WATER QUALITY INDEX (WQI) CALCULATION FOR THE EVALUATION OF PHYSICO-CHEMICAL QUALITY OF RAINWATER COLLECTED IN RESERVOIRS FULL OF SAND (RFS)

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ABSTRACT

The RFS system is an innovation of rainwater storing in Madagascar, it can be considered as an alternative system for supplying water to the population, especially in Southern Madagascar. The Androy and Anosy regions, repeatedly encounter periods of severe drought, the precipitation as well as infiltration are low while evapotranspiration is high. Not only the water supply for the population of these areas still remains a major challenge but the concern of water quality is another problem too, is why we have highlighted from this study examines the physico-chemical quality of this recovered rainwater from the calculation of its water quality indices (WQI) according to their storage.Indeed the WQI is a numerical expression used to assess the overall water quality from a large amount of data and it is easily understood by managers and decision makers. In this study, the WQI has nine physicochemical parameters namely: pH, conductivity, turbidity, calcium Ca^{2+}, sulfate SO_4^-, nitrate NO_3^-, Chloride Cl^-, and magnesium Mg^{2+} which are used to estimate the overall quality of the rainwater collected in the RFS system compared to the rainwater collected in different storage facilities. Fourteen (14) water samples are taken, including three samples from four sites where stagnant water is found in southern Madagascar, three water samples traditionally treated with rohondroho (Alluaudia dumosa) *and kibahy* (Terminalia monoceros) *plants, a treatment method used by the population in southern Madagascar to treat water for human consumption, four samples of rainwater stored in different types of reservoirs and three samples taken from the RFS in Masindray and Ambohidratrimo. The WQI during this study has showed a differentiation in the quality of the water according to the* *types of storage of the collected rainwater. For stagnant rainwater, the level of deterioration of water quality is significant depending on its lifespan. The treatment of water by plants only improves its physical quality, more precisely its turbidity, but increases the quantity of ions dissolved in the water. Furthermore, the quality of the water recovered in a RFS system show a good quality as far as physicochemical matter is concerned.*

Keyword : - *Rainwater, Water Quality physical chemistry, WQI (Water Quality Index), Storage, Madagascar*

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1. INTRODUCTION

Water is a natural resource essential for life in any ecosystem [26]. Maintaining its quality is a major concern for a society which has to meet increasingly important water needs [8]. According to the definition given by the guidelines of the World Health Organization (WHO), "safe drinking water does not present any significant risk to the health of a person who would consume it throughout his life, taking into account the possible variations in sensitivity between the different steps of life. "Access to drinkable water is still a major problem in developing countries such as Madagascar and other African countries. Indeed, in 2010, 783 million people did not have access to drinkable water from improved sources [32]. However, the United Nations report (2012) mentions that infectious diseases caused by microorganisms such as pneumonia and diarrhea are still one of the main causes of death over the world today. Moreover, by the end of 2000, diarrhea alone killed about five million people around the world [13] among them, 3.3 million were children under five. . Indeed, Madagascar cannot escape from these problems. The investigation on the analysis of the water consumed in Madagascar, especially in the southern zone of Madagascar, shows several forms of contamination. The disparities in its drinking water supplies persist between the two areas of residence: rural and urban, the rural one still being, in this field, disadvantaged[21]. Thus the women and children of the villages seek practical and economical solutions in order to obtain water; therefore they resort to ponds or natural impluvium known as SIHANAKE, some stagnant water next to their home, and then the whole family uses them without worrying about its effects on their health as it is cheap. As far as a public health is concerned, the consequences of unsafe drinking water are catastrophic. The symptoms of infection caused by bacteria, viruses and parasites are mainly transmitted through contaminated water with feces.

The RFS system, a buried tank full of sand [Malagasy patent filed in 2012], is a rainwater harvesting technique that allows rainwater to be stored for a certain time. A kind of water catchment infrastructure that can be installed during the rainy season to enable quick access to water, avoiding long journeys, for a significant period of the year. Collected water can be a primary source of water supply with various uses: for drinking, irrigation and watering livestock throughout the year. This type of infrastructure can be a solution for the population in the South, in fact, these regions do not have access to the distribution opportunity and where other sources of water supply are not accessible and / or too expensive for population. The collected rainwater is used as a back-up reserve to preserve conventional water sources, in other words to reduce the pressure on other resources, especially during the dry season.

Providing water is one thing, but providing drinking water is another one [24]. It is on this concept that this study has defined as purpose of highlighting the quality of the water recovered in the RFS system using the method of calculating and comparing the water quality index. This research tries to verify the hypothesis that rainwater is naturally of good quality, however affect its quality are not only the nature of the reservoirs that contain it but the path of runoff to storage. The results of this research are proposed for serving as a basis for reflection and decision support for the sustainable management of natural resources such as rainwater, for the benefit of the development of the concerned region.

