



Spatial Distribution of Nitrate Level in a Deep Aquifer Located in an Agricultural Region (North Tunisia)

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Abstract

The Guenniche deep aquifer (from 75 to 300 m), located in the Bizerte governorate (North Tunisia), is used to supply water for drinking, irrigation, and other needs. It is underlying three small-scale industrial zones and an agricultural area that uses chemical fertilizers and animal manure to improve soil fertility. The present research deals with the physicochemical properties of the groundwater in Guenniche deep aquifer by analyzing ten (10) boreholes in both the wet season (October 2015) and the dry season (May 2016). The results showed that the levels of nitrate were between 8 and 111 mg/L for the wet season and the dry season, respectively. The World Health Organization sets the nitrate limit at 50 mg/L, and 45 mg/L is the national standard. Three boreholes located in the region of El Alia in the south east of the study area exceeded the standards in the dry and wet seasons. Human activities on the surface, in addition to the non-existence or poor condition of sewer channels, are the major factors behind the degradation of Guenniche deep groundwater. This research suggests an urgent need for continuous monitoring of groundwater, particularly those water bodies intended for drinking purposes. Recommendations to the officials and policymakers of the government are given to move toward finding permanent solutions in this matter for the future protection of Guenniche deep aquifer.

Keywords

Deep aquifer • Nitrate • Pollution • Guenniche plain • North Tunisia

1 Introduction

The signs of urban progress, accelerating population growth, and the growing demand of consumption and production have put greater pressures on the natural resources, including the climate, natural ecosystems, and the aquatic environment (Li et al. 2019; Walha et al. 2007; Zammouri et al. 2013; Zereg et al. 2018; Troudi et al. 2019). Groundwater quality control is crucial to ensure long-term durability and to protect them from all forms of pollution, because it is a life-supporting resource for mankind and has the aim to protect both of the human health and the environment (Li et al. 2019; Wu et al. 2019; Yin et al. 2019). In Mediterranean countries, groundwater is mostly used as a source of potable water, and it is being more and more affected by human activity because of urban, industrial, and agricultural waste, which could cause serious implications for the future food security and downgrade the potable water quantity of acceptable quality (Zereg et al. 2018; Biddau et al. 2019; Negm et al. 2020a, 2020b). Nitrate is a problem in several regions worldwide, originating from the overuse of fertilizers, plus the organic manures, human wastewater, and industrial effluents that reinforce its presence in high levels in groundwater (Wu et al. 2019; Yin et al. 2019; Biddau et al. 2019; Negm et al. 2020b). The World Health Organization (WHO 2006) determined the nitrate limit in drinking water at 50 mg/L (WHO), and 45 mg/L is the Tunisian norm (NT) (NT 2013). If these limits are to be surpassed, human health may be threatened by diseases; including spontaneous abortions, birth malformations, blue baby syndrome, increase in the risks of methemoglobinemia and gastric cancer, damage to stomach lining, mouth ulceration,

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non-Hodgkin's lymphoma, hypertension, and reproductive toxicity (Wu et al. 2019; Rivett et al. 2008; Paladino et al. 2018). The Guenniche plain is located in the far north of Tunisia, over an area of approximately 130 km². The importance of agricultural production makes the Guenniche plain one of the most active farming areas in Bizerte governorate (CRDA 1998). Not all municipalities are connected to the drainage canals (Troudi et al. 2019), and the number of residents in these municipalities rose by more than 15,000 inhabitants over three decades to reach more than 74,000 people in 2014 (INS 2014). There are three multi-industrial zones (textile, oil refinery, etc.) in the Guenniche plain area. The objective of the current study is to explore the nitrate levels, to compare them to national and international standards and to investigate the potential nitrate sources. The results of this study will advance the knowledge of the nitrate threat in the Mediterranean environment and may help regional and national authorities to take measures that lead toward protecting groundwater resources in areas of intense agricultural activity.

2 Materials and Methods

2.1 Study Area

The plain of Guenniche is located between latitudes 35° 10' N, 37° 15' N and longitudes 9° 66' E, 10° E, and it belongs to the southeastern part of Bizerte governorate (far north of Tunisia) (Fig. 1). The research area is made up of three municipalities El Alia, Menzel Bourguiba, and Menzel Djemil, and small rural localities: Hariza, Khétmine, Maghraoua, El Jouaouda, and El Azib. Wadi Guenniche is the most important stream in the study area which consists of

many other ephemeral streams (tributaries), such as Wadi El Malah, Wadi Nechrine, Wadi Hela, Wadi El Jaddara, Wadi Echrichira, and Wadi El Galaa (Fig. 1a).

