Aquifer Recharge by Treated Wastewaters: Korba case study (Tunisia)

This paper describes the evolution of groundwater quality after recharge with treated wastewaters.

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Abstract

The recharge of Korba aquifer (Tunisia) by treated wastewater (TWW) via infiltration basin is monitored since 2008 for the changes occurring in groundwater quality after three years of recharge through three significant parameters controlled throughout the studied area: salinity, nitrates concentrations and total coliforms. In this study period, the project shows an improvement of the salinity groundwater levels but no net change in the distribution of nitrate and bacteria else than displacement of the polluted area.

Introduction

Agriculture is considered as the biggest consumer of water in Tunisia as it uses up to 80% of the available freshwater. Groundwater, which represents an important source of available water in Tunisia, is overexploited at a rate that exceeds 103% of it's natural recharge. The use of different kinds of fertilizers has additionally damaged qualitatively and quantitatively the groundwater (El Ayni et al., 2012a; Kouzana et al., 2009) causing a decrease in piezometric levels, seawater intrusion (El Ayni et al., 2012b) and rising levels of contaminants like nitrates and other various salts.

Simultaneously, this high salinity groundwater is drilled to be used for irrigation therefore increasing agricultural land salinity and reducing land productivity. It sometimes turns up to complete loss of usefulness of the irrigated land (Gaaloul et al., 2003). On the other hand, the use of salty waters for animal drinking purposes may be hazardous for animals and may render milk or meat unfit for consumption. These waters need to be studied for their quality and suitability before being used in agriculture (El Ayni et al., 2011).

Key data and facts:

- High contamination in groundwater prior to recharge: salinity up to 8.5 g/L, nitrates (81-332 mg/L) and bacteria (30 - 11,000 per 100mL).
- Depletion of the aquifer due to the overexploitation of the aquifer for irrigation purposes prior to the recharge operation that would solve part of this problem.
- The salinity of the treated wastewater (TWW) varies from 1.8 to 5.4 g/L with seasonal fluctuations of bacterial and nitrate contamination.
- Infiltration basins for the TWW recharge are near the treatment plant.
- Infiltration capacity: 0.5 m/day.
- 3 basins with a total surface of 4500 m^2.
- The infiltration basins serve three objectives: retention of the suspended solids, oxidation of the dissolved organic matter and the oxidable nitrogen, removal of pathogenic micro-organisms.
- The main objectives are to reduce TWW pollution, to allow TWW reuse and to enhance the aquifer level and quality.
- Advantages and effectiveness of the project to cure high salinity. Nevertheless, contamination by nitrate and bacteria remains a major problem of the aquifer.

The situation is worsened when the phenomenon of bad groundwater quality is added to water scarcity as it is the case in many regions of the world including the Mediterranean countries. Tunisia is located in an arid/semi-arid region of the southern shore of the Mediterranean Sea. This is why this country searches for alternative water resources in order to fulfil its water needs, especially for agricultural utilization. The reuse of treated wastewater (TWW) has been applied in the last few decades in Tunisia to direct irrigation of authorized crops like greenspaces and golf courses. The interest is now focused on the reuse of TWW to recharge the aquifers, meanwhile solving several health, environmental, agricultural and economical issue. Many projects have been conducted elsewhere for the recharge of aquifers by TWW and have shown positive impacts on the aquifer e.g. in 1985 at El Paso (Texas, USA) where wastewater was treated by tertiary treatment serving dual purposes of the reuse of the wastewater and the restoration of groundwater (Sheng, 2005). In Dan region (Israel) tertiary treated wastewater was used for the recharge of an aquifer during a 300 days experiment, the resulting water met irrigation standards with non restrictive use as no bacteriological contamination was found in the aquifer (Idelovitch, 1978). On the other side, irrigation with waters from wells refilled by TWW can decrease fertilization use and costs due to the nutrients that it contains (Haruvy et al., 1999). Thus the reuse of TWW by recharging aquifer would help not only to struggle against water scarcity but also against marine intrusion in coastal areas. It is also a mean for groundwater remediation when using infiltration basin systems for recharging qualitatively deteriorated aquifer.
The aim of the present paper is to investigate the impact of recharging a deteriorate aquifer by tertiary treated wastewater in a semi-arid climate in Tunisia (Korba) especially by monitoring the groundwater salinity remediation. The results would allow us to evaluate the effect of TWW on this aquifer in order to suggest adequate solution to water scarcity and destruction of the regional aquifer as well as solving the problem of TWW safe elimination.

