7th International Conference on Water Resources and Arid Environments (ICWRAE 7): 361-366
4-6 December 2016, Riyadh, Saudi Arabia

Assessment of the Contribution of N-Fertilizers to Nitrate Pollution of Groundwater in North Morocco (Case Study: Water Table of Fès/Meknès)

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Abstract: Human activities exert many pressures on the quality of groundwater and advanced assessment programmes are needed to design sustainable water management strategies. Nitrate pollution of groundwater resources has increasingly become a global concern. Groundwater from water table of Fès/Meknès serves as the main source of water supply for drinking and irrigation within the province of Meknès (North Morocco). This study investigated (1) groundwater nitrate status as well as the pollution sources and (2) the spatial extent of groundwater nitrate pollution in the region. A total of 28 samples of groundwater were taken for measurement of nitrate concentration during 2007 and 2013, respectively. Our results showed that 58.32 % exceeded the World Health Organization's acceptable threshold (50 mg L^{-1}) in 2013. The detailed analysis of spatial distribution of the polluted wells revealed that the most are located within areas of irrigated agriculture. In addition, our further investigation of annual fertilizer application and the spatial distribution of polluted wells revealed that input of artificial nitrogen fertilizers to irrigated lands was strongly correlated to nitrate concentration within groundwater in these areas. Moreover, the transportation of nitrate through the aquifer has been mainly controlled by geology and pattern of groundwater flow and therefore, groundwater flow should be taken into account for future quality management of the aquifer. The results of this study will provide useful guidelines for utilizing of nitrate fertilizers in regards to groundwater quality to avoid repeating the problem of groundwater nitrate pollution.

Key words: Nitrate · Pollution N-fertilizer · Contamination · Water table Fès/Meknès · Morocco

INTRODUCTION

Protecting the quality of groundwater is a major challenge considering that at global scale, groundwater represents an important part of the water resources used for drinking and domestic purposes. In recent decades, the contamination of groundwater by anthropogenic activities became worrying. Among the contaminants, nitrate occupies an important place as it is generated by basic human activities (agriculture, domestic activities, industries, etc.) and Elevated concentrations of nitrate in groundwater represent human and environmental health risks: (i) excessive consumption of nitrate in drinking water has been associated with the risk of methemoglobinemia or 'blue baby syndrome' in humans, stomach cancer and nitrate poisoning in animals [1]; (ii) nitrate export into adjacent surface water bodies may induce an increased level of nutrients (eutrophication) affecting adversely biodiversity, mammals, birds and fish population by producing toxins and reducing oxygen levels [2].

The plain of Sais is an example of an agricultural area which is characterized by an increase in concentrations of NO_3-. The area is subject to agricultural intensification that starts generating the degradation of water quality processes. The Agency of Hydrolic Basin Sebou [3] reported that 27% of 65 sampled wells in the area have a value greater than 50 mg / l. The use of irrigation and fertilizers on fields is suspected to be the major source of contamination. However other potential point and non-point sources such as farm activities, landfills leachate, septic tanks, urbanwastewater and to a lesser extent, industry, may contribute to increased groundwater nitrate [3]. Because groundwater is a pat of potable water

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in Meknès/Fès region, the identification of contamination sources is essential for effectively managing groundwater quality.

Nitrate concentrations in groundwater are related to the temporal distribution of nitrogenous fertilizer application, as well as the rainfall and runoff rate in a region [4]. Although groundwater nitrate concentrations vary according to the amount of nitrate added to soil, nitrate concentrations in groundwater in addition depend on the aquifer's vulnerability to leaching [5]. However, the effect of N-fertilizer application on groundwater quality depends on many parameters such as N- fertilizer amount used, soil, etc.

We pursued main objective within this research to determine the nitrate concentration pattern and its relationship to utilization of N-fertilizers.

MATERIALS AND METHODS

Study Area: This study was conducted in the area know, it is located in northern Morocco, between urban centers of Meknes and Fez (Figure 1). It is bordered to the north by mountains of the Rif and south by that of the Middle Atlas.

