Groundwater Recharge Process in the Morondava Sedimentary Basin, Southwestern Madagascar

E. Mamifarananahary, J. Rajaobelison, V. Ramaroson
Madagascar Institut National des Sciences et Techniques Nucléaires (Madagascar-INSTN), P.O. Box 4279, Antananarivo 101 MADAGASCAR, e-mail : instn@moov.mg
J-J. Rahobisoa
Earth Sciences Department, Faculty of Sciences, University of Antananarivo, MADAGASCAR

The groundwater recharge process in the Morondava Sedimentary basin was determined using chemical and isotopic tools. The results showed that the main recharge into shallow aquifer is from infiltration of evaporated water. Into deeper aquifer, it is done either from direct infiltration of rainfall from recharge areas on the top of the hill in the East towards the low-lying discharge areas in the West, or from vertical infiltration of evaporated shallow groundwater. The tritium contents suggest that recharge from shallow aquifers is from recent rainfall with short residence time while recharge into deeper aquifers is from older rainfall with longer residence time.

1. INTRODUCTION

In the Morondava Sedimentary basin, Southwestern Madagascar, most people draw water from surface water, which is usually of bad quality and is a source of water related diseases. Groundwater from both shallow and deep aquifers is then the main alternative use for water supply. However, unmanaged groundwater resources exploitation poses threats for hydrogeological and ecological imbalances impact. Recharge origin(s) and process (es) need to be studied to good manage these resources and to provide sustainable drinking water for the population in this region.

The application of environmental isotopes is seen as major steps towards characterizing and quantifying groundwater in the Morondava Sedimentary basin water supply scheme. This will lead to groundwater management in the future. The present study was undertaken within the framework of the national project MAG/8/003 financed by the International Atomic Energy Agency (IAEA) and under the research project IFS W/3626-1 financed by the International Foundation for Sciences (IFS).

2. GENERAL BACKGROUND OF THE STUDY AREA

The study area is located in the Morondava Region, Southwestern Madagascar. It covers an area of about 3 152 km^2 (figure 1). Its climate is between the semi-arid South and the tropical humid Northwestern type. There are two distinct seasons, namely rainy hot summer and dry winter seasons. The rainy season begins in October and ends in May, while the dry winter season begins in June and ends in September. The annual mean temperature is 15ºC minima and 32ºC maxima. If the average rainfall rate is about 400 $mm.a^{-1}$ in the coastal plain, it increases up to 1000$mm.a^{-1}$ on the crystalline basement highlands. The Morondava and Andranomena Rivers are the main river of the study area.

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3. GEOLOGY AND HYDROGEOLOGY

3.1. Geological setting

Northwestern Madagascar is composed of a series of sedimentary sequences which covers the crystalline basement (Figure 1). In the study area, these sequences are tectonically influenced by the pre-Jurassic to Quaternary. The stratigraphy of the surface and the near surface sedimentary succession is as follow, from top to bottom [2]: a recent coastal alluvium sequence formed by new sand-dunes, Pleistocene: sand gravels forming old sand-dunes, Neogene: marly sandstone, Eocene: marly limestone and sandstone, Cretaceous: thin sandstone layer, Upper-Jurassic: sandy silt and marly limestone, Jurassic: continental sandstone, and Pre-Jurassic: lagoon sediments and marine deposits.

