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Groundwater NO_3 concentration and its potential health effects in Beni Moussa perimeter (Tadla plain, Morocco)

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Abstract

In this research, the concentrations of nitrates were investigated in well water sampled from the irrigated perimeter of Beni Moussa (Tadla plain, Morocco), and human health risks via ingestion and dermal pathways for individuals in different age brackets were assessed using the chronic daily intake, the dermal absorbed dose and hazard index (HI).

The results showed that the groundwater NO_3 contents were between 4.20 to 80.46 mg L^{-1}, with an average of 32.11 mg L^{-1}, indicating anthropogenic inputs caused by the infiltration of nitrates not consumed by plants or surface industrial and domestic wastewater into the shallow aquifer. Compared to the Moroccan standard, 17.78%, 40.00%, 37.78% and 4.44% of sampled wells showed poor, fair, good or excellent quality, respectively. For non-carcinogenic risk, the oral ingestion of nitrate appeared to be the main exposure pathway for local human receptors causing the high non-carcinogenic risk, and the dermal exposure met within the accepted precautionary criterion. Infants in the study area are more likely to experience adverse effects to higher nitrate level in groundwater (3.04E-01 < *HI* < 1.80E+ 00), followed by female (2.39E-01 < *HI* < 1.41E+ 00), then male (2.22E-01 < *HI* < 1.31E+ 00) and finally children (2.08E-01 < *HI* < 1.23E+ 00). The resulting spatial variation in *HI* values was greatly influenced by human activities and population density.

The results of this study could help to shape effective environmental management measures for enhancing the groundwater quality and ensuring safe drinking water.

Keywords: Beni Moussa irrigated perimeter, Groundwater, NO_3 contamination, Public health risks, Assessment

Introduction

Agriculture has become an unavoidable component of the global economy due to its role in the food supply safe, nutritious, abundant and sustainable to feed a world population that continues to grow. However, Agriculture that is the single largest user of freshwater on a global basis is a major cause of degradation of surface and groundwater resources through erosion and chemical runoff (Sekhon 1995). The pressure to produce enough food has had a worldwide impact on agricultural practices such as intensification that needs an expansion of irrigation and massive use of fertilizers and pesticides. These practices poorly managed can lead to contamination of the surface and groundwater by nutrients and pesticides (Gunningham and Sinclair 2005). These different products used in excess represents nonpoint source pollutants which could be transported by rainwater and irrigation water in excess through soil and bedrock, and reach groundwater and surface water reservoirs (Irace-Guigand et al. 2004; Konstantinou et al. 2006). Although the pollutants may have originated from an agricultural point source, their long-range transport makes it a nonpoint source of pollution which is difficult to manage and control, being local,

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regional and transboundary (Novotny, 2005). Hence, the ecological effects of these pollutants on specific waters that vary and may not always be fully assessed range from simple nuisance substances to severe ecological impacts on aquatic ecosystems and human health (Malki et al. 2017; Ward et al. 2018).

Nitrate is one of the parameters that characterize the water quality. Their presence in excess can contribute to unbalance aquatic environments, both surface (Vitousek et al. 1997) and groundwater (Datta et al. 1997). Their main sources are man-namely agricultural activities as spreading massive amounts of nitrogen fertilizers and manure (livestock manure), and to a lesser extent, sewage discharge. The most affected areas are the alluvial plains, privileged places of intensive agriculture, which collect water catchment (Bednarek and Zalewski 2007). During the last five decades, this kind of water pollution constitutes a problem of global concern and has been identified as a major environmental problem for water resource management. Becoming one of the most widespread kinds of the non-point source pollution from agriculture and rural area (Rivett et al. 2008; Webb et al. 2005), it has been more and more devastating due to the development of agriculture production, and it will become one of the biggest challenges to sustainable development around the world.

Regarding their high solubility in water and low retention by soil, NO_3 reaches the groundwater when it's not utilized by plants and leached to the subsurface soil. Drinking water with a high level of NO_3 may pose ecological and health hazards on the human, especially newborn children. In recent years, some studies have reported growing health risks of nitrate pollution and dramatic increases of nitrate concentration of groundwater in intensive agricultural in many parts of the world (Serio et al. 2018; Soldatova et al. 2018), especially in arid and semiarid areas where irrigated agriculture is mainly developed (Adimalla and Li 2019; Barakat et al. 2019b; Wang et al. 2018).

