LOCALISATION OF AQUIFERS USING PHOTO-INTERPRETATION AND ELECTRICAL PROSPECTION IN TSIRANGOTY VILLAGE, AMBOVOMBE MUNICIPALITY, ANDROY REGION IN THE SOUTH OF MADAGASCAR

Jean Vasil RAFARALAHY [1], Boni Gauthier RAZAFINDRAKOTO [2], Bruno RAZANAMPARANY [3]

[1]*Phd Student, Forest and Natural Resources, Ph.D. School of Natural Resources Management, Higher School of Agricultural Sciences, Madagascar*
[2]*Lecturer, Mining Department, Polytechnic Higher School of Antananarivo, University of Antananarivo, Madagascar*
[3]*Professor, Department of Science, University of Antananarivo, Madagascar*

ABSTRACT

The village of Tsirangoty is located in the extreme south of the Androy region of Madagascar. More precisely, it is 7km south of Ambovombe town. The objective of this study is to identify areas with aquifer potential in the village of Tsirangoty and its surroundings (Ambovombe-Androy) in order to improve the conditions of access to clean drinking water for its inhabitants. The approach used is a combination of photo interpretation and electrical resistivity tomography to characterize the aquifers of this site. The results showed the presence of two superimposed aquifers in the study area. The first aquifer is a superficial aquifer at a depth of less than 20m with very limited and seasonal. On the other hand, it is an aquifer with good quality water and fewfree ions, therefore less salty water. The second aquifer is located at a depth of 120m. The conductivity of this second aquifer is much higher than the standards for clean drinking water, but a desalination technique is recommended. The upcoming drilling campaign can use this result to target favourable areas. All of the water inflows from these two superimposed aquifers located on the coordinates X= 609464m and Y= 7209295m allow us to have a productive borehole.

Keyword: *Hydro-geophysics, Electrical resistivity tomography, Aquifer, Groundwater, Ambovombe, Androy.*

1. INTRODUCTION

Clean drinking water is a vital element for human life. Worldwide, water scarcity is caused by poverty, arid and semi-arid climate, drought and global climate change. Water supply is the most effective approach and introduction to poverty reduction programs because of the essential factors including awareness, participation, ownership and education. The capacity building of the population as well as the establishment of cooperation, and a system for operations, maintenance and management is necessary for the sustainability of the clean drinking water infrastructure [1]. As is the case with the entire southern part of Madagascar, in Ambovombe municipality, Androy region, the village of Tsirangoty is part of and faces enormous problems of access to clean drinking water. The water needs of the rural population and their main activities (agriculture, livestock, etc.) are generally only supplied by rainwater for a very short period of time during the year. The village and its surroundings do not benefit from surface water in perennial flow, and even surface water in spasmodic flow is inexistant in the study area. The villagers use surface water tables (north of the study area, in Ambovombe municipality) through traditional wells. These aquifers, of limited extension, are highly dependent on precipitation and, in the majority of cases, they run out before the return of the rains [2].

1.1 Geographical and geomorphological context

Tsirangoty is located in the extreme south of Madagascar. This village is part of the urban municipality of Ambovombe in the Androy region; a region that occupies the territory between the rivers of Mandrare in the East and Menarandra in the West. It is bordered to the north by the mountainous foothills of the Southern Bara Highlands and, to the south, by the Indian Ocean and the Mozambique Channel [3]. The village of Tsirangoty is located more precisely in the extreme southern part of this region, at a distance of 7 km from the centre of Ambovombe. Tsirangoty is situated in a low altitude coastal sedimentary zone of dune formation with a height exceeding 200m [4]. The number of the population is 1,590, distributed in four hamlets and 270 households (Source: Chiefof the Tsirangoty village). It is geographically located at coordinates X=609470m, Y=7209360m and altitude Z=166m in UTM (Universal Transverse Mercator projection) and according to the WGS 84 (World Geodetic System 1984) reference system.

