ORIGINAL PAPER

Spatio-temporal analysis of nitrates and piezometric levels in groundwater using geostatistical approach: case study of the Eastern Mitidja Plain, North of Algeria

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Abstract

The groundwater quality in the Mitidja plain has known an important deterioration during the last decades due to uncontrolled industrial waste discharges, intensive use of chemical fertilizers in agriculture, and an intense exploitation of groundwater resources. In this paper, we are interested in the Eastern part of the Mitidja plain, which covers an area of 495.52 km^2. This study area is characterized by its industrial and agricultural vocation, thereby the problem of groundwater pollution. The study will focus on the fluctuation of the groundwater table, and the interpretation of the water quality analysis result made by ANRH (National Water Resources Agency), during the period between 2006 and 2016. The last ones have been geostatistically approached. This allowed us to carry out a GIS-assisted mapping of the nitrate concentrations in the aquifer and to draw up an exhaustive report on the current state of the relationship between the fluctuation of water table and the nitrate concentration rates, also the spatial and temporal evolution of the aquifer. As a result, the geostatistical approach gave us the possibility to draw up Kriging maps of the nitrate level spatial distribution for the two field monitoring campaigns: 2006 and 2016 as well as groundwater fluctuation maps for the periods under consideration. The obtained result reveals that 72% of the sample's points have nitrate concentrations higher than 50 mg/l in rainy period in the 2 years 2006 and 2016. As for the dry period, the results show that more than 54% in 2006 and more than 81% in 2016 of the water samples analyzed are contaminated (exceeding the WHO's recommendation). A significant water table drawdown, between 2006 and 2016, is highlighted, which reached an average of around 23 m in low water and 26 m in rainy period (case of drilling *F1003*). This drop in the water table level can be explained by overexploitation of the groundwater caused by intensive pumping for irrigation, industry, and water supply, due essentially to the increasing scarcity of rainfall, which is a consequence of climate change, which has become increasingly prevalent over the last three decades. Given the upward trend in nitrate levels in recent years, there is a significant risk that nitrate levels will far exceed the 50 mg/l threshold recommended by the WHO in the next 10 years. It is therefore imperative to remedy this through the control of industrial discharges and the extension at the level of the agricultural community regarding the intensive use of chemical fertilizers and (in particular nitrogen) and groundwater (by controlling the pumping).

Keywords Pollution · Nitrates · Piezometric levels · Aquifer · Mitidja East · Geostatistics · Kriging

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Introduction

The point and diffuse contamination of groundwater by nitrates has been the subject of various studies worldwide (Power and Schepers 1989; Bijay-Singh and Sekhon 1995; Zhang et al. 1996; Arrate et al. 1997; Carpenter et al. 1998; Jégo et al. 2012; Bernard-Jannin 2015; Re et al. 2017). According to Domenico and Schwartz (1990), Appelo and Postma (2005), Shirazi et al. (2013), and Reddy (2013), groundwater quality depends on several factors, such as
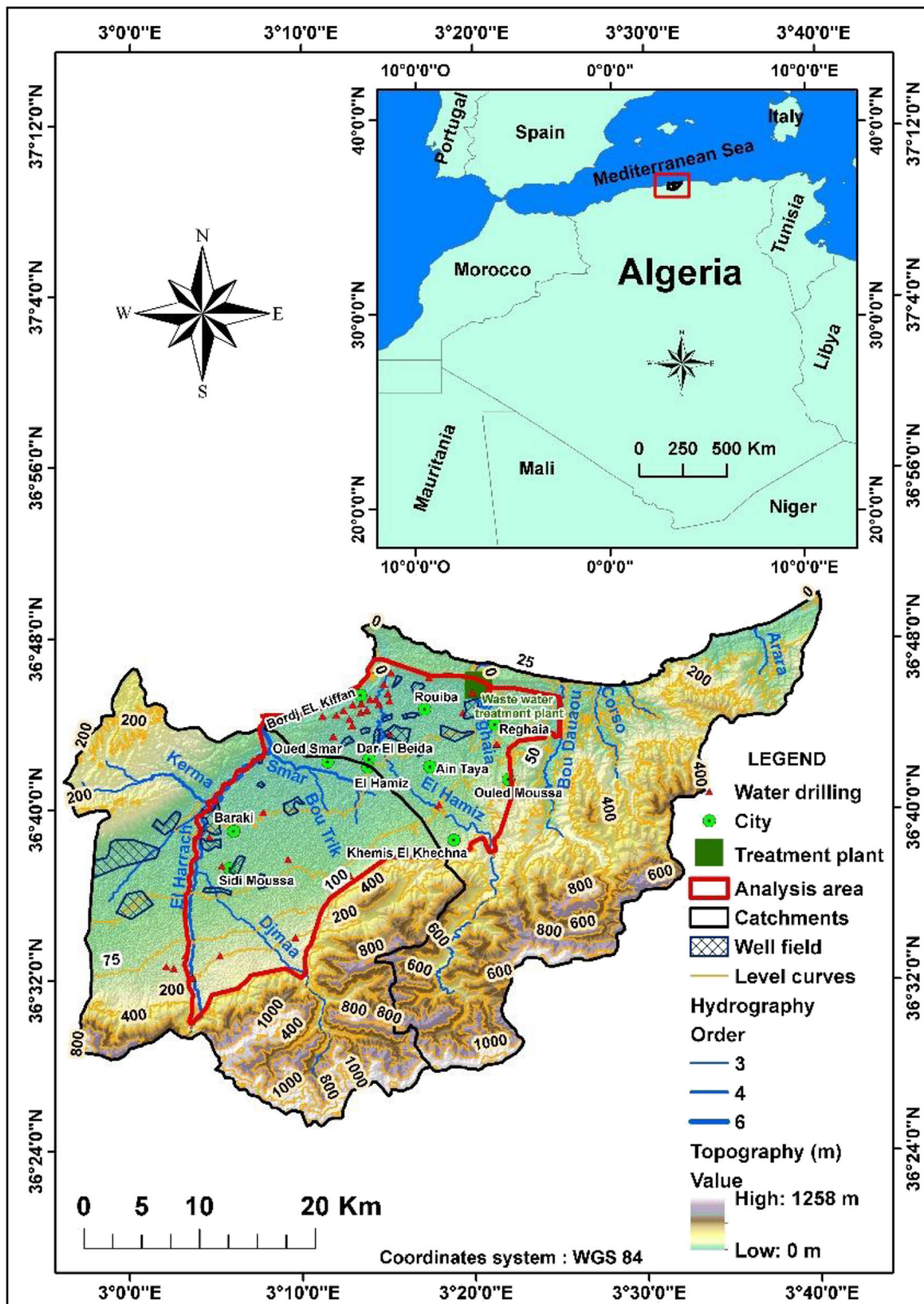
Fig. 1 Study area (East Mitidja)

