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Contribution of Remote Sensing for Monitoring Tapia Sclerophyll Forests (Uapaca Bojeri), Endemic Species of Madagascar, Case of the Tapia Forest of Itasy

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Abstract – Spatio-temporal land cover monitoring was analyzed using 2000 and 2019 remote sensing and geographic information system (GIS) Landsat images, in the sclerophyll forest area of the Itasy region. The objective of this research is to analyses the dynamics of land cover between 2000 and 2019, and to determine the factors of degradation of plant cover in this area. Socio-economic surveys were carried out in the municipalities of Arivonimamo II and Soamahamanina. The Maximum Likelihood Supervised Classification was applied to achieve Landsat image processing. Sclerophyll forests are down 29.59% in terms of area. On the other hand, shrub savannahs experienced a slight reduction of 8.75% while crops and bare soils showed an increase of 207.86% of their area, three times their initial area in 2000. Population growth, agriculture and the practice of wood energy are the three main factors of degradation of sclerophyll forests and its periphery.

Keywords – Sclerophyll Forest, Remote Sensing, GIS, Dynamics, Itasy Region.

I. INTRODUCTION

Many problems are related to the management of the environment and natural resources such as the devastation of forest ecosystems, one of the most affected elements. Thus, the extension of agricultural areas linked to population growth and especially bush fires are one of the main reasons of land cover degradation in the world. This fact is particularly evident almost in developing countries where plant space is under a lot of pressure due to poor management of natural resources.

In Madagascar, overpopulation leads to deforestation, which makes the forest area bare. In particular, the sclerophyll forests of Arivonimamo and Miarinarivo present one of endemic forests in Madagascar. This forest area continues to decrease because of the failure of forest administration which leads to overexploitation for wood energy, and this study was carried out in this context. The aim of this research is to monitor the deforestation of the sclerophyll forest in the Itasy region and to propose appropriate solutions to this situation. Specifically, this involves identifying the different land cover categories, assessing and mapping the land cover dynamics of 2000 in 2019, and also identifying factors that promote deforestation.

