^{2}H,^{3}H and ^{18}O TRACERS USED FOR A PRELIMINARY STUDY OF GROUNDWATERS VULNERABILITY TO CONTAMINANTS IN THE SOUTH-WEST OF MADAGASCAR

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Fresh water access is one of the main issues in the South-West of Madagascar. Most people in this area draw water from surface water which is usually of bad quality and source of stomach diseases. The only reliable water resource is groundwater. However, the latter is more or less vulnerable to geogenic and anthropogenic contaminants. Use of ^{2}H, ^{3}H and ^{18}O environmental tracers has contributed to localize and estimate the active and potential focuses of contamination in shallower and deeper aquifers, within the frame of a preliminary study of ground waters vulnerability to contaminants.

1.INTRODUCTION

Madagascar is a great island located in the Indian Ocean next to Mozambique (Africa). The South-Western area benefited of only 2.6 % of the water supply coverage, which is far smaller than the national average. The National Institute for Nuclear Sciences and Technology (Madagascar-I.N.S.T.N.), founded by Prof. Raoelina Andriambololona, is implementing in close collaboration with the Directorate of water and sanitation, a project entitled MAG/8/003 and financed by the International Atomic Energy Agency (I.A.E.A.). The objective of the project is to trace the origin of groundwater salinity and the vulnerability of the aquifers to pollution, by sampling water from the available equipped wells and boreholes between Mangoky river and Tsiribihina river.

This preliminary study shows already some significant insights by using ^{2}H, ^{3}H and ^{18}O tracers only.

2.STUDY SITE [4]

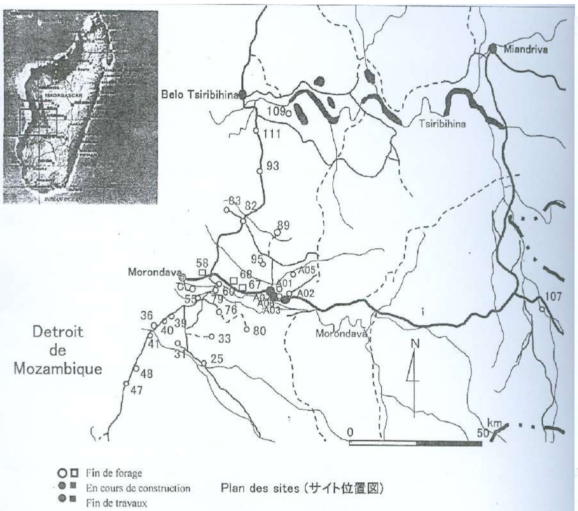


Fig.1 : Study site location

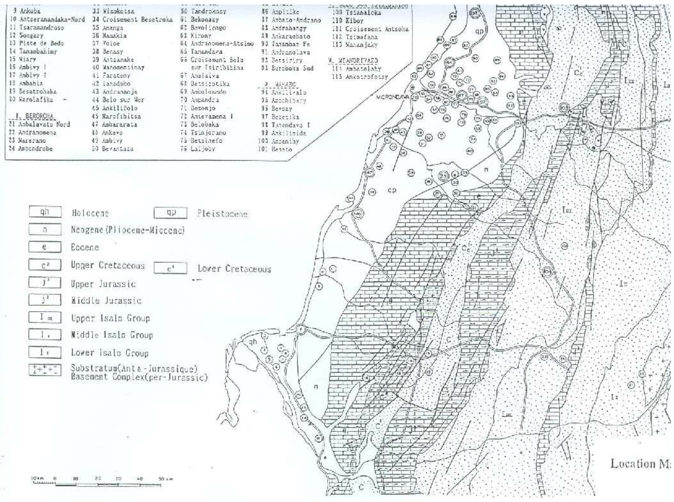


Fig.2 : geological map

The study site is located in the South-West of Madagascar in the Morondava river catchment (Fig.1).