geology, recharge quality, and soil types and others, as well as nitrate pollution from agricultural sources which considered to be the main cause of groundwater degradation in the European Union (Sutton et al. 2011).
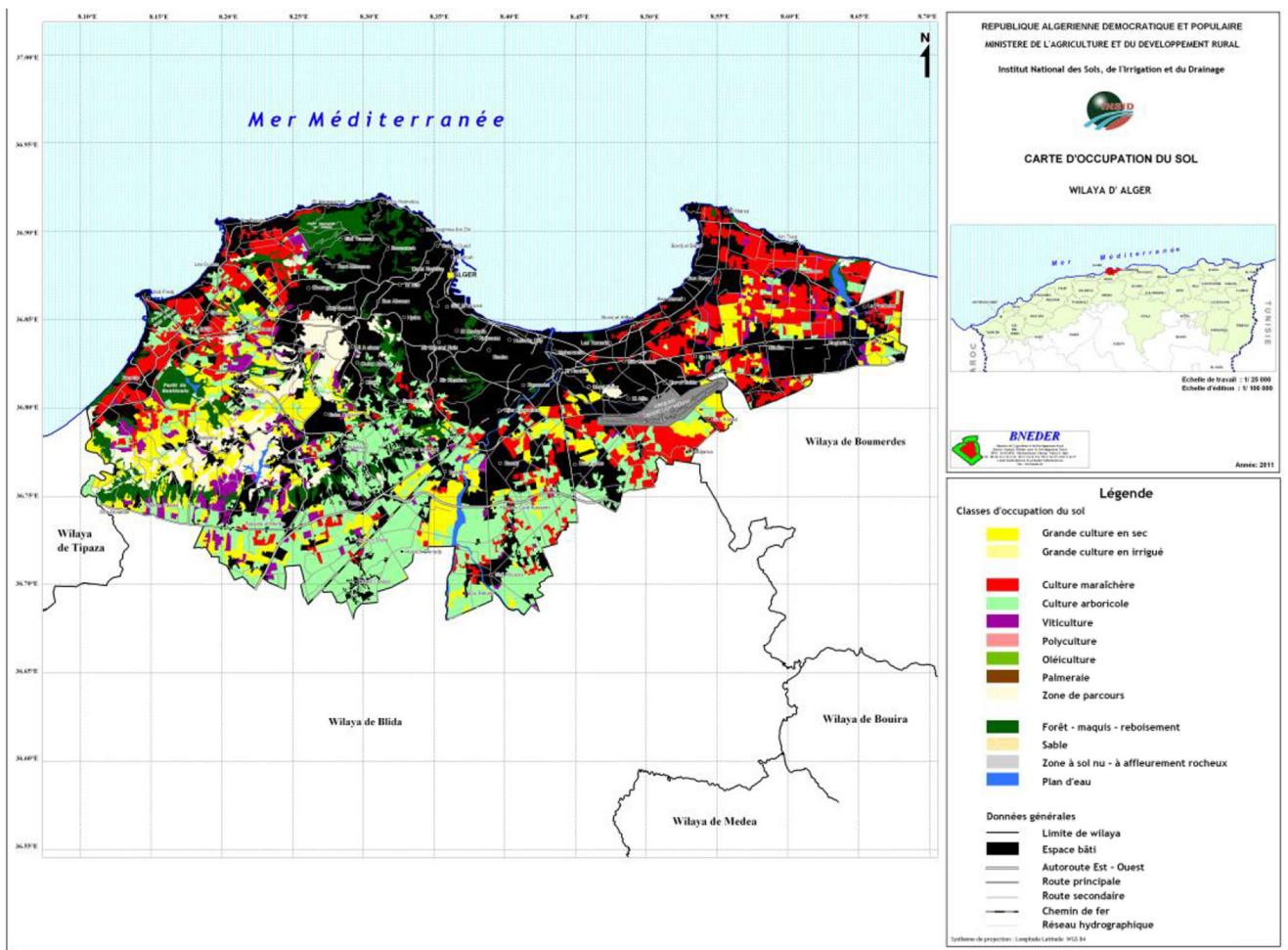
Fig. 2 Land cover map of the Mitidja EAST (BNEDER 2011)

Table 1 Data base (nitrates)

W021-5 (E008-4583)	X	Y	Z (m)	NO3_LW (mg/l)	NO3_HW (mg/l)
1985	552,750	385,600	25.47	-	64
1986	552,750	385,600	25.47	88	-
1987	552,750	385,600	25.47	50	-
1988	552,750	385,600	25.47	-	57
1990	552,750	385,600	25.47	-	85
1991	552,750	385,600	25.47	87	26
1997	552,750	385,600	25.47	-	190
1998	552,750	385,600	25.47	-	98
1999	552,750	385,600	25.47	78	-
2000	552,750	385,600	25.47	151	-
2002	552,750	385,600	25.47	-	32.0
2004	552,750	385,600	25.47	125.0	15.0
2005	552,750	385,600	25.47	63.0	125.0
2006	552,750	385,600	25.47	276.3	710.0
2007	552,750	385,600	25.47	-	69.0
2008	552,750	385,600	25.47	79.0	65.0
2009	552,750	385,600	25.47	87.8	68.0
2010	552,750	385,600	25.47	-	80.0
2011	552,750	385,600	25.47	8.0	-
2012	552,750	385,600	25.47	251.0	-
2013	552,750	385,600	25.47	-	76.0
2014	552,750	385,600	25.47	-	125.0
2015	552,750	385,600	25.47	63.0	64.0
2016	552,750	385,600	25.47	79.0	65.0

LW low water period, *HW* high water period

Table 2 Data base (piezometric level)

W021-5 (E008-4583)	X	Y	Z (m)	NS_HW (m)	NS_LW (m)
1986	552,750	385,600	25,470	-	2.42
1987	552,750	385,600	25,470	-	3.34
1997	552,750	385,600	25,470	3.05	-
1998	552,750	385,600	25,470	2.5	-
1999	552,750	385,600	25,470	-	3.2
2000	552,750	385,600	25,470	-	4.9
2002	552,750	385,600	25,470	4.95	-
2003	552,750	385,600	25,470	3.50	3.70
2004	552,750	385,600	25,470	3.10	3.40
2005	552,750	385,600	25,470	2.35	3.00
2006	552,750	385,600	25,470	2.60	3.10
2007	552,750	385,600	25,470	2.08	3.95
2008	552,750	385,600	25,470	2.31	3.90
2009	552,750	385,600	25,470	2.20	3.60
2010	552,750	385,600	25,470	4.95	5.60
2011	552,750	385,600	25,470	3.20	5.95
2012	552,750	385,600	25,470	2.6	-
2013	552,750	385,600	25,470	3.76	5.62
2014	552,750	385,600	25,470	4.00	5.10
2015	552,750	385,600	25,470	-	29.40
2016	552,750	385,600	25,470	28.50	31.2

In a study conducted in Senegal (in the Cap Vert region at the Dakar), Re V., Sacchi E. et al. (2017) showed that the interaction of agricultural activities and the infiltration of wastewater are the main causes of high nitrate concentrations in water intended for irrigation and human consumption, with values exceeding the WHO standards (50 mg/l; WHO 2011), with concentrations greater than 800 mg/l (Deme et al. 2006; Re et al. 2011; Diédhiou et al. 2012). Léonard Bernard-Jannin (2015) conducted a study in France in which they were able to find concentrations of up to 139 mg/l. Similarly, the work done by *Pierre Penant* in 2016, through the analysis of the main chemical elements in Benin, confirms very high nitrate

levels that may exceed 400 mg/l. Also, in Tunisia, in the region of Grombalia, V. Re, E. Sacchi et al. (2017) found that out of 25 water points sampled, 10 wells (40%) had nitrate levels ranging from 55 to 231 mg/l.