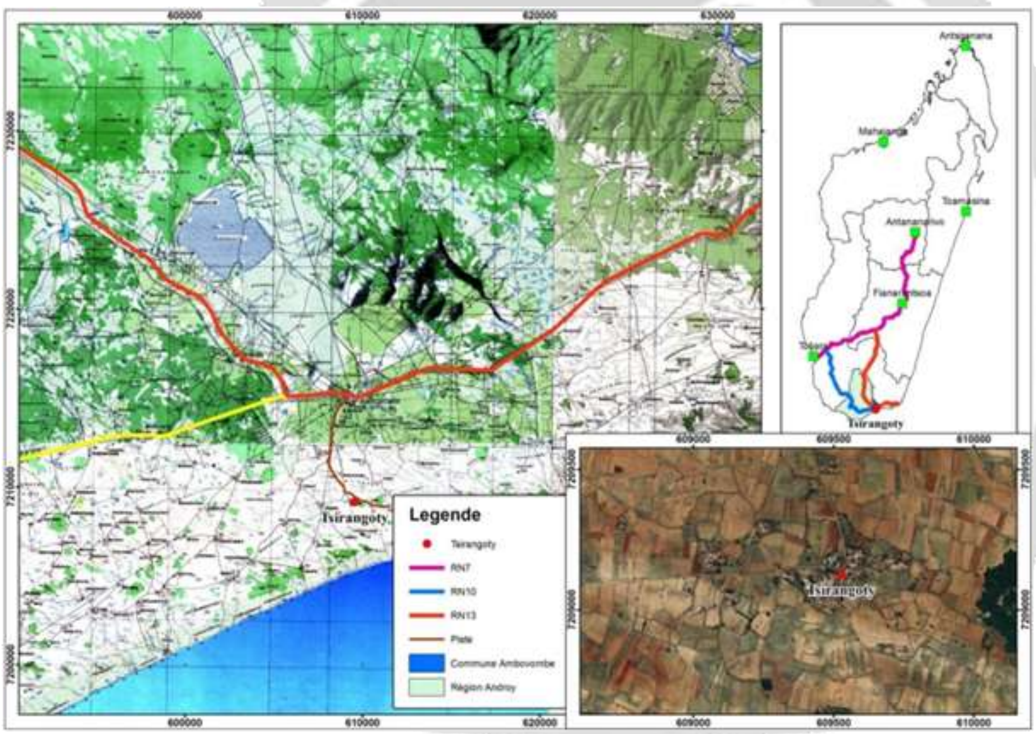

Fig -1: Location map of the study area

1.2 Hydrographic and climatic context

The Androy region is drained by three large rivers from the crystalline basement which flow in a general North-South direction: Menarandra, Manambovo and Mandrare. All these large rivers are not perennial and are reduced to almost zero or very low surface flow in the dry season (May to September). Their tributaries only have surface flow during a short period of the rainy season [3]. This area considered as the southern slope has a low rate of perennial river in Madagascar [5]. This situation puts the whole region in difficulty on the recharge of the groundwater table. In our study area, rivers or tributaries are almost inexistent.

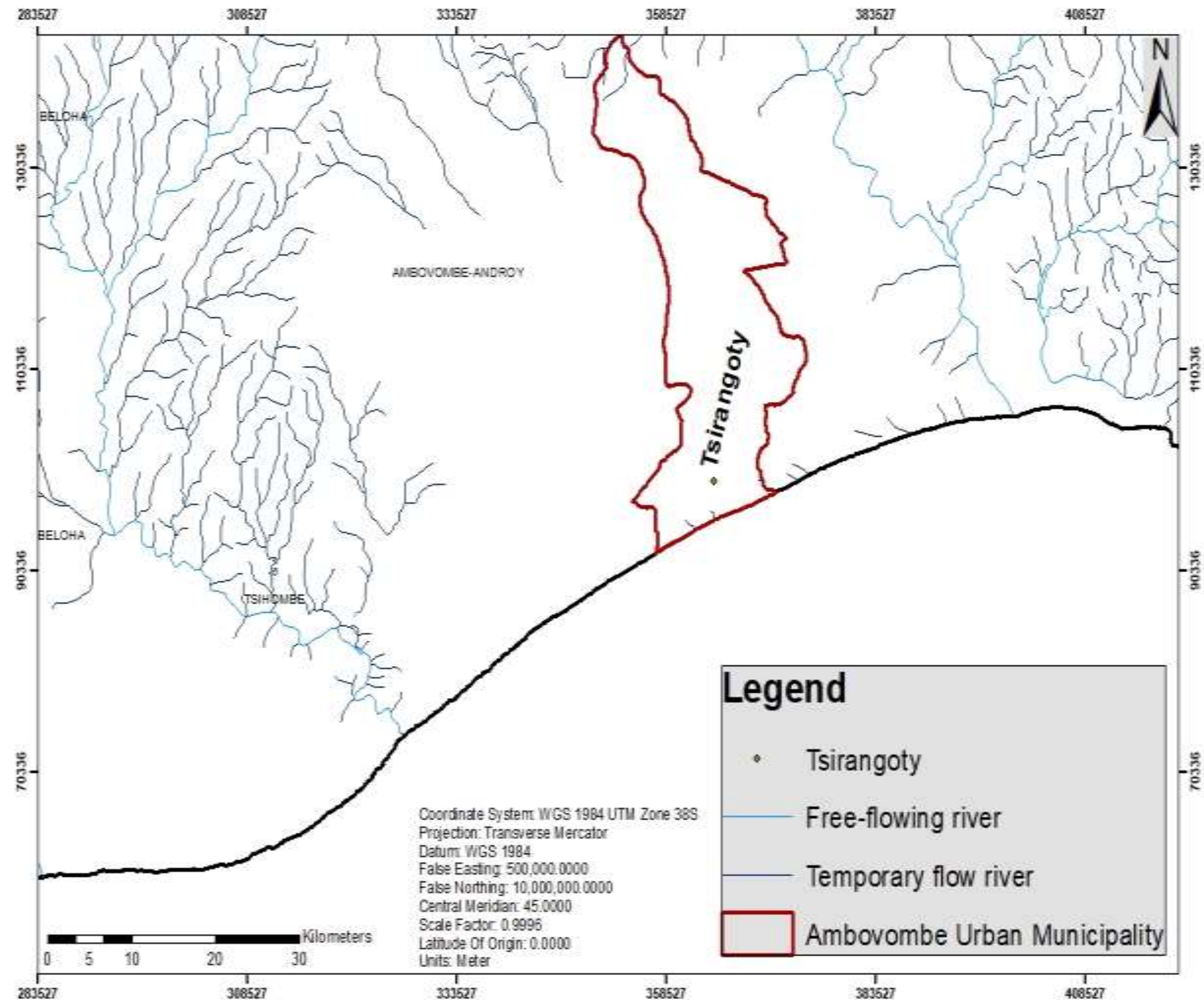

Fig -2: Hydrological map of the study area

The southern part of Madagascar has a semi-arid to arid climate, with an annual rainfall well below 400mm [5]. ETP (Potential Evapotranspiration) is 1200mm to 1300mm and ETR (Actual Evapotranspiration) is 350mm to 500mm. Hence the precipitation does not manage to sufficiently feed the groundwater table. The average annual temperature is 26°C, with maximum temperatures between 30 and 34°C being recorded in the months of October and November, with a small difference between the maximum and minimum temperatures. The graph below presents the variation in temperature and average precipitation over the course of the year from 1977 to 2017.

