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Development of a Watershed Management Plan to Protect Soil and Water Resources, Case of Imady Region Amoron'ny Mania

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Abstract

Unsustainable development has often threatened watershed ecology in many parts of the world, and population growth has played a major role in this process. Our study consists of the development of a watershed management plan. The degradation of environments by bushfire, timber exploitation, and firewood harvesting dew soil and pollutes spring water, in addition, there are also negative impacts on the physicochemical property of the soil. This research aims to put in place a watershed management plan to restore the soil and the soil pit against erosion. The development also allows for the protection of water resources and the pollution generated by this degradation. The study specifies the physical characteristics of the watershed: altitude, slope, and constant of Graveluis. We also examine the physicochemical properties of the soil: structure, texture, and pH. After the study of the soil, we also determined the measure of the flow of the source, the organoleptic analysis, and also the physicochemical and bacteriological analysis. The results of this work once made available to the authorities of the basic data could be exploited in the framework of the improvement of the quality of water intended for human consumption. To fight against water pollution, the easiest measure to apply is a large awareness campaign.

Keywords
watershed; water; soil; management plan; analysis

I. Introduction

The exploitation of forest space for the benefit of agriculture has shown this last year the current dynamics of the landscapes on a world scale. This evolution is marked in general by permanent erosion following the degradation of the environment in several countries of the world. Madagascar represents a concrete example of this phenomenon because of the continuous increase of its population and the consequences of climatic variation. These situations generally result in the disfiguration of the landscape and the dysfunction of the hydraulic system on most sites. This is the case in the Ankialo watershed. The integrated management of natural resources is progressively imposed to face this environmental concern.

In the study of this case, we propose to initiate a plan for the implementation of soil and water resources conservation. Water plays a crucial role in the economic development of a country and in the survival of natural ecosystems (Razafimandimby and Rakotonanahary Rabemananjara, 2013).

Deforestation and bushfires as well as the degradation of drainage systems are the main factors in the progressive destruction of the soil. Soil destruction results in physical and chemical deterioration, low agricultural productivity, and total environmental change. The natural resources and the environment of these affected areas can be corrected in an appreciable way by the introduction of new techniques of soil conservation. In this situation, the question is "is integrated management a solution to control the degradation of the Ankialo watershed?

The understanding of the importance of the conservation management of the soil and its ecosystem leads us to choose the subject "development of a watershed management plan to protect the soil and water resources, case of Fokontany Andraina Fototra".

The general objective of this research is to better understand the main features of the current dynamics of the landscape and to improve the knowledge of erosive phenomena, to make technical suggestions, and to stimulate the sharing of experiences in order to inform on the method of conservation of soils and natural resources.

II. Review of Literature

This study was carried out in the arrondissement of Ankialo Sud Fokontany Andraina Fototra, in the rural commune of Ambalakindresy.

2.1. Matérials

- A GPS
- A decameter
- QGIS software
- A cell phone
- A spade
- A USB key
- Containers
- A felt-tip pen, a triangle, a graduated ruler

2.2. Methods

a. Soil texture

It consists in digging a soil ditch and observing its structure and texture. Soil samples are taken from the ditches in the different parts of the basin: lower slope, mid-slope, and upper slope. The constituents of the solid fraction of the soil sample are then dissociated as much as possible by the joint action of water and agitation and by sedimentation. The respective heights of each level corresponding to sand, silt, and clay are measured to calculate the percentage of each component (Randrianasolo, 2019).

Figure 1. *Pedological ditch*

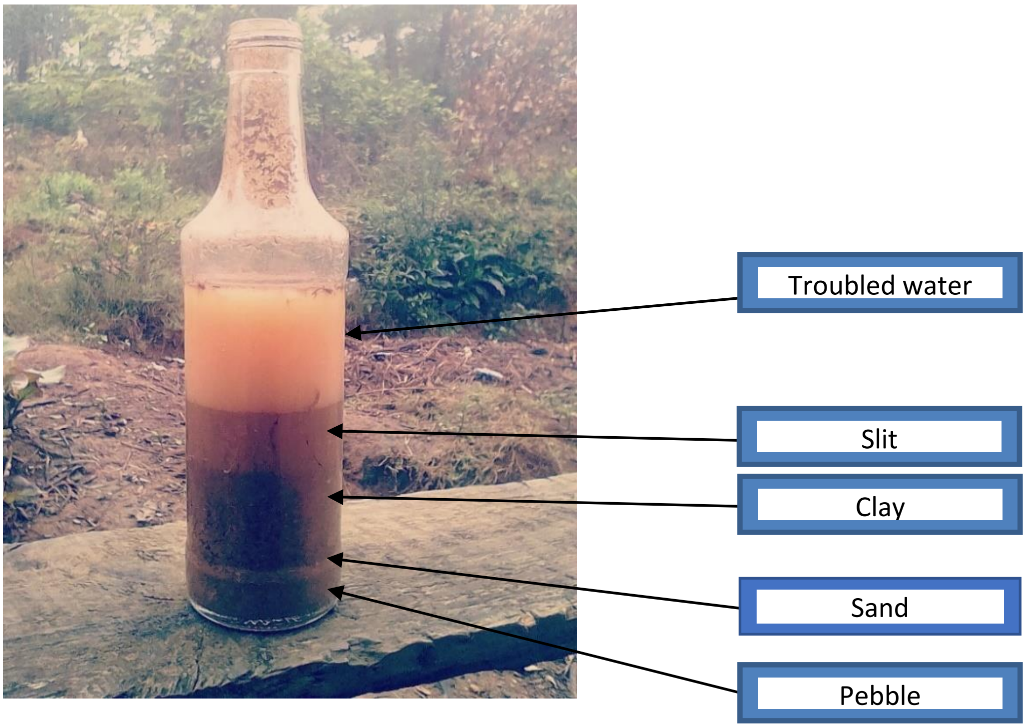


Figure 2.*Distribution of aggregates*

b. Structural Stability of a Soil

Take clods of soil and immerse them in water. Let it sit for 2 to 3 hours. The infiltration of water in the immersed clods of the earth will disperse its constituents if they are not well aggregated.

c. Flow Measurement

The measurement of flow rates makes it possible to determine the time taken to fill a bucket of a given volume in order to quantitatively characterize the water to be diagnosed. Volumetric measurements were made on the springs:

- N° 1 which is located on the lowlands of the watershed near the rice field. It is dedicated to the consumption and irrigation of rice fields. The spring originates at the bottom of the earth in the lowland,
- N° 2 which is located next to the first source. It has the same origin as the first spring. It is used for watering plants and for washing clothes.