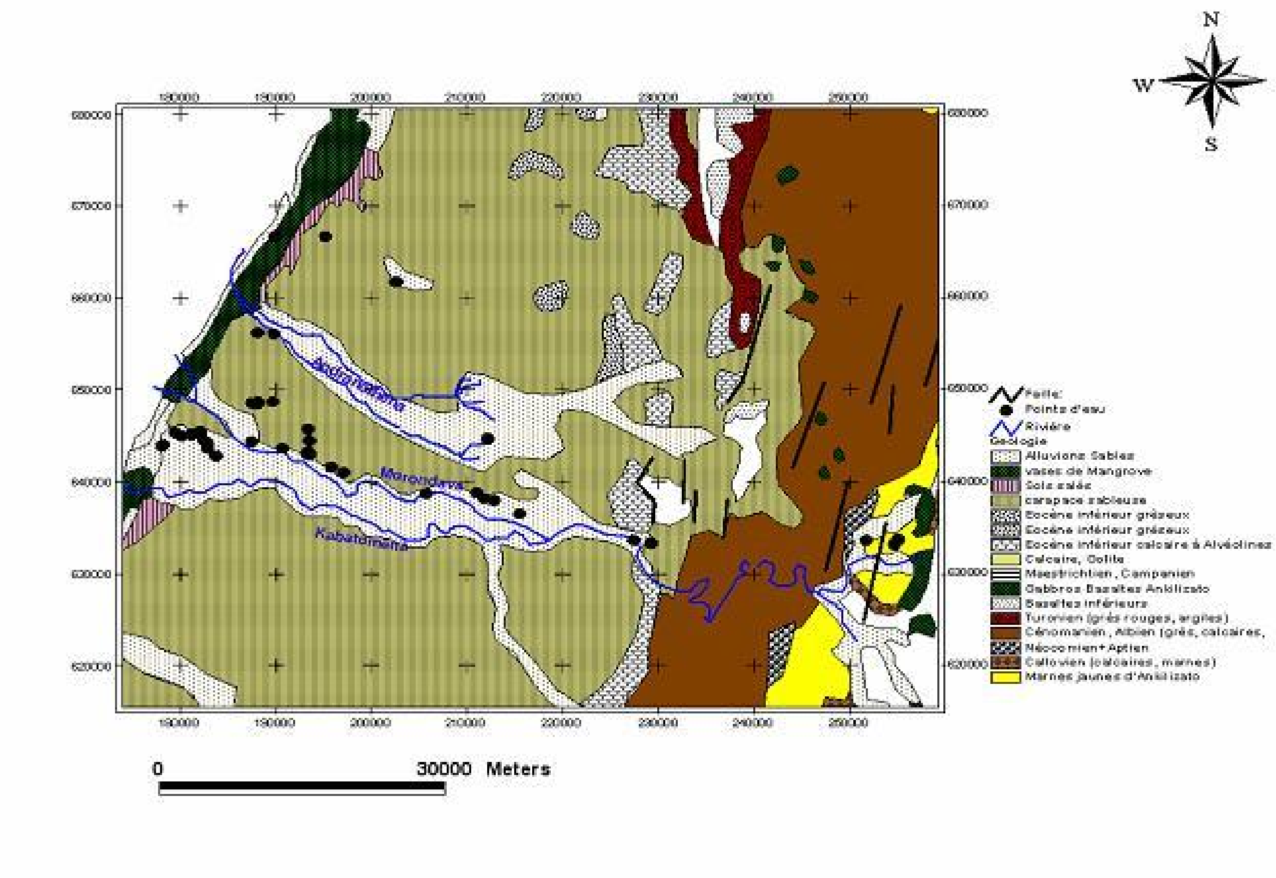

Figure 1: Geological Map of the study area and the sampling sites

3.2. Hydrogeological setting

Groundwater of the study area occurs in both types, namely, unconfined and (semi-)confined aquifers. Mostly, unconfined aquifers can be found in shallow layers of unconsolidated sand and gravel. Nevertheless, the same rocks and clayey sand will give mostly (semi-)confined aquifers for the deeper ones. The flow direction is quasi-uniform from E-SE to W-NW. Shallow aquifers have an average depth of 20 m. Wells harness shallower groundwater with piezometric levels ranging from 1 m to 3 m and around 4 m to 9 m deep. Their mean permeability coefficient is $K= 10^{-3}$ [3].