quality. This is especially important for small systems where the diurnal variations are pronounced.
Since domestic water use is relatively low in the concerned regions, the pollutant concentrations are relatively high which also has to be considered in the system selection and design.

The study area: Korba aquifer

The studied area is located in Korba, a coastal region in the North-eastern Tunisia (Africa). Geologically, the region (Pliocene-quaternary) is mainly composed by sandstones, conglomerates and clay. The dominant economic activity is agriculture with some agro-industries, textile industries and tourism. The principal cultivations are strawberry (270 Hectares), potatoes (1010 Hectares), tomatoes (3000 Hectares), pepper (3000 Hectares) and other vegetables (1200 Hectares).
The population of this region is about 100,000 inhabitants and the region is situated in a zone of moderate rainfall with an annual average between 450 and 500 mm/year. In order to respond to the increased water demand in this region, the aquifer has been highly exploited since the seventies what conducted to a decrease in the piezometric level of the aquifer and generated a degradation of the groundwater quality essentially due to seawater intrusion (Paniconi et al., 2001). The aquifer of the Eastern coast saw a net drawdown of the piezometric level and an alarming increase in salinity that followed the intensification of the local exploitations. This bad situation is related to the digging and the deepening of wells in order to increase the pumped water volumes in addition to the electrification of several wells. The piezometric level of the plio-quaternary aquifer has particularly felt as the piezometric level has seen a 10 m decrease between 1977 and 2004 near the Korba coast (Kerrou et al., 2010; El Ayni et al., 2012b). This situation resulted in marine intrusion, depriving the plio-quaternary aquifer of any contribution of subsoil water. The lowering of the piezometric level of the aquifer in this area is related to the still local increasing exploitation in addition to the low thickness of the saturated zone.

Korba treated wastewater plant

Reclaimed water used to feed the project is provided by the plant close to the infiltration basins which has begun to work in July 2002. This treatment plant is a low-load activated sludge treatment plant combined with finishing lagoons (Figure 1). It is dimensioned for 7500 m^3 of wastewater per day and actually receives about 5000 m^3 per day. It can provide 1500 m^3/day to the recharge site.

The recharge area and infiltration ponds

The aquifer recharge by using infiltration basin consists of water penetration in the soils. This water is generally biologically treated wastewater which goes through the unsaturated zone until it reaches the saturated zone of the aquifer by slow vertical percolation. The unsaturated zone acts indeed as a natural reactive filter that can reduce or remove microbial and organic/inorganic contaminants through biogeochemical processes enhancing mass transfer between soil phases. This process targets the geochemical reactivity and dynamics of the soil in order to improve water quality while maintaining environmental quality and protecting other resources. Thus, the infiltration basins serve as a tertiary treatment of the TWW. The retained site for Korba aquifer recharge project implantation is situated immediately close to the local treated wastewater plant. The initial feasibility study suggested the chosen implantation according to the geological specifications

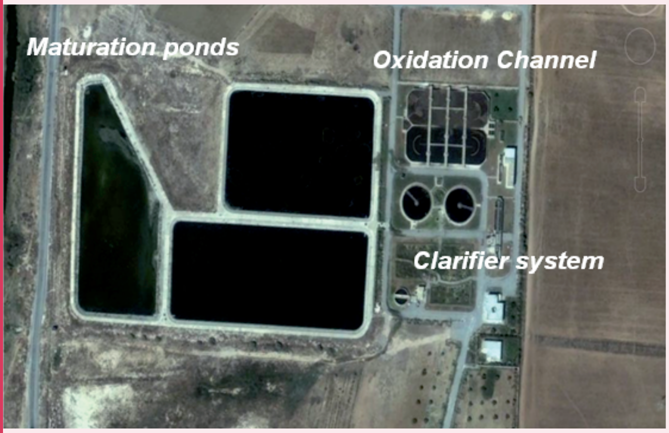

Figure 1. Korba wastewater treatment plant (© 2009 Google)