The application of the following formula contributes to the determination of source flows (Rabarijonina, 2019).

$$\boxed{Q = \frac{V}{t}}$$

Q: flow rate of the source (L/s)
V: volume of water collected (L)
t: time taken to get the volume of water collected (s)

d. Water Quality Standards

Samples from each source are tested in the laboratory to determine their chemical composition and the possible presence of bacteria. The comparison of the values obtained with the standards determined by the WHO (Brand, 1997) allows determining the quality of the water.

e. Delimitation of the Study Area

We take the measurements of the perimeter and the surface of the site concerned to delimit the Fokontany Andraina where the watershed is located and the village concerned. The determination of the shape of the watershed which is an element influencing the shape of the histogram. The shape of the basin is known from the value of K_G called *Gravelius* compactness index, calculated by:

$$\boxed{K_G = 0{,}28\frac{P}{\sqrt{S}}}$$

K_G : *Gravelius* compactness coefficient
P : perimeter of the watershed in m
S : surface area of the watershed in m^2
If $K_G > 1$ he shape of the watershed is elongated and
If $K_G < 1$ the shape of the watershed is circular (Brand, 2001).

III. Result

3.1. Soil Texture

The direct observation of the soil ditch shows that the soil can be distinguished in two layers, the upper one of blackish color and the lower one of a reddish color. Figure 3 shows the actual situation on the ground.

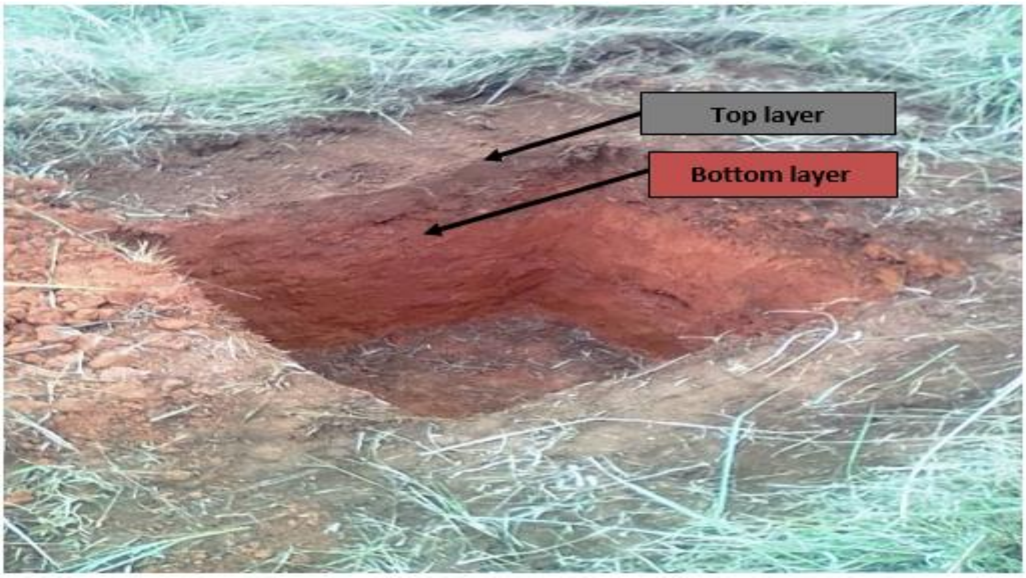
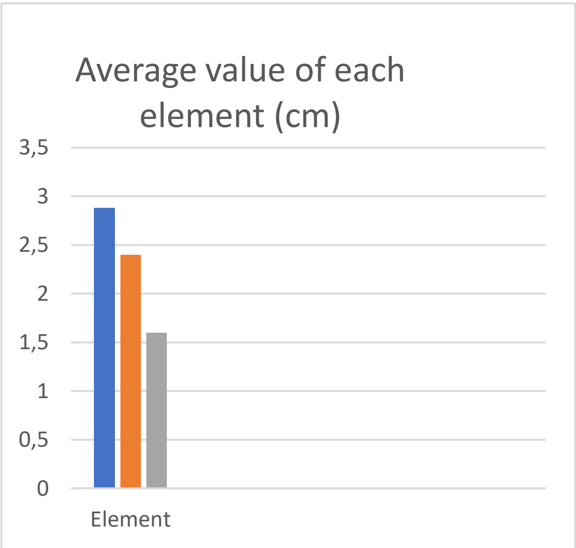
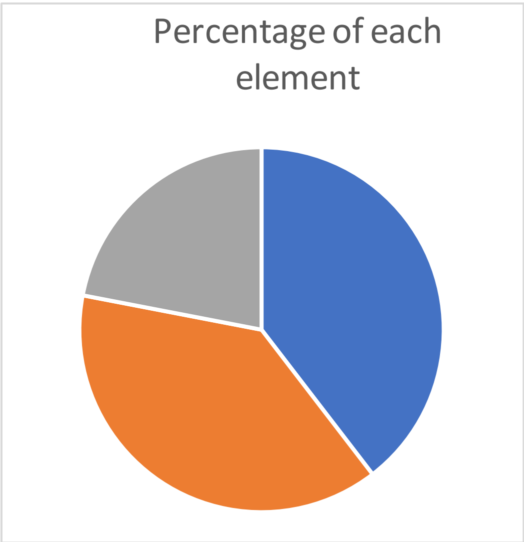


Figure 3.*The actual situation on the ground*

Here are the average values of each element in the three experiments:





Sand Clay Silt

Figure 4. *Average Value of Aggregates* ***Figure 5.*** *Percentage of Aggregates*

According to these calculation results that we have seen in the results part, the values of each constituent is respectively 36%, 20%, and 35% for sand, clay, and silt. To know the type of soil, we use the triangle with three axes to have knowledge of this phenomenon.