The climate in the Guenniche plain is defined as semi-humid climate with a mean rainfall of 600 mm/year, and the annual average temperature is 18.6 °C (INM 2016). The Guenniche plain is a region with important irrigated land, involving the use of a significant amount of nutrients (Troudi et al. 2019) (e.g., chemical fertilizers, organic fertilizers) and pesticides to ensure an important and good quality production. Regarding the geology and hydrogeology of the area, the Guenniche plain is a large basin created and filled after the great post-villafranchian tectonic phase by the Tyrrhenian Sea with Quaternary sediments, (Haj Ltaief 1995) represented by sands, alluviums, screes, sandstones, silts, clays, limestones, which are permeable and contain two aquifers more or less separated by clay intercalations (Haj Ltaief 1995; Ennabli 1966). The shallow aquifer of Quaternary age which is exploited by low-depth wells that are between 3 and 30 m deep (Haj Ltaief 1995), and the deep aquifer which dates back to the Mio-Pliocene age is between 75 and 300 m deep (Haj Ltaief 1995). It reaches Eocene levels in some places (Haj Ltaief 1995). The aquifers communicate with each other based on the conducted data made in this region, either by the weakly permeable bases (sandy clays, clay sands, etc.) which separate them or by structural accidents in certain places (Haj Ltaief 1995). The deep groundwater flow direction is from the east to the west (Fig. 1b). Bizerte Lake is the main natural outlet of the Guenniche deep groundwater. The groundwater of this plain provides supplies for the potable water, all daily and industrial activities, and most importantly, it is the main source of irrigation water.

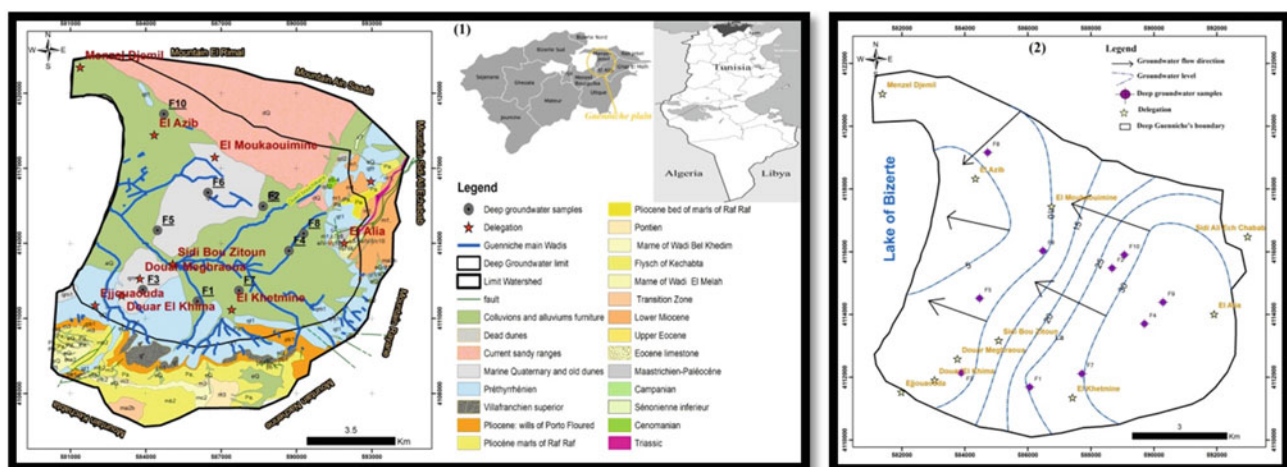


Fig. 1 a Location of the study area, geological map, and the borehole sampling points; b Groundwater deep Guenniche's level map

2.2 Materials and Methods

Ten (10) groundwater-monitoring borehole samples were collected in polyethylene bottles from active pumping wells belonging to the Guenniche deep aquifer at the end of the dry season (October 2015) and the wet season (May 2016). Before collecting each sample, groundwater is pumped for over 10 min to guarantee the presence of fresh water in each sample. Subsequently, and by the use of a portable field kit in situ, the temperature (T°), hydrogen potential (pH), and electrical conductivity (EC) are analyzed. All the samples are stored at 4 °C in an icebox until transported to the laboratory. Groundwater samples were filtered with 0.45 μ m millipore filter paper, acidified with nitric acid and stored at 4 °C into a freezer until the moment of the analysis at the Gdir El Golla laboratory of the National Company of Exploitation and Distribution of Drinking Water (SONEDE) in Tunis. The total dissolved solids (TDS) is determined by evaporation to determine the salinity of the borehole samples. The nitrate analysis is conducted by the use of the salicylate of sodium by molecular absorption (spectrophotometric method). The nitrite analysis was made by “the method of reactive Zambelli” (spectrophotometric method). The analysis is successful if the calculated ionic balance error of each groundwater sample is within the limits of 5%.