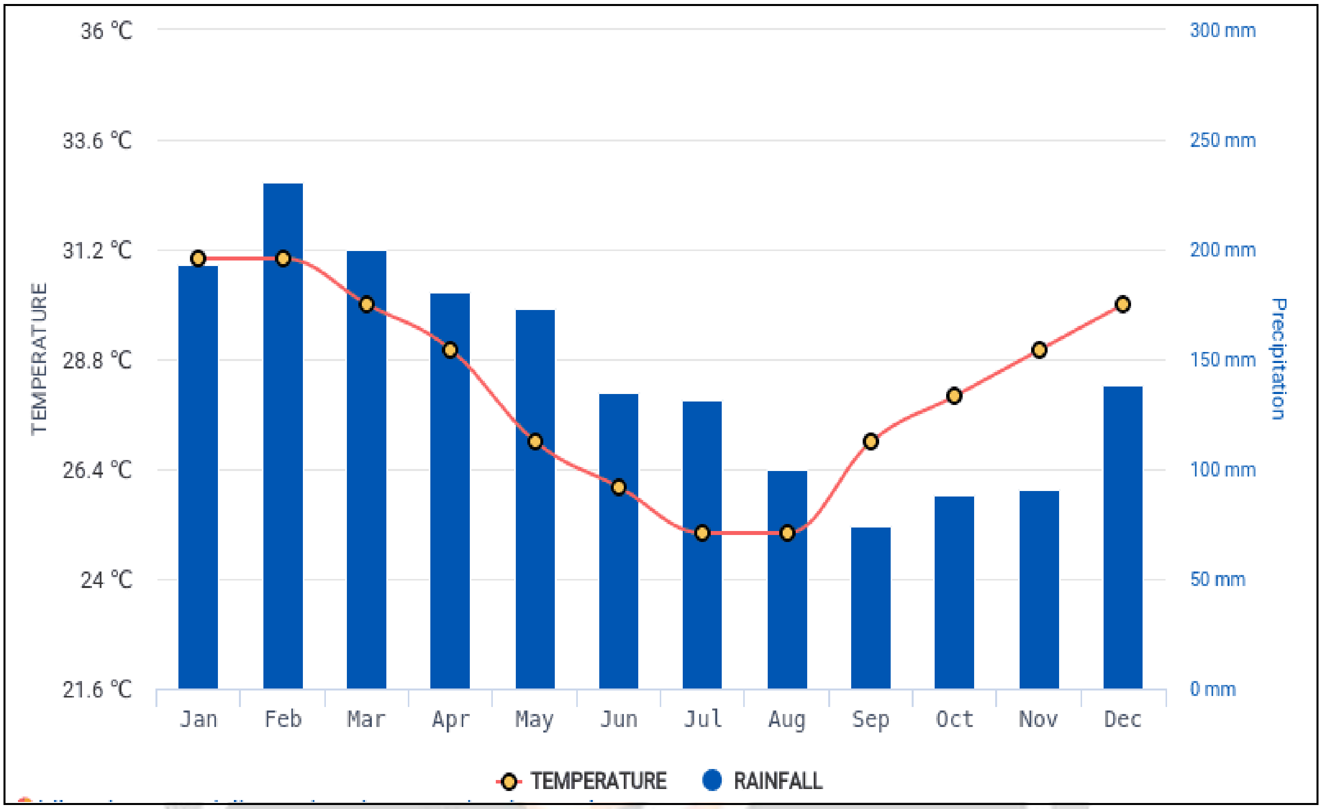

Chart -1: Average monthly of precipitation & temperatures, Ambovombe-Androy Madagascar, 1977-2017.
Source: http://hikersbay.com/climate-conditions/madagascar/ambovombe/conditions-climatiques-en-ambovombe.html?lang=fr

1.3 Hydrogeological context

Groundwater is the most exploited water resource in southern Madagascar, and a very important resource for economic and social development. This is the major source of water for public supply, for several cities and the only source available in the semi-arid south, in other dry regions and more precisely in our study area [6].
Three types of groundwater are found in our study area [7]:

- Middle Quaternary aquifer of Ambovombe; made up of fine clayey sands, whose static level is 5-10 m, the depth of the structure is 10 to 20 m with an aquifer power: 1 - 5 m;
- Early Quaternary aquifer; fine clayey sands whose top of the water table is between 50 to 150 m and the thickness of the aquifer varies from 1 to 10 m;
- Neogene aquifers; lithology, sandy sandstone whose top of the water table is between 50 to 150 and the aquifer thickness varies from 1 to 5m.

The first two types of aquifers are brackish while the third is brackish to saline. The first type of aquifer can be seasonal but the others are permanent. Work by JICA in 2006 confirms these three types of aquifer [1]. The physico-chemical characteristics of the water points encountered in the immediate vicinity of Ambovombe, visited and measured on 04/04/2006, are recorded in Table 1 below.

Table -1: Characteristics of the water points encountered in the study area

Identification	Village	Municipality	Depth (m)	Static level (m)	Conductivity (µS/cm)
FM001	Maroafo	Antaritarika	98	80	24000
F001	Fierenantsoa Amposy	Antanimora	67	15.97	1721
F006b	Bemamba Antsatra	Antanimora	76	16.75	1423
F009	Lefonjavy	Ambovombe	79	48.37	7820
F014	Ankoba Mikazy	Ambovombe	120	101	1720
F015	Tanambao	Ambovombe	150	134	7300
F018	Ambanisarika	Ambanisarika	200	153	13890
F022	Anjira	Antaritarika	120	60	11340
F030	Ekonka	Ambovombe	183	175.7	12250
SW1	Mitsangana	Ambovombe	30	22.36	2990
P009	Marobey	Ambovombe	20.2	19.4	2190

It can be seen in this table that the study area has two levels of aquifer; a quaternary aquifer of average quality which is found at a depth of 20m and the neogene aquifer of poor quality (brackish to salty) which is found at a depth or about 120m. The hydrogeological situation described above indicates that it is preferable to exploit the superficial aquifers and/or the deep aquifer, and it is preferable that future drilling should aim for the two aquifers because the first aquifer is very seasonal.