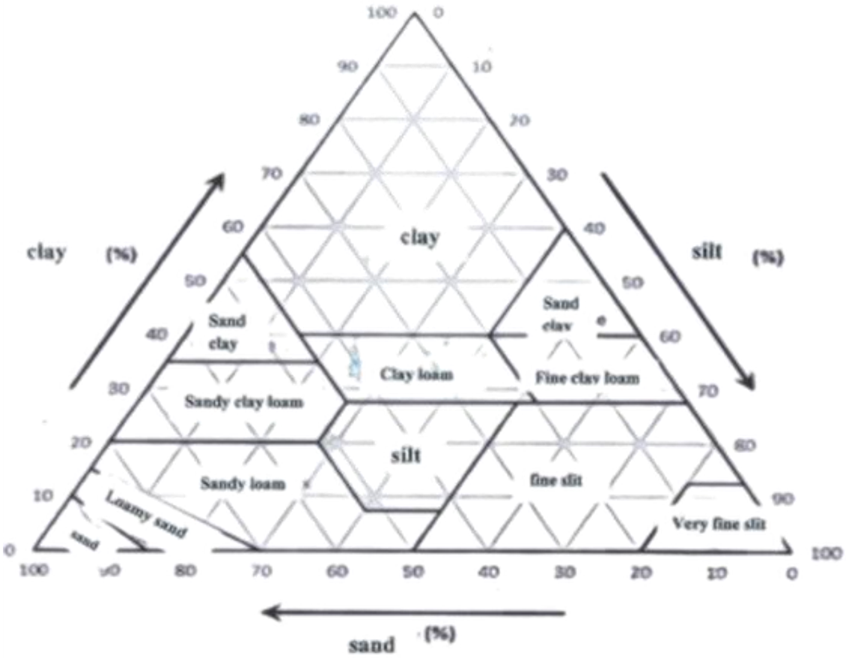
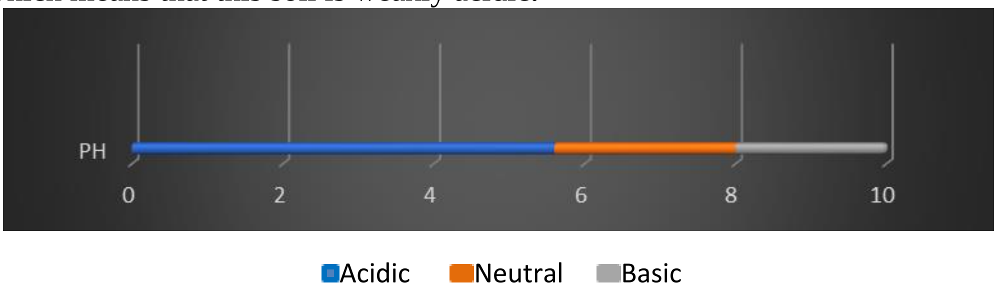


Figure 6. *Nature of the Soil Texture*

The three straight lines intersect in the silt section which means the nature of the texture is silt.

a. Soil pH

The average pH value is equal to 5.67. Using the pH definition, this value is between 4.5 and 6, which means that this soil is weakly acidic**.**



20

Figure 7.*Soil pH*

36

b. Spring Water Flow Rate

In the two following tables are the flow rates of the samples of the source N°1 and N°2.

Table 1. Flow rate of the samples of the source N° 01 measured by the volumetric method

Flow rate of the samples of the source N° 01 measured by the volumetric method			
SAMPLE	**TIME (s)**	**VOLUME(l)**	**FLOW ($l*s^{-1}$)**
01	75	15	0.20

02	73	15	0.21
03	65	15	0.23
04	64	15	0.23
Average	69.25	15	0.22

Table 2: Flow Rate of the Samples of the Source N° 02 Measured by the Volumetric Method

Flow rate of the samples of the source N° 02 measured by the volumetric method			
SAMPLE	**TIME (s)**	**VOLUME(l)**	**FLOW ($l*s^{-1}$)**
01	101	15	0.15
02	108	15	0.14
03	96	15	0.16
04	83	15	0.18
Average	99.50	15	0.16

The volume taken into account is 15 liters for all measurements. The average time obtained by averaging four tests is 69.25s for the first source, which, by applying the formula, gives a flow rate of 0.22 L. s^{-1}. For source N° 2, the average value of the flow rate obtained is 0,16 L.s^{-1}. The current capacities of the two sources are therefore respectively 19.008 m^3. d^{-1}, 13.824 m3.d^{-1}. The first source is high compared to the second.

c. Organoleptic Parameters of Water

The following table shows the organoleptic parameters of the water.

Table 3. Organoleptic Parameters of the Water

Parameters	**Nature**
State	Liquid
Color	Transparent
Odor	Odorless
Taste	Tasteless
Reaction	None
Temperature	25°C

According to this table, this water is fresh water.

d. Physicochemical and Bacteriological Analysis

The following table shows the physicochemical and bacteriological analysis.