3 Results and Discussion

Table 1 summarizes the statistics of physicochemical parameters at the Guenniche deep groundwater in the dry season (October 2015) and the wet season (May 2016).

The pH gives a rough idea of spatial and temporal variations of water by the quality and the infiltration rate of recharge water and of water–rock interaction in the aquifer (Abboud 2018). Results suggest that the groundwater samples were neutral to mildly alkaline in the Guenniche deep aquifer in both seasons, where the pH values ranged from 6.97 to 7.72 during the dry season and between 6.9 and 7.72 during the wet season, which makes them all in desirable

interval set by national (NT) and international (WHO) standards (Table 1). The results of the temperature in the Guenniche deep aquifer were convergent in both seasons and varied from 19.3 to 21.5 °C during the wet season, and from 19.1 to 22.3 °C during the dry season (Table 1), this indicates that there is no effect caused by the atmospheric climate. The electrical conductivity (EC) values ranged from 0.73 to 6.14 mS/cm for the dry season and from 0.89 to 5.84 mS/cm for the wet season with an average value of 2.6 mS/cm of the two periods (Table 1). EC and TDS are typically closely correlated in water (Hiscock 2005). TDS mainly indicated the various kinds of minerals present in the groundwater, and the Guenniche deep aquifer water samples exceeded the WHO standard limits at 1000 mg/L in eight boreholes analyzed and in two boreholes compared to 2000 mg/L limit set by the Tunisian standard (NT); they varied from 414 to 3842 mg/L for the dry season and from 510 to 3650 mg/L for the wet season with a mean value of 1580 mg/L for both periods (Table 1). The water saturation of major cations and anion salts, in combination with the water–rock dissolution phenomena initialization during the water flow from the surface to the lower depths, may explain the presence of high TDS values in all the water samples (Abboud 2018). The results of nitrite in each borehole sample and in the dry and wet seasons felt within the limit value of national (NT) and international (WHO) standards set at 0.2 mg/L (Table 1). Nitrate concentrations varied from 8.1 to 111.9 mg/L, in the dry season with a mean value of 42.9 mg/L and between 8.2 to 109.2 mg/L, with mean at 39.7 mg/L in the wet season (Table 1). Average nitrate concentration is the highest in F1, F2, and F7 to the west of El Alia region in both seasons compared (Fig. 2) to WHO and NT standards, with a slight level change in the three boreholes from season to season. The concentration of nitrate in P7 borehole exceeded the standards’ limit by 15 mg/L in both seasons. F1 and F2 exceed the WHO and NT limits to beyond 100 mg/L in both sampling periods (October 2015 and May 2016).

A total of 90% of the plain of Guenniche land is farmland, of which 70% is an irrigated land (CRDA 1998). The livestock numbers reached 31,565 sheep and 5526 cattle in

Table 1 Average values and range of physicochemical results of the Guenniche deep groundwater

Parameters	Dry season (October)			Wet season (May)			Standards	
	Min	Max	Mean	Min	Max	Mean	WHO	NT
T (°C)	19.1	22.3	20.8	19.3	21.5	20.53	–	–
pH	6.97	7.72	7.26	6.9	7.72	7.17	6.5–9.5	6.5–8.5
EC (mS/cm)	0.73	6.14	2.6	0.89	5.84	2.632	2.5	1.5
TDS (mg/L)	414	3842	1598.8	510	3650	1564.2	2000	1000
NO ₃ ⁻ (mg/L)	8.08	111.9	42.88	8.2	109.2	39.68	50	45
NO ₂ ⁻ (mg/L)	0.003	0.049	0.023	0.01	0.046	0.024	0.2	0.2