2. METHODOLOGY

2.1 Study zone:

The study areas are located in the Androy regions in the South and Analamanga in the high land of Madagascar.
The Region of Androy is geographically located in the extreme South of Madagascar. It lays in the territory included between the rivers of Mandrare in the East and Menarandra in the West. It has an area of 19,540 km2. It is limited to the North by the mountainous foothills of the Southern Bara Highlands and to the south by the Indian Ocean and the Mozambique Channel. Ad-ministratively, the Androy region has four (04) Districts namely: Ambovombe-Androy, Bekily, Beloha-Androy and Tsihombe. It is limited to the East and North by the Anosy region with the Districts of Amboasary Atsimo and Betroka respectively, to the West by the Atsimo-Andrefana region with the Ampanihy district. The Androy Region is classified among the semi-arid to arid regions of Madagascar, with an average precipitation of 400 mm of rain poorly distributed throughout the year. However, there is a significant decrease in the precipitation value from the northern zone towards the extreme South of the littoral zone. The annual average temperature is 28 ° C [23] . The hot season is between October and April with a monthly average of 24 ° C and a maximum in January. The cold season lasts from May to September with a minimum of 19 ° C in June and July. We chose the study sites where there are both ponds or Sihanake during the rainy seasons and also the use of reservoirs to store rainwater of different types such as concrete tanks with or not covers as well as concrete tanks covered with plastics and plastic tanks.

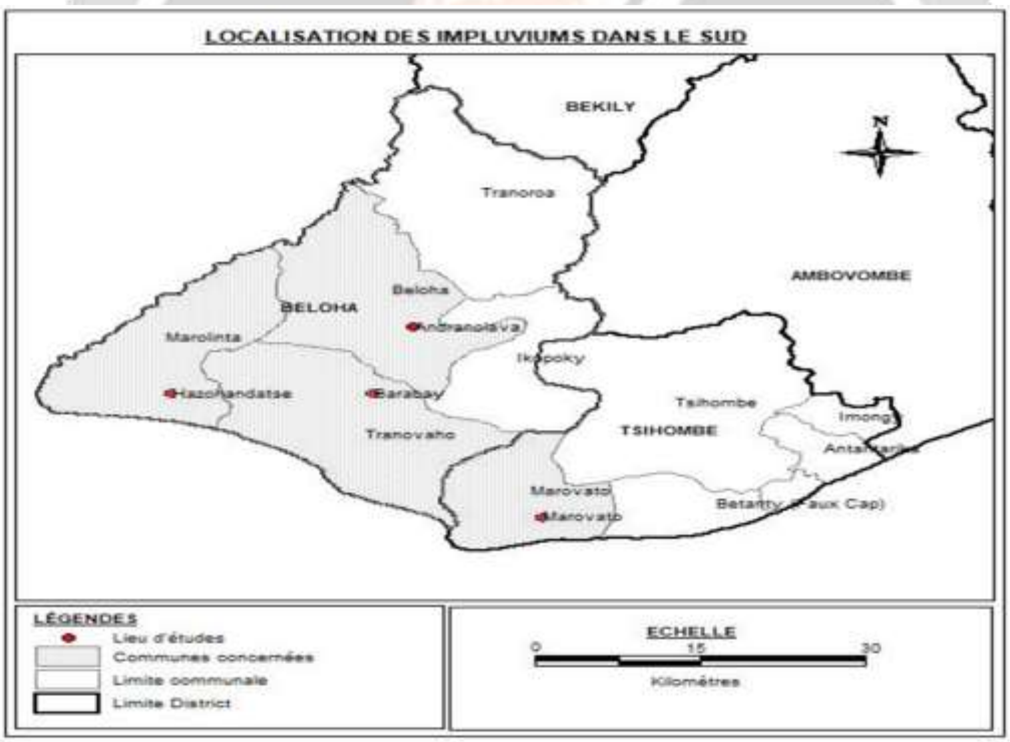

Fig1 : study localisation in the Southern of Madagascar

Masindray and Ambohidratrimo are located in the Analamanga region. The Analamanga region is located in the Precambrian crystalline basement of the central highlands of Madagascar. It is a gneissic-granitic basement consisting of Finite-Archaean and Neoproterozoic gneisses and granitoids. The basement is deeply altered and eroded, that leads to the formation of thick red lateritic soils covering the plains, dark brown soils laid on volcanic rocks or grey alluvial soils in the valleys [17]. The central highlands of Madagascar, where the study areas are located, are characterized by a humid intertropical climate marked by two very distinct seasons: wet season and dry season. The rainy season extends from November to April (hot summer) and the dry season from May to October. The average temperatures vary from 16 to 20 ° C [31]. The annual precipitations vary between 1200 and 1400mm [7]. Heavy rains occur during the rainy season, mainly between December and March.