Table 4. Physicochemical and Bacteriological Analysis

Parameters	Analysis results	
	Source N° 1	Source N° 2
pH	7.5	4.60
Nitrite content (mg/L)	0.005	2.600
Nitrate content (mg/L)	1.33	95.09
Conductivity (µS.cm^{-1})	18.7	18.7
Turbidity (NTU)	3.6	64.2
Fluoride content (mg/L)	1.2	1.25
Free chlorine content (mg/L)	0.05	0.10
Total chlorine content (mg/L)	0.05	0.10
Total coliforms (CFU)	3	10

Nine parameters were therefore determined.

3.3 Geographic parameters of the watershed

The following table shows the geographic parameters of the watershed.

Table 5. Geographic Parameters of the Watershed

Perimeter P (m)	Surface S (m^2)	Compactness K_G
504	13860	1.20

The basin is a sub-basin because its perimeter is less than 1 kilometer. The coefficient of *Gravelius* is equal to 1.20>1, which allows us to say that the shape of the basin is elongated.

a. Altitude

Here is what concerns the altitude.

Table 6. Altitude data

Type of altitude	Maximum	Minimum	Average
Measure (m)	1224	1208	1216

The maximum altitude is 1224 m and the minimum is 1208 m.

b. Average slope

Here is the average slope.

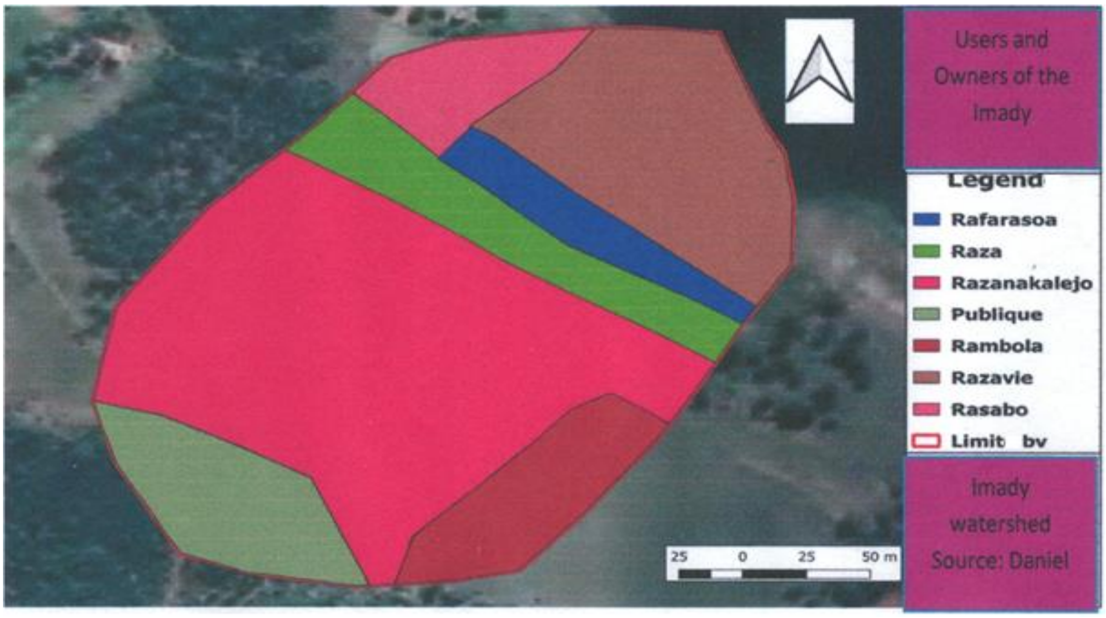
Table 7. Average slope

Max altitude (m)	Min altitude (m)	Equivalent length (m)	Average slope
1224	1208	142.40	11.24%

The average slope is therefore 11.24%.

3.4 Distribution of parcels by owners

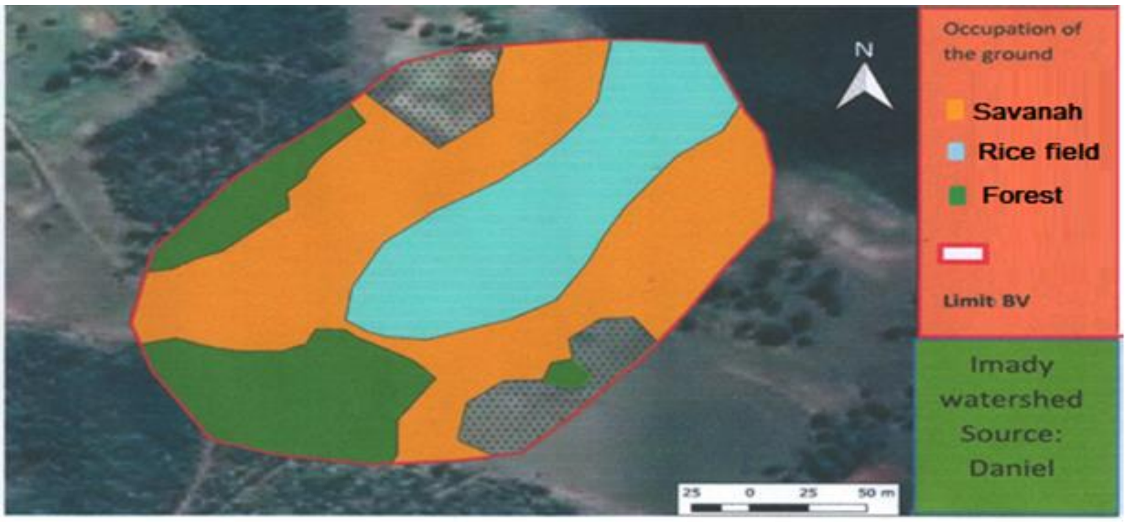
The IMADY watershed is occupied by a few individuals. The owners of this basin were known during the second field trip.