1.4 Geological context

Geologically, the study area is located in the sedimentary basin with a monoclinal structure and a slope towards the south, from north to south, from bottom to top by continental neogene and continental quaternary. The continental Neogenes are formed of clay, mudstones, sand, clayey sand and clayey sandstone. For the continental quaternary, three dune periods can be distinguished:

- The ancient dunes of the ancient Aepyornian or Tatsimian;
- Medium or Karimbolian dunes ;
- Recent or Flandrian dunes.

The formations are sands of probably Aeolian origin cemented by a significant proportion of limestone (called calcareous sandstones), and which give the undulatory morphology going towards the coast. The superficial deposits are red sands, white sands, alluvium and Ambovombe sands [7] [8].

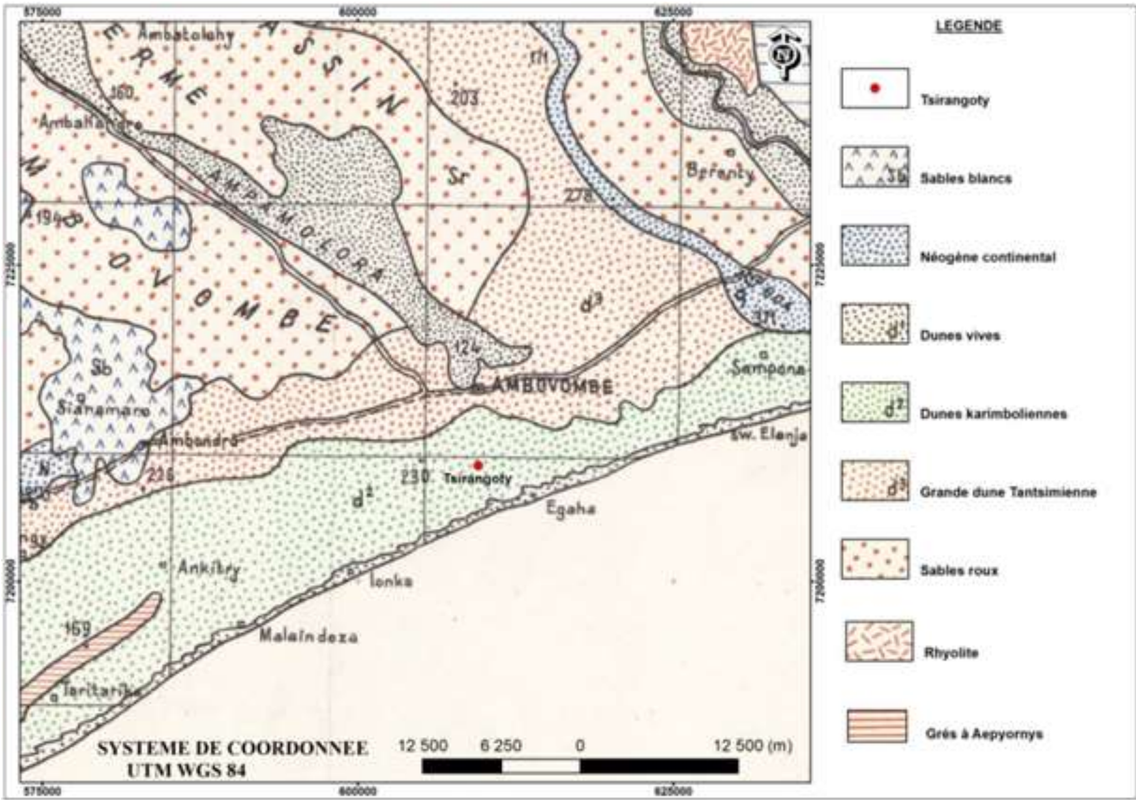

Fig -3: Extract from the geological map of Ambovombe
Source: geological map from FTM, Madagascar

2. MATERIAL AND METHOD

We used two complementary approaches in order to localise drilling points to access aquifers:

- Photo-interpretations to determine alignments or lineaments (main direction and distribution of fractures);
- Geophysical prospecting (Imagery by Electrical Tomography).

Following interpretations of the hydrogeological, hydrological and climatological maps of the study area, these two approaches are presented and interpreted below. Satellite imagery was analysed in order to obtain the major direction of fracture on a large scale, notably aerial photographs taken in 1949 and 1950 (source: FTM or Foiben-Taosarintanin'i Madagasikara), which were compared to visual observations on the ground and the images in format .tif files downloaded from https://earthexplorer.usgs.gov/. The processing of satellite data is carried out with Geomatica from PCI and ArcGIS 10.7.1. The ground resistivity measurements are carried out using a resistivity meter coupled to a measuring device which can be placed on the surface of the ground. There are a large number of measuring devices, but they are all composed of four electrodes. A current I is injected through two electrodes (A & B) and the potential difference ΔV is measured between two potential electrodes (M & N). The addressable electrodes are grouped into two sets of 30 electrodes, i.e. a total of 60, separated by 5m i.e. a line length of 295m. The two types of aquifer likely to be found inside the prospecting area were targeted by geophysical work in a North-South direction. Therefore, we use the type of Wenner-Schlumberger configuration to detect the quaternary sheet and the type of pole-pole configuration to see the extent of the Neogene sheet at depth.

Wenner-Schlumberger configuration

Wenner-Schlumberger configuration is a configuration with a constant system of spacing rules with a note of factor "n" as this configuration is the comparison of the distance between A-M (or B-N) electrodes with spaces between M-N as in figure 3. The resistivity determination process uses 4 electrodes placed in a straight line. This configuration is a combination of the Wenner configuration and Schlumberger configuration. In the measurement by the spacing factor (n) = 1, the Wenner-Schlumberger configuration is similar to the measurement in the Wenner configuration (distance between electrode = a), but on the measurement with n = 2 and so on, the Wenner-Schlumberger configuration is the same as the Schlumberger configuration. The current electrode and the potential electrode are greater than the distance between the potential electrode) [9].