The landscape consists of Sais relief accidents, organized in a north-south direction. The study area we have defined interests only 200 sq km against 2, 000 km² for the entire region.

Methodology: Collection and Analysis of Samples: In the study area, groundwater is an important source of drinking water and this source is vulnerable to contamination. In this research, twenty-eight sampling wells were considered to analyze aquifer nitrate levels during the intervals 2007 and 2013. The position of sampling wells is shown in Fig. 2. According to the methods described by American Public Health Association (1992), groundwater samples were collected. Global positioning systems (GPS) and sampling map are used to determine the position of sampling wells.

The data on the condition of the groundwater quality of the water table Fez-Meknes were obtained from a database retained by the Agency of Sebou Hydraulic Basin (ABH Sebou).

Basic statistics for groundwater nitrate concentrations are presented in Table 1. Nitrate concentrations of sampling wells during 2013 were compared to the WHO maximum specified threshold for drinking water quality guidance.

Land Use Map: Several methods can be used to determine nitrate contamination from different sources. A mechanistic simulation model was developed for predicting, under field conditions, the unsaturated water flow and nitrogen transfer [6]. Another approach applies correlates between land use types and groundwater nitrate concentration [7].This study is based on the assumption that land use management influences the nitrogen loading and its causes, to leach out from the agricultural land into the aquifer. The most common land uses within the study area were found irrigated agriculture and agricultural bour, accounting for proportions of the total area of 19 % and 91% respectively. Much of the irrigated area is located in the action area of the DPA El Hajeb (65%) and that of Meknes (20%). The land use pattern has not significantly changed during 2008 and 2013.

The annual average application rate of nitrogenous fertilizers at 102 points on the irrigated lands (in particular under arboriculture and vegetable crops and to less extent wheat) was determined by interviewing the local people. The least and highest annually applied N-fertilizer amounts were recorded as 150 and 1000 kg ha^{-1} $year^{-1}$. The most commonly applied fertilizers were ammonium nitrate and urea. To determine the relationship between nitrogen loading of agricultural land and groundwater nitrate concentrations, data for N-fertilizer rate were analyzed.

Spatial Distribution of Groundwater Nitrate Concentration: Data obtained from the Agency of Sebou Hydraulic Basin (ABH Sebou) showing groundwater nitrate concentrations were prepared for 2007 and 2013. A total of 28 samples were collected and analyzed during 2007 and 2013, to determine the spatial distribution of nitrate pollution in groundwater. The spatial distribution of nitrate pollution within the aquifer extent was extracted through the ordinary Kriging interpolation technique in a geographic information system (GIS).

Groundwater Flow: In the plateau of Meknes, the flow of the sheet is on the eastern and western borders of southeast to the northeast and south to north on the board of the center with an average gradient 0.7 to 1.3%. In the plateau of Sais Fez, the flow is from southwest to northeast in the part East and southeast to northeast in the western part, while in the center, the web flows from south to north with a steady 2% slope to the south and irregular enough north of the order of 0.6%.

Table 1: Descriptive statistics of groundwater nitrate concentration during the years 2007 and 2013

Year	Number of samples	Mean (mg L^{-1})	Standard deviation (mg L^{-1})	Minimum (mg L^{-1})	Maximum (mg L^{-1})
2007	28	57.48	50.79	3.96	202
2013	28	75.87	83.02	9.82	443