In Morocco, agriculture is an important sector for economic and social development. The sector generates nearly 40% of employment and contributes to the national GDP at 15%. Launched in April 2008, the ambitious Green Morocco Plan aims to increase the level of production of certain crops through, among others, the intensification of small farm agriculture and the professionalization of small farms. As agriculture develops and becomes more intensive in its use of land and water resources, its impact on natural ecosystems becomes more and more apparent (Barakat et al. 2017; Ennaji et al. 2018; Oumenskou et al. 2019). The arid climate of the country which is beneficial from the high temperature for agriculture to make these areas capable of high crop yields and may enhance the sustainability of rural areas promotes intensive irrigation that explains the strong water consumption of the sector (93% of the total water demand in Morocco). However, the intensive irrigation associated with the abundant use of fertilizers and pesticides has considerable potential for contaminating groundwater by some pollutants such as nitrates. In recent years, several studies have focused in isolation to this problem in different regions; Results reveal that the irrigated agricultural in Morocco has negative impacts on groundwater quality (Barakat et al. 2018; Javadi et al. 2011; Laftouhi et al. 2003; Malki et al. 2017; Marouane et al. 2015). In the specific case of the Tadla plain Mio-Plio-Quaternary aquifer (Central Morocco), the effects of the excessive use of fertilizers associated with intensive irrigation on the groundwater quality have been shown by few previous studies (Aghzar et al. 2002; Hammoumi et al. 2013). To the best of our knowledge, there are very limited studies on the investigation of groundwater pollution with nitrate effects on human health and environment (Barakat et al. 2019a). So, the present study has been conducted, throughout the years 2011–2015, to determine the spatial and temporal nitrate variability of shallow groundwater in Beni Moussa irrigated perimeter (Tadla plain) and to identify occurrences vulnerable to NO_3 contamination. The study has also attempted to provide reference information on drinking water safety and to evaluate human health risks via ingestion and dermal pathways for individuals in different age brackets. For this, the human health risk assessment was applied. The spatial distributions of NO_3 concentration and hazard index (*HI*) representing the non-carcinogenic risk were analyzed by using the Geographical Information System (GIS).

Materials and methods

Study area

The Tadla plain located at the center of the Oum Er Bia River Basin in central Morocco (Fig. 1). It's bordered to the north-east by phosphate plateau, by Atlas Mountain to the south and El Abid River to the west. The plain covers a surface area of about 3600 km^2 with 80% of them is agricultural. The topography of this plain is regular, with a mean elevation of 400 m.

To cope with the climatic hazard, particularly drought, Morocco has invested in the construction of irrigated perimeters including the perimeter of Tadla, at the Tadla plain. The total area of this irrigated perimeter is about 98,300 km^2, including two sub-perimeter, Beni-Moussa and Beni-Amir, situated respectively to the north and south on either side of the Oum Er Rbia River. The irrigated perimeter has been growing more and more intensively since its management in 1954 due to its fertile soils and important water resources (Barakat et al. 2017). It belongs to arid to semi-arid climate, in which