In Algeria, Hadjoudj (2008) found that groundwater in the eastern Mitidja region was the most polluted by nitrates, with mean concentrations in the order of 120 mg/l in the ANRH network and 50.3 mg/l in the AEP network. According to the follow-up report of the Mitidja monitoring network (ANRH 2013), nitrate pollution of the water table is due to strong industrial activity coupled with urban effluent discharges, but also to intense agricultural activity (vegetable crops) and
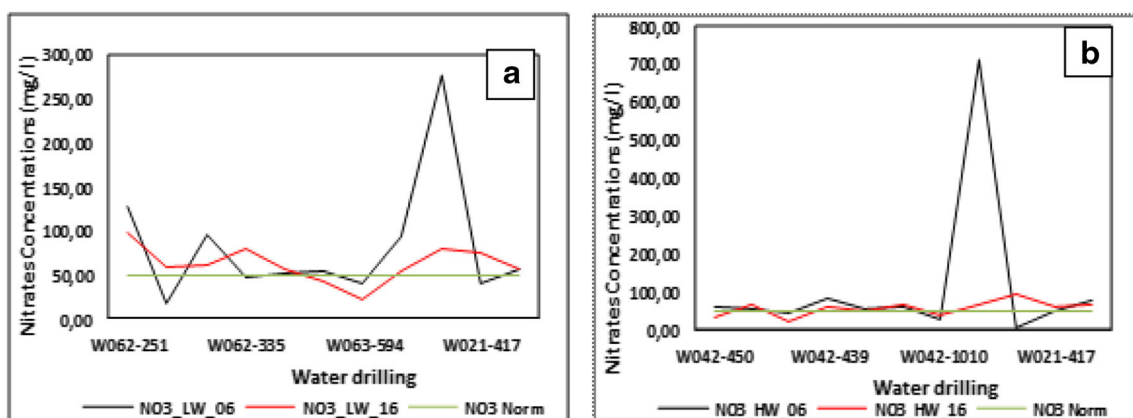
Fig. 3 Nitrate evolution (low (**a**) and high (**b**) water period, for 2006 and 2016)
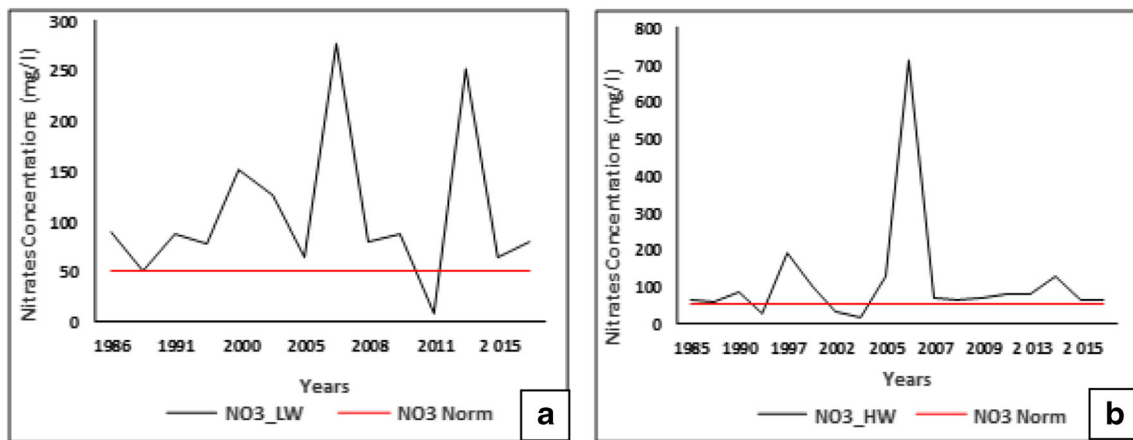
Fig. 4 Nitrate evolution in well drilling P021-5 (E008-48583: Sud Ain Taya), low and high water (**a**, **b**) (period: 1985–2016)

uncontrolled landfills. According to the same source, the permeability of the soil and the subsoil, as well as the proximity of the roof of the water table (10 to 15 m) to the soil surface, are all parameters favoring pollution of the ground water. Nitrate concentration recorded; in the quaternary aquifers, groundwater during the campaigns carried out by the National Water Resources Agency (ANRH) during the period 1985 to 1991 varies from 8 to 26 mg/l in high water periods, and between 40 and 287 mg/l in low water. In 2013, 14) of the 32 water points sampled and analyzed recorded nitrate concentrations exceeding the *WHO*-recommended standards.

As a result of established findings by the various research projects mentioned above, it is essential to update the database of the aquifer contamination by nitrates, comparing it with the fluctuation of the water table for the 2 years taken into consideration, namely 2006 and 2016; it is evident that the analysis of nitrate and the record of piezometric levels in the Mitidja EAST region is essential. It should be based on a geostatistical approach of the different parameters (nitrates and piezometric levels).

The main objective of the study is, therefore, to characterize and highlight the spatio-temporal variability of the nitrates and piezometric levels, based on geostatistical modeling. The latter

will thus enable a better understanding of the problem of groundwater nitrate pollution, by establishing different variogram models highlighting the evolution of the parameters studied. The geostatistical approach makes it possible to quantify and evaluate the risk of contamination of groundwater, through a set of data, in order to deduce an intervention plan with beneficial and fair remediation solutions.

Materials and methods

Study area

The Mitidja East study area is located in the northern part of Algeria. It is a part of the Mitidja alluvial plain, which is the most important sublittoral plain in Algeria with a significant agricultural activity. It covers only 3% of the total surface area of northern Algeria, but it has about 10% of the surface water resources and nearly 20% of its groundwater potentials. The Mitidja East covers an area of 495.52 km^2, WSW-ENE orientation; it is oriented parallel to the coastal relief of the Sahel from Algiers in the North and the Blideen Atlas in the South. Wadi Reghaia in the East and Wadi El Harrach in the West
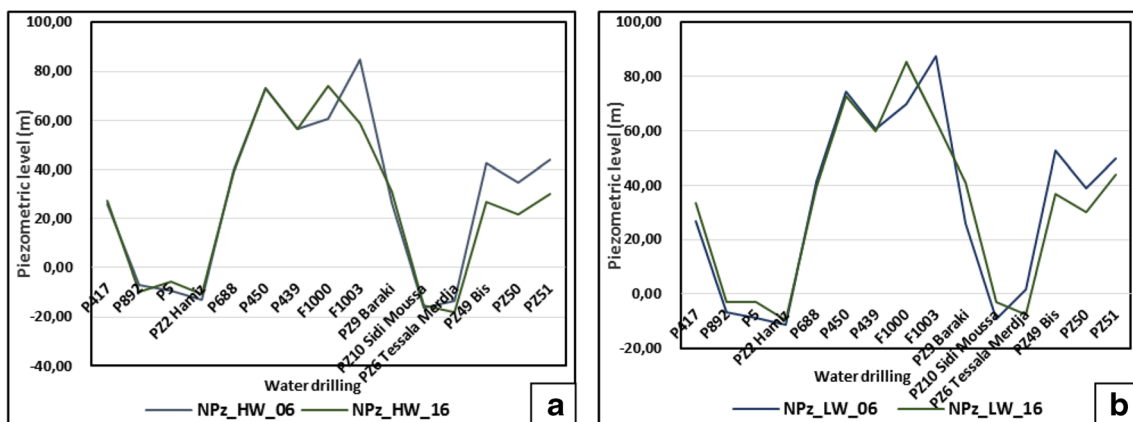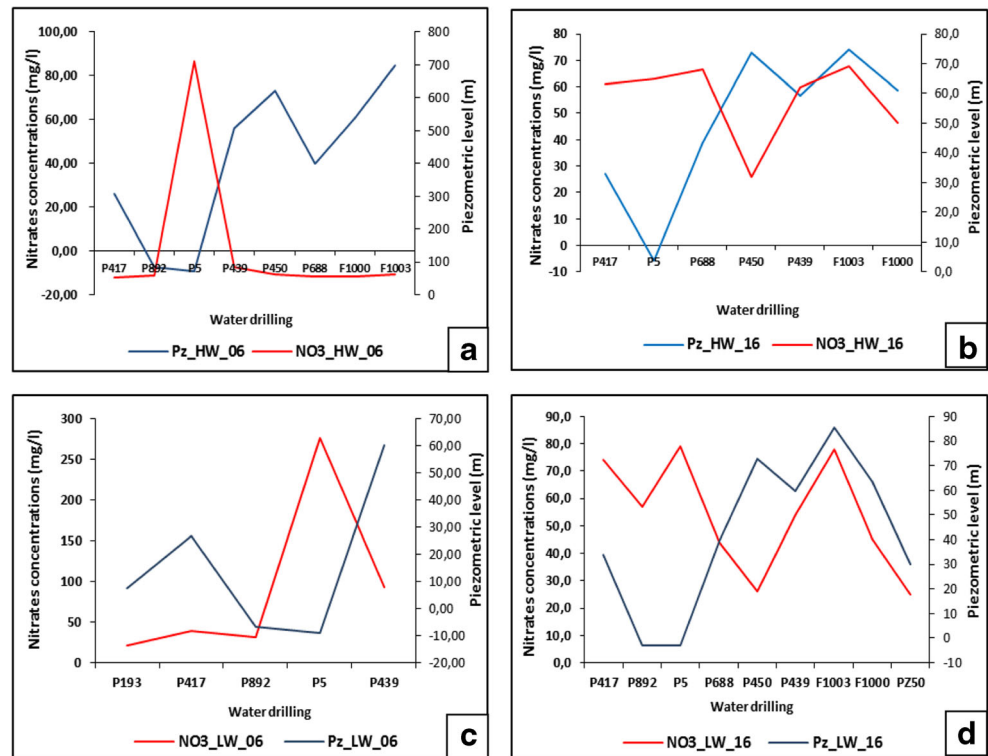