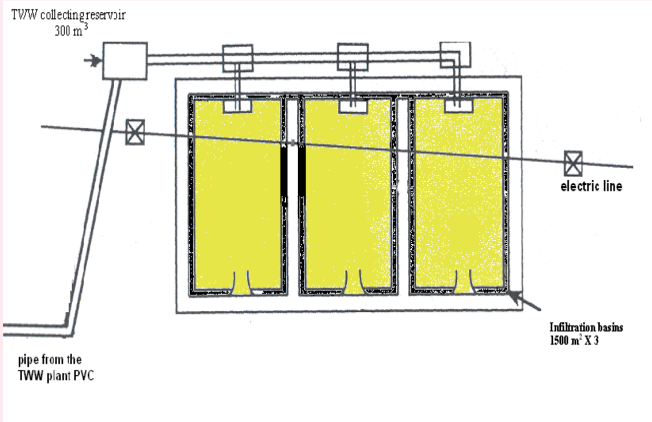

Figure 2. Infiltration ponds for aquifer recharge by TWW

of the site and constructed in order to receive 1500m^3/day of treated wastewater according to the parameters shown below.

The characteristics of the recharge basins are (Figure 2):

1. TWW collecting reservoir: 300 m^3
2. Infiltration capacity 0.5m/day
3. Three infiltration basins 1500 m^2 each (Figure 3).
4. Capacity of the infiltration basins: up to 1500 m^3/day
5. Estimated annual recharge: 0.5 million m^3/year
6. Pipe diameter for basins feeding is 400 mm

The durability of the infiltration process calls for an alternation in the use of the infiltration basins to allow the aeration of the non-saturated zone and also the ponds cleaning in order to restore their infiltration capacity (CRDA, 2008). The advantage for the infiltration ponds technique is the possibility of using the soil as an additional treatment of the wastewater. The disadvantages are the utilization of a large area and the high maintenance costs to avoid clogging that can be a barrier against infiltration process often occurring when treated wastewater is used for aquifer recharge.

Monitoring groundwater quality changes

In order to assess the impact of the recharge of the aquifer by TWW, three significant parameters were analysed from groundwater before and after three years of recharge, as well as in TWW during this period of time. They were salinity, nitrates and total coliform. The analysis were performed in the laboratory of the International Center of Environmental Technologies of Tunis (CITET) that is accredited ISO 17025 since 2001 and followed the ISO (International Organization for Standardization), NF (French standard) and EN (European Norm) procedures as described in Table 1.

Twenty three groundwater samples were collected from different locations by using local piezometers and surface wells (see location points on Figure 4). A GPS is used to identify the exact location of each sampling points. They were first collected in 2008, before the beginning of the operation of recharge by TWW and three years after recharge, in 2011. As for the TWW used for the recharge, they are directly sampled from the outlet of the treatment plant by using an auto-sampler from 2008 to 2011.

Figure 3. Filling one of the recharge ponds with TWW in Korba

Table 1. Chemical and Biological Analysis Methods

Parameters	Method	Reference
Electrical Conductivity, Salinity	Electrochemistry	NF EN 27-888
Nitrate	Ion Chromatography	NF EN ISO 10304-1
Total coliform	MPN multiple-tube fermentation	NF T 90 - 413