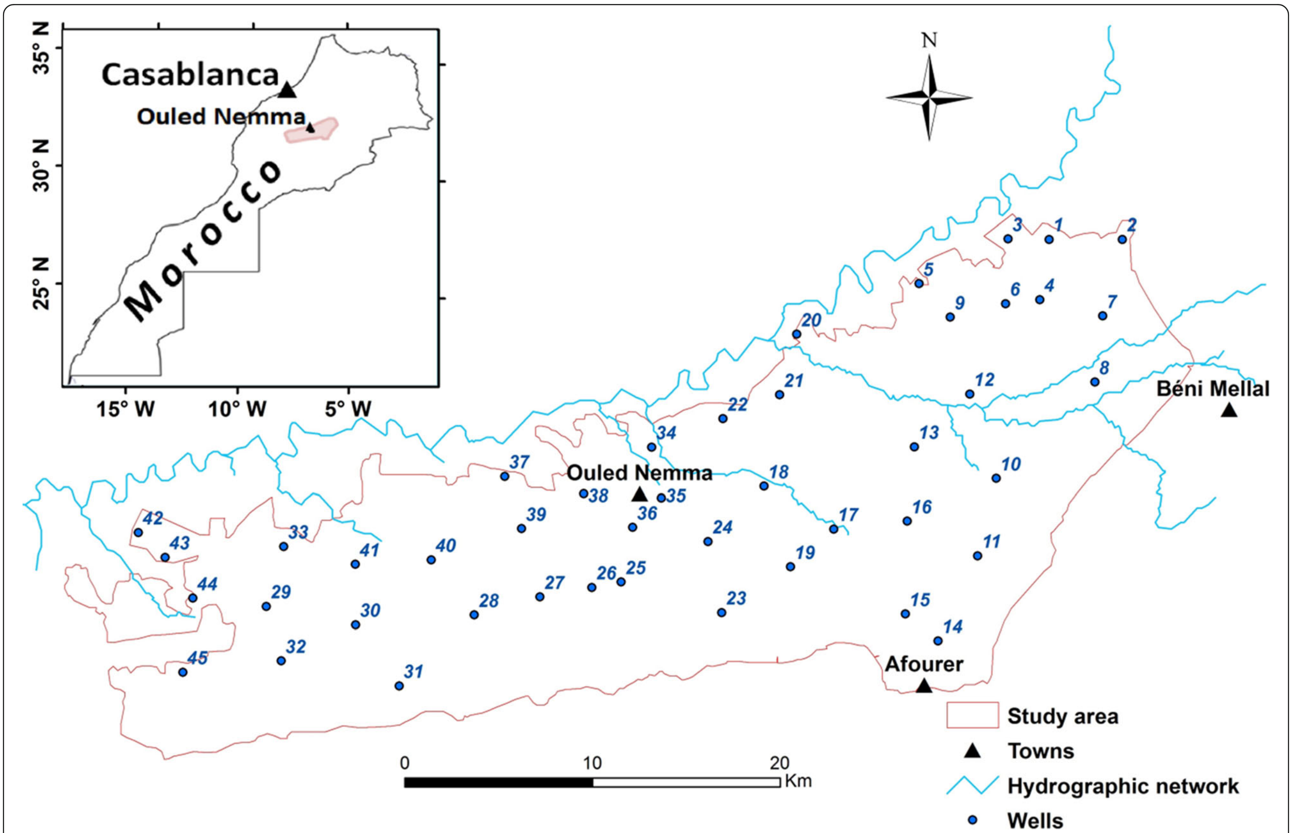

Fig. 1 Location of the study area and groundwater sampling wells

high temperatures during the dry season (summer) from Mai to October; and cold and rainfall during the wet season (winter) from November to April. The mean annual precipitation of the study area varied from north to the Atlas Mountain (south), with values from 310 to 550 mm (Cances 2005). The mean yearly temperature oscillated between − 6° and 46 °C, with the coldest temperature is generally observed during January, and the hottest in August. The average yearly evaporation can reach 2500 mm.

The Tadla basin bounded to the northeast by the phosphate plateau and to the southeast by the Atlas of Beni Mellal, is attached to the western Meseta and have a synclinal morphology. The Paleozoic bedrock is overlain by the Mesozoic-Cenozoic sedimentary cover (Er-Raïoui et al. 2001; Jabour and Nakayama 1988; Verset 1988). The geological formations are mainly composed of limestone, marls, and sandstone and presented an age of the Palaeozoic to Quaternary. These geologic formations contain the water resources derived from (i) the karst aquifer of the Atlas Mountains and (ii) the multilayered system of the Tadla plains composed of four aquifers: (1) Mio-Plio-Quaternary, (2) Eocene, (3) Senonian, and (4) Turonian (Liass) (Bouchaou et al. 2009). In the last three decades, the general trend towards more intensive and industrialized agriculture has led to the over-exploitation of the fresh groundwater resources to meet irrigation needs. In addition, land-use changes due to the growing demand for urbanization (Barakat et al. 2019c) and the pressure for industrial development make these resources vulnerable to pollution such as nitrates and heavy metal (Barakat et al. 2019a; Barakat et al. 2019b; Oumenskou et al. 2018).

Sampling and analysis

The monitoring grid and sampling strategy were planned by the Tadla Agricultural Development Regional Office (ORMVAT) to cover a wide range of the study area and to obtain information on water quality evolution. Under the groundwater quality monitoring program realized by ORMVAT, a total of 920 groundwater samples were collected at Beni Moussa irrigated perimeter from 46 shallow wells at an average rate of 4 samples per year during the 5 years (2011–2015). The sampling times in a year are chosen to average out the water quality changes linked to the seasonal hydrological cycle (seasons of autumn, winter, spring and summer). The sampling wells covering the entire irrigated Beni Moussa perimeter were positioned using GPS as presented in Fig. 1. The samples were analyzed for piezometric level (PL), pH, electrical conductivity (EC) and nitrates (NO_3). These monitored parameters were chosen by ORMVAT based on the degradation processes (nitrate pollution or salinization) recognized in the Tadla irrigated perimeter and on the probable risks of degradation following agricultural practices used in the area. The analytical quality was ensured out of the way using the same analytical techniques following the standard methods (Rodier et al. 2009). The results were expressed as an average annual value in m, dS/cm, and mg L^{-1} of PL, EC and NiO_3 values, respectively.

Methods

Nitrate pollution assessment

The 5-years (2011–2015) data from the database of the ORMVAT (Morocco), used for the spatial analyses in this study, were evaluated for quality of groundwater in Beni Moussa area regarding its potential nitrate pollution. The basic descriptive statistics, namely the min, max, mean and standard deviation (SD), were examined for all measured variables at each well, using Microsoft Excel 2010 (Table 2). The groundwater quality parameters were also compared to Moroccan-Stds (2002) and WHO (2004) water quality standards to assess the suitability of groundwater for drinking and to detect the pullulated monitored wells. Regarding the Moroccan groundwater assessment grid, there are four groundwater quality classes based on NO_3 content in groundwater (Moroccan-Stds 2002), i.e., NO_3 concentrations of > 50, 25–50, 10–25, and < 10 mg L^{-1} represent the groundwater quality of as poor, fair, good, and excellent, respectively. Pearson's correlation analysis was applied to the data to evaluate the relationships among various measured parameters.

Human health risk assessment

Exposure characterization Nitrates at abnormally elevated concentrations in water pose risks to the health of humans who may be exposed through water drinking and direct dermal contact. To assess human exposure to this pollutant, some models were established by Unites States Environmental Protection Agency (USEPA) (Ahada and Suthar 2018; Xu et al. 2018) based on concentration and distribution of chemical pollutants, on intensity, frequency and time of exposure, and then estimation and prediction. In this study, the empirical model proposed by USEPA (1989) was applied used to weigh the potential non-carcinogenic effects of NO_3 in groundwater. The chronic daily intake (CDI) through oral intake of NO_3 is calculated as follows:

$$CDI = \frac{C_w x\ IR\ x\ EF\ x\ ED}{BWxAT} \tag{1}$$

where *CDI* is the chronic daily intake of groundwater (mg/kg/d); C_w corresponds to the average groundwater NO_3 concentration (mg L^{-1}); *IR* indicates the ingestion rate (L d^{-1}); *EF* is known as the exposure frequency (day $year^{-1}$); *ED* is the average exposure duration (year); *BW* denotes the average body weight (kg), and *AT* represents the average exposure time ($AT = EF \times ED$, d).