Fig. 5 Piezometric level evolution for 2006 and 2016 (low and high level (**a**, **b**)

Fig. 6 Nitrate evolution and piezometric level evolution. **a** High water 2006, **b** high water 2016, **c** low water 2006, and **d** high water 2016

(Figs. 1 and 2) also border it. The main exploited surface water resources currently in the study area are listed below: Hamiz dam, Reghaia dike, Water transfer from the Keddara dam. The mobilization and exploitation of the groundwater resources in the East Mitidja Plain are done at the main groundwater catchment fields: Baraki, HaouchFlit, Hamiz, Boureah, O.Adda, and Haouch Bel Abess.

Concerning the climate, the region is characterized by a semi-arid one, with a dry season from May to September and a cold and wet season from October to April. The average rainfall is 607.25 mm, the inflow was estimated as 35.25 mm, i.e., 5.8% of the rainfall; on the other hand, the runoff is estimated at 50.75 mm, i.e., 8.36% (Water balance 1970–2004). This is due to the geomorphological characteristics of the catchment area and the predominance of impermeable geological formations, thus favoring runoff than infiltration (Djoudar 2014).

From geological point of view, the Mitidja is an area of continuous subsidence. The latter gave birth to an active sedimentation whose elements come from the reliefs of the Blidéen Atlas. At the end of the Pliocene and the Quaternary, two aquifers were individualized: the *Astian* formed by limestone and sandstone of continental origin and the *Quaternary* formation composed mainly of coarse alluvium (gravel, pebbles, silts, and clays in varying quantities).

Methodology

In order to carry out the study, the hydrochemical and piezometric data, of 26 water points, provided by the laboratory of the

National Agency of Water Resources (ANRH) will constitute the database (Tables 1 and 2). Water sampling and the measurement of piezometric levels were carried out at the existing wells, boreholes, and piezometers, during two periods of the year: dry and wet water. Two years (2006 and 2016) were analyzed through the monitoring and comparison of the fluctuation of piezometric levels and the evolution of nitrate levels in groundwater, on 10 years of interval, which will allow us to know the current and future state of the water quality of the region considered. A geostatistical approach was applied, allowing us to draw up a kriging map of piezometric and nitrate levels.

In order to draw up a comprehensive report on the current state of nitrate pollution in the groundwater of the Mitidja EAST aquifer, statistical and geostatistical analysis will be applied on two essential parameters: nitrates and piezometric levels (high and low water 2006 and 2016), through an ArcGis mapping.

The latter can make it possible to identify the relationship between the two parameters and to counter the poor configuration of the current network, whose data are insufficient and heterogeneous from 1 year to the next.