Boreholes develop deep aquifers at depth between 50 to 82m. Deeper aquifers have a relatively high transmissivity varying from 4.10^{-2} to 7.10^{-2} $m^2.s^{-1}$.

4. SAMPLING AND METHODOLOGY

Groundwater samples are collected from existing wells and boreholes at various depth of each aquifer from recharge areas to discharge areas. Figure 1 shows the location map of the sampling site in the study area. Rainwater and some surface water were also collected. Sampling campaigns were conducted from June 2003 to June 2005. Samples were analyzed for chemical and isotopic (^{18}O, ^{2}H and ^{3}H). Groundwater samples were also done for ^{14}C analyses. Parameters such as pH, temperature, alkalinity and electric conductivity were determined in the field. Samples were collected in plastic polyethylene bottles for chemical and isotope analyses: 50 mL bottle for stable isotope analysis, 500 mL bottle for enriched tritium analysis, 500-mL bottle for major anions and 250 mL bottle for major cations. 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. The isotope analyses were carried out in the laboratory of the International Atomic Energy Agency, Vienna and in the laboratory of the Schonland Research Institute in Johannesburg, South Africa. Stable isotopes were analyzed by Mass Spectrometer, whereas radioactive isotopes by Liquid Scintillation Counting (LSC). The chemical analyses were performed at the laboratory of Madagascar- INSTN by Ion Chromatography.

5. RESULTS AND DISCUSSION

5.1. Hydrochemistry

The quality of groundwater varies from fresh to saline (EC> 1500 μS/cm to up to 7000 μS/cm), due to high chloride contents. Groundwater cations and anions analyses by Piper Trilinear Diagram are depicted in Figure 2. The cations are mainly calcium, sodium and potassium type, while the anions are bicarbonate and chloride type. However, the groundwater type is mainly calcium-bicarbonate type, which might be issued by anorthite hydrolysis or limestone dissolution. In some area, sodium-chloride type is also found, especially in coastal area. This is probably influenced by seawater intrusion or marine aerosols infiltrated in the aquifer.

The four samples of collected rainwater show a sodium-chloride water type, suggesting precipitation from coastal stations.

5.2. Isotope composition

5.2.1. Stable isotope

The $\delta^{2}H$ and $\delta^{18}O$ plot of shallow and deep groundwaters, and precipitation in Morondava basin is shown in Figure 3. The isotopic composition scatters below the world meteoric water line (WMWL), characterizing evaporation effect. Two groups of groundwater can be recognized on the $\delta^{2}H$ and $\delta^{18}O$ (Figure 3). The first group represents groundwater from deep aquifer, more depleted in stable isotopes, while the other consists groundwater from shallow and some deep aquifers, representing the more enriched in the isotope compositions. The stable isotopic composition of the first group is quite similar to that of world meteoric water, and lies on the WMWL, suggesting recharge by direct infiltration of rainfall. However, those samples are mainly from deep and confined aquifers. Thus, groundwater in this group comes from lateral infiltration of meteoric recharge.

The isotopic compositions of the other groundwater group suggest that recharge is effect by evaporation. The evaporation process may occur from temporary storage or ponding of rainwater in the surface area before infiltration or from capillarity evaporation of infiltrated water. Groundwater from deep aquifers in this group is from semi-confined aquifers, suggesting vertical infiltration of evaporated shallow groundwaters, in other words, an aquitard leakage.