***Map 01**: Watershed Users* *Source: Daniel Raz. 2022*

3.5 Land use

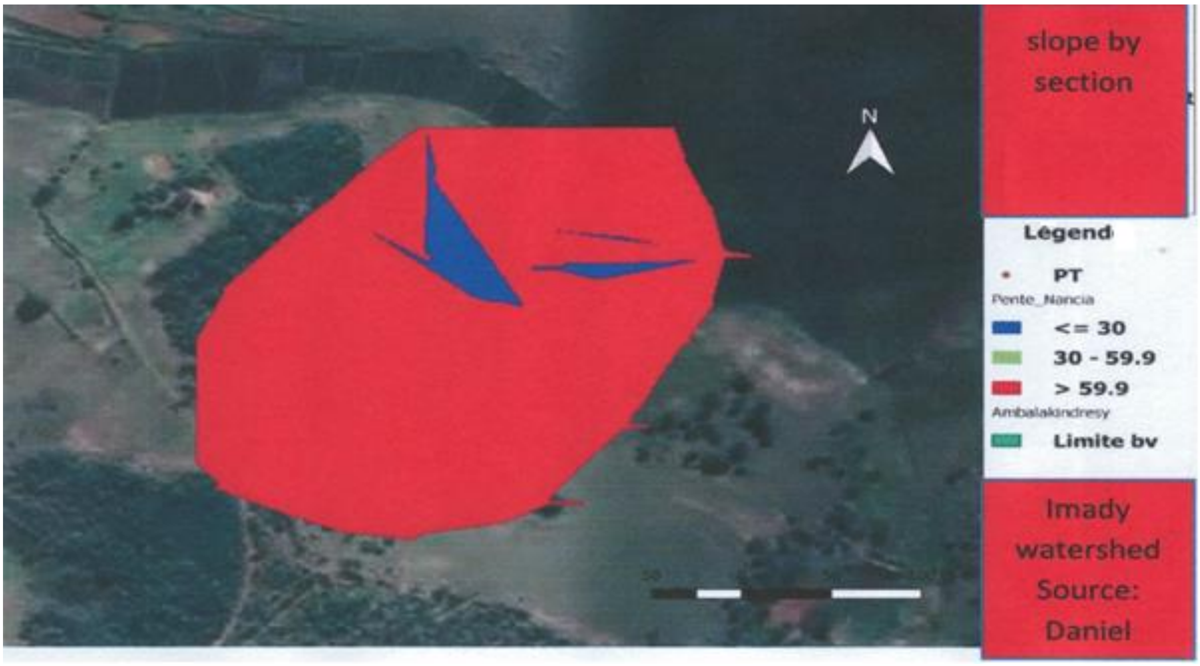
The occupation of the soil is represented in the Map N°02 mentioning the vegetable species that they contain.



***Map 02**: Land use* *Source: Daniel Raz. 2022*

3.6 Slope per section

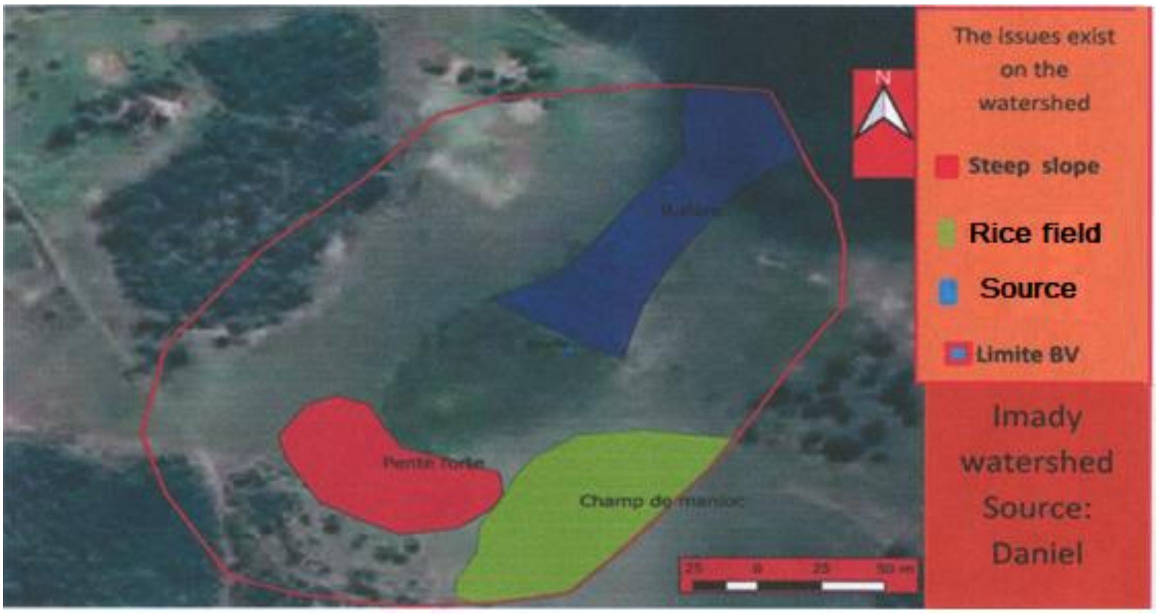
The perception of the slope of the basin depends on the altitude. Map 03 shows the slope distribution of the IMADY South basin.



