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Environmental risk assessment of groundwater quality and treated wastewater reuse on aquifer recharge: a case study in Korba, Tunisia

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ABSTRACT

Water resources associated with the Mediterranean arid to semiarid environment in Tunisia are at risk of degradation in terms of quantity and quality, especially due to groundwater over-exploitation. Therefore, the reuse of treated wastewater (TWW) for the artificial recharge of groundwater has been implemented as an alternative, particularly in Korba coastal area of Tunisia. The aim of the current study was to assess the environmental risk of the groundwater quality as well as the reuse of TWW for Korba local aquifer recharge. On one hand, results showed high levels of chloride, ammonia, and sodium adsorption ratio (SAR) in the TWW and high electrical conductivity, nitrate, chloride concentrations, and SAR in groundwater. Heavy metal concentrations were commonly under the detection limit. On the other hand, groundwater was contaminated with pesticides. Environmental risk monitoring of TWW is fundamental to assess its safety reuse on the aquifer recharge and in presenting a coastal barrier against seawater intrusion. Also, it will allow for more effective allocation of resources in future monitoring programs and it can contribute to the environmental management of the treatment plant.

Keywords: Groundwater; Treated wastewater; Recharge; Physicochemical analysis; Heavy metals; Pesticides

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1. Introduction

The increasing water demand and limited water resources in Tunisia have led to the exhaustion of the quantity and the quality of water systems, particularly an excessive groundwater abstraction resulting in the depletion of the aquifer system [1,2]. The most prevalent examples of overexploited aquifers in Tunisia are the coastal aquifers invaded by seawater [1,3–5]. To ameliorate water balance, using non conventional water resources mainly wastewater reuse has been experienced in Tunisia for artificial groundwater recharge, since the 1970s to satisfy the agricultural irrigation demand as well as the urban and industrial uses [6]. One of the selected sites for artificial recharge in Tunisia is the coastal aquifer of Korba located in the Cap Bon peninsula, which is deeply overexploited leading to decline of the piezometric head and inducing seawater intrusion [3,4]. In order to reduce declines of groundwater levels, artificial recharge was implemented by surface spreading where a daily volume of 1,500 m^3/day of treated wastewater (TWW) pumped from Korba wastewater treatment plant (WWTP) percolates from infiltration basins through the unsaturated groundwater zone.

Although, artificial recharge using TWW is considered as promising solution to meet the increasing demand and to remediate the intensive groundwater pumping, environmental, and health concerns should not be neglected [7]. Thus, TWW quality should be monitored to guarantee the public health, environmental safety and to ensure the groundwater quality in a sustainable way [8,9]. Consequently, environmental samples of TWW as well as groundwater should be screened to assess the environmental risk of artificial recharge. In fact, on one hand, due to inefficacity of treatment technology, TWW has high salinity level and can contain high concentrations of heavy metals, organic, and bacteriological contamination which may impact groundwater through recharge process [10]. On the other hand, due to overexploitation for irrigation purpose as well as following the application of diverse fertilizers, the groundwater quality was deteriorated by excess salts and nutrients; high level of nitrates and bacteria [11]. In addition to nutrients, pesticides are other major sources of aquifer pollution with respect to the impact of agriculture on the environment. Indeed, pesticides cover a wide range of compounds including insecticides, fungicides, and herbicides and they are used widely to eliminate pests to improve agricultural crop growth. However, by the early 1960s, undesirable effects of pesticides on the environment were outlined, mainly the groundwater contamination. Indeed, pesticides are carried in rainwater runoff from farm fields and absorbed into the soil and then ending up in the ground water [12,13]. The presence of many pesticides which contain highly toxic chemical compounds in groundwater poses a health risk to human and to aquatic life as well [14]. Therefore, there is a pressing need for the assessment of groundwater vulnerability to pesticides contamination to prevent the environmental health risk associated with these persistent compounds.

The current study aimed to investigate the environmental risk of groundwater quality and the reuse of TWW in Korba artificial aquifer recharge system. The study's findings will support the usefulness of physicochemical analyses as screening tools to assess the quality of Korba aquifer and the safety of TWW reuse. As a consequence, the survey will orient for an effective decision making concerning an alternative to groundwater degradation in terms of quality and quantity.