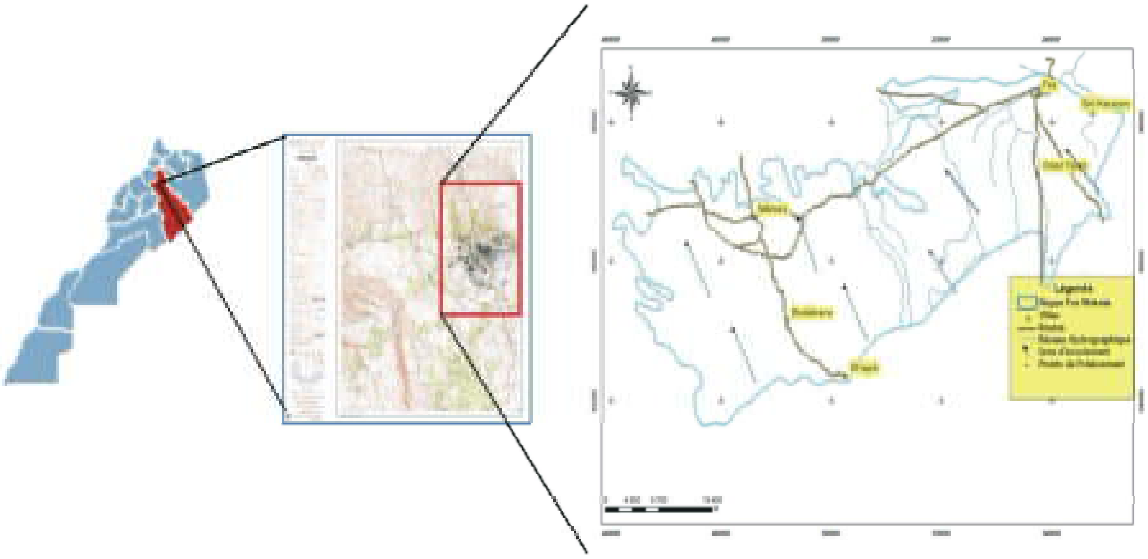

Fig. 1: Location of the study area

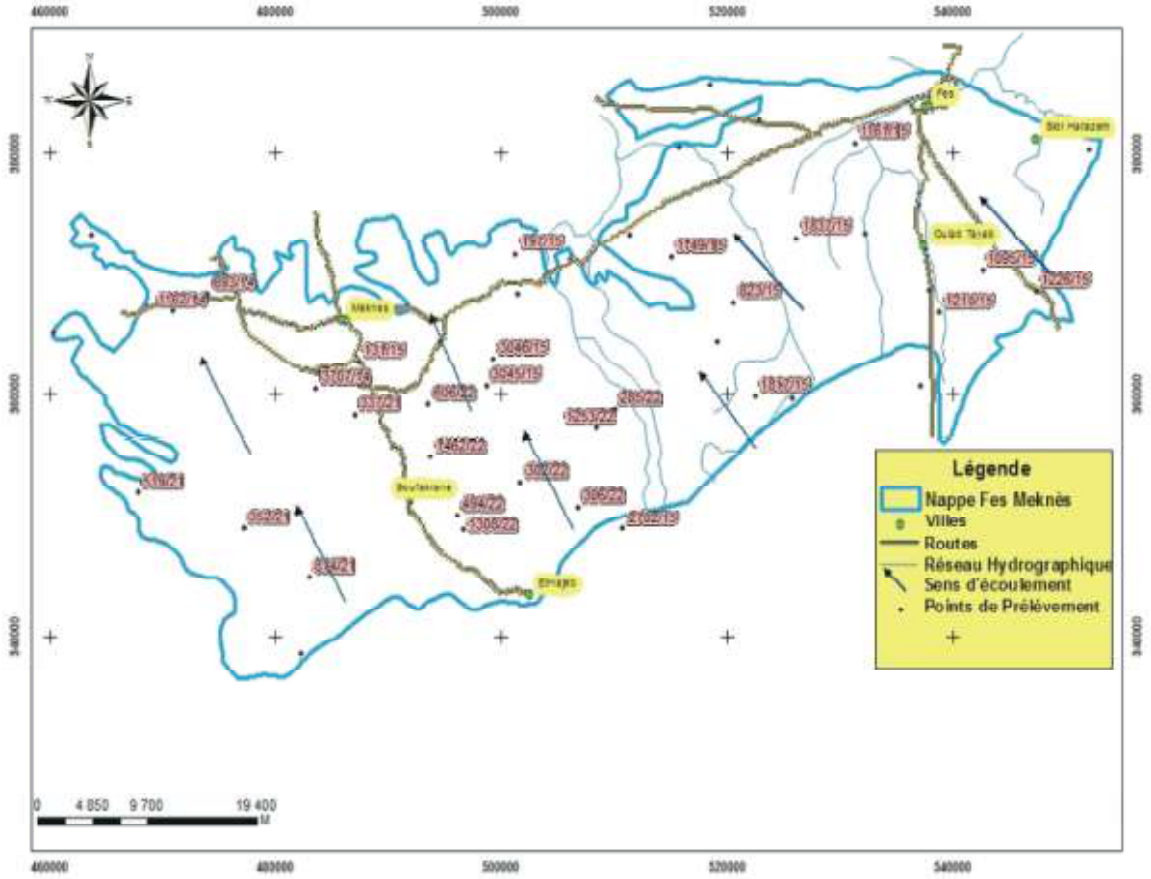

Fig. 2: Geographical position of the study area showing sampling wells

The water table is inflated downstream of the overflow sources Lias (Group ribaa-Bittit-Akkous) and near important sources within the Fes Sais may indicate a contribution by leakance of the deep aquifer. Contact with the plain of Sais with prérifaines wrinkles, waters seem trapped in the Douyet region and share and to the east and west along the two drainage areas: Oued Oued Fes N'JA.

RESULTS

Nitrate concentrations of samples taken in 2013 are shown in Fig. 3, along with the maximum threshold specified by WHO (50 mg L^{-1}) as a reference. Referring to Fig. 3, nitrate concentrations of 16 wells (58.33%) out of total number of 28 exceeded the threshold allowable for human consumption. Interpolating the position of all wells exceeding the WHO nitrate threshold value and referencing the positions to the land use map showed that all the identified wells are located within irrigated farming land.

Impact of Farming Activities: Since most of the wells showing high nitrate concentrations were located within irrigation farming land, we attempted to determine how agriculture and farming activities affect groundwater nitrate levels.To determine the relationship between surface nitrogen