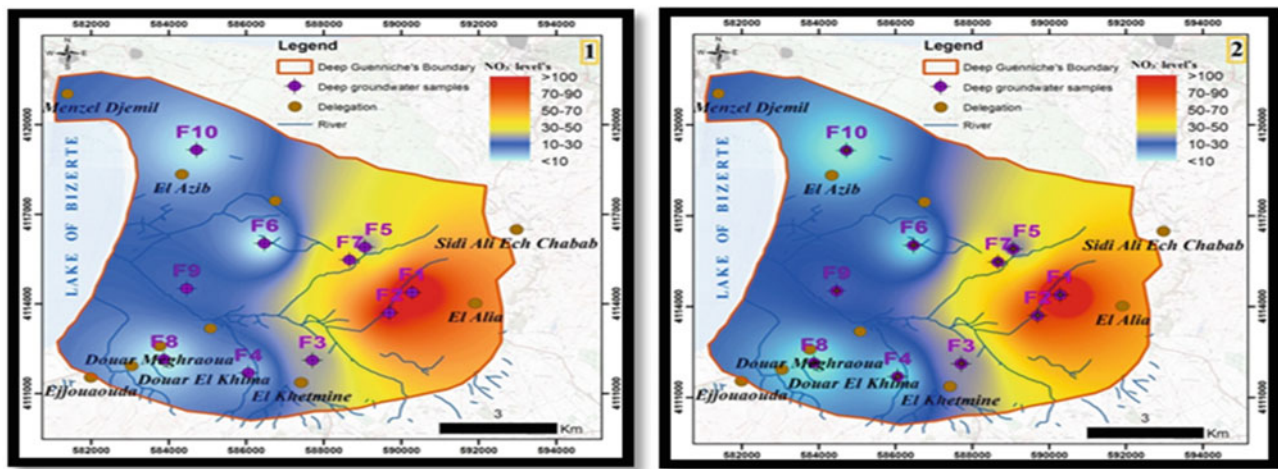


Fig. 2 Spatial distribution of nitrate levels (mg/L) in 1 the dry season and 2 Wet season in the deep aquifer of the plain of Guenniche

2015 in the study area with an estimation of 100 kg/ha/year of nitrogen from farm fluxes (CTV 2015). During the sampling, an accumulation of high quantities of animal manure was noted, even close to the studied boreholes, strengthening the hypothesis of nitrate migration to the groundwater. Nitrate levels in groundwater increase with the application of chemical fertilizers. The most frequently used fertilizers in the area are the DAP N-P₂O₃ and Ammonium and super 45, with an application rate of over 450 kg/ha/year (CTV 2015) and 300 kg/ha/year, respectively, in the leguminous activity farms. The drainage from fertilized fields and contaminated water bodies can also serve as a source of nitrate. Previous studies by (Zereg et al. 2018; Wu et al., 2019; Yin et al. 2019; Biddau et al. 2019) indicated that the main source of the presence of the nitrate elements in the water is associated with the different human activities in the surface which are reflected by groundwater pollution. The west of El Alia region is a rural area lacking adequate infrastructure like sewer systems, so the wastewater discharges in the surface enters the streams of Wadi Guenniche and El Mellah. It is the main reason which explains the presence of high nitrate levels found near these ephemeral streams. The study of Hamza et al. (2010) stated that the shallow aquifer has been classified as vulnerable to pollution by nitrate elements due to its low depth and the type of soil (permeable in most of the area's surface) which facilitates the transport of those elements by surface water and the infiltration of irrigation water; consequently, the transport of NO₃⁻ from the surface to the shallow aquifer. The shallow and deep aquifers are separated by semi-permeable layers in some areas (Haj Ltaief 1995), and the presence of a fault in El Alia region to NE-SW direction, of 25 km long and 4–5 km deep (Kacem 2004), could explain the presence of nitrate in the vicinity of

the boreholes. To the west (toward the lake of Bizerte), the yellow and blue colors in the map (Fig. 2) indicate very low nitrate levels, which can be explained by the impermeable rocks that separate the shallow from the deep aquifer (Haj Ltaief 1995), thus, protecting the deep aquifer from all surface anthropogenic pollution.

4 Conclusions

The results of the samples taken from the Guenniche deep groundwater during the dry and wet seasons showed high levels of NO₃⁻ up to 100 mg/L in two boreholes, and in one, the level was 60 mg/L. Three boreholes located in El Alia region exceeded the national and international standards (Fig. 2). The chemical and organic manure are the principal sources of NO₃⁻, in addition to the discharges of wastewater in the rural areas which are not connected to the sanitation channels. The permeability of the soil is one of the reasons behind NO₃⁻ elements' transport from the surface to the shallow aquifer and may, thus, be transmitted to the deep aquifer through the semi-permeable bottom (in some places) and through the fault located in El Alia region. Pinpointing pollution and natural causes as being at the origin of water contamination is of huge importance to address the problem efficiently and to apply the best policies regarding the groundwater resources' management. It is really important in the future work to increase the number of borehole samples and study the hydrogeochemical and stable isotopic in the Guenniche groundwater system which would provide the best approximation of the link between the different aquifers, as well as the hydrogeochemical modeling study of the Guenniche groundwater in order to help protect these vital resources.

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