Fig2: study localisation in the Analamanga region of Madagascar

2.2 Sampling

The data used in the context of this study include data relating to the physico-chemical analyzes of the collected rainwater. Fourteen (14) water samples are taken, including three samples from stagnant water located in the south of Madagascar, three water samples traditionally treated with rohondroho (Alluaudia dumosa) and kibahy (Terminalia monoceros) plants in a treatment method popular with the population south of Madagascar to treat water for human consumption, four samples of rainwater stored in different types of reservoirs and three samples taken from the RFS in Masindray and Ambohidratrimo. The evaluation and visualization of the results were carried out using Excel 2010 software.

2.3 Analysis technique

The water quality parameters measured in the field were temperature by a thermometer; the pH meter (ECOscan pH5) to measure the pH; the turbidimeter (hannah) to determine the turbidity; conductivity meter for measuring conductivity; and at the laboratory the determination of the contents of chemical elements such as nitrate (NO_3^-), nitrite (NO_2^-), ammonium (NH_4^+), sodium (Na^+), as well as the analysis of potassium (K^+), magnesium (Mg^{2+}) cations , calcium (Ca^{2+}), chloride (Cl^-) has been made by the technique of UV spectrometry and titrometry.All the water samples were successively analyzed three times within a short interval by the same person, and by the same instrument on the same day. The precision of the analytical results varies within 5%, the results are taken on average.

Table1:Table of major and minor ions minimum detection limit [37]

Chemical species	Minimum detection limit ($mg.l^{-1}$)
Ca^{2+}	0.14
Mg^{2+}	0.19
K^+	0.05
Na^+	0.25
NH_4	0.15
CL^-	0.16
SO_4	0.25
NO_3	0.13
Silice	0.45

3.Water quality index (WQI)

The Water Quality Index (WQI) is a simple method used as part of the analysis of general water quality by the means of a group of parameters reducing large amounts of information to a single number, generally with no dimension, in a simple and reproducible way [1]. This method has initially been proposed by Horton (1965) and Brown et al. (1970) [14] [3]. To calculate this index, Horton (1965) [14] proposed the first formula which takes into account all the parameters necessary to determine the quality of surface water and which reflects the composite influence of various important parameters for the assessment and management of the water quality [19][27]. This index has been used for the first time to highlight the physico-chemical changes likely to occur during the year and their impact on the quality of the supply water [15] [16].

The WQI is determined by comparing nine (9) water quality parameters measured in this study, namely pH, the electrical conductivity, turbidity, calcium, magnesium, sodium, chlorure, sulfate and nitrate. The WQI is calculated by using the weighted arithmetic index method [5]. This method consists of classifying water quality according to the degree of purity usi by using the most commonly measured water quality variables. This is the method most used by researchers for the calculation of the WQI. Ghosh et al. (2013) [11] have used the weighted arithmetic index method for the study of groundwater and pond water quality in Sirsakala village, while Kumari and Rani (2014) used it in the groundwater quality assessment in Smalkhan, Haryana, India. The weighting reflects the relative importance of each variable to the overall assessment of water quality. It depends on the allowable value of each variable stipulated in the water quality standards [18].

The calculation of the WQI is done in three steps, the first of which amounts to determine the quality or the sub-index (qi) corresponding to the i^{th} parameter of the water. This is a number that reflects the relative value of this parameter in a situation where the water is polluted given the concentration of this parameter compared to its allowable standard value. q_i is calculated using the following expression:

$$qi = 100\ [(V_i - V_{id})/(S_i - V_{id})]$$

With

V_i is the measured value of the i^{th} parameter at a given sampling point

S_i is the acceptable value of the i^{th} parameter;

V_{id} is the ideal value of the i^{th} parameter in pure water; it is equal to zero for all water parameters, except fluoride, dissolved oxygen and ph which are respectively 1.0mg / l; 14.6mg / l and 7.

The weighting (Wi) of the various water quality parameters is inversely proportional to the recommended standards for the corresponding parameters.

$$Wi = K / Si$$

With

Wi is the weight of the i^{th}parameter;

S_i is the acceptable value of the i^{th} parameter;

K is a constant of proportionality given by the relation [Kalavathy et al., 2011]

$$K = 1 / [1 / S1 + 1 / S2 + \ldots + 1 / Sn]$$

The IQE is determined from the relationship

$$IQE = \sum_{i=1}^{n} qi\,Wi / \sum_{i=1}^{n} Wi$$

The acceptable limit values used are taken from the Malagasy drinking standards [12] and the values recommended by the WHO[33]. They are given in Table 3 with the weightings of each parameter considered in the calculation of the WQI.

Five quality classes can be identified according to the values of the IQE water quality index.

Table 2 : WQI Classification value [5] [6] [2]

Water quality assessment grid	
0 - 25	Excellent quality water
26 - 50	Good quality water
51 - 75	Low quality water
76 - 100	Very low quality water
More than 100	Not-potable water

4. RESULTS

To calculate the IQE index and to evaluate the water quality, the relative weight (Wi) of each physicochemical parameter and the proportionality constant k are calculated first of all using the maximum values of the Malagasy potability .