2. Study area

Korba study area is located in the Cap Bon peninsula at the north-eastern part of Tunisia (Fig. 1). It is characterized by a semi arid Mediterranean climate with a mean annual precipitation of 450 mm/year, a mean annual evapotranspiration of 1,100 mm, and a mean temperature of 19℃. Korba plain is intensively used for agricultural activities which are irrigated chiefly using groundwater [15]. Korba coastal aquifer, covering an area of 438 km^2, consists of two hydrogeological units, including the Plio-Quaternary at the northern part and the late Miocene at the southern one. Korba aquifer exploitation started in the 1960s mainly for irrigation purposes and after 1977 the piezometric depression was noticed due to Chiba wadi damming. Then, the groundwater overexploitation in 1980 worsened the situation up until 1996 when a concentric depression of 5 m below sea level in Diar El Hojjaj lead to a seawater intrusion to the aquifer. As a consequence, groundwater salinity has been increasing, since the 1970s due to seawater intrusion reaching 7–25 g/l for some wells.

The WWTP of Korba which started its activity in July 2002 was dimensioned to carry a treatment capacity of 7,764 m^3 per day and a biologic capacity of 3,146 kg BOD_5 per day. It handles an influent flow of 4,757 m^3 per day of domestic and industrial influents and serves up to 74,898 inhabitants. After accomplishing the influent pretreatment, the

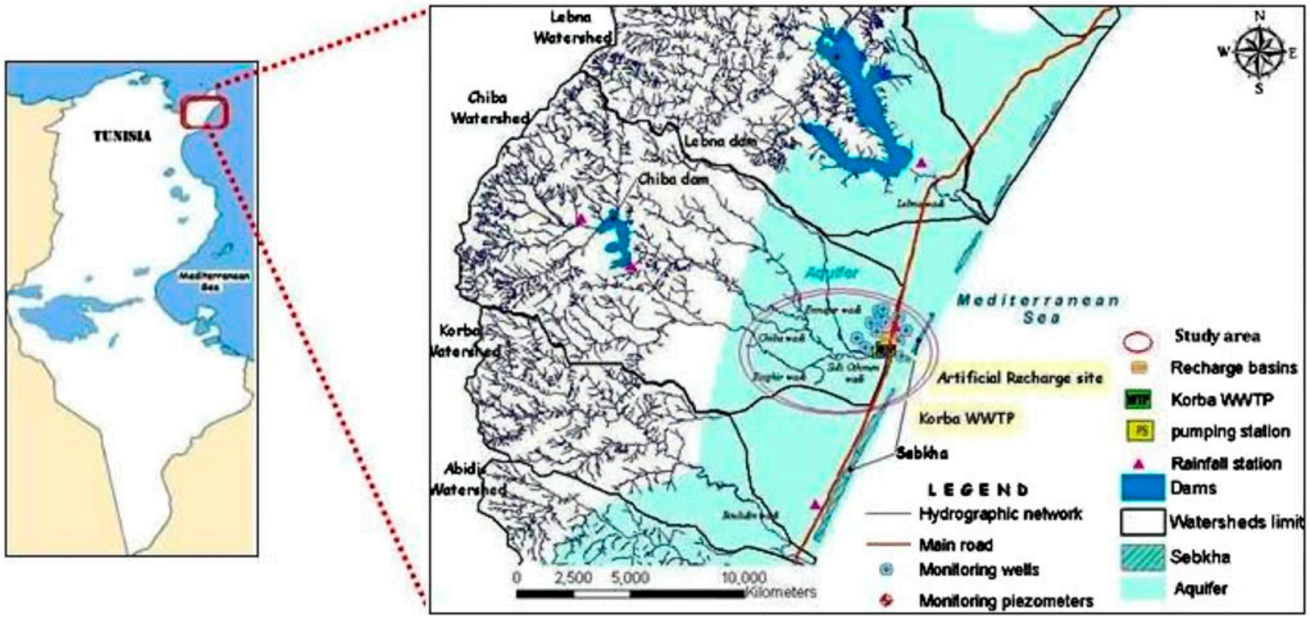

Fig. 1. Location of the study area in Tunisia.

treatment of wastewater is achieved using activated sludge, extended aeration, and maturation pond. At 300 meters at the northern part of Korba WWTP, is located the recharge site of 4.46 ha and which started its activity on December 2008. 1,500 m^3 of the treated effluent from the WWTP was diverted in a daily basis to three spread infiltration basins of 300 m^3 capacity and 0.5 m/day infiltration velocity [16].

3. Materials and methods

Underground water was sampled in November 2011 from two piezometers located inside the recharge site as well as from 11 monitoring wells surrounding the recharge site. TWW was sampled directly from the outlet of the treatment plant. To perform physicochemical analysis, the TWW samples and groundwater samples were stored in plastic bottles, transported in a cooling box (4˚C) to the laboratory, and analysed in the same day.

