Chemical Analysis of Groundwater in the Ankavia Antalaha Watershed, Madagascar

BEJOMA Michael[1], RAHELIVAO Jean Elie[2], RAZAFINDRAPATA Augustin[2], BEJOMA Jean Rosny[2], MASIZARA Elida[3], KALL Briant[4]

[1]Mention Earth Life Science and Environment, University of SAVA, Madagascar

[2]Water and Environment Engineering, University Institute of Environmental and Social Sciences, University of Antsiranana, Madagascar

[3]GENESIS Laboratory, Department of History and Geography, University of Antsiranana, Diégo Suarez, Madagascar

[4]Mention Physics, University of Antsiranana, Madagascar

Abstract— *Groundwater in the ANKAVIA watershed remains a relevant research topic related to water consumption in Madagascar, concerning both its quality and quantity. It then discusses the importance of rational management of water resources in all regions of the island. The SAVA region is one of them. Very few people have benefited from drinking water, which is necessary to assess their potential impact on public health. This study aims to evaluate the quantity of mineral elements contained in the water of the Ankavia catchment basin in the Antalaha District of the SAVA Region. The analysis was carried out by X-ray fluorescence spectrometer (Amptek EXP-2). Samples of the water from piezometers were taken at different sites, notably the ANKAVIA basin. Several categories of mineral elements were identified in the samples: essential nutrients (calcium), as well as potentially undesirable elements such as copper, cobalt, nickel, manganese, zinc, lead and iron. The concentrations vary significantly according to the water sampling points. This study highlights the presence of heavy metals at trace levels in certain piezometer waters, highlighting the importance of consumer vigilance and that of competent regulatory authorities.*

Keywords— *Piezometer waters, Mineral elements, Heavy metals, SAVA region.*

I. INTRODUCTION

Malagasy State has adopted for some years the policy of supply and conveyance of drinking water for the population, especially for rural areas that do not have access to drinking water [10]. The Malagasy people continue to have little access to safe drinking water, especially in the SAVA area. She sees herself through the ramifications of many projects that affect water management. In this case, the study of water quality is necessary to ensure its potability [14]. Only about 10% of the population of the urban area of ANTSIRANANA (DIANA and SAVA) have a private connection to the drinking water network, the rest is mainly supplied by the various public standpipes installed in all areas of the city [15]. A large part of the population therefore uses wells to meet their daily water needs. The main problem related to water consumption in Madagascar concerns both its quality and quantity [11]. It then discusses the importance of rational management of water resources in all regions of the island. The SAVA region is one of them. Very few people have benefited from drinking water [13].

II. METHODOLOGY

A. Location and description of the study area

The studies were conducted in the Ankavia watershed of the Antalaha District of the SAVA region. The Ankavia River is the main source of water supply for the city of Antalaha, which had 282,158 inhabitants in 2020 (INSTAT 2020). The samples are taken in three areas of the downstream part of the basin, namely the commune of Marifinaritra, the commune of Antombana and the commune of Antalaha.

A. Scope of the study

This study was carried out at the Laboratory of Nuclear Physics and Environmental Physics (LPNPE) of the University of Antananarivo, Madagascar. The elemental analyses were carried out by energy-dispersive X-ray fluorescence spectrometry (ED-XRF), a technique allowing the simultaneous identification and quantification of chemical elements present in the samples. The samples will be collected in the downstream part of the Ankavia watershed of the ANTALAHA District. The purpose of this study is to identify the contents of the elements present in these waters of the piezometer at the sampling points. The test results must be comparable to the relevant standards of the Malagasy Ministry of Public Health and the European Food Safety Authority (EFSA).