loading of farm land and groundwater contamination by nitrate, data for annually applied nitrogen fertilizers were analyzed. A Pearson correlation coefficient value of approximately 0.76 was obtained, indicating a strong positive correlation between groundwater nitrate concentrations and the average annually applied nitrogen load. Having been correlated significantly, a linear regression was undertaken between nitrate concentrations in groundwater and nitrogen loading of irrigated farm land with results being is shown in Fig. 4.

Figure 4 illustrates the positive correlation between the application rate of nitrogen fertilizers and nitrate concentrations in groundwater. Excess application of nitrogenous fertilizers by farmers leads to nitrate leaching and percolation into the aquifer, subsequently causing an increase in groundwater nitrate concentrations. These results showed that the applied fertilizers have a large adverse impact on groundwater in the study area.

Evaluation of the Spatial Distribution of Nitrate in Groundwater

Spatial Distribution of Nitrate in Groundwater during 2007: The spatial distribution o f nitrate in groundwater

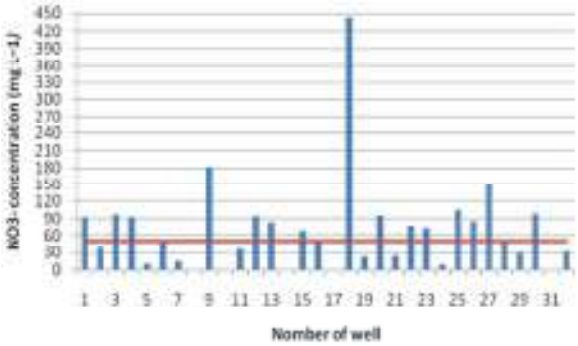

Fig. 3: Nitrate concentrations (mg L^{-1}) of sampled wells during 2013 and the World Health Organization threshold indicating maximum allowable nitrate concentration for drinking water

