Evidence of improper sanitation on groundwater quality in thiaroye aquifer, Dakar, Senegal: an isotopic approach

Introduction

Groundwater pollution is a major concern in many parts of the world since it is the main resource for public water supply in rural and urban areas. In fact because of multiple uses of soil and rapid increase of population in developing countries, groundwater in urban aquifer is generally subject to several sources of pollution. So knowledge of factors that affect groundwater quality is therefore essential in water management decisions.

The quaternary Thiaroye sandy aquifer which is mainly localised in Dakar area is an important aquifer which contributes to drinking water supply for urban and rural public. However since recent decades, the demographic expansion of Dakar population followed by an anarchic soil use in suburban and the lack of municipal sewers in these parts have resulted in a strong deterioration of groundwater quality. High nitrate concentrations have been encountered in various parts of the aquifer particularly in urban and agricultural areas. Because of its shallow character and the nature of its reservoir which is mainly composed of clayey sand and the multiple use of soil, sources of nitrate in groundwater can be numerous including use of septic tanks, domestic organics waste, effluents, soil nitrogen mineralization, manure, agriculture…

The purpose of this study is to evaluate the chemical variation of groundwater, the anthropogenic influence on water quality and to identify likely sources of nitrate contamination using nitrogen isotopes techniques.

Site description and Geology

The study area covers an area of approximately 300 km^2 and ranges between Patte d'oie (Dakar) and Kayar **(Fig. 1).** Mostly located in the region of Dakar city whose population is estimated at 2508311 inhabitants, the study area also includes parts of the region of Thiès, which is located 70 km from the capital (Dakar). The relief is relatively flat with a maximum altitude of 43m located at Cambérène. The study area is also characterized by the presence of interdune depression which are locally termed Niayes where agricultural practices are developed. Along the North Atlantic Ocean façade appears a set of lakes for which the majority are dry except the hypersaline lake Retba.

The aquifer is essentially composed of unconsolidated quaternary clayey sand with variable thickness. The Thickness of sand varies from 5m to 75m and increase south towards north of the aquifer. The reservoir overlies a tertiary marly basement which outcrops in southern of the system **(Fig.2)**.

In Dakar suburban, the almost complete lack of municipal sewers system makes that human waste disposal is done by use of septic tanks system while domestic organic and liquid waste are often disposed into the ground.

The deposit of solid or organic waste in certain zones where groundwater is near the surface constitutes a threat to groundwater quality. **Figure 3** show some instances of naturals deposit of waste in sensitive areas where the groundwater appears in surface.

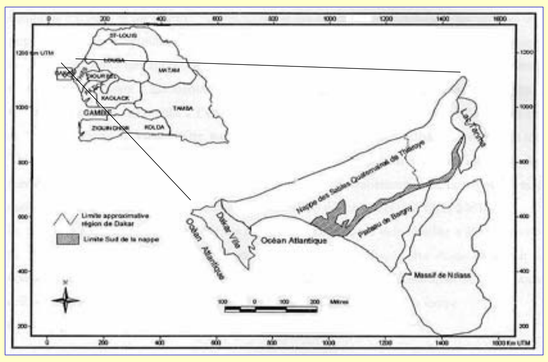
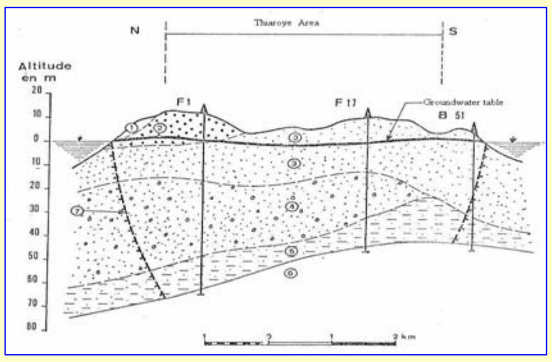


Fig. 1: Location of the study area



Legend :

1-Recent white dunes
2-Yellow dunes – Camberene system
3-Ogolien red dunes
4- Acheuléen pebbly alluvia
5- Inchiriens sand
6- Tertiary marly basement
7- Salted bevel

Fig. 2: Nature of sand formations in Thiaroye (Martin, 1970).