B. Sampling strategy

The sampling strategy plays an important role in carrying out a given research. Generally speaking, there are two types of methods on quantitative sampling, that is to say non-probabilistic methods and probabilistic method. But between these two methods, we chose the probabilistic methods. This probabilistic method aims to collect samples that are as representative as possible of the studied population. Water is being collected from 05 sites (BM 068/24, BM 072/24, BM 074/24, BM 075/24 and BM 077/24), in the month of June 2024.
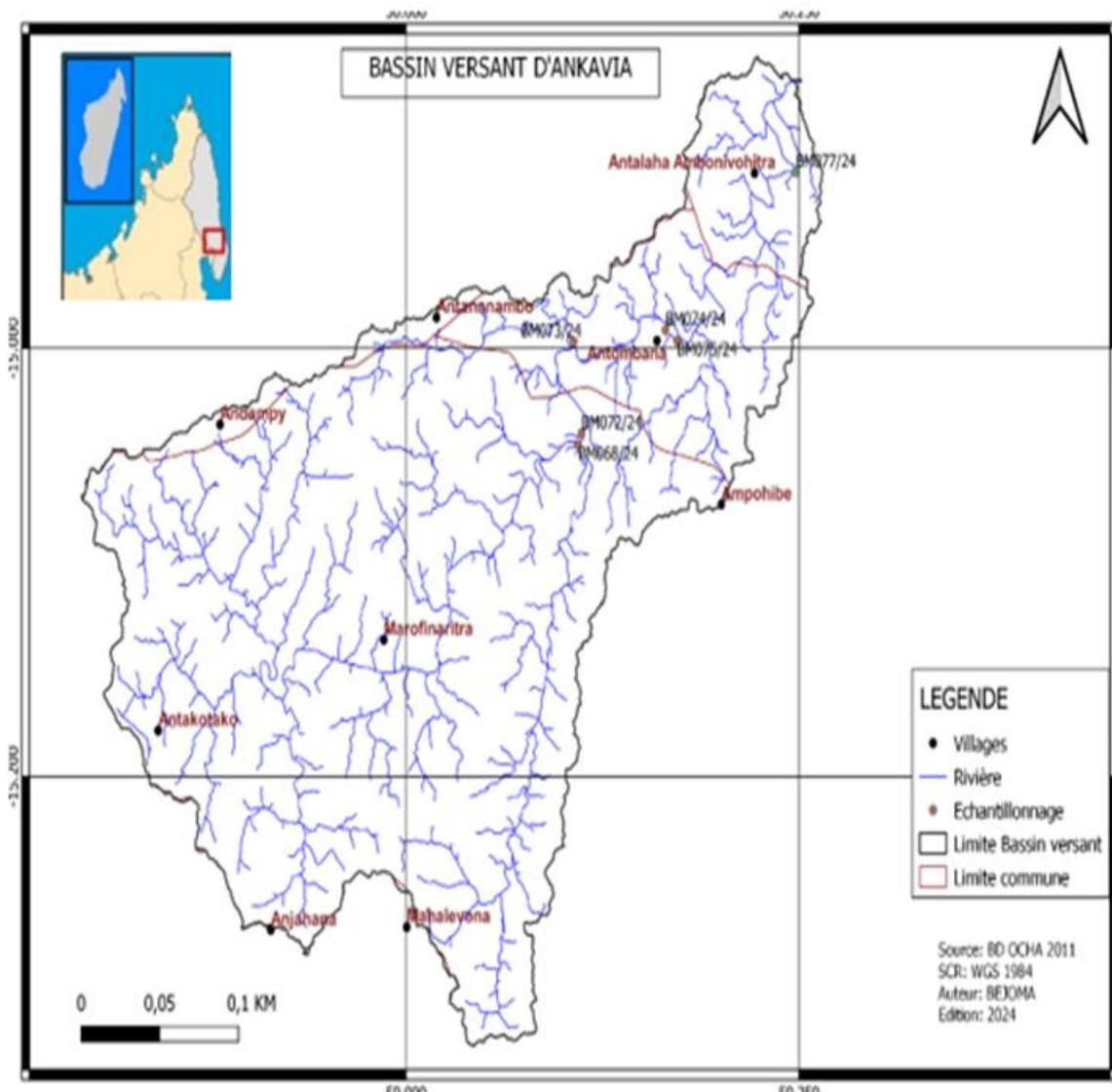
Fig. 1. Location of the study area.

C. Data acquisition and processing

The acquisition of spectra was carried out with the software DPP-MCA (Amptek, version 1.0.0.12), with the following parameters:
- Acquisition time: 500 seconds per sample,
- Number of channels: 2048,
- Amplification gain: 12,5.