Geostatistical analysis

In order to highlight the evolution of nitrate concentrations in relation with the fluctuations in piezometric levels for the 2 years under consideration, 2006 and 2016, it is imperative to use geostatistics approach. This approach will allow us to carry out a homogeneous analysis of the data, the spatial structuring, as well as the errors that taint them. The first step is to conduct an
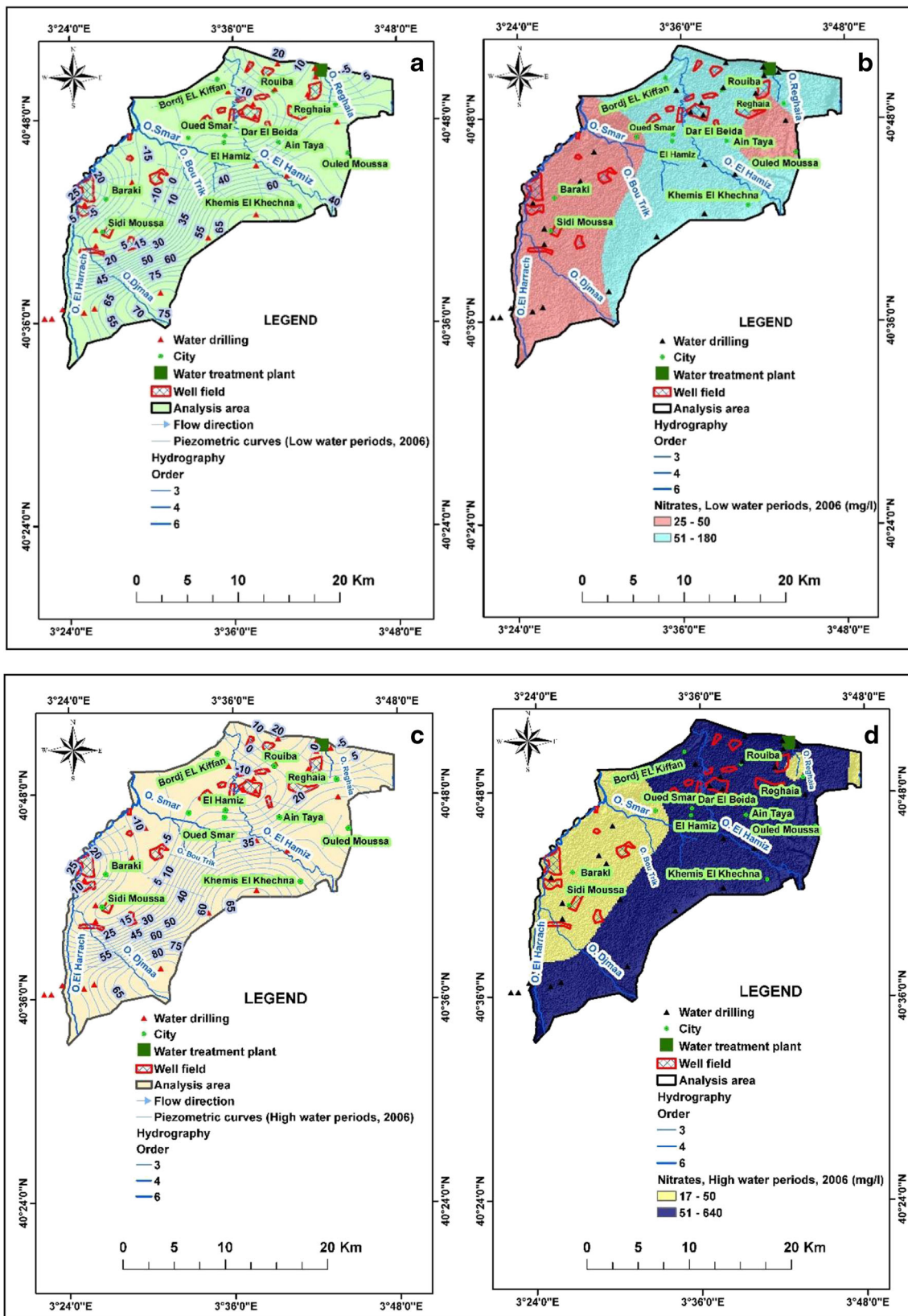
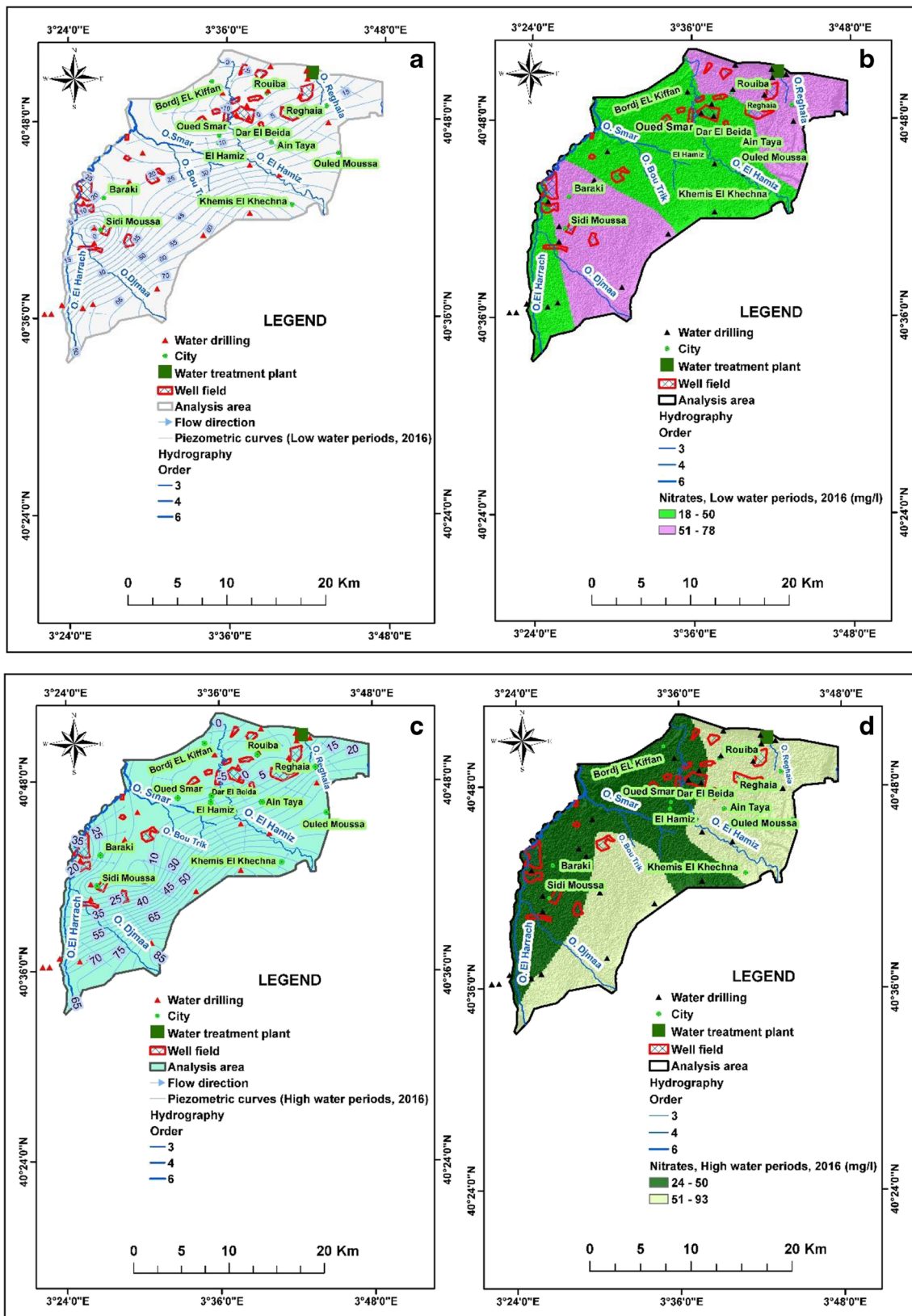**Fig. 7** Kriging map of piezometric level (**a**, **c**) and nitrates (**b**, **d**) (low and high water period, for 2006)
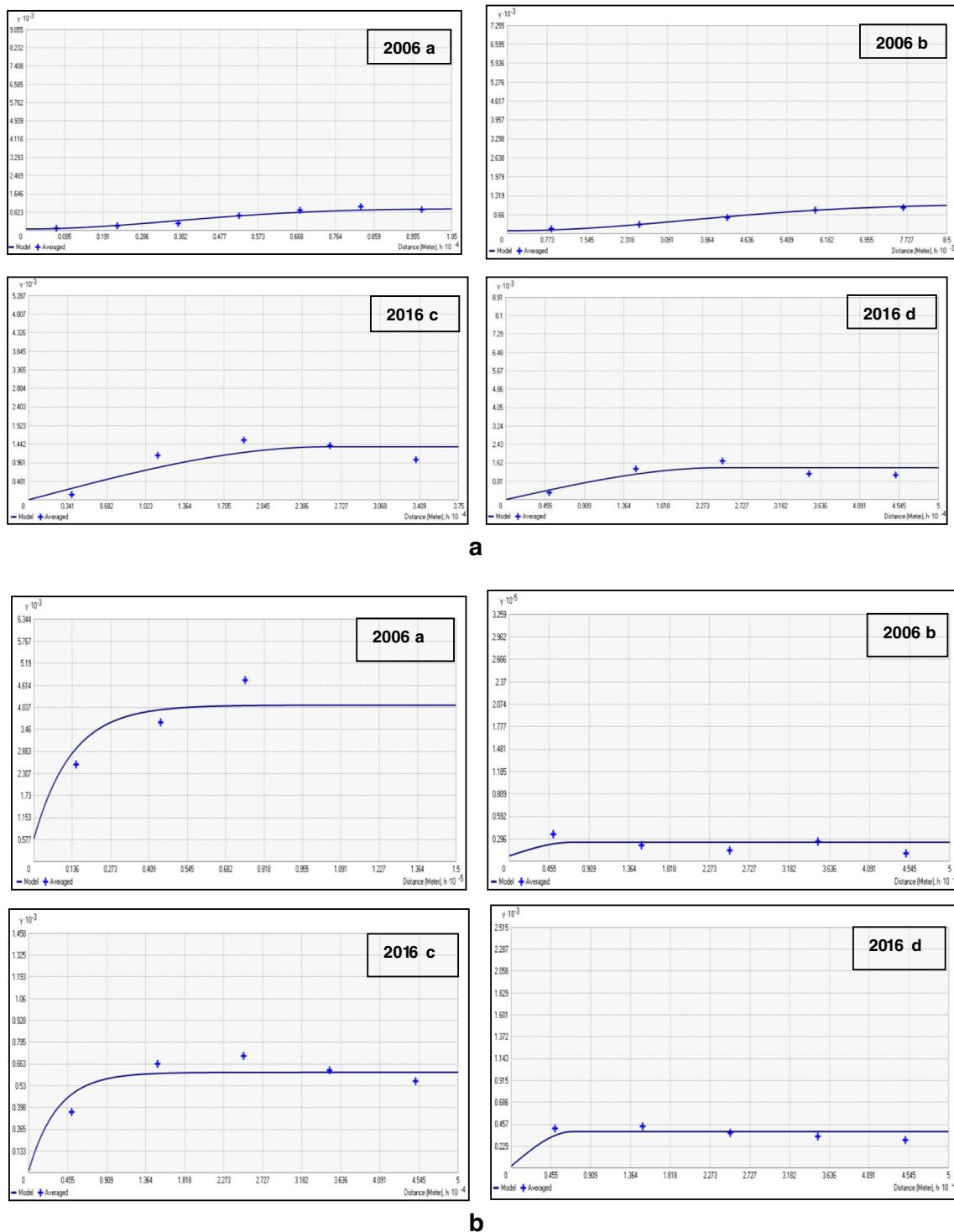
Fig. 8 Kriging map of piezometric level (**a**, **c**) and nitrates (**b**, **d**) (low and high water period, for 2016)
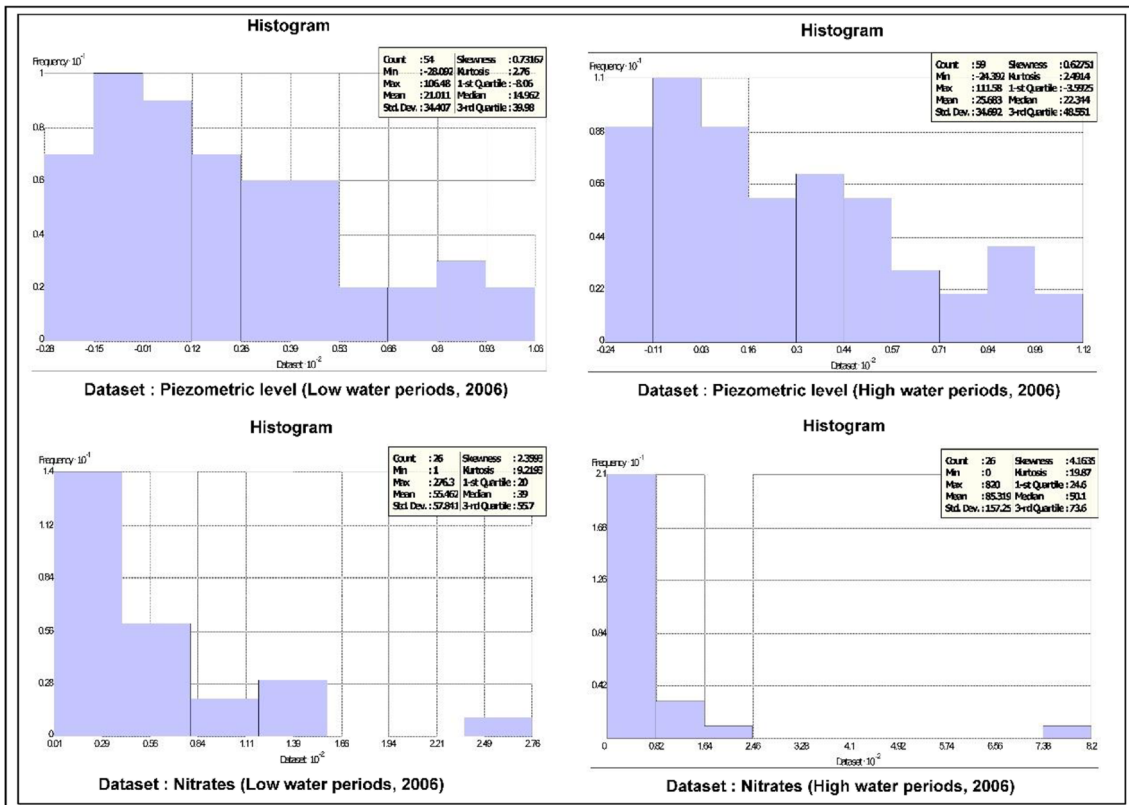
Fig. 9 Semi-variogram plot of piezometric level (**A**) and nitrates (**B**) (low and high water period for 2006 (a and b) and 2016 (c and d))