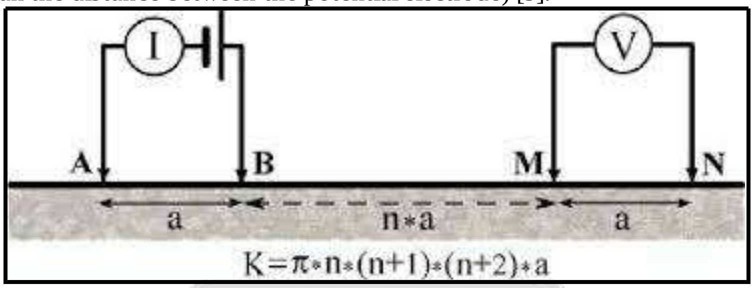

Fig -4: Wenner-Schlumberger configuration

Pole-pole configuration

This configuration is specifically for deep depth investigations. The electrodes B and N are placed at infinity, we only deal with A and M. This device is theoretically simple since the potential measured at M is due to A alone. In practice, however, this device is cumbersome because of the length of the cables necessary to make the effect of the electrodes placed at infinity negligible.

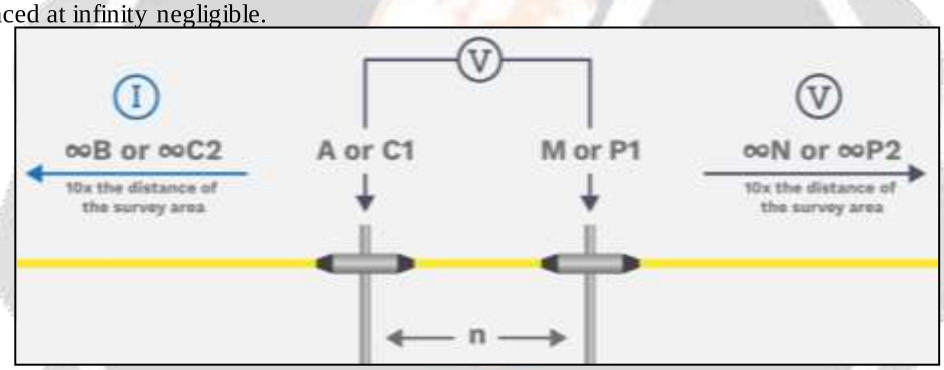

Fig -5: pole-pole configuration

Source : https://www.agiusa.com/pole-pole-array-electrical-resistivity-methods

3. RESULTS AND DISCUSSION

3.1 Image interpretation results: Identification of lineaments and discontinuity networks

The area study is in a low altitude area and constituted by a Karimbonian dune. The study site is located between two ridge lines in a west-east direction where the lowlands have been landscaped into crop fields. This lowland zoneconstitutes the preferential direction of surface water during the rainy season and is capable of supplying the surface aquifer of this zone. We present here only the major direction, more precisely the crest line, in order to determine the direction of the hydro geophysical profiles.