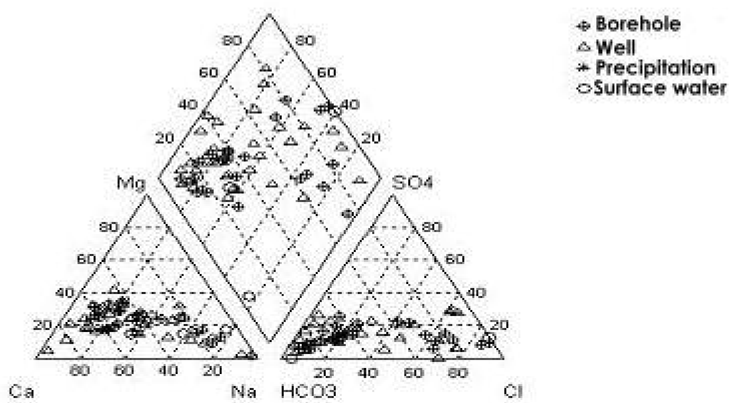

Figure 2: Piper diagram of well and borehole waters in the Morondava basin

5.2.2. Tritium

The ^{3}H contents from shallow groundwater have a mean value of (1.26 ± 0.45) TU and in deeper aquifer the mean value of ^{3}H contents is of (0.36 ± 0.39) TU. The lowest ^{3}H content was found for the groundwater of the deep aquifer, whereas the high ^{3}H content values over the study area were from shallow aquifer. It may be concluded that recharge from shallow depth aquifers is directly from recent rainfall with short time residence and the recharge into the deeper aquifers is from older rainfall with high transit time, leading to slower groundwater velocity.

6. CONCLUSION

Groundwater quality is generally good for domestic purposes. Saline water has been found in some areas in the coastal aquifer, probably influenced by seawater intrusion or marine aerosols infiltrated in the aquifer. The main hydrochemical types of water are calcium bicarbonate and sodium chloride types. The main recharge into shallow aquifer is from infiltration of evaporated water. The groundwater recharge into deeper aquifer is either directly from infiltration of the rainfall from recharge areas on the top of the hill in the eastern part of the study area towards the low-lying discharge areas in the western part; or from vertical infiltration of evaporated shallow groundwater (aquitard leakage). The tritium contents suggest that recharge from shallow depth aquifers is from recent rainfall with short residence time and the recharge into deeper aquifers is from older rainfall with longer transit time.

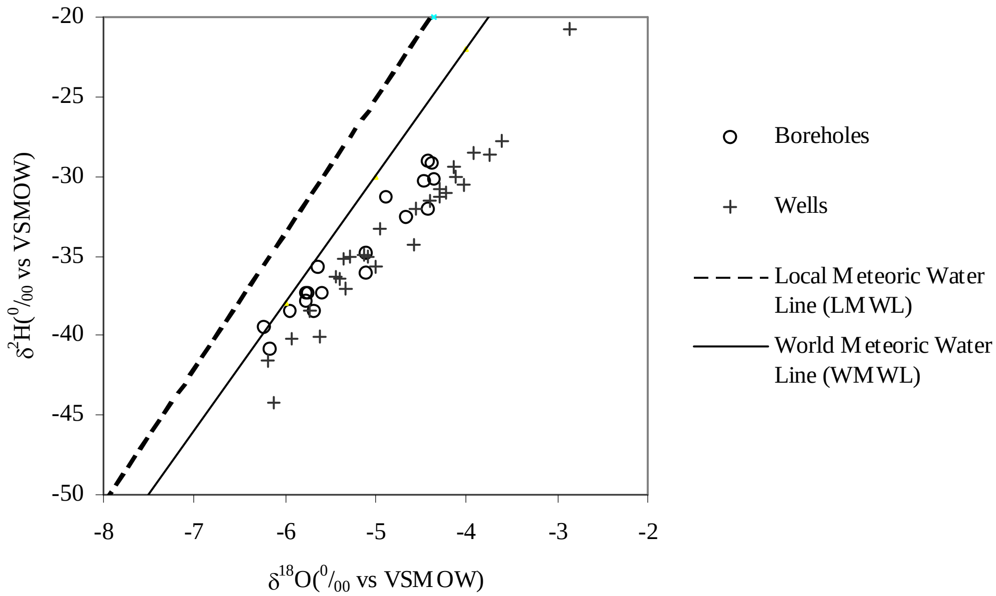

Figure 3: Isotopic Composition of groundwater in the Morondava Basin

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