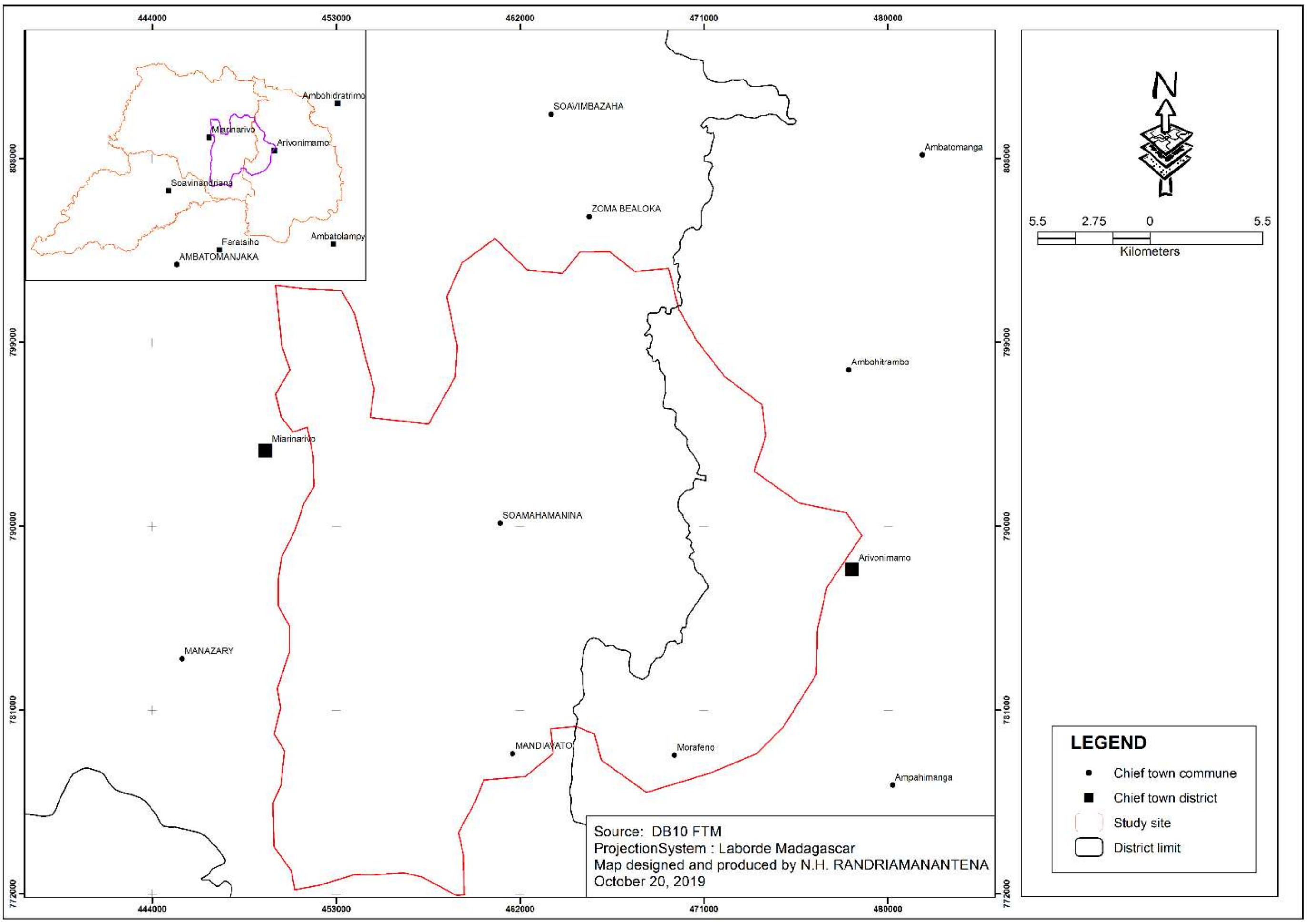
II. MATERIALS AND METHODS

2.1. Study site

The sclerophyll forest of the Itasy region is located to the east of this region. More specifically, between 46°54' and

47°10' East longitude and 19°8' and 18°52 South latitude. The investigation area is located about 50 km west of the capital of Madagascar and is an integral part of the district of Arivonimamo and Miarinarivo *(cf. Map 1)*. This area is subject to a tropical climate of altitude characterized by two contrasting seasons: a dry, cool season from April to October; and a warm season from November to March. The temperature reached a maximum of 26.7° in January and a minimum of 7.1° in August. The average temperature is 17°. Annual precipitation ranges from 800 to 1,000 mm.

The sclerophyll forest represents the last vestige of primary forest vegetation in Arivonimamo and Miarinarivo. They take the form of a clear forest dominated by tapia. This natural forest formation is complemented by the reforestation forests of Eucalyptus, whose purpose is to replace the tapia forest in their role of energy wood production.



Map 1: Study Site Location Map

2.2. Materials and Data

Several satellite images were used during this research: Landsat ETM+ and OLI&TIRS 30 m resolution images acquired at the same time of the year in order to reduce interpretation issues related to phenological changes in vegetation and differences in colour between soils. The choice of images is based on four criteria: coverage, spatial resolution, years and shooting seasons. And we selected images that were taken during the dry season to have very low cloud coverage data. Following these criteria, the selected Landsat images are therefore taken from scene 159/73 taken on 23 July 2000 by the Landsat 7 ETM+ sensor and on 15 August 2019 by the OLI-sensor LANDSAT 8 SHOTS. All these Landsat images have been downloaded for free from the US Geological Survey

(USGS) website. All these images have been georeferenced in projection Laborde Madagascar. The computer hardware used to process the data in this study consists of a number of software packages. This is the software ENVI 5.2, which was used for the processing of satellite images and Arcgis.10.2.2, which was used for thematic analyses and cartographic rendering, for extraction, digitalization, the combination and integration of the different vector layers.