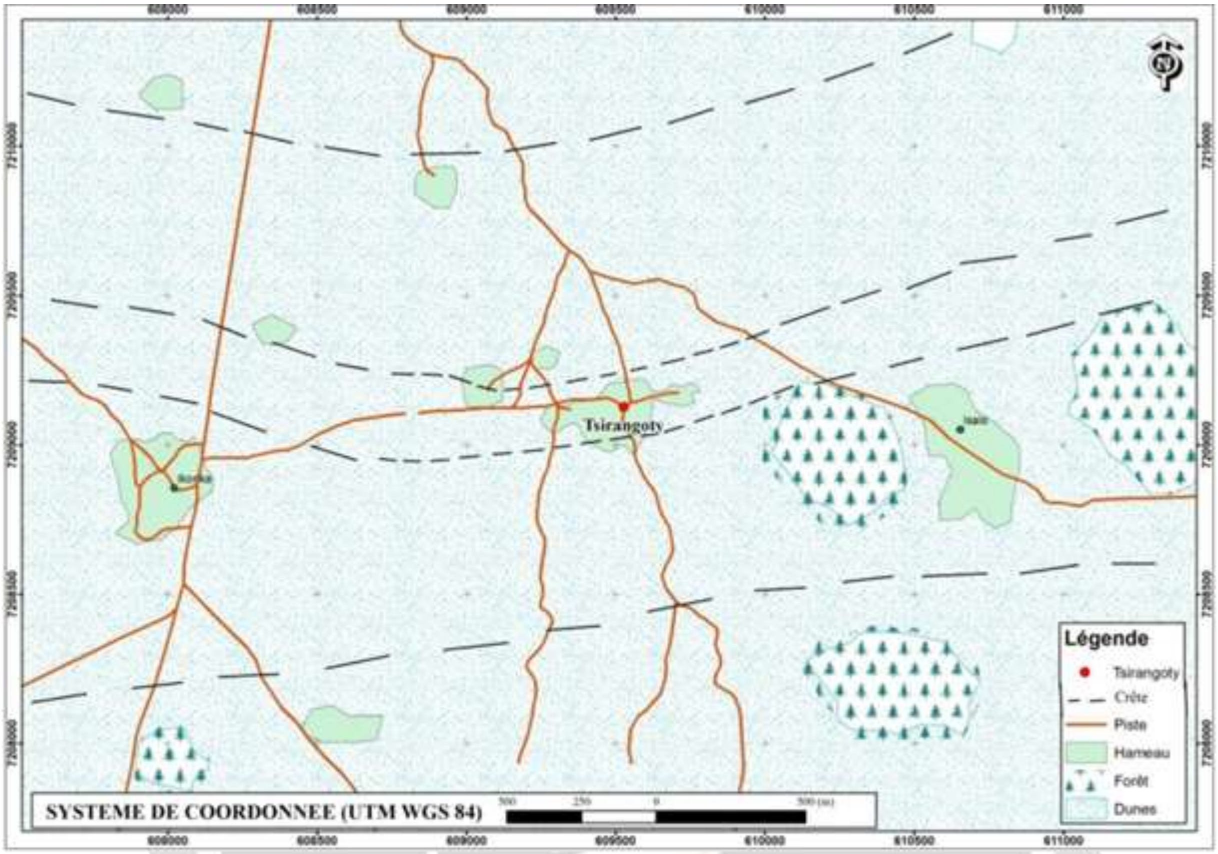

Fig -6: Summary map of lineaments in the study area

The evaluation of the hydrogeological potential above shows the necessity of the electrical geophysical method (electrical panels) for the detailed study of the area. It is therefore preferable to make geophysical profiles in a North-South direction in order to locate and delimit the probable aquifer in the area.

3.2 Results and interpretation of electrical panels

Four electrical panels were spread out inside the site, almost in a North-South direction and of the same length (295m). The purpose of the use of Electrical Tomography Imaging (ERT) is to characterize the nature of the groundwater table within the site. Table 3 shows the start and end coordinates of each profile.

Table -2: Characteristics of the water points encountered in the study area

Profile	X (m)	Y(m)	Alt (m)
ERT1	609520	7209298	163
	609576	7209005	166
ERT2	609475	7209363	166
	609420	7209074	168
ERT3	609437	7209468	168
	609390	7209176	165
ERT4	609356	7209468	168
	609339	7209176	166

The figure below gives an overview of the location of each profile.

Fig -7: Map of the location of the geophysical lines

Two configuration modes have been adopted for data acquisition:

- Wenner – Schlumberger (WS) configuration for an investigation depth of around 50m. Its purpose is to collect data on the first aquifer.
- Pole-pole configuration (PP), which must have an investigation depth of up to 150m deep. Its purpose is to delineate the deep aquifer.

3.2.1 Profile No.1, ERT No.1

Profile No.1 (ERT No.1) is spread out in the overall North-South direction. Both types of configurations have been made on this profile. The geoelectric section of Wenner – Schlumberger configuration obtained highlighted the succession of the three formations (cf. Figure 8):

- The cover formation, moderately resistant with an electrical resistivity value of less than 50Ωm. It is made up of clayey sands (Karimbolian dune);
- The moderately conductive formation, with an electrical resistivity value of around 40Ωm. This formation shelters the first surface layer which is the quaternary layer. It is local and is located between X=115m and X=125m from the beginning of the profile ;
- The less resistant formation constitutes the semi-permeable substratum which supports the first sheet completes the sequence.

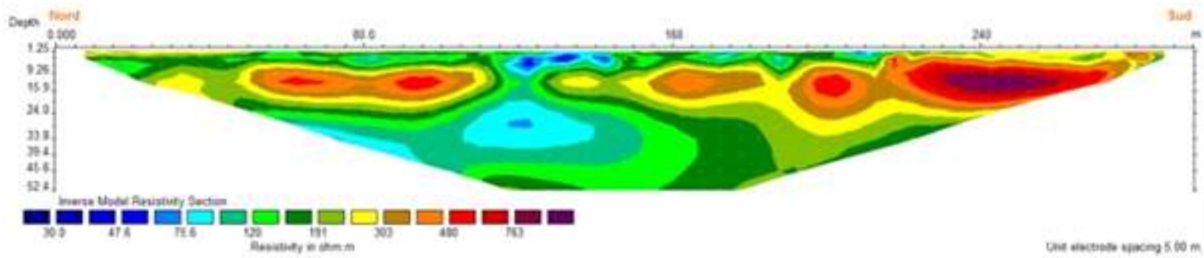

Fig -8: Geo-electric section of profile No.1 of the WS type

For the geoelectric section of Pole – Pole configuration (cf. Figure 9). It shows the deep aquifer and is located mainly in the southern part of the profile whose roof is 120m deep.

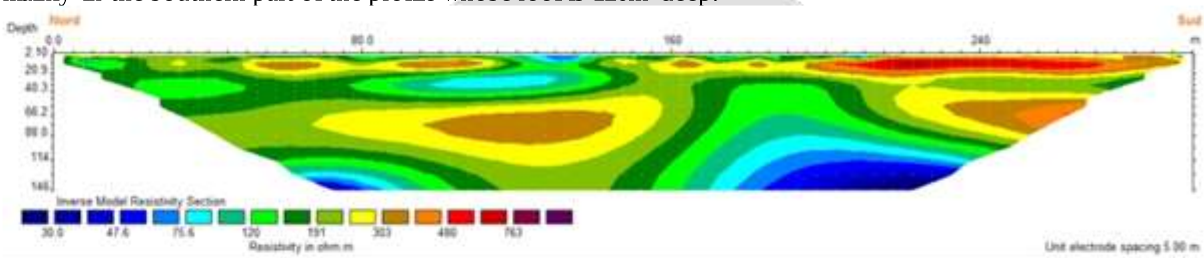

Fig -9: Geo-electric section of profile No.1 of PP type

The two sections clearly show the presence of two layers: one superficial with a conductive characteristic and the other much deeper with a more conductive nature. However, the two layers do not overlap in the same place.

3.2.2 Profile No.2, ERT No.2

Profile No.2 (ERT No.2) is spread out in an overall North-South direction (see Figure 7). Both types of configurations have been made on this profile. The geoelectric section of Wenner – Schlumberger configuration obtained highlighted the succession of the same formations as that of profile No.1. However, the superficial aquifer that interests us is at the point of abscissa X=70m of the profile, and it is located at 12m depth with an estimated power of 2m (see Figure 10).