The dermal absorbed dose (DAD) is calculated as follows (USEPA 2004):

$$DAD = \frac{C_w x\ K_i\ x\ CF\ x\ EF\ x\ ED\ x\ EV\ x\ SA}{BW\ x\ AT} \tag{2}$$

where *DAD* is the dermal absorbed dose (mg kg^{-1} d^{-1}), K_i is the dermal permeability coefficient (cm h^{-1}); *CF* is the unit conversion factor; *EV* is the exposure time during bathing and shower (min day^{-1}); *SA* is the skin surface area available for contact (cm^2) that was calculated using Eq. (3), where *H* represents the person's height.

$$SA = 239x\ H^{0.417}\ x\ BW^{0.517} \tag{3}$$

In this study, infants (< 5 years old), children (5–17 years old), and male and female adults are considered. The values of health risk assessment parameters in Eqs. (1), (2) and (3) are determined according to the exposure parameter values recommended by the USEPA and the Moroccan reference data (Table 1).

Non-carcinogenic risk estimation The water contamination by nitrates could cause public concerns, and why it became a challenge for the Tadla perimeter managers

Table 1 Human exposure parameter values used to estimates the hazard index (*HI*)

	Male	Female	Children	Infant	Refrences
IR	2.5	2.5	1.5	0.78	USEPA 2014
EF	365	365	365	365	USEPA 2014
ED	30	30	12	0.65	USEPA 2014
BW	70	65	45	16	Present study
AT	10,950	10,950	4380	237.25	Present study
K_i	0.001	0.001	0.001	0.001	USEPA 2004; 2018
CF	0.001	0.001	0.001	0.001	Yang et al. (2012)
EV	1	1	1	1	USEPA (2004)
H	170	158	150	100	Present study
SA	18,298	17,081	13,821	6838	Present study

owing to potential groundwater pollution and their adverse health effects. So, this study attempted to estimate the human risk by using the hazard quotient (*HQ*) usually representing potential non-carcinogenic risks. This quotient is computed respectively for oral ingestion and dermal contact of water as follows:

$$HQ_o = \frac{CDI}{RfD_o} \tag{4}$$

$$HQ_d = \frac{DAD}{RfD_d} \tag{5}$$

where HQ_o and HQ_d are the hazard quotients through oral ingestion and dermal absorption of water, respectively; RfD_o and RfD_d are respectively the reference dose of NO_3 of ingestion (1.6 mg day kg^{-1}) and dermal absorption (0.8 mg day kg^{-1}) of water (USEPA 2014).

The sum of HQ_o and HQ_d (Eq. (6)) corresponds to the hazard index (*HI*) that represents the non-carcinogenic.

$$HI = HQ_o + HQ_d \tag{6}$$

Where $HI < 1$ suggests that the non-carcinogenic risk is acceptable, and $HI > 1$ means that the potential health risk excesses the acceptable level for the exposed human (Chen et al. 2016; Ennaji et al. 2018).

Results and discussion

Spatiotemporal distribution of nitrates in groundwater

The descriptive statistics of PL and physicochemical parameters (pH, EC, and NO_3) of groundwater in Beni Moussa area (Tadla plain) are presented in Table 2.

The results of PL indicated that was in the range of 0.83–37.50 m with an average of 10.73 m. As shown in Table 2, the analyzed groundwater samples were weakly acidic to basics with a pH range of 6.84–7.86. Moreover, the pH values fall within the recommended Moroccan and WHO guidelines (6.5–8.5). The groundwater of the study area is characterized by EC ranged from 0.75 to 8.20 dS m^{-1} with an average value of 2.28 dS $m^{-}1$. Compared to the Moroccan groundwater quality grids (Moroccan-Stds 2002), the EC values are below the permissible limit and indicated that 13.33%, 4.44%, 62.22% and 20% of all groundwater wells had very poor, poor, fair and good water quality, respectively. The relatively high-EC groundwater is mainly associated with soil quality and anthropogenic activities. According to the previous study conducted by Barakat et al. (2017), the soil salinity results revealed that 2.16% of the study area was poor suitable for intensive agriculture, 54.43% was medium suitable and 43.41% was good suitable in the Beni Moussa perimeter.

The NO_3 contents of the studied groundwater samples fluctuated between 4.20 and 80.46 mg L^{-1}; the mean was about 32.11 mg L^{-1} (Table 2, Fig. 2). The proportions of groundwater samples in which NO_3 contents were in the poor, fair, good or excellent quality classes were 17.78%, 40.00%, 37.78%, and 4.44%, respectively. High percentages of samples with poor to fair quality suggested anthropogenic sources for nitrates in groundwater. According to previous studies (Barakat et al. 2019a; Barakat et al. 2018; Barakat et al. 2019b; Faouzi and Larabi 2001), the farmer-related activities such as the use of livestock manure and fertilizers and the agricultural industry were important sources of nitrates to groundwater. Compared with related Moroccan standard from groundwater (Moroccan-Stds 2002) of 50 mg L^{-1}, the NO_3 contents were only slightly high at 17.39% of groundwater samples. Regarding the annual quality based NO_3 levels, most of these sampled wells showed the same quality from 2011 to 2015 (Fig. 3).