2.3. Methods

The ENVI software made it possible to produce two land use maps based on satellite images from 2000 and 2019. Here the radiometric bands capable of providing information on the vegetation cover were superimposed by additive synthesis of the primary colors. Thus, the color composition in false colors with the combination of bands 2, 3 and 4 for the ETM+ image and 3, 4 and 5 for the OLI&TIR image were used. The supervised classification method according to the maximum likelihood algorithm was used. The classification as well as the Corine Land Cover (CLC) classification has been adapted to reflect each land use category. In total, 100 GPS points were collected along two transects, or 50 points per transect. This is a transect in the developed vegetation zone, another in the moderately degraded vegetation zone and one in the highly degraded vegetation zone. The accuracy index and Kappa were used to validate the classifications. The land cover maps produced provided the basic data for landscape analysis and quantification. The areas of the different land cover categories were calculated and diagrams were drawn to assess the rate and intensity of change. Descriptive and diachronic approaches were used for analysis.

2.3.1. Calculates the rate of change

The occupancy category dynamic will be assessed by calculating the rate of change *E(i,k)* of its area as follows. If the area of occupation category of year i and Sk, that of the other year k, with k >i. E(i, k) will be equal to:

$$E(i,k) = \frac{S_k - S_i}{S_i} \times 100$$

If *E (i, k)* = 0, this means that there is stability in this land use category;

If *E (i, k)* < 0, it is concluded that there is a decrease in this category;

If *E (i, k)* > 0, this category has an extension or evolution.

This index is calculated for all land cover categories. It makes it possible to assess the development of the different categories of land use between two periods.

2.3.2. Calculation of annual average rates of spatial expansion

The annual average rate of spatial expansion T expresses the proportion of each land cover category that changes annually.

Based on the size of these categories, this rate was calculated using Bernier's formula:

$$T = \frac{\ln S_k - \ln S_i}{(t_k - t_i)\ln e} \times 100$$

2.3.3. Calculating the Rate of Change of Land Use Categories

In order to determine the rate of change of the identified land cover categories, the following formula was adopted:

$$V = \frac{S_{p2} - S_{p1}}{t_2 - t_1}$$

With

V= Rate of change (extension or regression in km2/year);

SP1= Area occupied by category of occupation in year 1 (km2)

SP2= Area occupied by category of occupation in year 2 (km^2)

t1= year 1; *t2* = year 2.

2.3.4. Detection of changes

For the evolution of land use: a diachronic study of satellite images from 2000 and 2019 was carried out. The purpose of this study is to identify the transformations that occurred between two periods following the 2000 and 2019 land cover map crossings. After automatic vectorization, classification results are exported in vector format (shape) for cartographic processing using GIS Arc 10.2.2 software. The growth of two land use maps in 2000 and 2019 allowed the evolution of all landscape units to be mapped over these 19 years. This crossing was carried out on the basis of a codification of the land use unit classes *(cf. Table 2)* and a comparison of the codes between the two maps. This is an approach to verifying changes from code changes for homologous vectors.

Change Rate Calculation: Following the completion of the 2000 (t1) and 2019 (t2) land use maps, a comparative analysis of the two was conducted. The balance of changes in land cover and the rate of change between the areas of land cover units between 2000 and 2019 were determined on the basis of the formula as follows:

$$T = \frac{1}{t_2 - t_1} \times \ln\frac{S_2}{S_1}$$

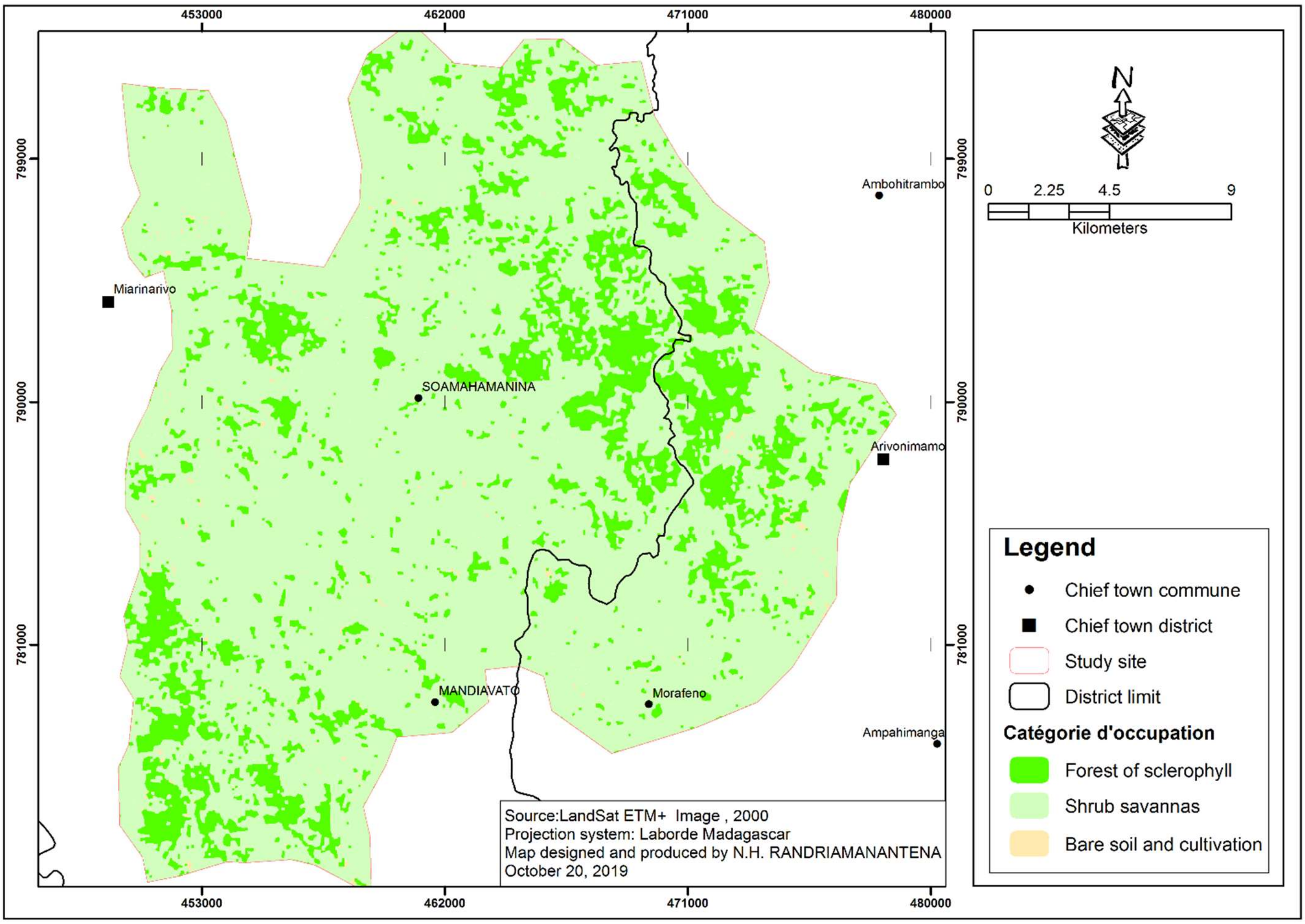
with S1 and S2 corresponding respectively to the areas of a category of land use in year t1 and year t2;
T: rate of change (%);
ln: the Neperian logarithm.

The positive balance sheet values represent a progression of the class surface during the analyzed period and the negative values indicate the loss of a class surface between the two dates. Values close to Zero indicate that the class remains relatively stable between the two dates.