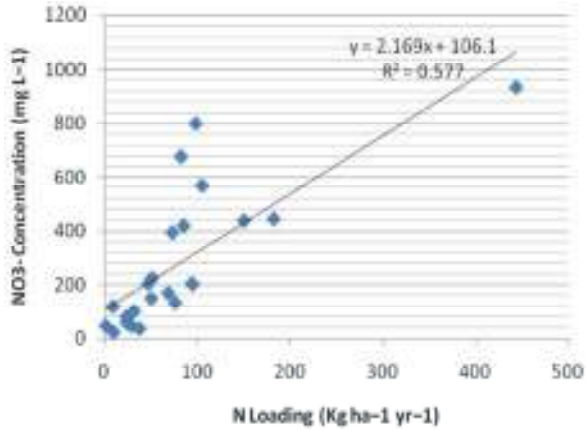

Fig. 4: Relationship between nitrogen loadings of irrigated farmland and nitrate concentrations in groundwater

within the study area during 2007 is shown in Fig. 5a. The majority of the study area showed nitrate concentrations 50 mg L^{-1} among others. Within a small portion of the north part of the study area, nitrate concentrations exceeded the WHO threshold. In addition, groundwater nitrate levels within the restricted eastern part of the aquifer had nitrate concentrations of 100mg L^{-1}, close to the WHO maximum drinking threshold and it is probable that this region shows high groundwater nitrate contamination and degraded water quality.

Spatial Distribution of Nitrate in Groundwater During 2013: The spatial distribution of nitrate in groundwater during 2013 can be seen in Fig. 5.b. The results of analyzes of samples have located the different areas of nitrate concentrations (Figure 7). Nitrates are found in almost all wells of our study area with values ranging between 9.82 and 443 mg NO_3 /l.