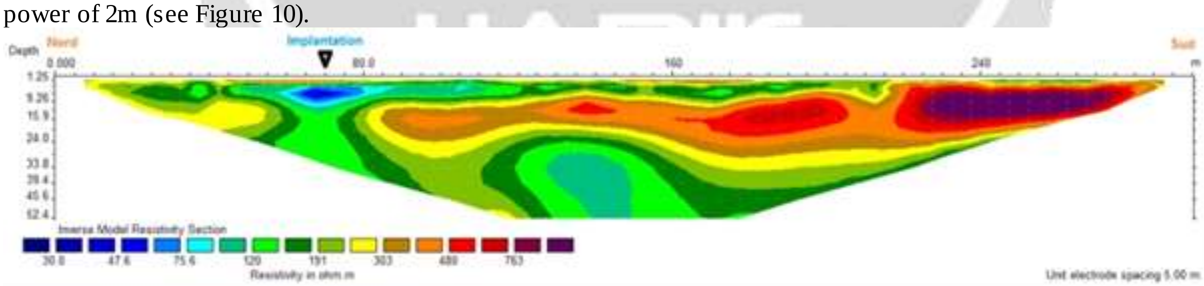

Fig -10: Geo-electric section of profile No.2 of WS type

The Pole-Pole configuration geoelectric cross-section (see Figure 11) shows the deep aquifer that is located mainly in the two extremities of the profile and whose top is at a depth of 120m. The northern part is more interesting because there is a place where the two layers overlap. Hence, we suggest drilling an underground water exploitation borehole at the abscissa point X=70m of the profile. More precisely, at the point of coordinates X= 609464m and Y= 7209295m in the UTM coordinate system.

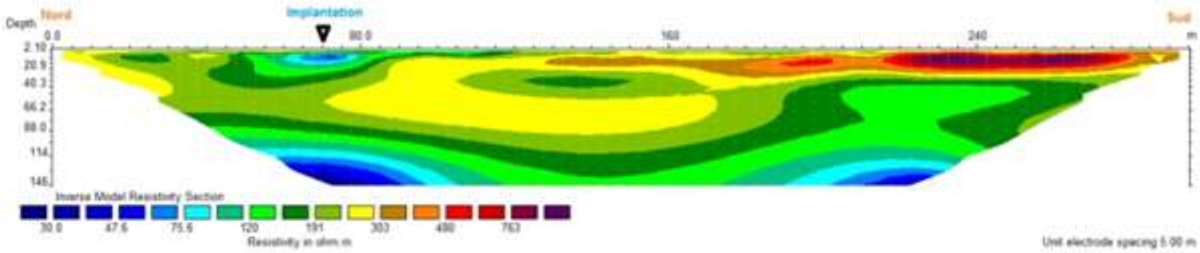

Fig -11: Geo-electric section of profile No.2 of PP type

3.2.3 Profile No.3, ERTNo.3

Profile No.3 (ERT No.3) is spread out in an overall North-South direction (see Figure 7). Only the Wenner–Schlumberger type configuration was made on this profile. The geoelectric section obtained still highlighted the three formations identified for the first two profiles, but the local aquifer is located here between X=155m and X=180m, it is 8m deep with a very low power (cf. Figure 12).

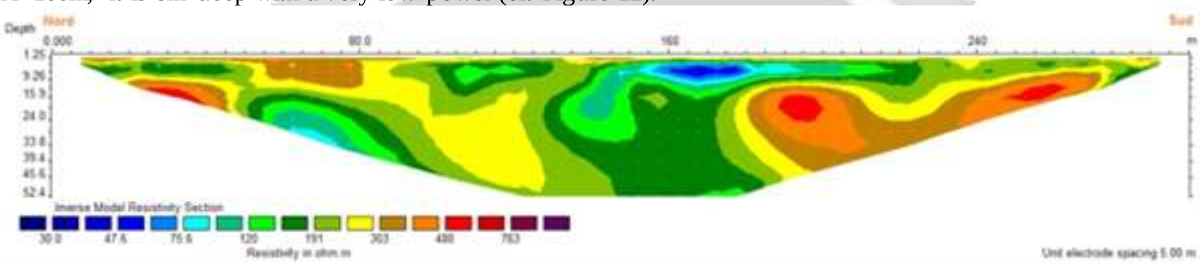

Fig -12: Geo-electric section of profile No.3 of WS type

3.2.4 Profile No.4, ERT No.4

Profile No.4 (ERT No.4) is spread out in a generally north-south direction and located to the west of the sector (see Figure 7). Both types of configurations have been made on this profile. The Wenner – Schlumberger configuration geoelectric section obtained on this profile shows the same formations encountered as that of the first three profiles (see Figure 13). The aquifer formation encountered on this profile is very limited in lateral extension and depth; it is practically unusable.

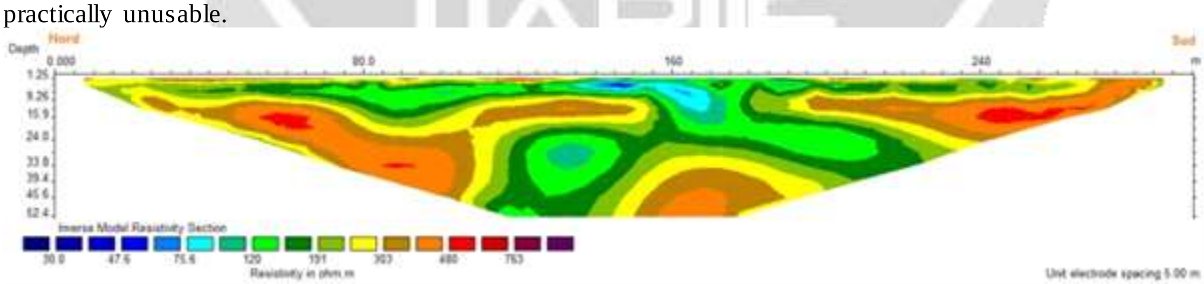

Fig -13: Geo-electric section of profile No.4 of WS type

The Pole-Pole configuration geoelectric section (see Figure 14) shows the deep aquifer. Although it is located less deep (90m), given that its resistivity value is very low (20Ωm), the water quality remains very salty. This section also confirms that the first layer is insignificant.