The spectra processing and quantitative analysis were carried out using XRS-FP2 software (Amptek), using the fundamental parameters algorithm for the conversion of spectral intensities into elemental concentrations. The calibration of the system was carried out using a series of single-element and multi-element reference standards.

D. Standard by the competent entities on drinking water

Standards have been established which set in particular the maximum levels not to be exceeded for a certain number of harmful substances likely to be present in water.

Fig. 2. X-ray fluorescence spectrometer device (Amptek EXP-2) used for sample analysis.

TABLE 1: Standard on chemical parameters (mg.l^{-1}) [9]

entities	Ca	Mg	Fe	Mn	Zn	Pb	Cd
State Malagasy	400	50	0,5	0,05	5	0,05	0,005

As	Ni	Cu	Cr	Co
0,05	0,05	0,05	0,05	0,02

III. RESULTS AND DISCUSSIONS

Five (05) samples were analyzed and taken in different locations, coming from the study area in the Ankavia watershed. The results of these analyses show that they contain several elements such as: Lead, Arsenic, Chromium, Cadmium, Copper, Cobalt, Nickel, Manganese, Zinc, Iron and Calcium.

A. Analysis results

Table 2 represents the average concentrations of mineral elements in the water of the piezometer.

TABLE 2: Concentrations of mineral elements in the water of the piezometer.

	BM 068 /24	BM 072 /24	BM 074 /24	BM 075 /24	BM 077 /24
Ca (mg/L)	56,85 ± 1,78	128,70 ± 0,24	99,38 ± 0,69	22,84 ± 0,04	26,35 ± 0,78
Cu (µg/L)	12,02 ± 0,78	78,88 ± 0,29	65,24 ± 0,36	31,62 ± 1,36	20,63 ± 0,87
Co (µg/L)	< LD	45,21 ± 0,45	< LD	61,65 ± 0,48	45,33 ± 0,96
Ni (µg/L)	< LD	< LD	< LD	< LD	< LD
Mn (µg/L)	89,58 ± 1,45	72,14 ± 0,56	76,66 ± 2,78	1741,63 ± 6,80	1215,52 ± 7,03
Cr (µg/L)	< LD	< LD	< LD	< LD	< LD
Cd (µg/L)	< LD	< LD	< LD	< LD	< LD
Pb (µg/L)	22,41 ± 0,54	10,74 ± 0,42	12,45 ± 0,87	5,88 ± 0,02	9,4 ± 0,01
Zn (µg/L)	< LD	< LD	< LD	< LD	< LD
Fe (µg/L)	148,02 ± 2,87	200,14 ± 3,14	458,87 ± 5,78	869,61 ± 6,87	2093,21 ± 12,78
As (µg/L)	< LD	< LD	< LD	< LD	< LD
Al (µg/L)	36,55 ± 0,08	45,88 ± 0,78	84,21 ± 3,56	42,42 ± 0,27	95,12 ± 6,66

< LD: lower than the detection limit.

Aluminum concentrations range from 36,55 ± 0,08 µg/L (BM 068 /24) to 95,12 ± 6,66 µg/L (BM 077 /24). The sample BM 077 /24 is distinguished by an exceptionally high content, representing more than twice the nearest concentration (BM 068 /24: 36,55 ± 0,08 µg/L). Relatively small standard deviations (< 4 µg/L) indicate good analytical reproducibility. The high inter-sample variability observed, particularly for manganese and aluminum, could be attributed to geographical, seasonal or methodological factors during sample collection and preparation.

Cobalt was quantified in only three samples: BM 072 /24 (45,21 ± 0,45 µg/L), BM 075 /24 (61,65 ± 0,48 µg/L) and BM 077 /24 (45,33 ± 0,96 µg/L), with similar concentrations. The other two samples show values below the detection limit.

Iron concentrations range from 148,02 ± 2,87 µg/L (BM 068 /24) to 2093,21 ± 12,78 µg/L (BM 077 /24), showing a relatively homogeneous distribution compared to the other analyzed elements. The average concentration is around 753,97 ± 6,288 µg/L.

The copper concentration was detected in all samples BM 068 /24 (12,02 ± 0,78 µg/L), BM 072 /24 (78,88 ± 0,29 µg/L), BM 074 /24 (65,24 ± 0,36 µg/L), BM 075 /24 (31,62 ± 1,36 µg/L) and BM 077 /24 (20,63 ± 0,87 µg/L). This heterogeneous distribution suggests significant inter-sample variability for this element.