Table 3: calculation of the relative weight (Wi)standard of the studied Physico-chemical parameters

	Unity	Malagasy Standard	Si	1/Si	Wi
Ph		6,5-9	9	0,111111	0,04699248
Turbidity	NTU	5	5	0,200000	0,08458647
conductivity	µS/cm	3000	3000	0,000333	0,00014098
calcium	mg/l	200	200	0,005000	0,00211466
magnésium	mg/l	50	50	0,020000	0,00845865
ammonium	mg/l	0,5	0,5	2,000000	0,84586466
chlorure	mg/l	250	250	0,004000	0,00169173
sulfate	mg/l	250	250	0,004000	0,00169173
nitrate	mg/l	50	50	0,020000	0,00845865
			∑1/Si	2,364444	
			k	0,422932	

The table (4) summarizes the results obtained during the analyzes of the physico-chemical parameters of the water sampled at the study sites. Thus the sampling sites are designated as follows:

A = initial water sihanaka Barabahy point 1
A1 = water treated with kibahy point 1
I1 = water from the roof of point 1 stored in a covered concrete impluvium
A2 = water treated with rohondroho point 1

B = initial water point 2 Hazohandatse
B1 = water treated with kibahy and rohondroho point2
I2 = water from the small pond stored in a concrete impluvium covered with tarpaulin at point 2
D = initial water point 3 Andranolava
D1 = water treated with kibahy point 3
I2 = rainwater collected from a roof stored in a concrete impluvium
E = water from a vast Sihanake of Tsihombe point 4
M1 = rainwater collected in a RFS Masindray after 15 days of the last rain
M2 = rainwater collected in a RFS Masindray in the dry season
T1 = rainwater collected in a RFS Ambohidratrimo

Table 4: analysis result

Milieu	Ph	conductivity	calcium	magnésium	ammonium	chlorure	sulfate	nitrate	turbidity
A	10,31	289	7,3	10,2	0,2	30,4	77,53	4,62	38,6
B	10,07	1522	8,1	11,05	0,19	35,5	16,18	3,6	44,4
D	8,11	65,9	7,34	1,96	0,22	0,16	66,32	24,06	39,3
E	8,01	85,2	11,27	10,2	0,18	14,2	5,22	18,54	42,1
A1	12,38	1316	12,6	15,6	0,36	85,2	77,53	0,32	8,47
A2	13,02	1518	11,5	17,3	0,358	56,8	121,13	0,38	7,2
B1	13,04	1731	12,65	2,51	0,351	113,6	101,62	1,08	7,84
D1	12,76	1691	18,5	2,5	0,356	35,5	3,41	4,32	7,1
I1	7,54	190,3	6,32	1,19	0,314	7,1	10,73	0,26	7,67
I2	7,98	170,5	10,65	1,19	0,271	6,4	6,87	0,26	8,9
I3	8,01	214,4	7,4	4,93	0,262	5,08	7,25	0,26	7,4
M1	6,73	56,9	5,2	6,075	0,15	3,55	0,92	0,17	6,7
M2	6,68	45,4	1,6	0,972	0,15	4,26	0,8	0,23	6,9
T1	6,72	52	6,08	2,3	0,16	0,91	0,25	0,22	6,4

The correlation matrix of the physico-chemical parameters of rainwater is presented in the following table.

Table5: correlation matrix

	Ph	*conductivity*	*calcium*	*magnésium*	*ammonium*	*chlorure*	*sulfate*	*nitrate*	*turbidity*
Ph	1								
conductivity	0,91780034	1							
calcium	0,77936397	0,709676385	1						
magnésium	0,5104082	0,419346768	0,25025546	1					
ammonium	0,78373508	0,693745005	0,73410699	0,20968903	1				
chlorure	0,866019	0,823304468	0,5675369	0,432271	0,66958132	1			
sulfate	0,71580606	0,513098108	0,29207027	0,53027093	0,53367064	0,7234305	1		
nitrate	-0,12872169	-0,241419355	0,07962967	-0,02667591	-0,24000925	-0,23279868	0,05810265	1	
turbidity	-0,0537637	-0,098629099	-0,06114069	0,26181255	-0,40963358	-0,13501492	0,07118318	0,72617465	1

After calculating the overall WQI quality index using the results of physico-chemical analyzes and the standard values of the Malagasy standard, the water quality class is determined for the fourteen samples relating to the study sites. Thus, four quality classes: excellent, good, bad and not drinkable are identified (see Table 3).