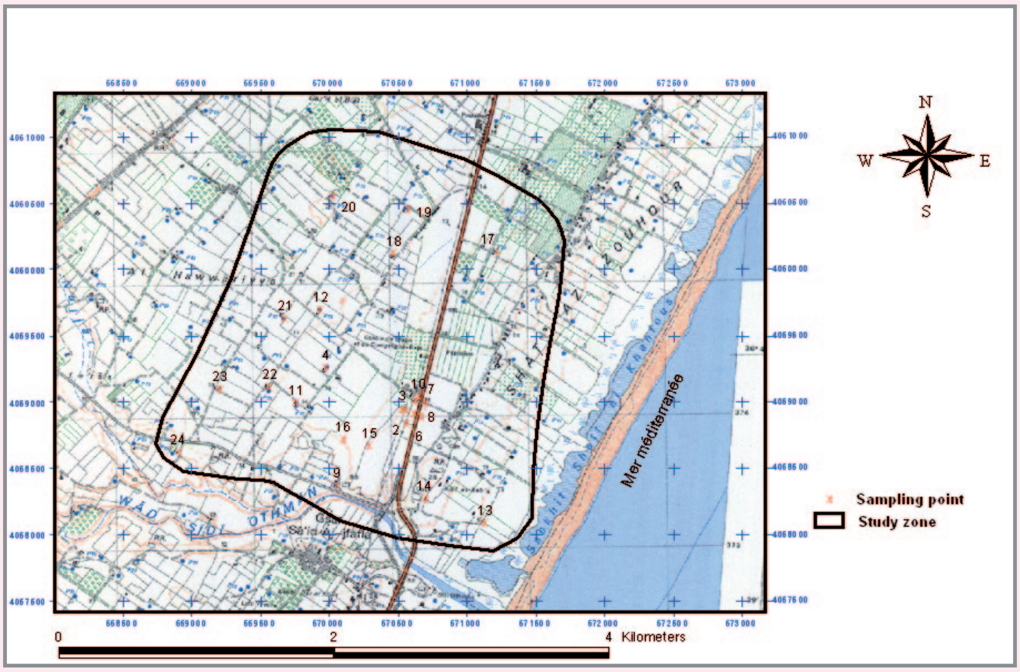

Figure 4. Sampling points location in the study area.

The results of the analysis are represented on charts drawn with ARcview/GIS software. It uses the colour system adopted by the SEQ-groundwater (quality evaluation system for groundwater) that is one of the reference used for groundwater quality and its suitability for various uses, as there is no threshold value for these waters unlike for wastewaters (Agences de l'eau, 2003). The colours ordered as blue, green, yellow, orange and red, indicate in decreasing order the capacity of the analysed water to be used for irrigation purposes, in relation to the concentration of the studied parameters like here for salinity, nitrate and total coliforms occurence.

Aquifer salinity remediation

Salinity is one of the main parameter for characterizing the quality of a groundwater. Two charts were drawn concerning the salinity distribution in the study region. The first represents the salinity of the groundwater before starting the recharge (Figure 5) and the second after three years of the aquifer recharge (Figure 6).

Referring to the distribution of salinity prior to recharge (Figure 5), it can be noted that the Northern and South-western part of the site is strongly salted: the recorded concentrations exceed 2.5 g/L and reach 7.0 g/L in the extreme North. The South-eastern part shows a relatively good quality since salinity varies between 0.5