During the field survey, some physicochemical parameters were measured *in situ* such as the temperature, pH, and electrical conductivity (EC). The remaining physicochemical parameters were analyzed in the laboratory. The analysis of major ions (Mg, Ca, Na, and K) and heavy metals (Al, Cd, Cu, Fe, Pb, Cr, Mn, and Ni) were undertaken by an atomic emission inductively coupled plasma ICP, those of Ammonia, Nitrate, Nitrite, Orthophosphate, and sulfate by the spectrophotometry or colorimetry method and then Bicarbonates and Chloride by titrimetry method. Our samples were analysed for pesticides using gas chromatography coupled with MS detector (GC/MS). In fact, analyte detection was implemented by GC/MS after samples extraction, solid phase separation and organic extract recuperation. Analyte confirmation is fulfilled by comparing the analyte mass spectra and retention times to reference spectra and retention times for calibration standards acquired under identical GC/MS conditions.

4. Results and discussion

4.1. Physicochemical and heavy metal analyses

The EC value for all samples showed a high salinity level in the aquifer, which is due to sea intrusion induced by groundwater overexploitation [3–5]. Then, based on analyzed cations, the sodium adsorption ratio (SAR) index was calculated by the following formula to assess the excess of sodium in irrigation water, relative to calcium and magnesium.

$$SAR = Na^{+}((Ca^{2+} + Mg^{2+})/2)^{-1/2} \quad (1)$$

where Na, Ca, and Mg are, respectively, sodium, calcium, and magnesium concentrations in meq L^{-1}.

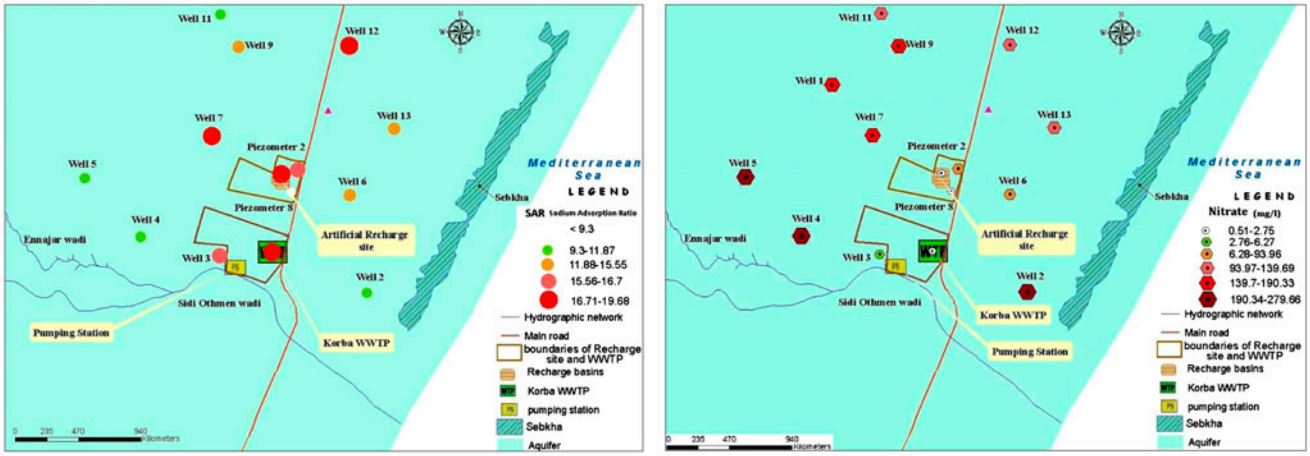

Fig. 2. Spatial distribution of the SAR and nitrate.

The SAR reached the lowest value of 2.6 for piezometer 8, while the highest value was 19.68 for well 12 (Fig. 2). SAR are higher than 9 for all the monitoring wells as well as for piezometer 2 which make this groundwater severely restricted to tolerant crops [17]. Excess Sodium in irrigation water can affect flow rate, permeability, infiltration, and soil structure promoting soil dispersion. For a proper evaluation of the ultimate effect on water infiltration rate of water into surface soil, both salinity (EC) and the SAR must be considered. In our case, given the high salinity values, the infiltration rate will not be affected. SAR value was 19.6 for TWW which poses a great risk to crops and to the soil irrigated with this TWW [17]. In addition, water salinity results were reinforced by chloride analysis which had an average of 4,736.5 mg/L for the monitoring wells and 7,701.44 mg/L for TWW. Due to marine intrusion effect, salinity problem is outlined when salt concentrations in soil solution exceed crop threshold levels for salt tolerance which vary between crop species. Consequently, salt accumulation in the root zone leads to yield reductions [18]. This salty groundwater should be severely restricted to highly tolerant plants and for neutral or alkaline soils. For the TWW, it cannot be used for irrigation as it exceeds the standard value for chloride (2,000 mg/L). Whereas, there is no risk of decrease in TWW infiltration rate in case used for irrigation or aquifer recharge. According to [19], the suitability of saline water for irrigation should be evaluated by taking into account the specific conditions of use, including the crop growth, soil properties, irrigation management, cultural practices, and climatic factors. By after, the highest potassium concentrations were achieved by wells 2, 7, and 13. Although, potassium is required for plant growth its excess might cause severe problems to plants.