Table 6 : Classification of water samples

Site		WQI	Class
STAGNANT WATER	A	107,260318	NON POTABLE
	B	114,83501	NON POTABLE
	D	106,809854	NON POTABLE
	E	104,564289	NON POTABLE
TREAT WATER	A1	88,3273321	very low quality
	A2	87,3925192	very low quality
	B1	87,1361612	very low quality
	D1	86,0119081	very low quality
RAINWATER STORED	I1	67,4174168	low quality
	I2	63,2582941	low quality
	I3	59,3297874	low quality
RAINWATER STORED AT RFS	M1	37,4597054	good quality
	M2	37,8271311	good quality
	T1	38,6036807	good quality

5. DISCUSSION

5.1 PH

The pH or potential of hydrogen determines the concentration of H^+ ion in water. This parameter conditions a large number of physico-chemical balances. The pH values of the sampled water are between 6.72 and 13.04, thus for the case of concrete impluviums, the pH varies from 7.54 to 8.01 and from 6.68 to 6.73 for the RFS system (see table). By comparing them with the WHO standard (6.5-8.5), the pH of the water coming from the rainwater harvesting systems meet the WHO recommendation for the RFS system (mean pH = 6.84) and concrete tanks (average pH = 7.84). On the other hand, the water coming from the so-called SIHANAKE stagnant water in the South region does not correspond to the WHO standard and is slightly basic with an average pH of 9.13; water traditionally treated by plants is found to be largely basic with an average pH of 12.8. Another study states that the pH of rainwater collected downstream from roofs often remains acidic [33] [34] [35] . But the high pH values after runoff have been explained by the existence of calcium and magnesium ions in atmospheric deposits leached by rainwater[20].

Milieu	Ph
A	10,31
B	10,07
D	8,11
E	8,01
A1	12,38
A2	13,02
B1	13,04
D1	12,76
I1	7,54
I2	7,98
I3	8,01
M1	6,73
M2	6,68
T1	6,72

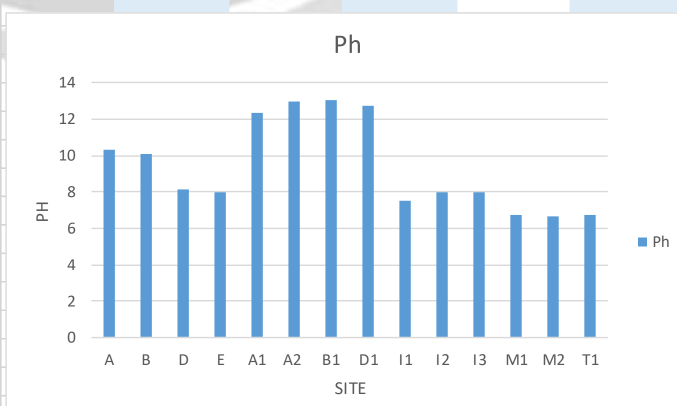

Chart 1: pH rate

5.2Conductivity

Conductivity enables to determine the ability of water to conduct electricity. Indeed, it allows to judge the quantity of salts dissolved in water [25] and to verify the existence of pollution in the water [10]. It can be seen that the conductivity values are all within the norm (less than 2000µS / cm). Thus the conductivity of the water of the impluviums (average = 148.06µS / cm) is better than the water of the sihanake in terms of quality (average = 490.52µS / cm) and it is even more important for the water treated traditionally (1214µS / cm This phenomenon of water conductivity differentiation is explained by certain studies [29] [33] [28] focusing on the cations and anions commonly present in water which has been collected in downstream of roofs: calcium, magnesium, sodium, potassium, ammonium, phosphorus, chloride, sulfate, nitrate and nitrite. Overall, the roof water is weakly charged with ions and the variation concentrations depends on meteorological parameters as well as on the nature of the collection surface. In a study carried out in Greece on the quality of water from roofs, the predominant cations were Ca2 + and Mg2 +, they came mainly from erosion of rocks and construction materials used for roofs. Regarding the anions, the NO3- and SO42- ions showed the highest concentrations [20].

Site	conductivity
A	289
B	1522
D	65,9
E	85,2
A1	1316
A2	1518
B1	1731
D1	1691
I1	190,3
I2	170,5
I3	214,4
M1	56,9
M2	45,4
T1	52