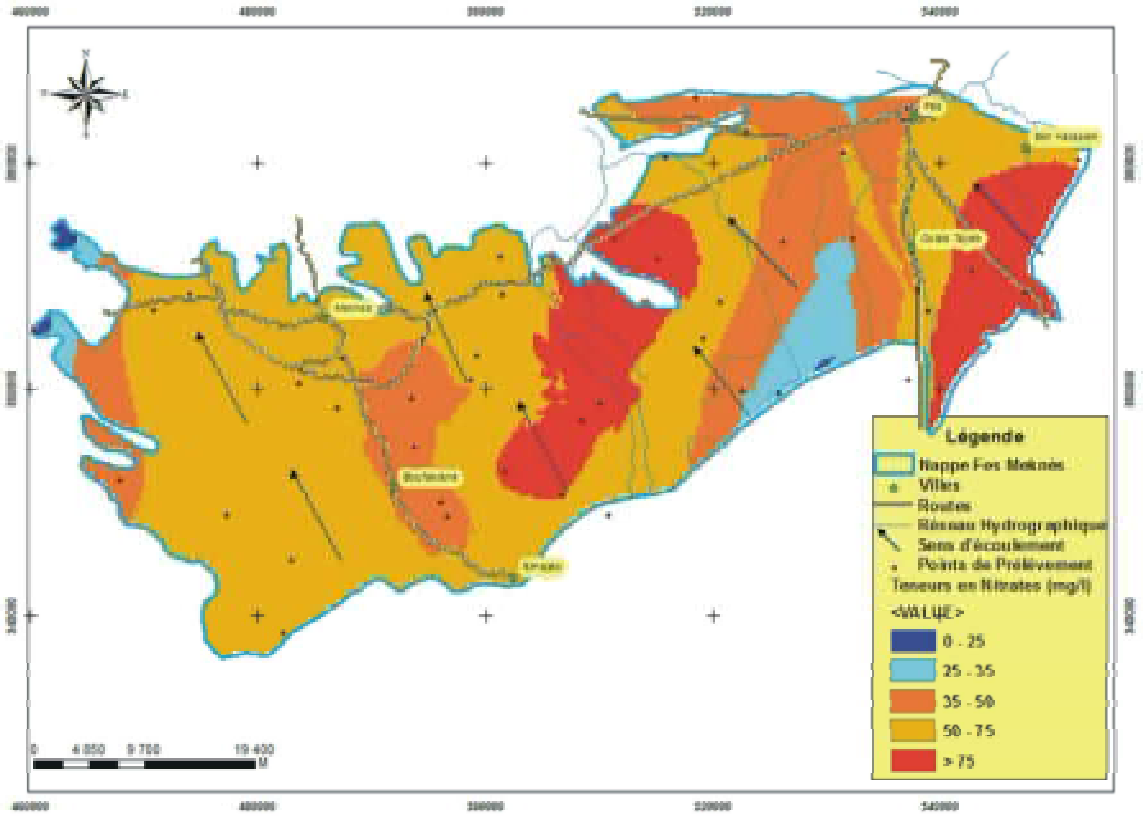

Fig. 5: b Spatial distribution of nitrate in groundwater during 2013

According to the results found in the map (Figure 5); all points beyond the potability threshold of 50 mg / l are concentrated in the know of Meknes and in the east where agricultural development is so high intensive use of nitrogen fertilizers.

Evaluation of the Groundwater Flow System and Pollution Movement: To investigate the effect of the groundwater flow system on the groundwater nitrate distribution pattern, maps for groundwater nitrate concentrations during 2007 and 2013 were overlaid with the groundwater flow map. Results showed that the spatial distribution of nitrate pollution can be explained by the groundwater flow system. Nitrate pollution of the aquifer has spread in line with the groundwater flow in the plain of Meknès part of region. There was less spreading of nitrate pollution in eastern part of the region due to a lower aquifer hydraulic gradient, indicating that regions within the aquifer vulnerable to nitrate pollution can be predicted from the groundwater flow patterns. Moreover, the N-fertilizer input level, irrigation system and improper management of livestock manure are major factors affecting the nitrate pollution of groundwater.

DISCUSSION

Comprehensive monitoring of groundwater quality is vital to ensure safe human consumption [8]. In the present study, it was found that in 16 wells out of total number of 28 (58.33%), nitrate concentrations exceeded the WHO nitrate threshold (50 mg L^{-1}) for safe human consumption in 2013 and all polluted wells were located within irrigated farming lands where heavy and intense agricultural activities and operations occur. The analyses indicated that there is a strong positive correlation between groundwater nitrate concentrations and irrigated agricultural land use, which is consistent with previous studies [9]. Therefore, agricultural activities are likely to affect aquifer nitrate concentrations in the study area [10].

Other researchers have shown that in cases of less control of pesticide and nitrogenous fertilizer application, nitrate concentrations in groundwater along with the spatial extent of pollution gradually increase [11]. Nonetheless, the effect of N-fertilizer application on groundwater quality depends on N-fertilize application rate along with several other parameters such as soil characteristics, crop type, hydrological parameters, etc.

An investigation of the fertilizer application rate within the study area showed that the least and highest annual nitrogen applications rates are 150 and 1000 kg ha^{-1} $year^{-1}$ in the central and western parts of study area, respectively. The extent of nitrogen loading of irrigated lands showed a positive correlation to groundwater nitrate concentrations with the Pearson correlation coefficient being 0.76.

The spatial distribution map of groundwater nitrate concentrations for 2007 indicated that the WHO nitrate threshold was exceeded in the plain of Meknès of the study area. The spatial distribution map for groundwater nitrate concentrations for 2013 indicated that nitrate pollution has been extending considerably to same place of the aquifer. In addition, groundwater nitrate concentrations within the aquifer have exceeded the WHO acceptable threshold of groundwater nitrate concentration for human consumption in small parts of the eastern aquifer region.

CONCLUSION

Comprehensive management of groundwater resources affects both the quantity and quality of aquifers. In this research, we tried to examine the effect of the present aquifer and fertilizing management within plain of Sais in Morocco on groundwater nitrate pollution. This research has demonstrated that the amount of applied nitrogenous fertilizer is strongly correlated to nitrate concentrations in groundwater.

However, to determine the exact threshold amount of fertilizers application, more researches are needed to consider the environmental characteristics (e.g., soil type, vegetation type and leaching processes of nitrate).

Considering the nitrate pollution threshold, very few non-polluting crops can be distinguished in this region, which calls for an urgent adoption of agriculture management to protect water resources from further deterioration.

Finally, we believe that our results will provide useful information for groundwater quality management to avoid repeating the problem of groundwater nitrate pollution.

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