Manganese exhibits the highest inter-sample variability with concentrations ranging from 1741,63 ± 6,80 µg/L (BM 075 /24) to 1215,52 ± 7,03 µg/L (BM 077 /24). The samples can be classified into two groups: a low content group (BM 068 /24, BM 072 /24, BM 074 /24) with concentrations ranging from 72,14 ± 0,56 µg/L to 89,58 ± 1,45 µg/L, and a high content group (BM 075 /24 and BM 077 /24) with values greater than 1741,63 ± 6,80 µg/L.

Furthermore, our results show that the waters of the piezometers are composed of Lead which is a toxic element at low concentration but that of BM 075 /24 is higher than that of BM 068 /24. They are also composed of Calcium which is a nutrient at a very high concentration. During the analysis, other elements were found such as: Nickel, Chromium, Cadmium, Zinc and Arsenic but their value was below the detection limit.

B. Discussions

These results reveal that well waters are rich in nutrients with some undesirable elements and trace elements such as heavy metals not negligible.

This variability can be attributed to geographical, seasonal factors, or soil conditions in the collection sites of the SAVA region of Madagascar.

- Aluminum

Aluminum was detected in all the samples, these values range from 95.12 ± 6.66 µg/L (BM 077 /24) to 36.55 ± 0,08 µg/L (BM 068 /24). Aluminium can be toxic at high concentrations, causing allergic reactions, respiratory problems and, in cases of high chronic exposure, carcinogenic effects. The Malagasy State recommends a limit of 0,005 mg/kg body weight per day to avoid toxic effects. The observed concentration remains very low and does not present a significant health risk [1].

- Calcium

Calcium has a concentration ranging from 22,84 ± 0,04 mg/L to 128,70 ± 0,24 mg/L, these values are acceptable compared to the standard of the Malagasy state [9] although the concentration is very low for water intended for human consumption.

- Copper

Copper was detected in all samples, these values range from 12,02 ± 0,78 µg/L (BM 068 /24) to 78,88 ± 0,29 µg/L (BM 072 /24). Copper is an essential trace element playing a crucial role in collagen synthesis, energy metabolism, and antioxidant function [4]. The European Food Safety Authority (EFSA) has established an adequate intake of 1.5 mg/day for pregnant and breastfeeding women (EFSA Panel on Dietetic Products, Nutrition and Allergies, 2015). The acceptable daily intake was recently revised to 0,07 mg/kg body weight [7]. The concentrations observed in our samples are well below the established toxicity thresholds.

- Manganese

Manganese shows the highest inter-sample variability (72,14 0,56 µg/L to 1741,63 ± 6,80 µg/L). This element is essential for macronutrient metabolism, bone formation and radical defense systems [2]. EFSA recommends an adequate intake of 3 mg/day for adults, including pregnant and

breastfeeding women. Although no upper tolerable limit could be established by EFSA due to insufficient data [6], the observed concentrations remain within acceptable ranges for human consumption.

- Iron

Iron concentrations range from 148,02 ± 2,87 µg/L to 2093,21 ± 12,78 µg/L, showing a relatively homogeneous distribution. Iron is essential for oxygen transport via hemoglobin and cellular energy metabolism. The European Food Safety Authority (EFSA) recommends a reference intake of 16 mg per day for women of reproductive age and continues to recommend this throughout pregnancy and breastfeeding [5]. Observed concentrations contribute modestly to recommended daily intakes.

- Cobalt

Cobalt was quantified in only three samples (BM 072 /24, BM 075 /24 and BM 077 /24) with similar concentrations (50.73 µg/L). Cobalt is exclusively known for its biological role as a central component of vitamin B12 (cyanocobalamin) [16], essential for the formation of red blood cells and neurological functioning [11]. No specific recommended dietary intake has been established for cobalt alone, as the needs are covered by vitamin B12 intake. Toxicity studies indicate that adverse effects are unlikely below blood levels of 300 µg/L [12].

- Lead

Lead has a content ranging from 5.88 ± 0.02 µg/L to 22.41 ± 0.54 µg/L, it is closer to the standards imposed by the Malagasy state [9]. The observed concentration remains very low and does not present a significant health risk.