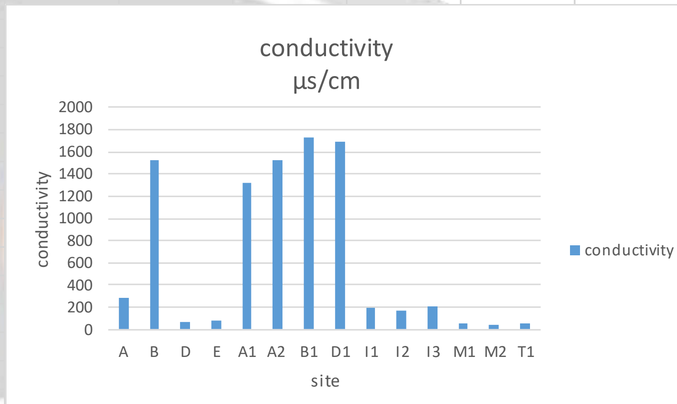

Chart 2: conductivity measurement

5.3Sulphate

It is a major building block of the compounds dissolved in water. Their discharge into water is mainly through atmospheric deposition and industrial effluents. Sulphate characterizes the SO_4^- ion concentration. On average, the sulphate contents of the water coming from the rainwater collection systems recorded during the analyzes of the water samples are lower than the levels suggested by the WHO standard (50 mgl^{-1}), for impluviums in concrete with an average 28.72 mgl^{-1} and for the RFS with an average 0.88 mgl^{-1}. Traditional treatments increase the levels of sulphates introduced into the water; indeed the sulphate concentrations in stagnant water are on average 42.69 mgl^{-1}, and 59.22 mgl^{-1} after treatment with plants. The low sulphate values contained in the RFS system are in agreement with the study carried out by[20] stipulating that: the ions NO_3^- and SO_4^{2-} come from the combustion of fossil resources. Thus, higher nitrate and sulphate values are reported in areas with heavy traffic and in very crowed populated residential areas. That is to say, that the RFS system reduces the recovery water to be exempt from fossil resources.

Site	sulphate
A	77,53
B	16,18
D	66,32
E	5,22
A1	77,53
A2	121,13
B1	101,62
D1	3,41
I1	10,73
I2	6,87
I3	7,25
M1	0,92
M2	0,8
T1	0,25

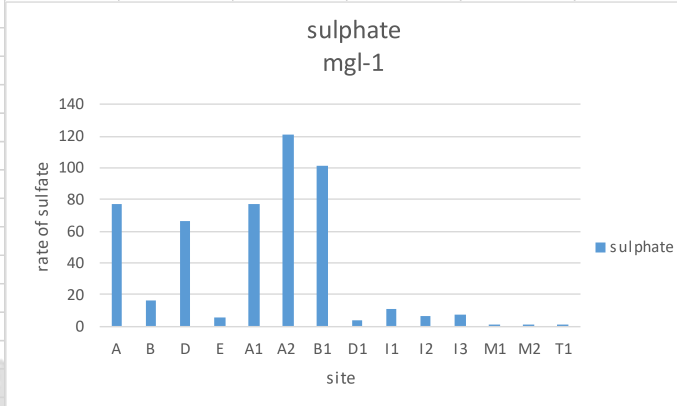

Chart 3: rate of sulphate

5.4 Nitrates

Nitrates are the final stage in the oxidation of nitrogen and represent the form of nitrogen with the highest degree of oxidation in water. The concentrations of nitrate ions NO_3^- are largely linked to human activities. According to these results, it can be found that the nitrate levels in the waters of the impluviums are low and are in accordance with the standard imposed by the WHO ($50mgl^{-1}$). As the study by Melidis et al. (2007) [20] indicates, the ions NO_3^- and SO_4^{2-} come from the combustion of fossil resources. Therefore, higher nitrate and sulphate values are reported in areas with heavy traffic and in heavily populated residential areas. These low levels show that the waters from the impluviums are almost protected from organic matter, which cause source of pollution.

Site	nitrate
A	4,62
B	3,6
D	24,06
E	18,54
A1	0,32
A2	0,38
B1	1,08
D1	4,32
I1	0,26
I2	0,26
I3	0,26
M1	0,17
M2	0,23
T1	0,22

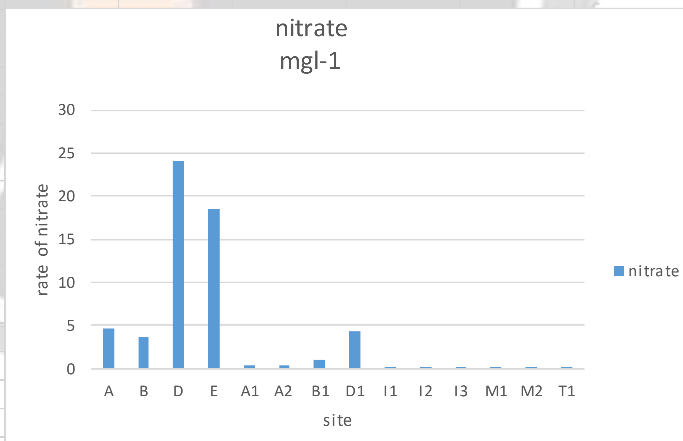

Chart 4: rate of nitrate

5.5 water quality index (WQI)

Referring to the classification of water quality to the water quality index; the water collected by the RFS system is of excellent quality in terms of physico-chemical quality compared to other rainwater storage systems. Stagnant rainwater only provides water that is not drinkable either. Depending on the type of storage, which is a determining factor on the quality of the water, the covered impluviums are more recommended than uncovered and concrete impluviums**.**

SITE	WQI
A	107,260318
B	114,83501
D	106,809854
E	104,564289
A1	88,3273321
A2	87,3925192
B1	87,1361612
D1	86,0119081
I1	67,4174168
I2	63,2582941
I3	59,3297874
M1	37,4597054
M2	37,8271311
T1	38,6036807