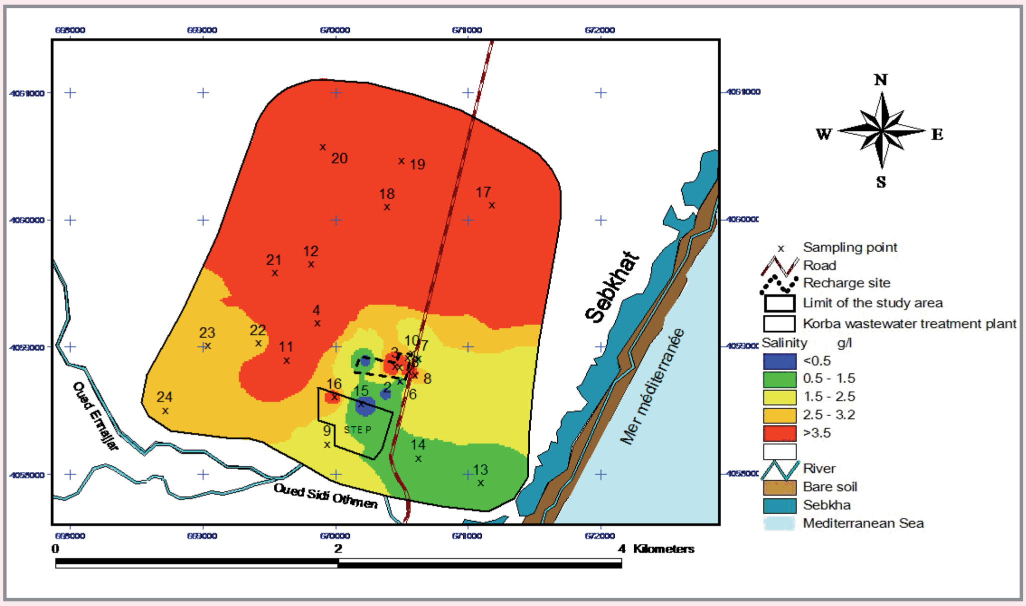

Figure 5. Salinity distribution around the recharge site before the recharge operations

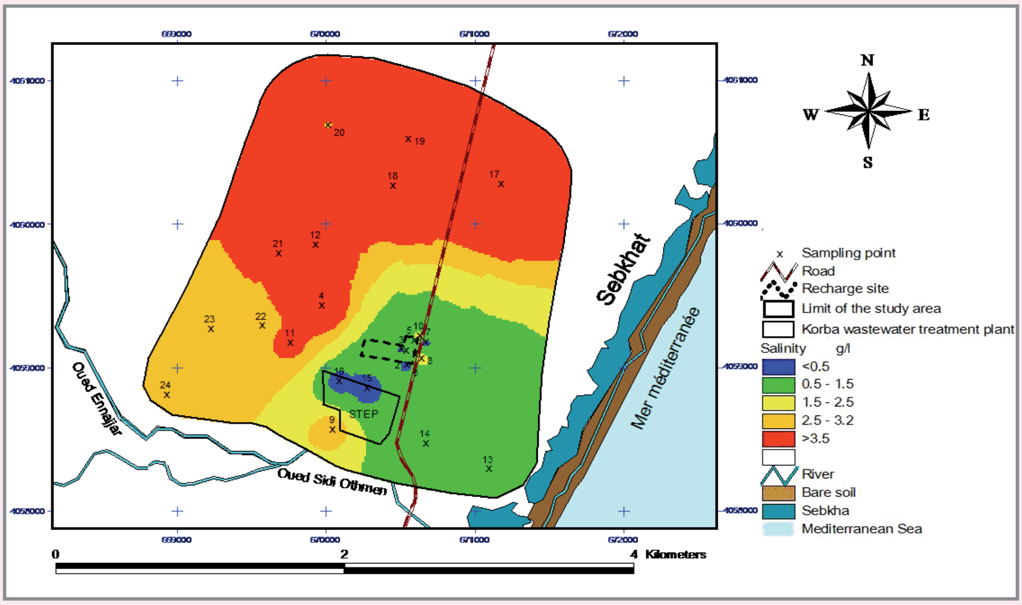

Figure 6. Salinity distribution around the recharge site after 3 years of recharge

and 2.5 g/L. The initial quality of the aquifer in this area is low regarding salinity. More than 50% of water of the study region is of bad quality in terms of salinity. These high levels of salts are ascribable to several origins. They are mainly due to the progression of salted bevel of the sea due to the multiplication of well pumping and the reduction of the refill of the aquifer by rainfall or surface waters (Ben Alaya et al., 2009). The high evaporation during irrigation with pumped water exacerbated by the hot meteorological conditions can also concentrate the salt in the waters before they infiltrate through the soil towards the aquifer.

The analysis of the TWW during the recharge period show salt concentrations ranging from 1.8 to 5.4 g/L. After three years of aquifer recharge by these TWW, changes in salinity levels had occurred in almost all points close to the recharge plant (Figure 6). There is a clear lowering of groundwater salinity near the recharge site and all the South-eastern area. The area with lower salt concentrations (between 0.5 and 1.5 g/L) extended towards the North.