IV. CONCLUSION

This present work will allow to know the water qualities and their respective contents used by the populations in the district of Antalaha. The concentration found by the chemical parameters remains insufficient for water intended for human consumption, especially the abundant parameters in drinking water such as calcium, where the values are very low compared to the standards. These results underscore the critical importance of rigorous monitoring of metal contaminants in well water, particularly those intended for regular consumption. They also call for a better understanding of the sources of contamination and the implementation of effective preventive measures to protect consumer health.

REFERENCES

[1]. Cowie MR et al, (1997). "The epidemiology of heart failure". Eur Heart J. 1997;18(2):208-225.

[2]. European Food Safety Authority. "Scientific Opinion on Dietary Reference Values for manganese". EFSA Journal. 2013;11(11):3419. doi: 10.2903/j.efsa.2013.3419.

[3]. European Food Safety Authority. "Scientific Opinion on Dietary Reference Values for zinc". EFSA Journal. 2014; 12(10):3844. doi: 10.2903/j.efsa.2014.3844.

[4]. European Food Safety Authority. "Scientific Opinion on Dietary Reference Values for copper". EFSA Journal. 2015;13(10):4253. doi: 10.2903/j.efsa.2015.4253.

[5]. EFSA Panel on Dietetic Products, Nutrition and Allergies. Scientific Opinion on Dietary Reference Values for iron. EFSA Journal. 2015;13(10):4254. doi: 10.2903/j.efsa.2015.4254.

[6]. EFSA Panel on Nutrition, Novel Foods and Food Allergens. Scientific opinion on the tolerable upper intake level for manganese. EFSA Journal. 2023;21(12):8413. doi: 10.2903/j.efsa.2023.8413.

[7]. EFSA Scientific Committee. Re-evaluation of the existing health-based guidance values for copper and exposure assessment from all sources. EFSA Journal. 2023;21(1):7728. doi: 10.2903/j.efsa.2023.7728.

[8]. Genchi G, Carocci A, Lauria G, Sinicropi MS, Catalano A. Nickel: "Human health and environmental toxicology". Int J Environ Res Public Health. 2020;17(3):679.

[9]. Malagasy State (EM), "Malagasy potability standards", Decree No. 2004-635.

[10]. Mamizara et al., « Chemical Analysis of Well water in the District of Ambilobe and Water from JIRAMA of Antsiranana I by Atomic Absorption Spectrometry (AAS) », International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET), 2025, 14(5): 11748 -11753, DOI: 10.15680/IJIRSET.2025.1405019.

[11]. Mamizara et al., « Evaluation of the Physical Quality of Well Water in the District of Ambilobe and JIRAMA Water of Antsiranana-I, D.I.A.N.A Region, Madagascar », International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET), May 2025, 14(5) : 11754- 11759, DOI: 10.15680/IJIRSET.2025.1405020.

[12]. Paustenbach DJ, Tvermoes BE, Unice KM, Finley BL, Kerger BD. "A review of the health hazards posed by cobalt". Crit Rev Toxicol. 2013;43(4):316-362.

[13]. Rasolozafy et al., « Analyse des elements majeurs et oligoelements dans les extraits aqueux de feuilles de landolphia myrtifolia par spectrometrie d'absorption atomique. » Am. J. innov. res. appl. sci. 2025; 20(6): 11-15. DOI: https://doi.org/10.5281/ZENODO.15534397.

[14]. Razafitsiferana T, et al., « Physico-Chemical Analysis of the Water of the Well of Ampombilava in the District of Nosy-Be ». Ressources and Environment 2017, 7(3): 81- 86. DOI: 10.5923/j.re.20170703.03.

[15]. Théophile R, et al., « Analysis of Physico-Chemical Parameters and Quality Control of Water in Anjavibe Lake in the Bemagnondrobe Borough Situated in Nosy-Be District ». Ressources and Environment 2017, 7(5): 124-130. DOI: 10.5923/j.re.20170705.02.

[16]. Tvermoes BE et al., "Cobalt toxicity in humans-A review of the potential sources and systemic health effects". Toxicology. 2017; 387:43-64.