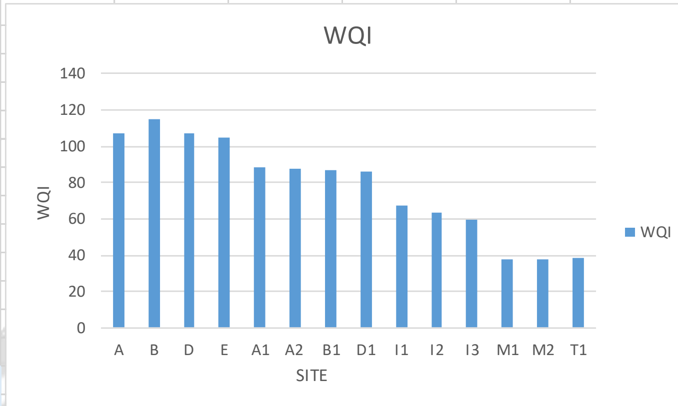

Chart5 : WQI

6. CONCLUSION:

This study has focused on the measurement of the overall quality of rainwater collected in the South part of Madagascar and on the Highlands, of the collected water treated traditionally and of the water collected by the RFS system. The WQI Global Water Quality Index was a very useful tool in making the right decision and estimating comparatively the quality of the collected rainwater. During this study the WQI has shown a differentiation in the quality of the water according to the types of storage of the collected rainwater. For stagnant rainwater, the level of deterioration in water quality becomes significant depending on the weather of the first rain. The quality of water treated by plants only improves its physical quality, more precisely its turbidity, but increases the quantity of ions dissolved in the water. In addition, the quality of the water recovered in a RFS system is of average quality from a physicochemical view point. This still requires protective measures for these systems during its implementation. As a result, the adaptation of a RFS system is necessary to make it an alternative source of water supply in the Southern part of Madagascar.

In perspective, the evaluation of the quality of the recovered rainwater could integrate other additional parameters such as microbiological parameters in addition to physicochemical and heavy metal parameters in the WQI calculations and in the monitoring of water quality.

REFERENCES:

[1] **Abbasi, T., & Abbasi, S. A**. (2012). Water quality indices. 1st ed.,Elsevier, Amsterdam, The Netherlads, (384p), Paperback ISBN: 9780444638366.

[2] **Aher, D. N., Kele, V. D., Malwade, K. D., & Shelke, M. D.** (2016).Lake Water Quality Indexing To Identify Suitable Sites For Household Utility: A Case Study Jambhulwadi Lake; Pune (MS). *Int. Journal of Engineering Research and Applications*, 6(5), (pp.16-21).

[3] **Brown, R. M., McClelland, N. I., Deininger, R. A.,** & O'Connor, M. F. (1972). A water quality index-crashing the psychological barrier. In Indicators of environmental quality (pp. 173-182). Springer,Boston, MA.

[4] **Brown, R. M., McClelland, N. I., Deininger, R. A., Tozer, R. G**.(1970). A Water Quality Index- Do We Dare? Water and Sewage Works, 117, (pp. 339–343). Brown et *al.* (1970)

[5] **Brown, R.M, Mc cleiland, N.J., Deiniger, R.A., O' Connor, M.F.A.,** "Water quality index –crossing the physical barrier", (Jenkis, S H ed) *Proc. Intl. Conf. on water poll. Res.*Jerusalem 1972,(6), (pp.787 – 797) ;

[6] **Chatterji, C., Raziuddin, M**. (2002). Determination of water quality index of a degraded river in Asanol Industrial area, Raniganj, Burdwan, West Bengal. *Nature, Environment and PollutionTechnology*, 1 (2) (pp. 181-189).

[7] **Davies, J.** Chapter 14 Hydrogeology, In: British Geological Survey, United States du 15/06/2004,

[8] **Foto, M. S., Zebaze, T. S. H., Nyamsi T. N. L., Ajeagah, G. A. et Njiné,T.** (2011). Évolution Spatiale de la Diversité des Peuplements de Macro invertébrés benthiques dans un cours d'eau anthropisé en milieu Tropical (Cameroun). European Journal of Scientific Research, 55(2), (pp. 291-300). (Foto et *al*., 2011)