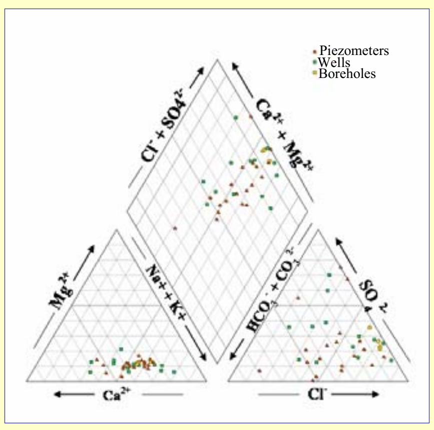
Fig. 3: Uncontrolled natural waste deposit in Thiaroye area

Sampling and analytical methods

During a field campaign in March 2007, 36 groundwater samples were collected in boreholes, piezometers and dug wells within the study area. Groundwater samples were filtered through 0.45µm and then preserved in polyethylene bottles of 250ml. Samples for cations analyses were acidified by nitric acid addition to a pH ≤ 2, while those for anions analyses were stored without preservation. Field measurements including physico-chemical parameters such as pH, temperature, TDS and electrical conductivity were made at the time of collection. The water levels were also recorded. HCO_3^- concentration was determined within 24h as total alkalinity by titration with H_2SO_4 (0.02N). All the other major ions analyses were performed at the Ruhr University of Bochum (Germany) using an Ion Chromatograph (ICP Dionex DX 500).

Nitrogen isotope analyses of groundwater samples were conducted following the method described by Silva et al. (2000) at the isotope lab of the Sediment- and Isotope-Geology department, Ruhr-University Bochum. Dissolved nitrate is enriched on anion-exchange-resin and finally precipitated quantitatively as AgNO3. The δ^{15}N-value is determined after flash-combustion using an elemental analyser Carlo Erba EA 1110 connected to a mass spectrometer Finnigan MAT DeltaC. The external reproducibility of δ^{15} N(NO_3^-) is ±0.3 ‰.

Results



Groundwater quality in the study area is characterized by low to high dissolved solid content (112 to 3390mg/l). Major cations and anions are plotted in trilinear diagrams, which display the chemical types of the groundwater. Six groundwater types can be identified: Ca-HCO3 ; Na-K-HCO3 ; Ca-SO4 ; Na-K-SO4 ; Na-K-Cl and Ca-Cl2. However groundwater is mostly dominated by Na-K-Cl und Ca-Cl2 types **(Fig. 4).**

Nitrate concentration in the study area range from 0.05 to 1390mgl/l with an average value of 205.37mg/l. **Figure 5** show the areal distribution of nitrate concentration in the study area. High nitrate concentrations were particularly encountered in urban areas and in the agricultural zone. Temporal evolution of nitrate is showed in **figure 6** which indicates a prominent increase of nitrate concentration in certain wells and boreholes compared to early nitrate values.

Fig. 4: Piper diagram showing the chemical composition of the analysed groundwaters in the study area