3.GEOLOGICAL AND HYDROLOGICAL CONTEXT

3.1. Geological context

A series of sedimentary sequences covers the crystalline basement (Fig.2) : the pre-Jurassic lagoon sediments and marine deposits which can reach 10 000 m, the continental sandstone sequence of Isalo (Jurassic) which is about 2 000 m thick, a thinner marls limestone sequence, shortened half-way, sandy silt and marly limestone sequences of the upper-Jurassic, a thin sandstone layer of the Cretaceous age overlain by alternating limestone and marl, the Eocene sequence mainly made of marly limestone and sandstone, the Neogene sequence composed of marly sandstone, the Pleistocene sequence with sand gravels forming old sand-dunes, and finally, a recent coastal alluvium sequence formed by new sand-dunes. Besides, a series of SSW-NNE oriented parallel faults, called "Bongo-lava", cross the limestone sequences of the Jurassic and Eocene ages respectively.

3.2. Hydrological and hydrogeological context [3]

Moonson winds, which are blowing from North-West to South-East, bring rainfalls inland to the Western part of Madagascar. The average rainfall rate is about 700 mm.a^{-1} in the coastal plain of Morondava. It increases westwards up to more than 1000 mm.a^{-1} on the crystalline basement highlands.

There are two distinct seasons : a hot wet season from October to May, and a cool dry season from June to September.

The most accessible aquifers are the Cretaceous sandstone reservoir and fissured limestone semi-confined or confined aquifers broken off by two SSW-NNE parallel faults ; the Eocene, Neogene and Pleistocene semi confined aquifers composed of permeable layers of marly sandstone. The flow direction is quasi-uniform from E-SE to W-NW.

4.SAMPLING METHODOLOGY

The first sampling campaign was carried out during the dry season, from 4 to 12 June 2003. Apart from three dug wells, both wells and boreholes are protected and equipped either with hand pump or lever. Wells harness shallower groundwater, with depth varying from 2 to 12 m, whereas boreholes harness deeper aquifers between 50 to 82 m depth.

28 samples were collected in plastic polyethylene bottles for chemical and isotope analyses: 50 mL bottle for stable isotope analysis, 500 mL bottle for tritium analysis, 500-mL bottle for major anions. Three drops of concentrated nitric acid were added to preserve the samples for major cations precipitation.

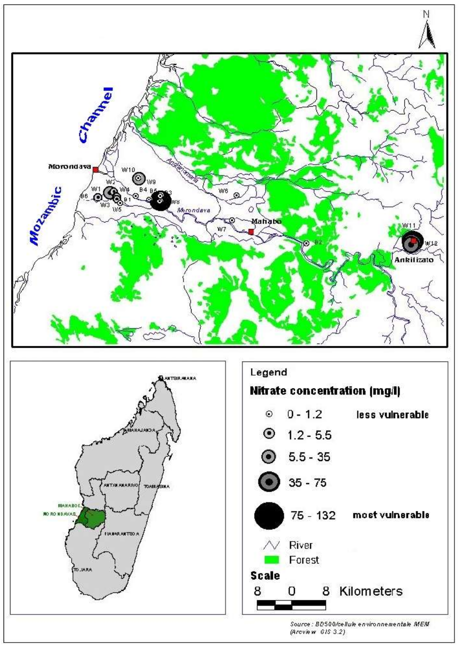
For all samples, bottles are filled to the brim to avoid internal evaporation.

5.RESULTS AND INTERPRETATION

The following parameters have been taken into account in the assessment of the aquifers vulnerability to contamination [1] : the self-purification related to the unsaturated zone thickness, the dilution power which can be assessed by the aquifer transmittivity, the residence time measured by ^{3}H and ^{14}C, the aquifers leakage assessed by ^{2}H and ^{18}O.