***Map 03**: IMADY Watershed Slope*   *Source: Daniel Raz. 2022*

3.7 Watershed Issues

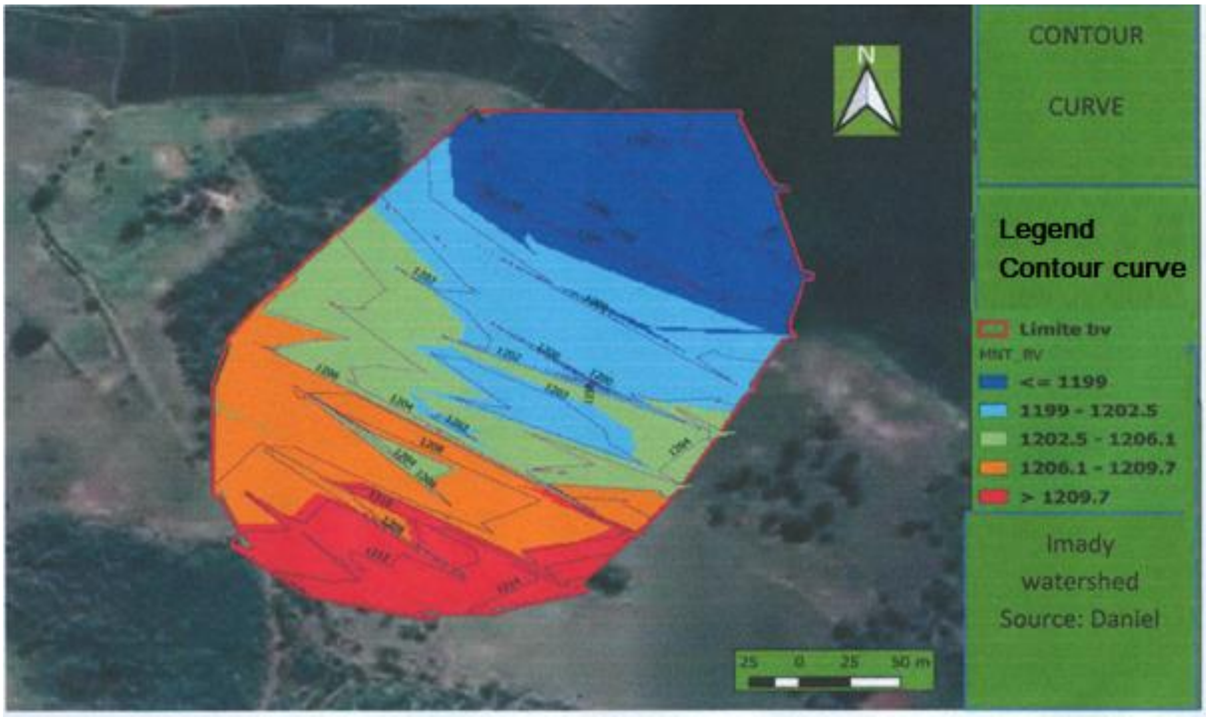
The existing issues in the basin are the cultivated fields upstream of the source, i.e. upstream of the water resource, including the rice field near the source and that the owner uses chemical fertilizer during the rice production period. As well as the presence of the steep slope on the upstream lower slope. Map 6 summarizes the issues in the IMADY South watershed.



***Map 04**: Watershed Issues*   *Source: Daniel Raz. 2022*

3.8 Altitude and Contour Lines

The watershed elevation is obtained by the cloud of points using Google Earth and the manipulation of QGIS software. Map 07 represents the different elevations and contours for this watershed.



***Map 05**: Contours and Elevation* *Source: Daniel Raz. 2022*

3.9 Delimitation of the Protection Perimeters

The protection perimeters are physically delimited spaces that aim to protect the immediate edges of the retained and its neighbor, as well as to prohibit or regulate the activities that could harm the quantity and quality of the captured water. As well as the delimitation of the protection perimeter is not obvious if there are rules to follow. The protection perimeter has been delimited into three parts.

The immediate protection perimeter is the area near the spring, it is about 30m from the spring.

The close protection perimeter is half of the slope up to 80 m from the spring

The remote protection perimeter, on the crest, is the part upstream of the mid-slope, it is located 120 m from the source.

The distribution of the protection perimeter is summarized on Map 06.

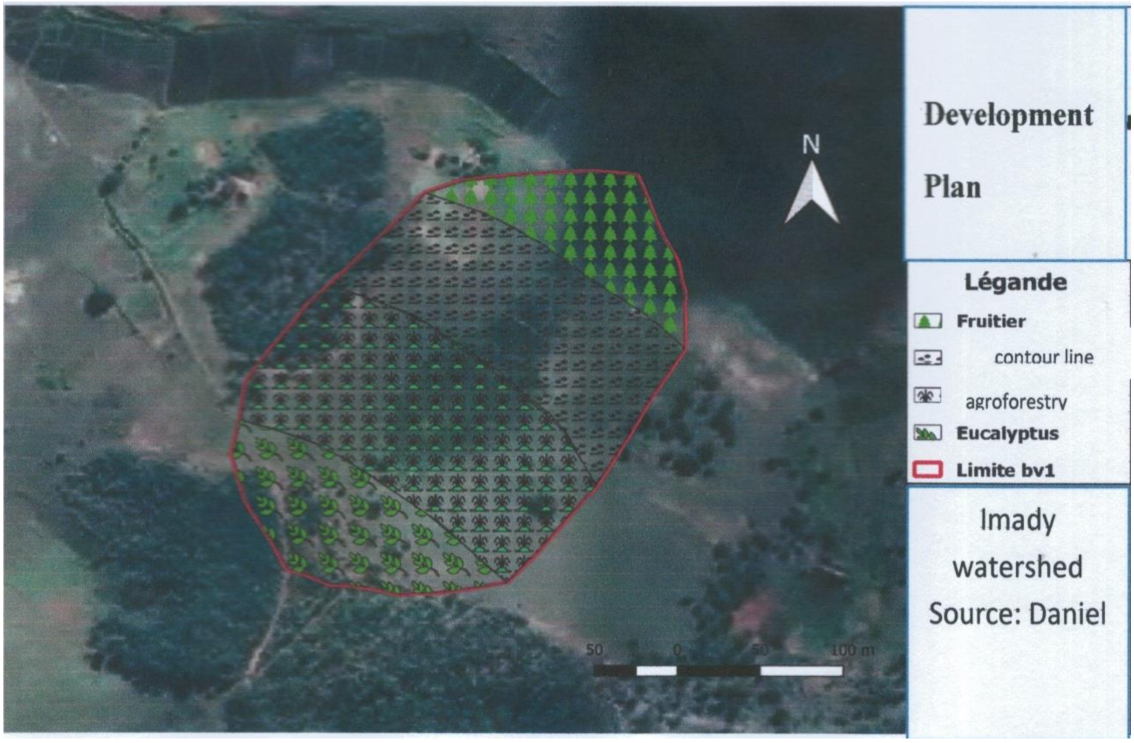
***Map 06**: Distribution of protection areas* *Source: Daniel Raz. 2022*

3.10 Proposal of the development plan

The proposal of the development plan is done within the PPE and PPR protection perimeter. According to direct observation in the field, the development plan should be divided into four parts.