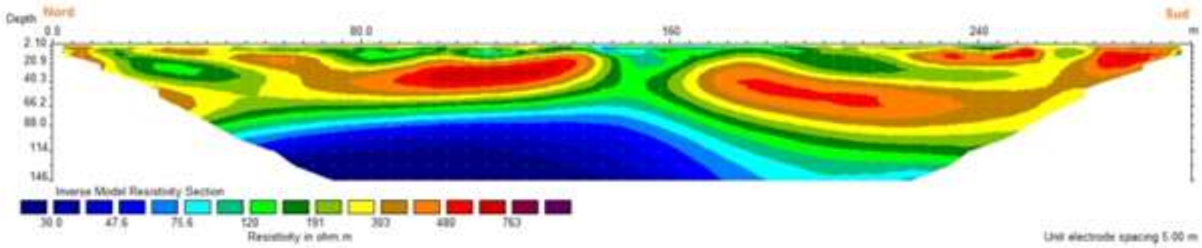

Fig -14: Geo-electric section of profile No.4 of type PP

The geophysical prospection supported by the hydrogeological investigation allowed us to know the hydrogeological situation prevails inside the Fokontany Tsirangoty. Two types of aquifer have been identified; a first superficial one is local and probably seasonal, but with an acceptable quality, whilst the second aquifer is deep with remarkable extension but of poor quality (even salty brackish water). It is preferable to place the collection site in the area where the two layers have been encountered at the same time. The abscissa point X=70m of profile n°2 (ERT2) responds well to this criterion (Cf. Figure 10).

4. CONCLUSIONS

The geological and hydrogeological situations showed the existence of aquifers in the study area, exactly inside the prospected area. Classic methods based on photo-interpretation, geophysical prospecting and hydrogeological investigation were adopted to characterize the hydrogeological structure of the studied area. Photo-interpretation allowed for delimitation of the different morphological entities existing on and around the study area. The low ground between two ridge lines which is located north of the village of Tsirangoty constitutes the preferential direction surface water during the rainy season; this is the area where the surface aquifer is likely to be found. Hence the geophysical work was done in this area. The four geophysical profiles spread out inside the study area showed the succession of geoelectrical layers present in the subsoil. Sections showed the presence of:

- superficial aquifer; less than 20m deep with a very limited and even seasonal water capacity (water height)power;
- deep aquifer located in the clayey sand formation at a depth of 120m. This is thick but of poor quality.

Hydrogeological documents have confirmed the presence of these two aquifers; superficial and deep. The surface layer is quite good quality and it is much less loaded with free ions, in other words, less salty. The deep aquifer exploited on the wells around Ambovombe has much higher electrical conductivity. We therefore recommend drilling a borehole for water exploitation in the place determined by the geographical coordinates, X= 609464m and Y= 7209295m. We recommend capturing any inflow of water at the level of the surface aquifer and the deep aquifer; the depth of the structure is 145m in order to have a sufficient flow. We also recommend setting up a water treatment system to reduce electrical conductivity and make it drinkable. The reverse osmosis filter is an example of a filter recognized today.

5. ACKNOWLEDGEMENT

We would like to thank "Ny Tanintsika-Feedback Madagascar" and their financial partners for giving us all the financial means necessary to carry out this hydro-geophysical study work. Ny Tanintsika is a Malagasy association created in 2002 with the support of "Feedback Madagascar" (a Scottish charity under register number 023568, which has been working in Madagascar since 1995). Ny Tanintsika-Feedback Madagascar contributes to reducing poverty and improving the sustainable management of natural resources through capacity building, the implementation of social, economic and environmental development activities and the promotion of good governance.

6. REFERENCES

[1]. JICA. Japanese International Cooperation Agency (2006), Etude.

[2]. Nouradine et al. (2021), application de la méthode du panneau électrique pour l'identification des zones favorables en eau dans la ville de mongo et ses environs (Guera-Tchad), 12ème Colloque GEOFCAN.

[3]. CREAM (2013). Centre de Recherches, d'Études et d'appui à l'Analyse Economique à Madagascar, Monographie de la région Androy, Madagascar, 124 pages.

[4]. GARO JOELSON Sebille (2012), Approche multidisciplinaire de l'étude hydrogéologique du bassin d'Ambovombe Androy dans l'extrême sud de Madagascar, thèse de doctorat, Université d'Antananarivo.

[5]. P. Chaperron et al. (1993), fleuves et rivières de Madagascar, ORSTOM & CNRE, Paris, 499pages de l'approvisionnement en eau potable d'Ambovombe Androy. Madagascar : Rapport principal, 178pages.

[6]. Upton K, Ó Dochartaigh BÉ, Monteleone M. et Bellwood-Howard, I. (2018). L'Atlas de l'eau souterraine en Afrique: Hydrogéologie de Madagascar. British Geological Survey. http://earthwise.bgs.ac.uk/index.php/Hydrog%C3%A9ologie_de_Madagascar [Consulté le 2021].

[7]. RAKOTONDRAINIBE J.H., (2006). Synthèse de la géologie et de l'hydrogéologie de Madagascar, 15pages.

[8]. BESAIRIE, H. Recherches géologiques à Madagascar, l'extrême sud et le sud sud-est. Service géologique A.258.

[9]. Jamaluddin and Emi Prasetyawati Umar 2018 IOP Conf. Ser.: Earth Environ. Sci.118 012006