Land clearance and nitrate-rich groundwater in a Sahelian aquifer, Niger

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Abstract Over the last decades, a continuous increase in groundwater reserves has been observed in southwest Niger due to a rapid clearing of the native vegetation. In this rural region, high levels of nitrate occur in groundwater, which are difficult to explain given the lack of any usual source of pollution. Groundwater surveys show that important increases in nitrate content occur during exceptional recharge events near infiltrating ponds, indicating a current nitrogen flux to the aquifer. Groundwater samples with nitrate contents of between 1 and 100 mg l^{-1} have $\delta^{15}N$ values between +3 to +8‰, a range fully consistent with natural derivation from the soil. These results strongly suggest that a break in the nitrogen cycle following land clearance is the main source of dissolved nitrate in this unconfined aquifer.

Key words environmental isotopes; groundwater quality; land use; Niger; nitrate; semiarid

INTRODUCTION

Nitrate (NO_3^-) in drinking water is a major contaminant, frequently occurring in unconfined aquifers. In semiarid West Africa, sources of nitrate in groundwater have either been linked with direct anthropogenic pollution in towns (e.g. Girard & Hillaire-Marcel, 1997) or with leaching of fertilizers in rural areas (e.g. Uma, 1993). In southwest Niger, nitrate values well above the WHO recommended limit (50 mg l^{-1}) occur in rural groundwater, despite the fact that possible anthropogenic pollution is very limited (no industrial fertilizer, few latrines). In this region, intense clearing of the native savanna has been taking place for the last decades, resulting in a 10% increase in groundwater reserves (Leduc *et al.*, 2001). The question thus arises whether land clearance could also be responsible for some of the observed nitrate-rich groundwater. Natural fluctuations in nitrate content in selected wells and boreholes, as well as $\delta^{15}N$ analysis of dissolved nitrate, are considered here in order to answer this question.

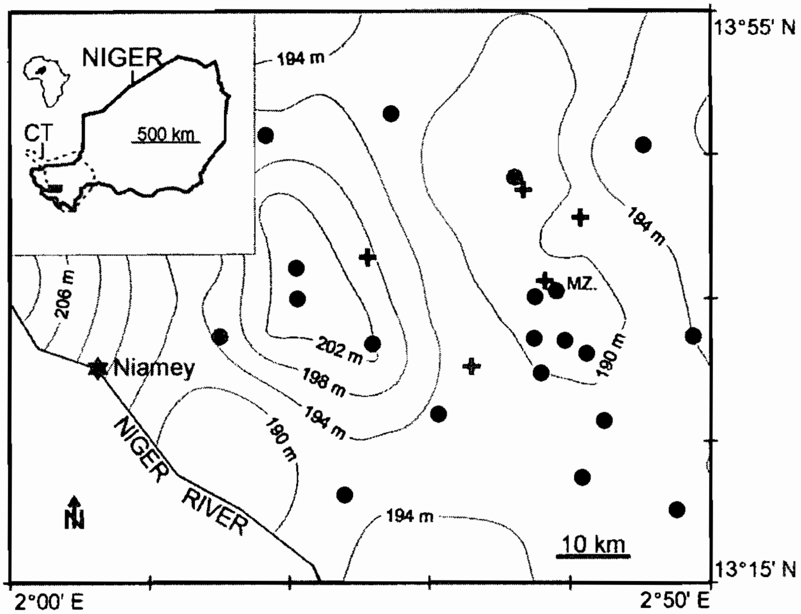

Fig. 1 General map of Niger with the Continental Terminal (CT) outcrops, and potentiometric map (2001) of water table elevation in the study area. • groundwater sample; + soil sample; MZ: Maourey Kouara Zeno well.

STUDY AREA

The study area covers approximately 3500 km^2 of the Continental Terminal, a clayey to sandy porous formation that outcrops over 150 000 km^2 in southwest Niger (Fig. 1). In this whole area, a continuous unconfined aquifer has been recognized (Boeckh, 1965). Westwards, the Niger River flows over the Precambrian basement and is a natural outlet of the aquifer. The natural vegetation consists of wooded savanna, but more than 80% of the landscape is now a patchwork of fallow and rain-fed millet fields. The climate is semiarid with a mean annual rainfall of 567 mm (Niamey) and a potential evapotranspiration of 2500 mm year^{-1}. During the rainy season, from June to September, runoff concentrates in temporary ponds, natural outlets of closed basins of the order of 1 to 2 km^2. Most of the concentrated water rapidly infiltrates and this indirect process is the main source of groundwater recharge.