In the first part, the highest part of the basin, a eucalyptus plantation was created. The second apart following the eucalyptus is managed by agroforestry. The third is part of the field for the culture of sisal and *Vepris ampody* and *Vepris sp* following the technique of culture in curves of level. The last part is developed by the plantation of bananas and coffee, and tapia.

The purpose of this plan is to stop erosion, conserve the resource, reduce the speed of runoff, forestry recovery of the watershed, and meet water needs. Map 07 summarizes the proposed management plan.



Map 07: *Development Plan* *Source: Daniel Raz. 2022*

3.9 Discussions and Recommendations

Discussions and recommendations centered around soil, source water, and watershed management.

a. Soils

Slope soils suffer, more than any other soil, from numerous landslides, as well as intense mechanical erosion, especially during rainy seasons. If the slope is not protected by an appropriate vegetation cover, the whole of the alluvial deposits and the valleys located downwards will quickly become established.

A soil with too high salinity (higher than 1gr/l) is unfit for agricultural production, does not shelter any fauna, does not contain any fresh water, and favors the proliferation of algae and "**halophilic**" bacteria, which cause:

- Significant yield reduction, especially in rainfed crops.
- Une baisse de la variation des plantes, y compris les plantes non cultivées.

- **Soil correction work**

The correction of the soil by leveling and profiling, by putting in place ridges (crop beds) high enough to push back and maintain the level of the salty water table at a minimum depth of 2.5 m, would allow the roots of the crops to be put out of reach of the possible rise of the salty water.

- **The cultivation of the treated soil**

It must be maintained continuously, after the previous operations, by choosing specific crops:

- Crops that can withstand a total chlorine content between 8 and 10gr/l such as sugar beet, asparagus, onions, garlic, and radish.

- Crops that can withstand a total chlorine content of 6 and 8gr/l such as eggplant; cabbage; carrot; spinach; pumpkin; tomato; rice; wheat and cotton.

This is the advice of the specialists of "Chloride tolerance of different crops. 2019 K+S Minerals and Agriculture GmbH - Bertha-von-Suttner-Str. 7 - 34131 Kassel".

b. Water from the Springs

The objective of this work was to study the quality of the water catchment in the district of Ankialo South Village Andraina Fototra in the Haute Matsiatra region in general, the problem of pollution is mainly related to the insufficiency of sanitation. The environment of the said region is polluted and one can easily notice the household waste littering the courtyards of the concessions and the streets, as well as the household wastewater which flows or forms stagnant puddles around the wells and in the uncured gutters.

Analyses were carried out at the Laboratory of Research in Molecular Biology Level II of the Faculty of Sciences - University of Fianarantsoa. This was revealed in all the cases of bacterial contamination during this study. It is as well chemical as bacteriological.

Chemically, the pH of water ranges from 4.60 to 7.6. The pH is a factor of investigation of the acidity or the alkalinity of water. This acidity is due to the siliceous and lateritic soil of the Haute Matsiatra region. Referring to the WHO standards (pH between 6.5 and 8.5) for drinking water, less than 35% of the water analyzed is not recommended for human consumption.

For nitrite content, the results vary from 0.005 mg/L to 2.6mg/L. According to the WHO, the normal level is set at 3 mg/L. Nitrite is toxic to the human organism and its presence in significant quantities degrades the quality of water. The toxicity linked to nitrite is very significant because of its oxidizing power. Also, the results show an increase in the contents. This is due to the fact that the infrastructure was without coping, and is most exposed to runoff. On the other hand, the nitrate content varies from 1.33 mg/L to 95.09 mg/L. The normal level is 50mg/L according to the WHO. Although nitrates have no direct toxic effects except at high doses, the fact that they can give rise to nitrites leads to toxicity. The results show a slight increase in nitrate levels. The levels show pollution of organic origin linked to the infiltration of water from cesspits.

As far as sulfate levels are concerned, they are almost absent in all the waters analyzed. Compared to the standard set 250mg/l as an indicative value of the WHO.

Finally, turbidity varies from 3.06 NTU to 64.2 NTU. Its normal rate is fixed at 5NTU according to the WHO. Turbidity affects the potability of drinking water. Consumers often have requirements regarding this parameter. The turbidity of water is due to the presence of finely divided suspended matter: clays, silts, silica grains, organic matter, etc.

It can be seen that most of the analyzed waters have contents of different physicochemical parameters that exceed the WHO recommendation. The analyzed waters are very loaded with salt as the results indicate. This may be due to the absence of a protection perimeter and the fact that runoff water can easily get into the catchment area.

Bacteriologically, the number of total coliforms varied from 3 to 10 CFU/ml in 100 ml of sample to more than 15 CFU/ml in 100 ml in the sludge. The number of total coliforms in the analyzed waters exceeds the WHO recommendation (10 total coliforms in 100 ml of sample). The very high number of total coliforms can be explained in part by the lack of maintenance of these infrastructures. Indeed, these infrastructures are for the most part poorly maintained.