For the nutrient quality, in one hand, the highest nitrate levels were detected especially for well 4 and 5 having concentrations of 279.66 and 251.28 mg/L, respectively (Fig. 2). This result confirmed previous studies conducted in korba in 2005 showing that the aquifer is being contaminated by nitrate (average of 185 mg/L) [11]. This high nitrate level in groundwater is explained by the intensive agricultural activities including fruit trees and crop fields applying nitrogen fertilizers. Moreover, the shallow water table is more vulnerable to nitrate pollution due to agricultural activities, irrigation return flow, livestock manure ([20]), and sewage network. On the other hand, TWW has very low nitrate level of 0.51 mg/L, although the nitrate level in this piezometer 2 (50.8 mg/L) still much inferior to nitrate concentration in the surrounding wells having an average nitrate level of 181 mg/L, it is greater than that of the TWW due to the nutrient oxidation occurring during the infiltration process to transform ammonium in nitrate. In fact, a case study in Arizona, confirmed that during the infiltration process, nitrification of the ammonium in wastewater due to frequent aeration of the soil profile occurs [21]. Furthermore, the TWW showed high levels of ammonia (107.2 mg/L) which impacted consequently the piezometer 2 located in the recharge site and which have 14.76 mg/L. Although this result might be interpreted by a lack of conversion in the oxidation stage of the treatment of the ammonium into nitrates and nitrites, it should be taken into account that the low quality of effluent issued from the WWTP in terms of ammonium could deteriorate groundwater quality and threaten the safety of artificial recharge using TWW.

Also, the nitrogen content is excess in wastewater, being leached from irrigated soils and resulting in high nitrate level in groundwater recharge [21], whereas the surrounding wells showed low levels of ammonia (1.8 mg/L).

Finally, heavy metal analysis involving (Aluminum, Cadmium, Copper, Iron, Lead, Zinc, Chromium, Manganese, and Nickel) confirmed that these trace pollutants are under the detection limit in both groundwater and TWW.

4.2. Analysis of pesticides in groundwater

The pesticides application in the studied area was identified by on site questions asked to local farmers. Obviously, three types of pesticides are used (Table 1).

Among our sampling points, samples from piezometer 2, piezometer 8, well 1, well 3, well 6, well 9, and well 11 were analyzed for pesticides. The measured concentrations of total pesticides in the

Table 1
Examples of pesticides applied in Korba area

Pesticide	Type	Chemical family	Chemical formula	Use
Tétradifon	Insecticide	Sulfones and sulfonates	Tétrachloro-2,4,4′,5 diphénylsulfone	Mites in crops
Propamocarbe	Fongicide	Carbamates	Chlorhydrate of *N*-(3-diméthylaminopropyle)-carbamate of propyl	Mildew in potatoes
Métribuzine	Herbicide	Triazinones	Amino-4 ter-butyl-6 méthylthio-3triazine-1,2,4one-5	Weeds in potatoes and tomatoes