5.1. Active focus of nitrate pollution

The nitrate vs. TDS diagram (Fig.4) shows that NO_3 does not correlate with TDS, suggesting occasional input of NO_3 due probably to anthropogenic activities. According to the nitrate concentration map (Fig.3), which shows the polluted wells location, W11 and W12 on Eastern highland of the site, and W8 on the dunes, are the most active focuses of nitrate pollution of which concentrations exceed the W.H.O. (World Health Organisation) limit value of 50 mg.L^{-1}.



Source : BD500/cellule environnementale MEM (Arcview GIS 3.2)

Fig.3 **:** Active focus of nitrate pollution.

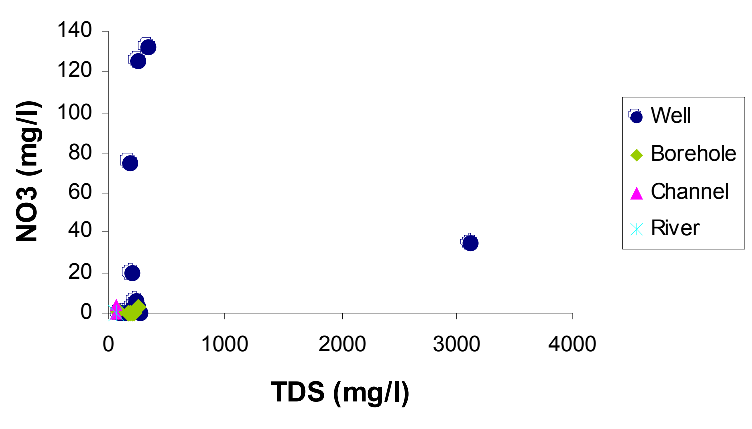


Fig.4 : Nitrate vs. Total Dissolved Solids (TDS) diagram

5.2. Potential focus of pollution

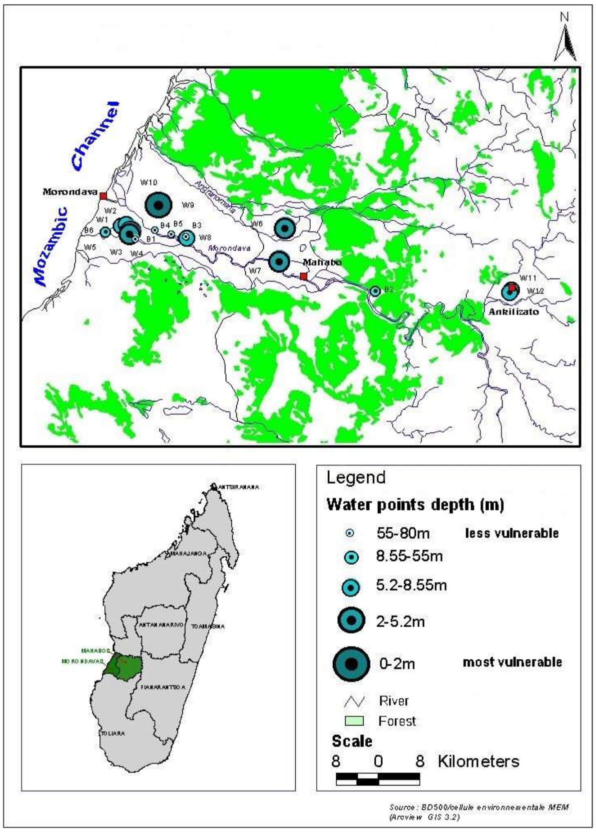
5.2.1. *Phreatic aquifers vulnerability.*

The phreatic aquifers are harnessed by wells of which mean depth is MD = (5.10 ± 0.10) m, and the mean tritium content is MT = (1.36 ± 0.45) TU, equivalent to a mean residence time of about 120 a. On the other side, their mean permeability coefficient $K= 10^{-3}$ is medium. With a relatively shallow unsaturated zone, a mean residence time close to human being life-expectancy and a medium mean permeability, we can infer that the phreatic aquifers are globally vulnerable to contamination, the most vulnerable (depth<MD and ^3H>MT) being W4, W6, W7, W11(Fig.5 and Fig.6).