Over 10 000 water table level measurements were made in the last decade in about 150 wells with a bimonthly to annual frequency. Depth to the water table varies between 5 m below the dry valleys and 75 m below the lateritic plateaux. In the last decades, intense land clearing has enhanced runoff and groundwater recharge has increased from about 1–5 mm year^{-1} in the 1950s to more than 20 mm year^{-1} in the 1990s (Favreau *et al.*, 2002).

The groundwater geochemistry has been well established by more than 150 chemical analyses (Elbaz-Poulichet *et al.*, 2002). The groundwater temperature is around 30°C; the water is acid (pH between 5.0 and 6.0) and circulates in an oxidizing medium (Eh values between 300 and 500 mV). Total dissolved solids (TDS) values are low, consistent with the quartzitic nature of the aquifer (median of 50 mg l^{-1}). The dominant anions and cations are NO_3^-, HCO_3^- and Na^+, Ca^{2+}, respectively. As for other tracers (e.g. ^3H, ^{14}C) no difference is apparent between groundwater sampled at different depths below the water table.

CHEMICAL DATA (NO_3^-)

Variations in nitrate content

In the aquifer studied, any increase in groundwater mineralization is mainly linked with an increase of the nitrate content. Sampling points at short distance from infiltrating ponds (<500 m) exhibit a median nitrate value of 45 mg l^{-1} (28 analyses), one order higher than points located at a larger distance (3 mg l^{-1}, 50 analyses). As denitrification can be neglected in this unconfined aquifer with relatively high dissolved O_2 values (saturation >50%), this observation suggests a recent increase in the nitrogen flux to the aquifer. ^3H data as well as transient hydrodynamic modelling indicate that these high nitrate groundwaters have a residence time in the aquifer of less than 50 years.

In addition to bimonthly to annual regular surveys, seasonal changes in groundwater level are continuously recorded at about ten sites (Leduc *et al.*, 2001). Since 1997, regular groundwater sampling for nitrate analysis has been performed, taking into account the changes in groundwater electrical conductivity (EC). Figure 2 displays the nitrate fluctuations in Maourey Kouara Zeno, a shallow well located 50 m from an infiltrating pond, together with the recorded groundwater levels. Whereas the nitrate content was only 3.8 mg l^{-1} in 1997, the exceptional recharge events of 1998 resulted in a groundwater nitrate peak of 178.0 mg l^{-1}, followed by a slow decrease as the groundwater level dropped. The large recharge event of mid 2000 showed a similar pattern. This correlation suggests that nitrogen is leached from a common and lasting (sub)surface soil source.

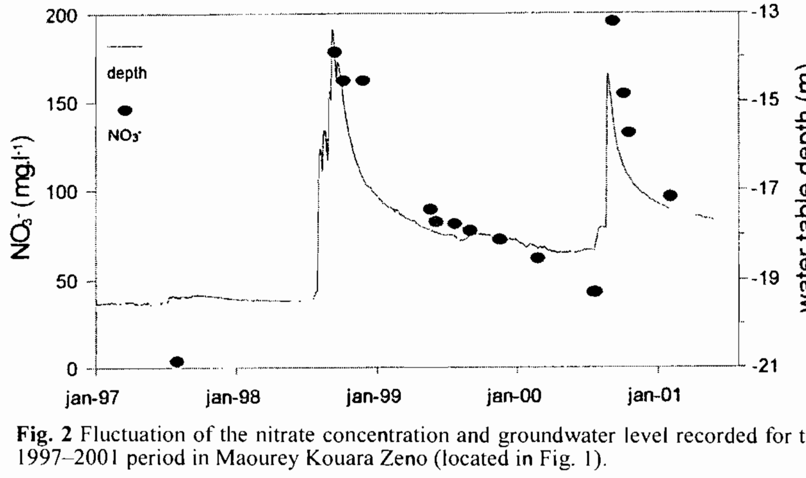

Fig. 2 Fluctuation of the nitrate concentration and groundwater level recorded for the 1997–2001 period in Maourey Kouara Zeno (located in Fig. 1).

Nitrogen sources

Potential nitrogen sources are limited in the study area. Atmospheric deposition is relatively high (~0.7 mg m^{-2} $year^{-1}$ of NO_3-N) but needs to be involved in the soil cycle to be a source for groundwater. Less than 20% of the population use latrines and this source of nitrogen is likely to be of little importance for groundwater. Industrial fertilizers have been applied to a very limited extent since the early 1990s but their use is not significant at the study scale. Surface water in ponds always has very low salinity during the rainy season (EC <50 μS cm^{-1}) and has NO_3^- contents that are always below 7 mg l^{-1}. Another nitrogen source must be sought.