Differences in NO_3 contents between studied wells could be linked, in addition to the source of NO_3, to source proximity, groundwater recharge coefficient and precipitation intensities, piezometric level variations, evapotranspiration, soil texture and permeability...

Non-carcinogenic risk assessment

The drinking water normally contributes to the total nitrate intakes in the human body. However, the high nitrate in drinking consumed for a longer period without

Table 2 Statistics of analyzed parameters of groundwater samples in the study area, and Moroccan-Stds (2002) and WHO (2004) guidelines for drinking water

	Wells					Moroccan std.	WHO std.
	Min	Max	Mean	SD	N		
PL (m)	0.83	37.50	11.49	5.77	208		
pH	6.84	7.86	7.20	0.18	230	6.5–8.5	7.0–8.5
EC (dS/m)	0.75	8.20	2.03	1.32	230	2.70	0.60
NO_3^- (mg/L)	4.20	80.46	31.92	15.57	230	50	50

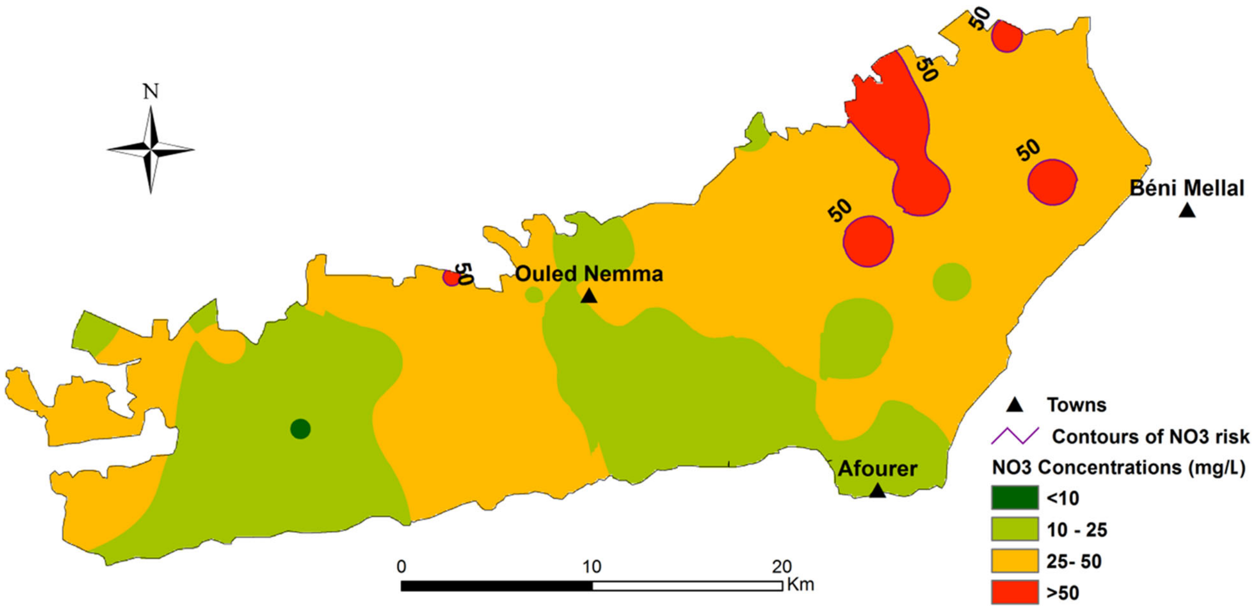

Fig. 2 Spatial distribution of groundwater nitrates

taking safety precautions could pose a risk to human health.

High levels of nitrates observed in some studied wells used in addition to agricultural irrigation for domestic purposes could pose a risk to human health via different exposure pathways such as oral and dermal. Moreover, a nitrate risk assessment of human health is of prime importance.

The HQ_o of nitrate were of 2.19E-01 – 1.29E+ 00, 2.35E-01 – 1.39E+ 00, 2.04E-01 – 1.21E+ 00 and 2.98E-