For fecal coliforms, the number varies from 5 to 15 CFU/ml in 100 ml of samples to more than 455 fecal coliforms in 100 ml of samples in each study site. The number of fecal coliforms in the analyzed catchment waters exceeds the WHO standard (0 fecal coliforms in 100 ml of sample).

All the waters analyzed in this study have very high levels of coliforms (total coliforms and fecal coliforms). According to the guideline values of the World Health Organization (WHO), well water should be free of fecal contamination, i.e. it should not contain fecal coliforms.

Physicochemically and bacteriologically, all the waters are polluted. This situation is due to the exposure of their water to important sources of pollution which involves the very nature of the soil. Each of these sources intervenes according to a mechanism whose knowledge would be essential to avoid any contamination of the water catchment. Among them, the most important are, first of all, the pollution of the water according to the distance between the wells and the latrines.

3.10 Recommendations

To ensure protection against contamination, it is advisable to locate water points at least 20 meters from any source of pollution according to the standards of the hygiene service. Indeed, studies have shown that the spread of pollution from a latrine to the groundwater depends on the speed and direction of water flow. The speed of circulation is even related to the physical structure of the soil, its granulometry, and the degree of fluctuation of the rocks. In addition, the design of some infrastructure elements did not take into account the slope of the soil. Therefore, the results of the analyses attest to the presence of ongoing fecal pollution. A large part of this pollution can be attributed to the existence of latrines near the wells which do not meet any distance norms, nor any geological factor such as the inclination of the soil.

The results of this work will provide the authorities with basic data that can be used to improve the quality of water intended for human consumption. The easiest way to combat water pollution is to conduct a broad awareness campaign. Here are some recommendations for the very near future:

a. To the Administrative Authorities

- ✓ Health education by encouraging media awareness.
- ✓ A permanent control of the sources.
- ✓ Extending the drinking water supply network and increasing the number of standpipes in neighborhoods that are not yet adequately equipped.
- ✓ Establish national standards for the quality of drinking water.
- ✓ Establish a proper sewage disposal system.
- ✓ Require compliance with water protection standards.

To the people

- ✓ Maintain a minimum distance of 15 meters between pits and latrines.
- ✓ Avoid emptying cesspools in the streets and use competent services to do this work.
- ✓ Develop water sources.
- ✓ Adopt measures to make water drinkable at home.

To development partners

- Maintain constant support for the reinforcement of sanitation works.
- Maintain their support in financing water pollution control activities.

Watershed management

The proposal of the development plan is done in the perimeter of protection PPE and PPR. According to direct observation in the field, the development plan must be divided into four parts.

The first part is the highest part of the basin and is landscaped by planting eucalyptus. The second part, a part following the eucalyptus is managed by agroforestry.

The third part is part of the field for the food crop following the technique of culture in a level curve.

The last part is developed by the plantation of bananas and coffee (Bertha-von-Suttner, 2019; Lu and *al.*, 2015).

The aim of this plan is to stop erosion, conserve the resource, reduce the speed of runoff, cover the watershed, and satisfy the need for water.

b. Prohibition of Burning

Indeed, not only does the brush stabilize the soil thanks to its root system, but its leaves also act as a mulch (protective mat) preventing the impacts of the drops from disintegrating the soil structure, and thus limiting its erosion by the torrential waters. The tall grasses will therefore simply be cut and left in place to form a mat protecting the soil. This practice allows:

- ❖ Increase water infiltration through root penetration, and keep the soil moist longer by reducing evaporation through mulching.
- ❖ Maintain the proliferation of the organic population of the soil, the main actor in the biodegradation of the organic matter,
- ❖ Prevent the destruction of aggregates, a condition for good aeration and optimal retention of the soil solution,
- ❖ To ensure optimal retention of nutrients essential for a better production yield, by reducing the lateral migration of nutrients,
- ❖ Contour plowing can also be used for cultivation on gentle slopes. When the slope is greater than 4% and plowing the entire perimeter in one piece, even along the contour line, is not recommended, alternate strip cultivation is used (two neighboring strips that do not contain the same crop). The strips will be oriented according to the contour line and in continuous transversals. The width of each strip will depend on the drainage quality of the soil. If the slope is greater than 20%, crop rotation is necessary to protect the soil.

IV. Conclusion

This study was conducted in the watershed of Ankialo South in the Village Andraina Fototra rural commune of Ambalakindresy. The studies of the characteristics of the soils, the source with its protection, and the proposal of the management plan were carried out. The value of the compactness index of Gravelius is 1.20. The latter implies that the watershed has an elongated shape and therefore favors low flow. The calculation of the flows gave 0.22Ls-1, and 0.16Ls-1 for the first and second sources respectively. This study provided fairly broad information about the watershed. The contamination of the catchment water is generally from the environment. This pollution is manifested by contents largely exceeding the standards of the WHO. Indeed, the analyzed waters have physicochemical properties that make them not recommended for human consumption. Moreover, bacterial pollution was very high and almost permanent in the studied catchment waters. The results also show an increase in the pollution of surface water. The causes of this pollution are multiple, such as poor protection of the catchment water, insufficient application of basic hygiene measures, poor design of cesspools and latrines, poor wastewater disposal, and the presence of garbage deposits in the groundwater recharge area.

The proposal of an anti-erosion management plan, the establishment of protection perimeters, and agroforestry management are the basis for the protection and conservation of soil and water resources. The cultivation in contour is the correction and reduces the speed of runoff. The awareness of the local population on the protection of watersheds and springs, so that they respect all the regulations in each protection perimeter, improve their mode of cultivation by following modern techniques proposed.

To sustain the protection of the catchment area springs, it is not enough to simply install protection perimeters, reforests the catchment area, raises awareness, and introduce the participatory approach. It is still mandatory to set up a water collection and treatment facility to eliminate impurities. New research is thus necessary at the level of these works whose idea is to know how to capture and treat water before its distribution to the consumers.

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