exploratory data analysis to identify and locate anomalous data, in order to describe the spatial variability of the variables studied (piezometric levels and nitrate content), particularly the scope of experimental variograms and anisotropy of the medium. This property allowed us to direct the choice of the interpolation method, towards the estimation proposed by kriging, taking into account the continuous variation of the data as well as the measurement errors.

Dataset : Piezometric level (Low water periods, 2006)

Dataset : Piezometric level (High water periods, 2006)

Dataset : Nitrates (Low water periods, 2006)

Dataset : Nitrates (High water periods, 2006)

a

Dataset : Piezometric level (Low water periods, 2016)

Dataset : Piezometric level (High water periods, 2016)

Dataset : Nitrates (Low water periods, 2016)

Dataset : Nitrates (High water periods, 2016)

b

◀ **Fig. 10** Frequency distributions and descriptive statistical parameters of variables: nitrates and piezometric level (low and high water period for 2006 (**a**) and 2016 (**b**))

The variogram is a tool for describing the spatial continuity of a sampled phenomenon. It is based on the idea that two samples separated by a short distance have an average more similar than two samples separated by a larger distance. The theoretical formulation of the semi-variogram $\gamma(h)$ made reference to the notion of variance applied to the difference between two samples $b(x)$ separated by a vector distance h (Cressie 1993).

$$\gamma(h) = \frac{1}{2} \text{var}[b(h) - b(X + h)] \tag{1}$$

However, in practice, $\gamma(h)$ is not known for any distance. So, this function is estimated by the experimental semi-variogram (ESV). The ESV is generally not reliable for long distances. Therefore, it is advisable to calculate it for the distances less than half of the maximum distance between two samples (Arnaud and Emery 2000).

$$\widehat{\gamma}(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(b_i) - z(b_i + h)]^2 \tag{02}$$

$N(h)$: number of pairs in distance class h.

$Z(b_i)$: regionalized variable (piezometric levels, nitrate contents) at the site.

The geostatistical analysis was performed following several steps before final kriging maps.

The study presented in this article was conducted in two stages:

– Estimation parameters of the experimental semi-variogram, distance, and number of lag distance
– Modeling of each variable at the study area level.

## Results and discussions

Evolution of piezometric levels

It should be noted that the evolution of piezometric levels in the alluvial groundwater of the East Mitidja is regularly monitored by the *ANRH*. The records conducted for the period 2001 to 2013 (to better explain the evolution of piezometric levels) reveal that between Baraki and Sidi Moussa, the piezometric levels measured in two piezometers (E007-9126-pz9 baraki, E007-9127-pz10 sidi moussa) show a spectacular improvement of about 10 m in 2013 compared with previous years. In the Eucalyptus region, the monitoring well (E007-9641-f 997/42) showed an uplift of 7 m between 2010 and 2012, following the shutdown of several AEP drill holes in the Baraki and Hamiz well fields (see graph of pz 2 hamiz E008-4212) (ANRH 2013), knowing that the piezometric level is a function of the large catchment fields as well as the hydrological cycle (deficit or surplus).