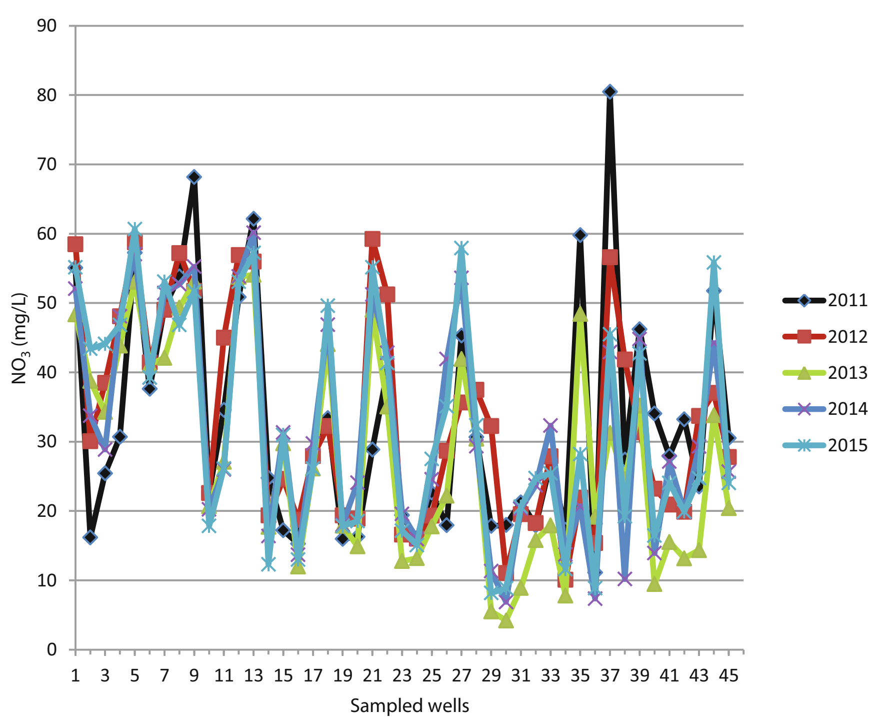

Fig. 3 Average NO_3 concentrations in the sampled wells

01 – 1.76E+ 00 for male, female, children and infant, respectively. These results showed that 40% of wells had HQ_o exceeded 1, implying the water of these wells cannot be recommended for consumption without treatment. As shown in Table 3, The HQ_o of nitrate decreased in the order of infant, female, children and male. The HQ_d of nitrates for both infant, female, children and male were lower than 1 in all studied wells, with the higher were for infant and children. For instance, the HQ_d for infant, children, female and male were 5.23E-03 – 3.09E-02, 3.76E-03 – 2.22E-02, 3.45E-03 – 2.04E-02 and 3.20E-03 – 1.89E-02 (Table 3). These results illustrate that the oral ingestion for all receptors represented the high non-carcinogenic risk than the dermal exposure in the Beni Moussa area at Tadla plain.

The total HI used to evaluate the non-carcinogenic risk showed values ranging from 3.04E-01 to 1.23E+ 00 for with a clear difference between receptors (Table 4).

As listed in Table 4 and Fig. 4, infant in the study area are more likely to experience adverse effects to higher nitrate level in groundwater (3.04E-01 < HI < 1.80E+ 00), followed by female (2.39E-01 < HI < 1.41E+ 00), then male (2.22E-01 < HI < 1.31E+ 00) and finally children (2.08E-01 < HI < 1.23E+ 00). What is obvious because infants are more vulnerable to the developing toxicity.

The spatial distribution of HI was analyzed using GIS environment to delimit the areas with risks and to control the groundwater contamination. The inverse distance weighting (IDW) was used for the interpolation to generate HI map for each studied population. The generated maps showed a clear variation in the spatial distribution of HI values (Fig. 5). The high value of HI (close or high to 1) was recorded at Beni Moussa Northeast and at wells 27, 37 and 39. Beside the point pollution highlighted around some rural agglomerations, and villages, the Beni Moussa Northeast area is crossed by collectors used to drain the water from the rise in the water table and by streams especially Day River that is a pollutant- river, which receives domestic sewage and industrial effluents from the Beni Mellal city and some rural riparian agglomerations. This wastewater, which was used extensively in irrigation, caused soil and groundwater pollution by nitrates and other contaminants (Barakat et al. 2019a, 2019b, 2019c). Wells 27, 37 and 39 are located along a collector that drains wastewater especially from the Ouled Ayyad village and the sugar factory, explaining the high HI values in this zone. Besides, the massive use of fertilizers and chemical pesticides contributed to the degradation of groundwater and surface water quality. The practice of intensive irrigation also caused the leaching of soils and the transport of leached elements to the aquifer.

The content of nitrates in groundwater is very low and is generally less than 10 mg/l. However, anthropogenic activities such as agriculture, industry, domestic wastewater, can also result in additional nitrate in groundwater. This is especially the case of our study area as proven in the present study.

The shallow water table in the Beni Moussa irrigated perimeter is generally stored in Mio-Plio-Quaternary formations. The nitrate levels in the groundwater are mainly related to agriculture-related activities (Aghzar et al. 2002). The Beni Moussa economy is based principally on an agricultural sector (olives, cereals, sugar beet, citrus fruit, etc.) with an important trend towards the agri-food industry. The intensive use of compound fertilizers and organic manure in agricultural production contributes mainly to the increase of the content of nitrates in groundwater. In addition to this diffuse pollution, the point-source contamination is linked to urban and agro-industrial effluents (untreated sweets, pulp mills, dairies ...) that lead to the contamination of surface water and groundwater. This pollution of the water resources was highlighted in the region at Oued Oum Erbia (Barakat et al. 2016) and Day Rivers (El Baghdadi et al. 2015), in shallow groundwater in Beni Amir District (Barakat

Table 3 Statistics of results of HQ_o, HQ_d and HI for NO_3 in the studied groundwater

	Male	Female	Children	Infant
		HQ_o		
Min	2.19E-01	2.35E-01	2.04E-01	2.98E-01
Max	1.29E+ 00	1.39E+ 00	1.21E+ 00	1.76E+ 00
Mean	7.07E-01	7.61E-01	6.60E-01	9.65E-01
SD	3.21E-01	3.46E-01	3.00E-01	4.38E-01
		HQ_d		
Min	3.20E-03	3.45E-03	3.76E-03	5.23E-03
Max	1.89E-02	2.04E-02	2.22E-02	3.09E-02
Mean	1.03E-02	1.11E-02	1.22E-02	1.69E-02
SD	4.70E-03	5.06E-03	5.52E-03	7.68E-03
		HI		
Min	2.22E-01	2.39E-01	2.08E-01	3.04E-01
Max	1.31E+ 00	1.41E+ 00	1.23E+ 00	1.80E+ 00
Mean	7.17E-01	7.72E-01	6.72E-01	9.82E-01
SD	3.26E-01	3.51E-01	3.05E-01	4.46E-01