Changes in Nitrate concentrations in the aquifer

The two charts representing the nitrate concentrations before and after three years of recharge are drawn respectively in Figure 7 and Figure 8.

Initially and before the recharge, more than 90% of the area show high nitrate concentrations (Figure 7), exceeding 50 mg/L, that is the trigger value set by the European Groundwater Directive (EC, 2006) for a good

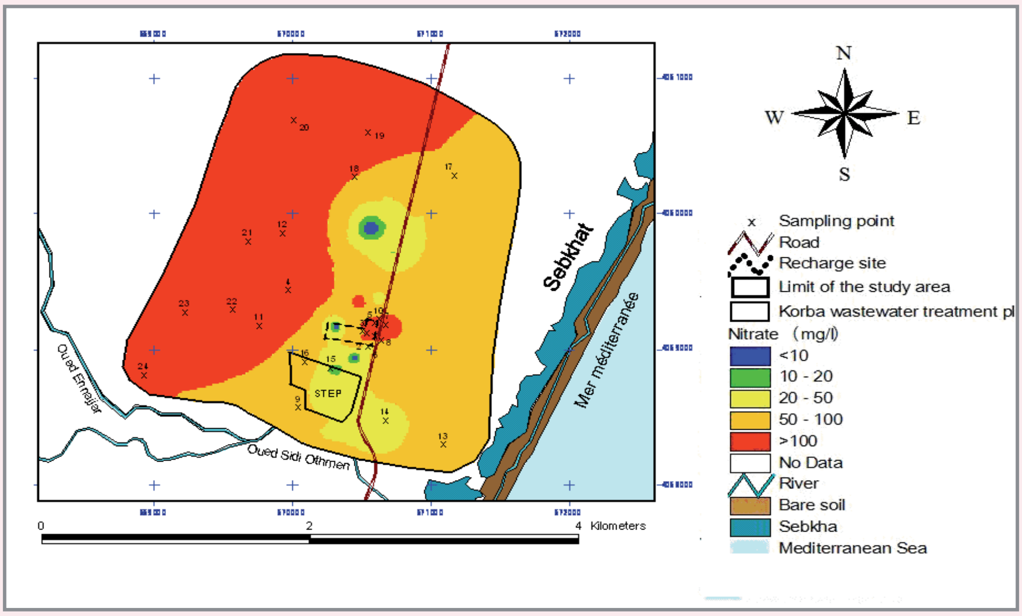

Figure 7. Nitrate distribution around the recharge area before recharge operations.