Table 3 Parameters of modeling (fitted and validated)

Variables	Year	Periods	Experimental semi-variogram omnidirectional (ESV)		Type of structure	Range (m)	Sill	Cross-validation	
			Lag distance (m)	Number of lag distance				MES	VES
Piezometric level (m)	2006	Low water	1500	7	Nugget effect model Gaussian model	- 9000	70 920	0.15	1.06
		High water	1700	5	Nugget effect model Gaussian model	- 8500	100 930	0.12	1.07
	2016	Low water	7500	5	Nugget effect model Spherical model	- 26,000	5 1370	0.043	0.99
		High water	10,000	5	Nugget effect model Spherical model	- 24,700	5 1400	0.064	0.97
Nitrates (mg/l)	2006	Low water	30,000	5	Nugget effect model Exponential model	- 40,000	6 3500	0.014	1.66
		High water	10,000	5	Nugget effect model Spherical model	- 10,000	700 25,000	0.07	1.16
	2016	Low water	10,000	5	Nugget effect model Exponential model	- 10,000	10 600	0.1	0.93
		High water	10,000	5	Nugget effect model Spherical model	- 7000	20 360	0.14	1.12

MES mean of standardized errors, *VES* variance of standardized error

Fig. 11 Variogram map of nitrates and piezometric level (low and high water period for 2006 (**a**) and 2016 (**b**))
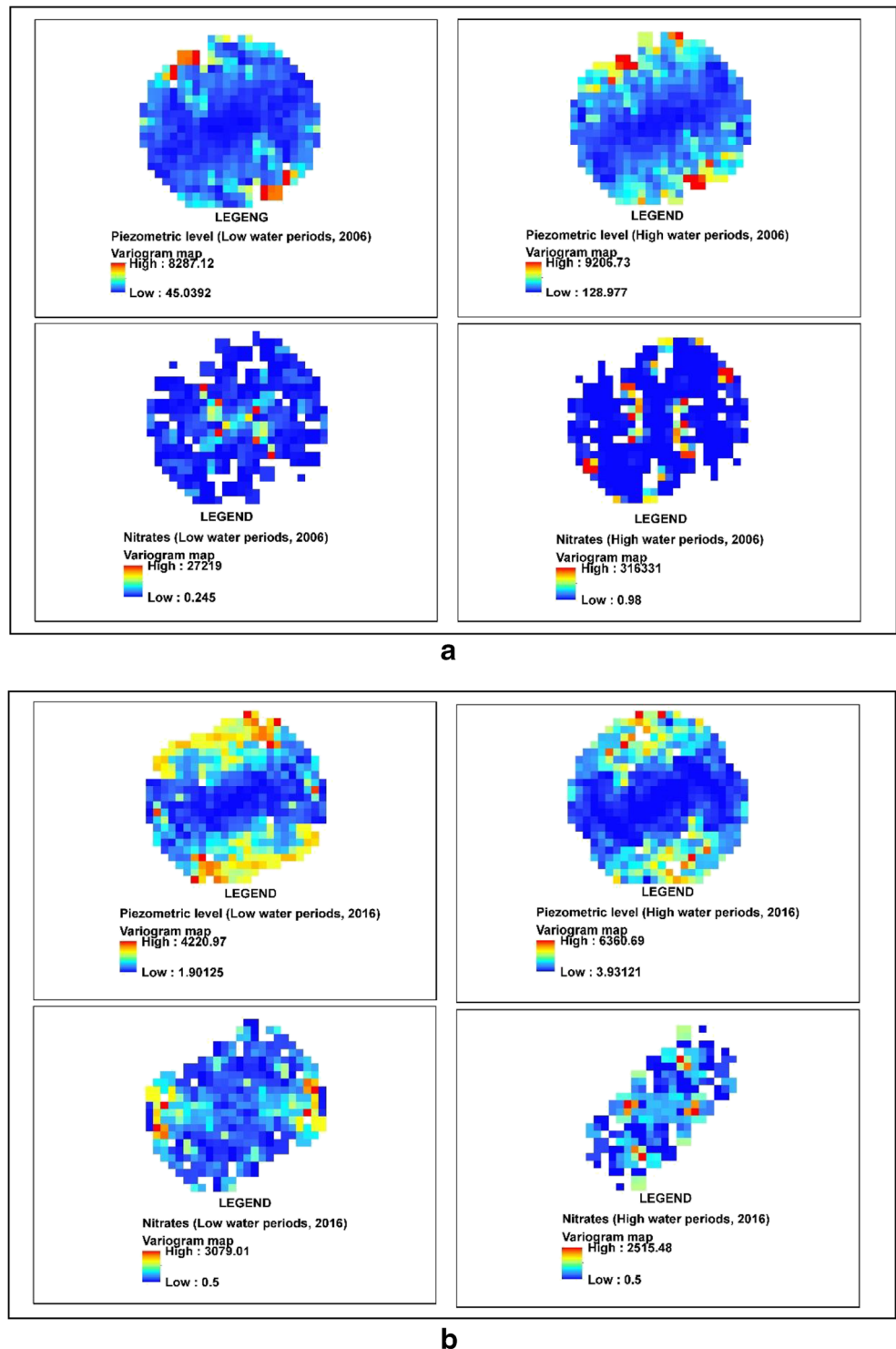
The graphs of high and low water levels in 2006 and 2016 were plotted to illustrate the evolution of the piezometric surface with respect to time (Fig. 5). These show a drawdown of the water table between 2006 and 2016, which can reach approximately 23 m in low water and 26 m in high water (case of drilling *F1003*). This state can be explained by overexploitation of the groundwater in this area through intensive pumping.

Nitrate evolutions

Figure 3 shows that the NO_3 concentrations exceed the WHO standard of 50 mg/l. Especially during the high water periods of the 2 years 2006 and 2016, during which more than 72% of the water points are contaminated. Same observation for the low water period; where in 2006 and 2016, respectively, more

than 54% and 81% of the water points analyzed had nitrate concentrations higher than 50 mg/l.

Monitoring well P021-5 (E008-4583, South of Ain Taya) recorded a significant peaks in 2016 (Table 1), whose contents reached values of 276.30 mg/l and 710.0 mg/l, respectively in low and high waters, which was the subject of a particular analysis (Tables 1 and 2) over a period from 1985 to 2016 (Figs. 4 and 5).

Indeed, the fluctuations in nitrate levels are alarming and clearly exceed the 50 mg/l standard.

- The results obtained corroborate well the findings of the various research studies mentioned above, i.e.:
- 49.83% of the analyzed samples exceed the standard of 50 mg/l. The most affected area is Rouiba, the catchment fields of Bouréah and Réghaïa, where the concentrations have been high since the year 2000 (Sghir and Touat 2012).
- In a study conducted in 2010, nitrate concentrations are higher than 50 mg/l toward Larbaa and Meftah side and in the extreme Eastern part of the study area. This can be explained by the volume of direct discharges of industrial and urban wastewater which exceed the capacity of the Reghaia Wastewater Treatment Plant and so spilled in the Reghaia Wadi (Djoudar 2014)
- *Louati* in 2015 has shown that from the 171 industrial plants visited, in the El Harrach sub-catchment area, 78 of them should be equipped by pretreatment devices, in order to reduce the pollution flows resulted and conveyed by the waste.