Table 4 Summary statistics of HI for NO_3 in the studied groundwater

	HI			
	Male	Female	Children	Infant
Min	2.22E-01	2.39E-01	2.08E-01	3.04E-01
Max	1.31E+ 00	1.41E+ 00	1.23E+ 00	1.80E+ 00
Mean	7.17E-01	7.72E-01	6.72E-01	9.82E-01
SD	3.26E-01	3.51E-01	3.05E-01	4.46E-01

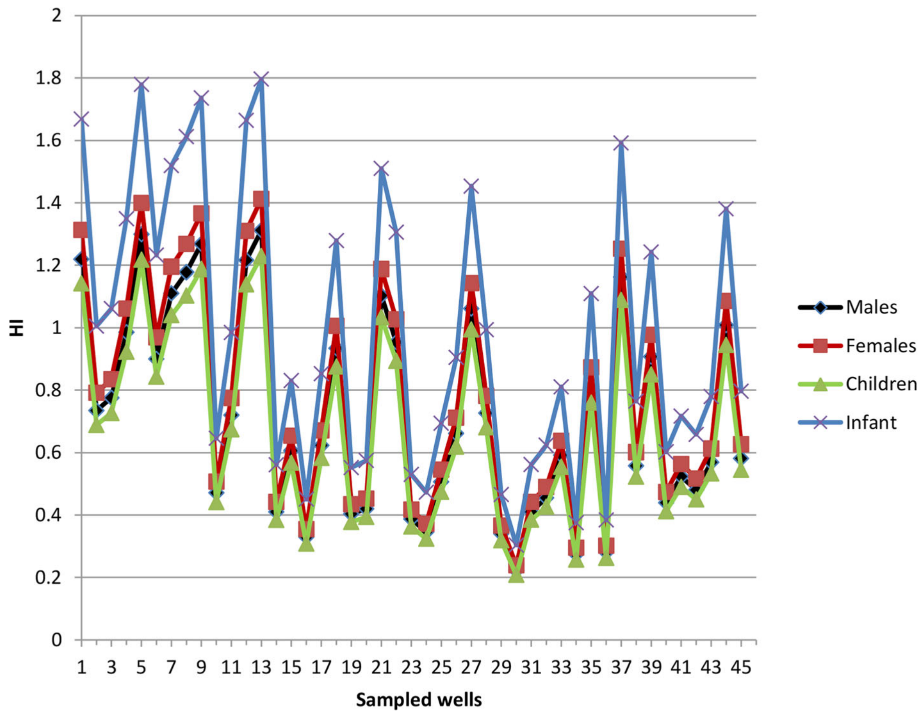

Fig. 4 Average *HI* values from in the studied groundwater samples

et al. 2019b) and suburban area of Beni Mellal city (Barakat et al. 2019a). Certainly, in the absence of sewage treatment plants and controlled public landfills, on the other hand, the study area will receive a continuous high pollutant load especially nitrate which degrades the quality of the water resources.

By analyzing the nitrate monitoring data, the regularity of the groundwater quality is much the same in time and space, and the nitrate concentrations that remain high in some wells (about 40%) are due to continued infiltration of nitrates not consumed by plants or surface industrial and domestic wastewater into the shallow aquifer. The nitrate vulnerability of the Beni Moussa aquifer (Tadla Plain) also depends on the permeability of soils that are permeable to extremely permeable ($20 < Ks < 450$ mm.h^{-1}) (Aghzar et al. 2002). Also, the properties of the Beni Moussa aquifer, particularly the shallow depth and the change in the height of the aquifer, largely contribute to the contamination of deep water. Also, the vertical exchanges between aquifers of the multi-layered system of Tadla via the many deep boreholes used for agricultural irrigation promote the spread of this nitrate pollution.

Following the outcome of the present study, serious groundwater contamination by nitrate in Beni Moussa irrigated perimeter is well highlighted and showed that the shallow groundwater in the area very susceptible to nitrate pollution due to various anthropogenic activities. This pollution of shallow aquifers in Beni Moussa area can spread to captive aquifers under impermeable levels through deep drilling carried out to satisfy the need for irrigation water. To limit the extent of nitrate contamination and its effects on human health, it is imperative to sensitize the population and farmers to the damage caused by these pollutants to rationalize the use of nitrates. Fertilizers, herbicides, and insecticides. Also, domestic and industrial wastewater treatment plants and controlled public landfills must be carried out to limit the pollutant load to the natural environment and degrade the quality of the water resources.

Conclusion

In this study, data on shallow groundwater nitrates in Beni Moussa perimeter of Tadla (Morocco) have been described evaluating the NO_3 pollution and its human health effects.