Results

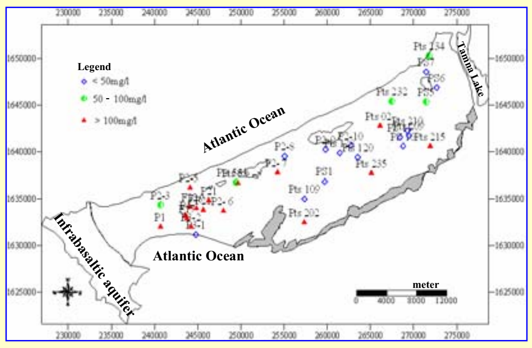


Fig. 5: Nitrate distribution in the study area

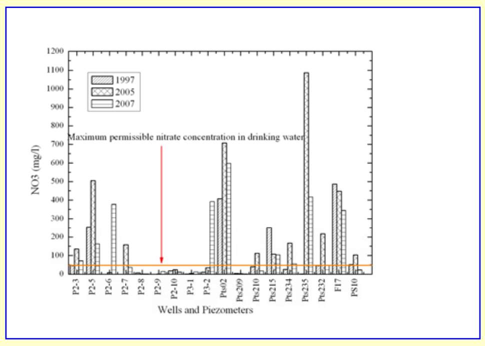


Fig. 7: Temporal variation of nitrate concentration in the study area

The δ15N(NO3-)-values range from +7.3 to +22.2 ‰ with an average value of +11.4 ‰. **Figure 7** show plot of δ^{15}N (NO_3) versus nitrate concentration for all groundwater samples. The wide scatter of points indicates that several sources of nitrate may be present in the study area. Because groundwaters with low nitrate concentration are not generally enriched in δ^{15}N(NO_3), denitrification is not considered to be a prominent process in the shallow groundwater of the aquifer. The denitrification process would lead to a decrease of nitrate concentration in groundwater coupled to an enrichment of 15N (increasing δ15N-values) in the remaining nitrate. The δ^{15}N values of the water from wells located in the urban areas range from +10.2 to +14.1‰ with an average value of +12.2‰ which is in the range of values for nitrate derived from human and animal waste (+10 to +20‰) (Kreitler and Jones, 1975). These measured δ^{15}N(NO_3) values indicate that groundwater nitrate pollution in the urban area is mainly derived from the contribution of septic tanks and leakage sewers. High values of δ^{15}N were also encountered in certain wells located near septic tank in rural area and support the source identification above. In three wells located in the eastern and central part of the study area, nitrate concentration ranges from 54.9 to 153 mg/l with an isotopic composition from +7.3 to +9‰. These δ^{15}N(NO_3) values which are in the range of values for nitrate derived from the nitrification of soil organic nitrogen (+4 to 9‰) (Heaton, 1986) indicate that the primary source of nitrate in these wells is probably the oxidation of natural soil nitrogen. δ^{15}N(NO^3) values around 10‰ in the southern of the study area and in the niayes area, where cultivated field are fertilized with animal manure and compost are coupled to nitrate concentration between 100 to 300mg/l. These values indicate that high nitrate concentrations may be derived from the mixture of nitrate from isotopically different nitrogen sources such as animal manure sources and soil organic nitrogen sources

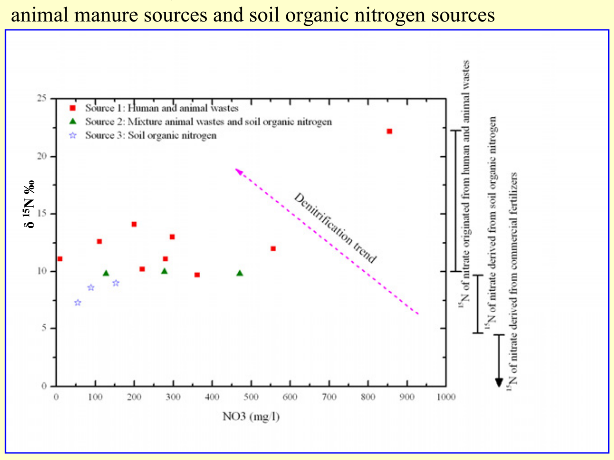


Fig. 7: Relationship between nitrate concentration and $\delta^{15}N_{(NO3-)}$ values

Conclusions

The assessment of groundwater quality shows an important increase of nitrate concentration in most of the sampled sites. 61% of groundwater sample contains nitrate levels above the recommended WHO limit of 50mg/l.

Temporal change in the nitrate concentration in groundwater can result from the influence of anthropogenic input and to the change in the proportion of nitrate from various sources.

Based on the application of natural variation of δ^{15}N(NO_3) in groundwater sources of high nitrate concentration can be associated in the study area to human waste by the use of septic system, oxidation of soil organic nitrogen and the mixture of these two sources.

References

Heaton, T.H.E. (1986): Isotopic studies of nitrogen pollution in the hydrosphere and atmosphere: a review Chemical Geology, 59: 87-102.

Kreitler, C.W., Jones, D.C. (1975): Natural soil Nitrate: The cause of the nitrate contamination of groundwater in runnels county, Texas.
Ground Water, 13: 53-62.

Silva, S.R., Kendall, C., Wilkison, D.H., Ziegler, A.C., Chang, C.C.Y., Avanzino, R.J. (2000): A new method for collection of nitrate from fresh water and the analysis of nitrogen and oxygen isotope ratios.
Journal of hydrology, 228: 22 - 36.

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