This can be also explained by an anthropogenic origin of these excess nitrate levels, which is mainly due to the excessive use of nitrogen fertilizers by farmers in the considered region (found in field surveys) and to industrial wastewater.

The comparison of the nitrate content evolution with the groundwater levels clearly shows that the nitrate concentration follows an inverse evolution with respect to the piezometric levels. It should be noted that, when the latter are lowered, nitrate concentrations increase to well above the threshold of 50 mg/l recommended by the WHO (Fig. 6)

Geostatistical analysis

The data statistical analysis showed that the skewness coefficient is lower than 1, except for the year 2006 concerning nitrates (Fig. 10). In fact, in the case of skewness values less than 1, several authors (Rivoirard 2001; Webster and Oliver 2001) suggest to not perform any normal transformation of the data. Therefore, in our study, no normal transformation is needed (Figs. 7, 8, and 9). Figure 10 shows the frequency distributions and descriptive statistical parameters of variable nitrates and piezometric level.

The omnidirectional experimental semi-variogram (ESV) for variables (nitrate concentrations and piezometric level) (Fig. 9) has been calculated in isotropic case because of the erratic behavior of the directional structures (Fig. 11). In practice, semi-variogram map allows to see if there are more continuous directions than others for a considered variable in the study space. After several iterations, the semi-variograms of 10,000 m and 30,000 m for nitrate concentrations and with 5 lags of 1500 m and 7 lags of 1700 m, 7500 m, and 10,000 m for piezometric level. Table 3 shows the number and type of the structures, the range in meter; the parameters of model adapted to these experimental variograms and the cross-validation procedure to test the robustness of the models, respectively, for low and high water 2006 and 2016 of the piezometric level and nitrate concentrations. The variogram map (Fig. 11) presents almost erratic structures suggesting the absence of any spatial trend (absence of anisotropy). For this reason, the kriging will be performed with these variables in sections below, which can use omnidirectional models regardless of the direction in space.

Table 3 summarizes results of experimental semi-variogram calculations as well as the adjusted models for each variable (nitrate concentration and piezometric level). The two variables showed a certain structured spatial correlation with generally spherical and exponential models of low nugget effect. There is also an exception with piezometric level of the year 2006 which is modeled as Gaussian with a null nugget effect. The result is checked by the cross-validation procedure. In fact, the distribution of the standardized errors is Gaussian, with a mean of standardized errors (MSE) close to zero and a variance of standardized errors (VES) around to the unit (Table 3). This implies that the fitted models are statistically robust.

In order to better understand the hydrodynamic behavior of the Mitidja East groundwater table and to assess the level of nitrate contamination of the latter, kriging maps of nitrate isovalues and piezometric levels for high and low waters were established (2006 and 2016) (Figs. 7 and 8) and which reveal

- Existence of a flow direction converging towards the Baraki and El Hamiz catchment fields, thus constituting depression cones at the level of these catchment fields, where we note piezometric levels varying from 10 to 15 m below sea level.
- The analysis of the two maps (2006 and 2016) shows that the streamlines indicate flows towards the catchment fields: Haouch Flit, Beraki, Bordj el kifan (Stamboul).

With regard to the evolution of nitrates, from the maps, we can draw up the following conclusions:

- In the 2006 high waters, nitrate concentrations exceed 50 mg/l and reach 600 mg/l in the south-western part (Meftah, Larbaa), as well as concentrations ranging from

0 to 180 mg/l in low waters throughout the eastern part of the study area.

– In 2016, significant nitrate levels ranging from 51 to more than 90 mg/l were found in the east and west parts of the study area. In the central part, we note concentrations between 18 and 50 mg/l.

– The temporal evolution of nitrates between 2006 and 2016 shows a decrease in nitrate levels in general. This decrease is clearly recorded at the central part of the East Mitidja plain, where we note nitrate values varying between 18 and 50 mg/l in 2016, compared with values varying between 51 and more than 600 mg/l in 2006.

The high nitrate concentrations recorded in 2006 (low and high waters) are mainly due to agricultural intensification through the excessive use of nitrogen fertilizers by farmers. As well as the existence of strong industrial activity in this study area: the industrial zone of Rouiba and Reghaia, the industrial zone of Oued Smar, Oued El Harrach, and the Bay of Algiers. The CELPAP Company (Baba Ali) which discharges its polluted water into the Terro wadi, which is about 2 km from the Baraki catchment area, the Baraki refinery, and the Meftah cement factory.

The significant decrease in nitrate concentrations in the central zone of the East Mitidja can be explained by the decrease in the use of nitrogen fertilizers by farmers (following extension and awareness campaigns and the rehabilitation of the Baraki and Reghaia wastewater treatment plants, thus allowing the discharge of treated wastewater of mainly industrial origin of better quality).

Conclusion

The present study focused on the monitoring of the groundwater table and nitrate evolution through a spatial and temporal analysis using a geostatistical approach, for two periods: 2006 and 2016 during low and high waters, in East of Mitidja plain. We were based on the monitoring of 26 monitoring points (wells and boreholes) through a monitoring network of the laboratory of the National Agency of Water Resources (ANRH). The results of the hydrochemical analysis of the water samples allowed us to carry out statistical processing and geostatistical approach, in order to highlight the relationship between two main parameters: nitrates and piezometric levels.

The kriging maps of isonitrate and piezometric level values have been established for both 2006 and 2016 periods (rainy and dry periods). We found that nitrate levels exceed 50 mg/l for more than 72% of the monitoring points sampled in the rainy period, compared with 54% and 81% in periods of the low water for 2006 and 2016, respectively. It should be noted that, in general, nitrate levels present a significant decrease in the central part of the East Mitidja. It may range between 18

and 50 mg/l in 2016, compared with 51 and over 600 mg/l in 2006. The high nitrate concentrations recorded in 2006 (low and high waters) are mainly due to intensified agricultural and important industrial activities which discharges its polluted effluents into the Wadi Terro, located about 2 km from the Baraki catchment area.

Indeed, the 2006 and 2016 piezometric kriging maps show clearly that the current lines are in the opposite direction to the flow direction, from the sea to the catchment fields: Haouch Flit, Beraki, Bordj el kifen (Stamboul), due to an overexploitation of the groundwater caused by intensive pumping for irrigation and drinking water supply, which strongly decrease the water table studied inducing the progression of the "salty wedge."

The geostatistical analysis shows a lack of anisotropy and gives statistically satisfactory modeling results through the mean standardized errors (MSE) and the variance of standardized errors (VSE). The interpolation by kriging appears to be very interesting in this case because, in addition to its quality as a linear unbiased estimator, it provides decision support tools for decision-makers in the form of maps of kriging isovalues, thus facilitating aquifer management.

As the origins of this pollution are industrial, agricultural, and urban, the water resource authorities should apply effective regulations to these sectors, through:

– Carry out awareness campaigns for farmers to moderate the use of nitrogen fertilizers.
– Control the installation of boreholes and wells as well as the groundwater pumping rates, in order to avoid the falling of the piezometric level that is strongly related to water quality.
– The installation of treatment plants in high polluting industries (treatment of effluents before discharge into the natural environment). As well as the improvement of the treatment of wastewater collected at the WWTP (wastewater treatment plant) level, in order to obtain better quality treated water, thus minimizing pollution.
– Make models of the groundwater table and solute transfers using numerical agro-pedological models and update the existing ones, taking into account the different parameters related to soil, climate (impact of climate change), and crops.

Compliance with ethical standards

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