Based on the assessment results, it appears that the nitrate concentration in groundwater of 4.20 and 80.46 mg L-1 exceeds the Moroccan standard from groundwater in 17.78% of sampled wells, indicating an anthropogenic contribution. Concentrations of NO3 were higher in the northeast of the studied perimeter. High levels of nitrates observed in some studied wells used, in addition to agricultural irrigation, for domestic purposes could pose a risk to human health. By different exposure

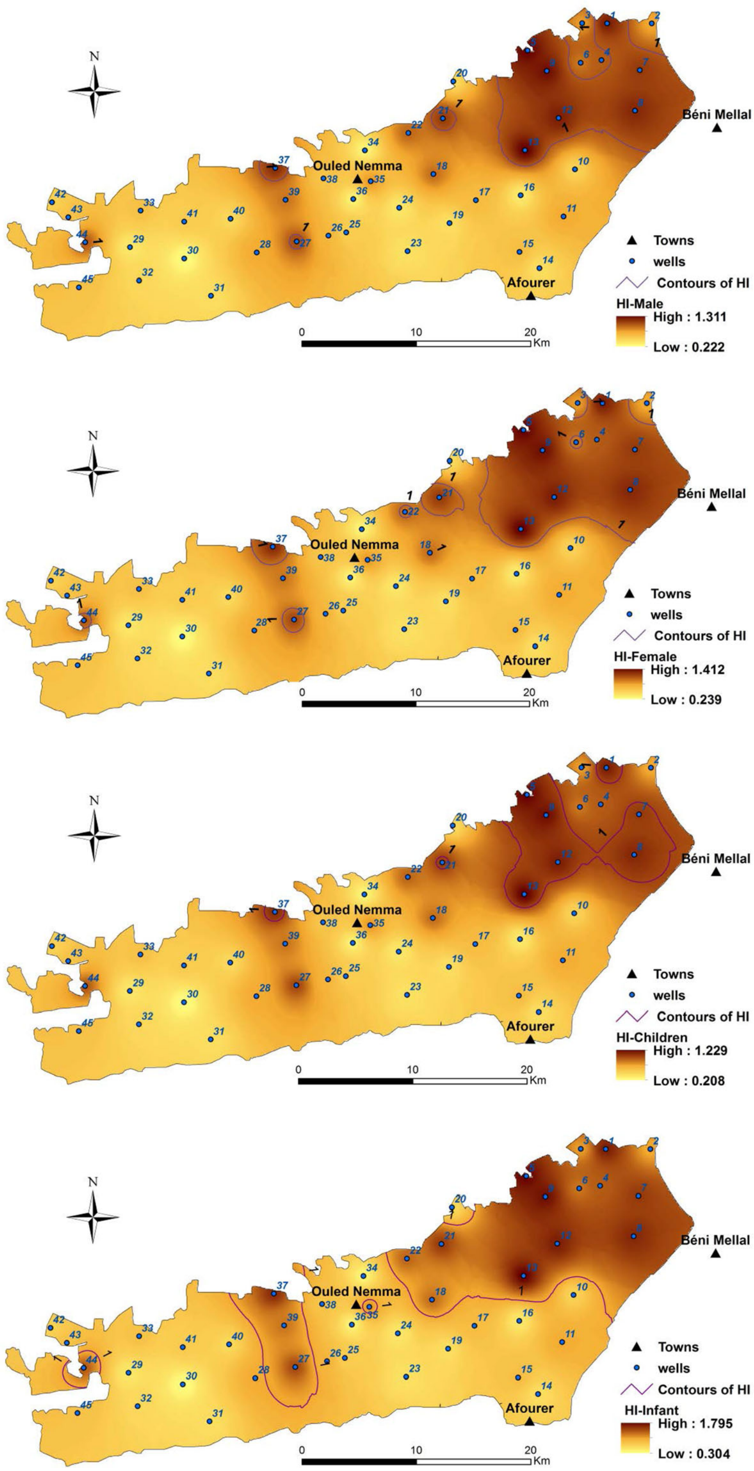

Fig. 5 Spatial distribution of non-carcinogenic risk of NO_3 for male, female, children, and infant

pathways such as oral and dermal, nitrates can consequently be accumulated in humans relying on groundwater for daily-uses. Moreover, a nitrate risk assessment of human health is of prime importance and has been assessed. By analyzing the non-carcinogenic risk results, the oral ingestion of nitrate appeared to be the main exposure pathway for local human receptors causing the high non-carcinogenic risk, and dermal exposure met within the accepted precautionary criterion. Infants (*HI*≈9.82E-01) in the study area are more likely to experience adverse effects to higher NO_3 levels in groundwater, followed by females (*HI*≃9.82E-01), then males (*HI*≃7.72E-01) and finally children (*HI*≃6.72E-01). The resulting spatial variation in *HI* values was greatly influenced by human activities and by the density of the population. The Beni Moussa Northeast contains urban and rural fabrics with a high population density compared to the rest of the perimeter. So, surface industrial and domestic wastewater, agricultural contaminants and practice of intensive irrigation seemed to be responsible for nitrate pollution and degradation of groundwater quality in the study area.

Hence, to make sustainable agriculture for developing economic and social sectors in the Beni Moussa perimeter, special attention should be paid to the nitrate contamination of the water resources. Effective measures should be attached to public awareness, pollution control, and remediation of contaminated areas, especially in the northeast part of the perimeter where it can endanger the groundwater. Also, it is essential to regulate fertilization, to properly treat industrial and domestic waste and wastewater.

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Authors' contributions
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