampled points (Fig. 6) in the southern tier is higher than in the north. Statistics show that the numbers of FC and TC are low in the south compared to the north. This indicates that the south is an unfavourable environment for the growth of FC. This is due to the very high salinity in this area (breakdown of FC and TC).

**Simulation of particle transport:** The advective transport of particles was studied in a permanent regime in 2008, and two areas were taken into consideration as the source of contamination. Four scenarios were chosen (500, 1,000, 5,000, 10,000 days). In all simulations, 100 particles were injected into the piezometric surface of the two study sites (Fig. 11). The direction of movement of the particles is the same as the direction of flow of groundwater. The particles migrate from north to south and southeast. The scenarios show that the contaminated areas are identical to those identified by FC and TC as well as by the nitrate concentrations.

## CONCLUSIONS

Discharge of domestic wastewater into pits has been carried out for a long time in this region. This study is the first to focus on the impact of these discharges on groundwater in this region. The impact of agricultural practices on groundwater is low. Fracturing facilitates groundwater flow and therefore, the transportation and movement of pollutants. The highest salinity was recorded in the southern part of the study area. The highest nitrates value was 245 mg/L, which was recorded to the west of the oasis, and concentrations exceeding 50 mg/L were recorded in the south and southeast. Similarly, the results of bacteriology prove the presence of contamination by discharges of wastewater into the groundwater of Figuig.

Analysis of the transport of contaminant using MODPATH code shows the migration of particles from north to south. The particles reach the south and southeast of the region of Figuig in a period of 27 years. This work is expected to assist local authorities in developing plans and in reducing the pollution to acceptable levels.

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