5.2.2. *Deeper aquifers*.

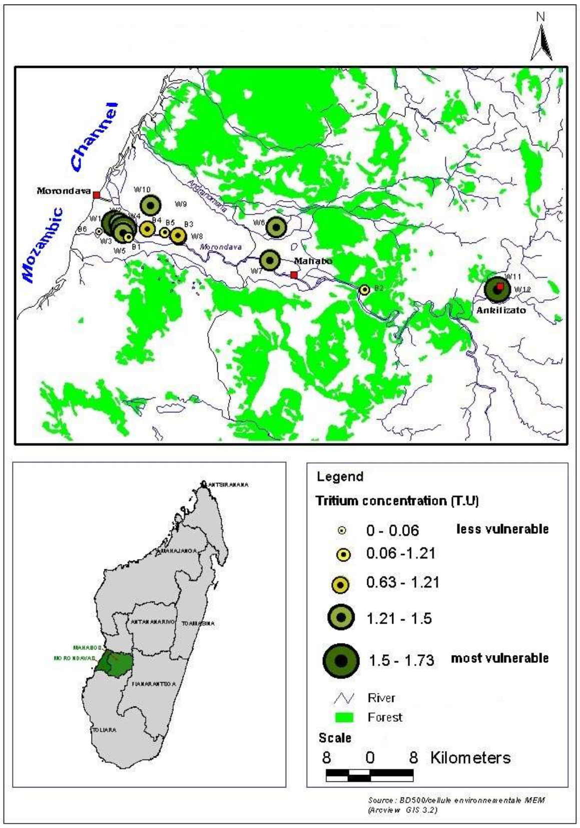
*Transmissivity : the transmissivity of the deeper aquifers is relatively high and vary from 4.10^{-2} to 7.10^{-2} $m^2.s^{-1}$ (source : Directorate of Water and Sanitation). This suggests a good dilution power for the deeper aquifers.

*Residence time and flow velocity : the few data available cannot provide a reliable mean residence time, however we can estimate an order of magnitude by calculating the flow velocity between B1 (upstream) and B6 (downstream). A transit time Δt = 2 500 a has been temporary inferred from the exponential model response curve from Pretoria rainfall tritium content [2], which would lead to a plausible groundwater velocity of $v \approx 2.28\ m.s^{-1}$



Source : BD500/cellule environnementale MEM (Arcview GIS 3.2)

Fig.5 **:** wells and boreholes depths map.



Source : BD500/cellule environnementale MEM (Arcview GIS 3.2)

Fig.6 **:** water points tritium contents map.

*Aquifers leakage : In order to assess the aquitards leakage of the deeper aquifers (between 35 and 68m depth) we have compared the stable isotope signatures of close well-borehole couples, such as (W5,B1), (W1,B6) and (W8,B3). The first two couples show distinct signatures between well and borehole water suggesting more or less impermeable aquitards, but this is not the case for the third couple which shows quite the same signatures for both well and borehole (around -4.60 ‰ for ^{18}O and -33.5 ‰) suggesting aquitard leakage, which could be either an additional source of dilution or contamination for the deeper aquifer at this location.

6.CONCLUSION

The Tritium contents show that the phreatic aquifers groundwater is relatively young and more or less evaporated, whereas the deeper aquifers groundwater is older. Rainfalls constitute the main groundwater recharge.

Nitrate seems to be the main groundwater contaminant and the most active focus of pollution are found in the dunes and highlands. The potential focus of pollution are W4,W6, W7, W11, in the phreatic aquifers, whereas the deeper aquifers are more protected thanks to a high groundwater transmissivity and a relatively low flow velocity, despite some localised aquitard leakage due to the semi-confined type of the deeper aquifers. ^{14}C should complement and confirm the Tritium values and ^{15}N analysis of the highest nitrate content samples are to be done in order to confirm the origin of nitrate

Ackowledgments

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