[9]**Geological Survey and Cabinet GLW Conseil**. 2008. [En ligne]. Disponible sur www.bgs.ac.uk/sadcreports/madagascar2008davieshydrogeologymappingreportfinaldraft.pdf 08).
[10] **GHAZALI, D. & ZAID, A**. 2013. Etude de la qualité physico-chimique et bactériologique des eaux de la source Ain Salama-Jerri (région de Meknès, Maroc). *Larhyss Journal*, (12) : 25-36.
[11] **Ghosh, M. K., Ghosh, S., Tiwari, R.,** "A study of water quality index assessment of ground water and pond water in Sirsakala village of bhilai-3, Chhattisgarh, India",*International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development*, 2013, (3(5): pp. 65-76)
[12] **Gouvernement de Madagascar (GM**), "Normes de potabilité Malagasy", Décret n° 2004-635
[13] **HOEK, W., KONRADSEN, F. & JEHANGIR, W. A.** 1999. Domestic Use of IrrigationWater: Health Hazard or Opportunity? *Water Resources Development*, 15:1-2.
[14] **Horton, R. K**. (1965). An index number system for rating water quality. *Journal of Water Pollution Control Federation*, 37(3), (pp.300-306).
[15] **House, M. A**. (1990). Water quality indices as indicators of ecosystem change. *Environmental Modeling & Assessment*, 15(3), (pp. 255–263).
[16] **House, M. A., Ellis, J. B.** (1987).The development of water quality indices for operational management, *Water Science and Technology*,19(9), (pp. 145–154).
[17] **Jeffrey, D**., "Hydrogeological mapping of north-central of Madagascar using limited data". 2009. [En ligne] Disponible sur http://nora.nerc.ac.uk/id/eprint/9062.
[18] **Kalavathy, S., Rakesh Sharma, T., Sureshkumar, P.,** "Water Quality Index of River Cauvery in Tiruchirappalli district, Tamilnadu", *Arch. Environ. Sci.*, 2011,(pp. 5, 55-61)
[19] **LiouS.M**., Lo, S.L., Wang, S.H. (2004). A generalized water quality index for Taiwan, *Environmental Modeling & Assessment*, *96(1–3)*,(pp. 35–52).
[20] **Melidis P., Akratos C.S., Tsihrintzis V.A. And Trikilidou E. 2007**. Characterization of rain and roof drainage water quality in Xanthi, Greece. *Environ.Monit. Assess.* 127(1-3), (pp:15-27).
[21] **Instat Et Unicef,2019** Enquête par grappes à indicateurs multiples-MICS6 Madagascar, 2018(pp.600-623).
[22] **Nations Unies, 2012.** Objectifs du Millénaire pour le développement 2012.
[23] **Plan Régional de développement Androy** 2005
[24] **Projet de normes togolaises de qualité pour l'eau de boisson**.2015 (pp.7)
[25]**Rodier, J., Bazin, C., Broutin, J.P., Chambon, P., Champsaur, H., Rodi,L.** (1996). L'analyse de l'eau naturelle, eaux résiduaires, eau de mer, 8ème édition, Dunod, Paris, France, (1383p).
[26]**Tampo, L., Gnazou, M., Akpataku, V., Bawa, L. et Djaneyé-Boundjou, G**. (2015). Applicat ion des méthodes statistiques à l'étude hydrochimique des eaux d'un hydrosystème tropical : Cas du bassin versant de la rivière Zio (Togo). *European Scientific Journal*, 11(14), (pp. 204-225).
[27]**Tyagi, S., Sharma, B., Singh, P., Dobhal, R.,** (2013).Water quality assessment in terms of water quality index. American Journal of Water Resources, 1(3), (pp. 34–38).
[28] **Sazakli E., Alexopoulos A. And Leotsinidis M**. 2007. Rainwater harvesting,quality assessment and utilization in Kefalonia Island, Greece. *Water Res.* 41(9):(pp.2039-2047).
[29]U**ba B.N. And Aghogho O**. 2000. Rainwater quality from different roof catchments in the Port Harcourt district, rivers state, Nigeria. *J. Water Supply Res Technol. – Aqua* 49(5):(pp.281-288).
[30]**United Nations (UN), "Madagascar",** Groundwater in Eastern, Central and Southern Africa,Natural Resources/Water Series, 1989, 19, 133-149, United Nations, NewYork. UN, 1989).
[31]**WATERAID**, 2013. Partout et pour tous. Une vision pour l'accès à l'eau potable, à l'hygiène et à 'assainissement après 2015. WaterAid, Londres, Royaume-Uni.
[32]**World Health Organization (WHO),** "Guidelines for drinking-water quality", fourth edition incorporating the first addendum. Geneva. 2017.
[33]**Rossillon F., Borght P. And Orszagh J.** 2007. Survey relating to the quality of rainwter stored in cistern for domestic use in Wallonia (Belgium). *Eur. J. WaterQual.* 38(2) (pp:169-180).
[34] **Yaziz M.I., Gunting H., Sapari N. And Ghazali A.W.** 1989. Variations in rainwater quality from roof catchments. *Water Res.* 23(6):761-765.
[35] **Simmons G., Hope V., Lewis G., Whitmore J. And Gao** W. 2001. Contamination of potable roof-collected rainwater in Auckland, New Zealand. *Water Res.* 35(6):15181524.
[36] **Shrivastava & Gupta,** "Methods for the determination of limit of detection and limit of quantitation of the analytical methods", *Chronicles of Young Scientists*, 2011, 2(1), 21-25. DOI:10.4103/2229-5186.79345