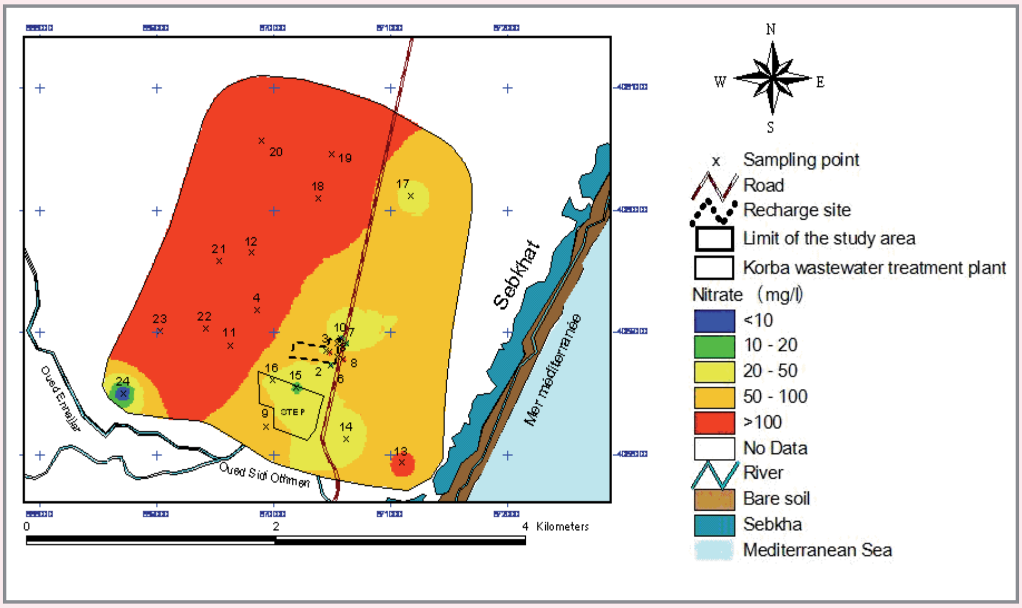

Figure 8. Nitrates distribution around the recharge area after 3 years of recharge.

chemical status of a groundwater. The most polluted area was identified in the Western side of the study area where nitrate contents exceed 100 mg/L and reach values as high as 300 mg/L. As this region is known to be mostly agricultural, these high values could be primarily due to the frequent use of artificial fertilizers in the intensive agriculture of Korba mainly vegetable crops with excessive water demand and nitrate fertilizers use. Even if the excessive use of fertilizers is considered the principal source of diffuse nitric pollution of groundwater by leaching, other point sources of nitrates like septic tanks can be accused. Furthermore, the high concentration of nitrates recorded in the groundwater near the wastewater treatment plant could be due to the infiltration of wastewater from maturation basins high in nitrogen pollution towards the aquifer.

The nitrate concentration of the TWW used to feed the aquifer is less than 5 mg/L. After three years of recharge with this TWW (Figure 8), it can be seen that there is a displacement in the nitrate contaminated area. The low nitrate concentration spot in the central area of the study region has disappeared and show now a higher nitrate concentration whereas the south-western area show new spots of low nitrate levels. There is also a slight improvement of the quality regarding nitrate near the recharge site.

The changes in bacteriological distribution

The microbial quality of water can be evaluated by the presence of indicators of contamination like the total coliform level. Their occurrence in the waters is a proof

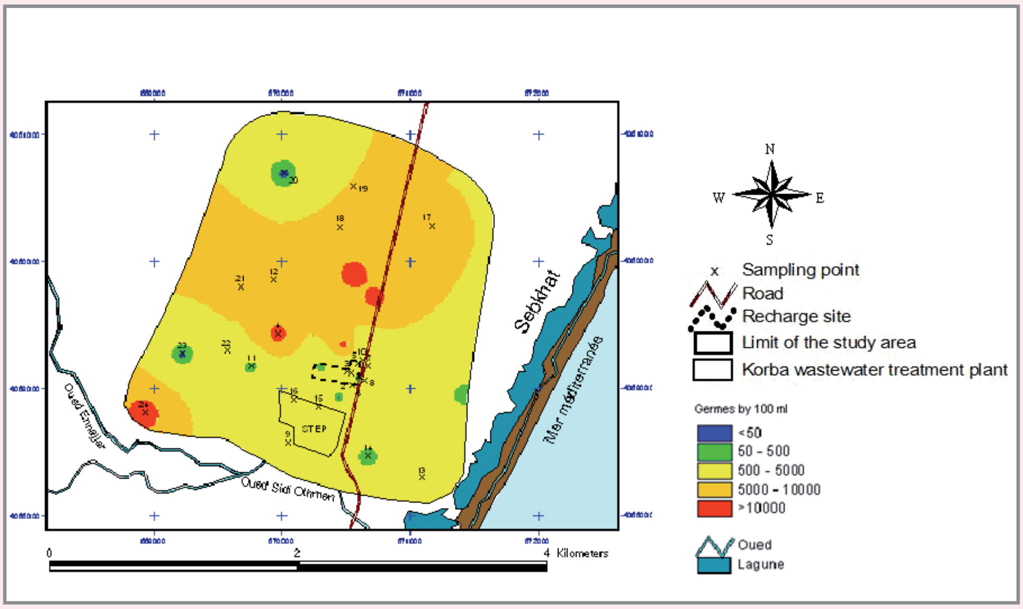

Figure 9. Total coliform distribution around the recharge site before the recharge operations