In semiarid areas, deforestation and soil nitrogen have been cited as a possible source for nitrate in groundwater (e.g. Kreitler & Jones, 1975). In our study area, groundwater recharge occurs through valley bottoms, where bushy vegetation used to grow before deforestation. Sampling and analysis of the soil nitrogen content of valley bottoms, that had been deforested for various periods of time, was conducted in August 2002 (Fig. 1). Soils deforested more than 30 years ago display total nitrogen contents in the range 0.13 to 0.32‰ by mass, much lower than for soils from still uncleared valley bottoms (0.63–1.02‰). These results inidcate a possible leaching of the soil nitrogen to the unconfined aquifer as a consequence of land clearing.

ISOTOPIC DATA ($^{15}N/^{14}N$)

In contaminant hydrogeology, the $\delta^{15}N$ analysis is frequently used to determine the origin of dissolved nitrates, as distinct $^{15}N/^{14}N$ fractionations can be expected from different nitrogen sources (e.g. Girard & Hillaire-Marcel, 1997). Twenty samples of groundwater with NO_3^- contents between 0.2 and 180 mg l^{-1} were collected for $\delta^{15}N$ analysis (Paris-6 University) in early 2001 (Fig. 1; Fig. 3). High levels of dissolved O_2 (>50% saturation) preclude any significant denitrification process for this unconfined aquifer.

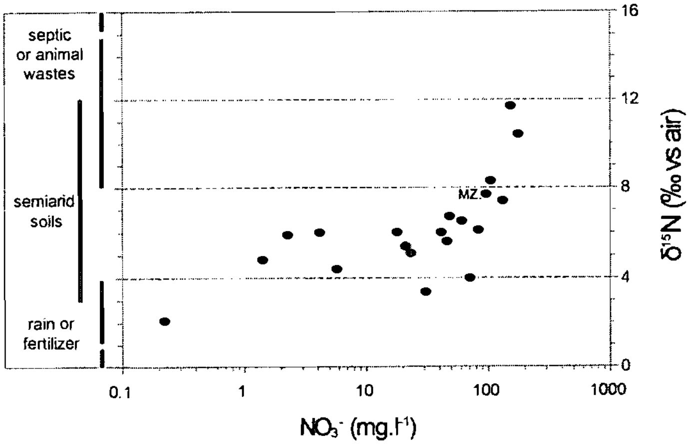

Fig. 3 $\delta^{15}N$ composition of nitrate in groundwater as a function of the nitrate concentration in 2001. The general range of isotopic composition of NO_3 in fertilizers, semiarid soils and latrine/farmyards is also displayed. MZ: Maourey Kouara Zeno.

The $\delta^{15}N$ data range from +2.1 up to +11.7‰ *vs* air, with 95% of the values between +3 and +12‰ (Fig. 3). This range is typical of semiarid soils. The lower $\delta^{15}N$ value corresponds to the lower NO_3^- content and could indicate a direct rainfall origin. Conversely, some groundwater samples with NO_3^- content above 100 mg l^{-1} have $\delta^{15}N$ values above +8‰ that could be explained by a septic or animal waste origin; however, at the study scale, this contribution is clearly not the major source of nitrate. As 80% of the $\delta^{15}N$ data fall solely in the range of soil values of between +4 and +8‰, these $\delta^{15}N$ analyses strongly suggest that leaching of soil nitrogen is the main source of nitrate for this unconfined aquifer.

CONCLUSION

In southwest Niger, about 25% of groundwater has nitrogen content in excess of the 50 mg l^{-1} limit recommended by WHO. Both spatial and temporal variations in nitrate content prove that the input to the unconfined aquifer has taken place in recent decades. Up to now, sources of nitrate identified in the Sahel were either linked with latrine/animal wastes in urban areas, or industrial fertilizers in rural places. However, in the studied area of the Continental Terminal aquifer, 80% of the measured $\delta^{15}N$ values of NO_3^--N can simply be explained by leaching of natural soil nitrogen. This explanation is consistent with both: (a) the intense land clearing that has occurred for the last 40 years, and (b) with the decrease in soil nitrogen of valley bottoms after deforestation. Elsewhere in semiarid Africa, soil nitrogen was recognized as a direct source for groundwater in the Namibian Kalahari (Heaton, 1984). Because our study area is representative of many Sahelian environments, leaching of soil nitrogen to unconfined aquifer following land clearance may be a common process in West Africa, even if it is not yet well documented.

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