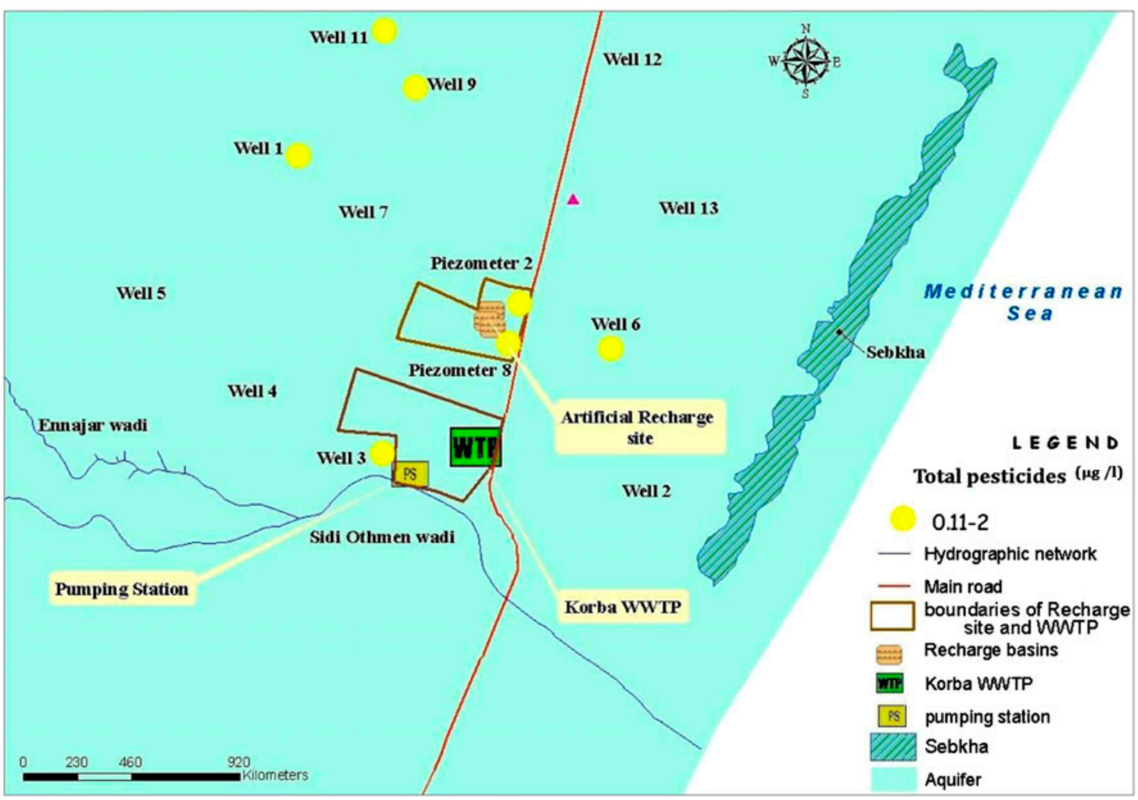

Fig. 3. Spatial distribution of total pesticides in Korba groundwater.

monitored wells are mapped in the Fig. 3. The judgment of the groundwater quality was based on Evaluation System of Groundwater Quality (SEQ) groundwater classification indices which indicate the alteration degree of the groundwater. The threshold for the different classes characterizing the groundwater water quality suitable for drinking purpose were defined based on the French and European standards mainly the French Decree no. 2001–1,220 and the European Directive 98/83/EC on water intended for human consumption. In our study case, the total amount of pesticides in all the monitored wells makes this groundwater unacceptable for human consumption unless a purification treatment would be applied. Previous findings supported the presence of pesticides in ground water, explaining that the factors affecting groundwater contamination by pesticides involve the annual amount of recharge, soil type, depth of aquifer from the surface, nitrate contamination, and soil pH. In fact, pesticides are carried along the water that is moving downward from the surface until they reach the groundwater [12,13,22]. However, some chemicals are more likely than others to move to groundwater depending on their solubility and capacity to be dissolved in water. Then, it depends on their adsorbtion to soil particles, and their persistence which allows them to evaporate or break down slowly and remain in the environment for a long time [12,13,23]. Furthermore, according to the USGS, at least 143 different pesticides and 21 transformation products have been found in the ground water. Numerous pesticides have been detected in groundwater throughout the USA. In Virginia, more than 40 pesticides have been detected in groundwater [23]. These toxic chemical compounds in groundwater pose a health risk to humans and aquatic life. In fact, they showed neurological, reproductive, and dermatological impacts [14]. Isoda et al. [24] found that some pesticides are endocrine disrupting chemicals such as dichlorvos which caused the proliferation of MCF-7 mammary cells, indicating an increased breast cancer risk from exposure to this chemical.

5. Conclusions

Korba aquifer is becoming contaminated with saline water due to sea intrusion induced by groundwater overexploitation. Troublesome levels of nitrate were detected as well due to heavy nitrogen fertilizers application. Moreover, SAR level severely restrict the use of this groundwater to irrigate highly tolerant plants and for neutral or alkaline soils. Then, the screening of groundwater for pesticides identified their use in Korba area to control environmental factors affecting crop production. Also, TWW still contain high contaminant level mainly ammonium next to high SAR level, which risks serious environmental implications, if introduced to groundwater. Heavy metals in groundwater and TWW were under the detection limit. Based on the previous findings, an improvement of the treatment efficiency as well as the implementation of a regular monitoring approach of TWW before recharge is crucial to avoid adverse health effects and to guarantee the safety of groundwater quality.

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