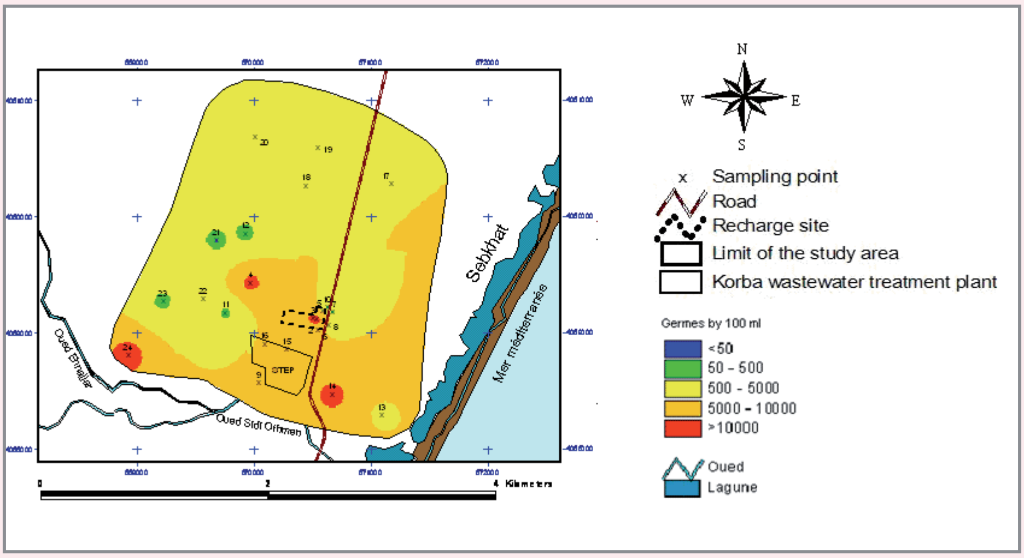

Figure 10. Total coliform distribution in the recharge site after three years of recharge

of faecal contamination and their abundance indicates a severe contamination. The chart showing total coliform distribution prior to recharge operations (Figure 9) indicates that, except for one point (point 20), all the groundwater of the study area is contaminated with more than 50 per 100mL total coliform, and cannot be used for drinking purposes. Half of the entire area has more than 5,000 total coliform per 100mL, making these waters unsuitable for animal drinking purposes and for irrigating leafy vegetables (El Ayni et al., 2012c). The origins of these contaminations are probably infiltrations from local cesspit and from the wastewater treatment plant itself.

After three years of recharge (Figure 10) with TWW having from 9,300 to 240,000 total coliform per 100 mL, the South-eastern part show a deterioration of its groundwater quality concerning bacteriological contamination from average quality (500 - 5,000 total coliform per 100 mL) to bad water quality (more than 5,000 total coliform per 100 mL). There is an improvement in bacteriological quality in the Northern area of study. These changes can be regarded as a displacement of the highly contaminated water towards eastern-south, reaching the area of recharge and the coast.

Conclusion

The comparison of the quality of the groundwater before (2008) and after three years of recharge (2011) resulting from the mixing of groundwater and infiltrated TWW showed the effectiveness of the project to cure high salinity which exceeded 1,5 g/L. The site thus played the role of a hydraulic barrier to mitigate the problem of marine intrusion and to limit its geographical extension. This evolution reveals the advantages of the project not only for limiting the intrusion of salted bevel but also for mobilizing a non conventional water resource and avoiding the residual impacts related to the rejection in the environment. Nevertheless, contamination by nitrate and bacteria remain a major problem of the aquifer and allowed the use of this water presently only for agricultural purposes. There is no net change in the distribution else than displacement of the polluted region. The pursuance of the monitoring for the future years will probably show a clearer tendency in changes of the distribution of these parameters helped by a future modelling study of the recharge operations and their evolution in terms of groundwater quality.

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