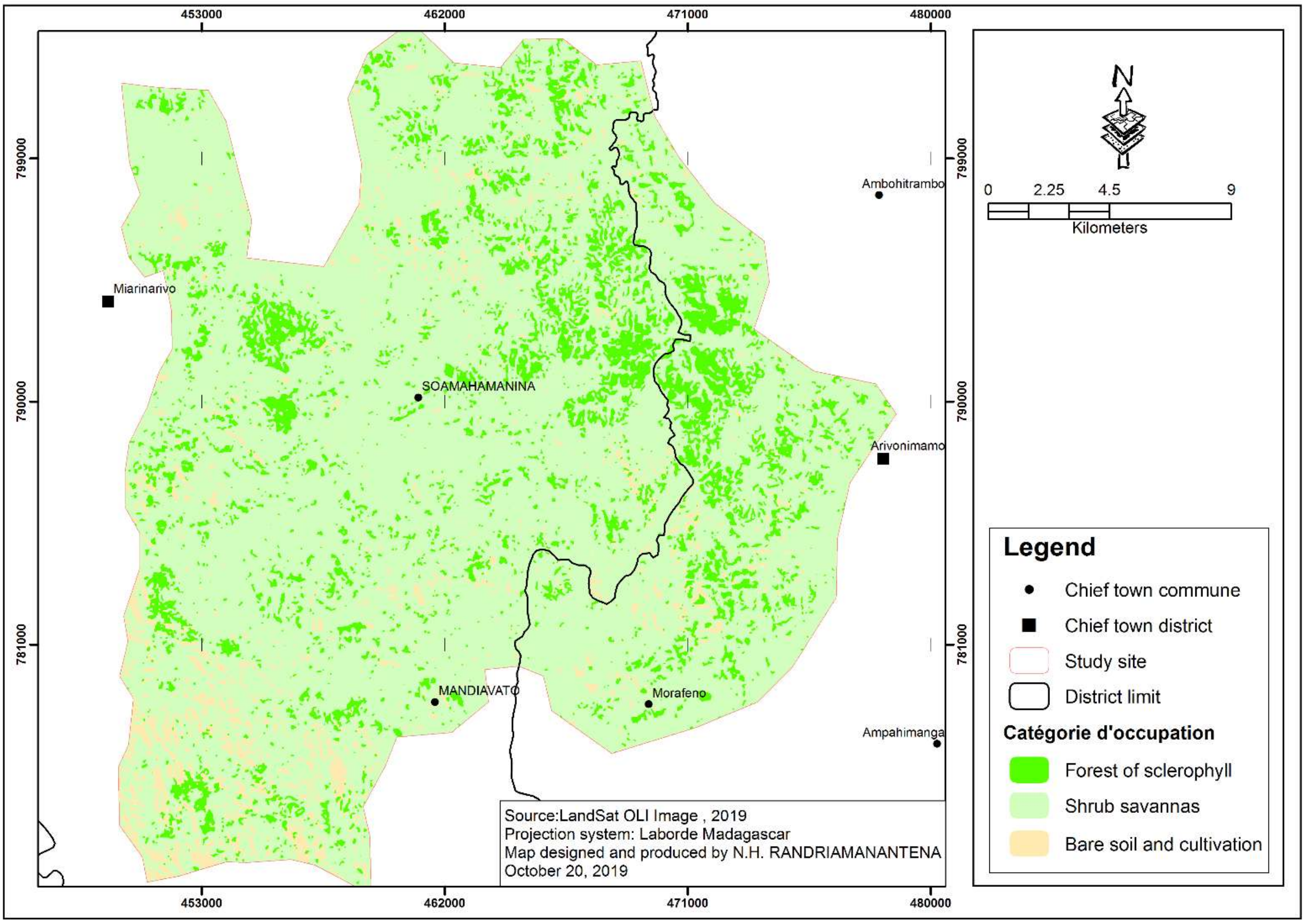
III. Results

3.1. Identification and Mapping of Different Occupancy Categories

As a result of the processing of satellite images confronted by the data collected in the field and the use of the old topographical maps, three categories of land cover were distinguished in the study site. These are sclerophyll forests (Tapia), shrub savannahs and bare soils (planting, crops). The analysis of the land cover maps established by the Landsat image processing of the year 2000 and 2019 shows a difference in the dynamics observed during the period 2000-2019. It appears that most sclerophyll forests have been converted into shrub savannah, crops, plantations *(Map 2 and 3)*. This reflects the fact that deforestation is more prevalent during this period.



Map 2: 2000 Itasy Sclerophyll Forest Land Use Map



Map 3: 2019 Itasy Sclerophyll Forest Land Use Map

Maps 2 and 3 show the spatial distribution of the different land use classes from 2000 to 2019, over the entire area of sclerophyll forests in the Itasy region. In 2000, the different classes of occupations are very well differentiated by very specific areas, with forest massifs in the western part of the commune of Arivonimamo II, east of the commune of Soamahamanina and east of the commune of Manazary. On the other hand, in 2019 a lot of the forest area reaches a considerable decrease especially the forest east of Manazary.

3.2. Spatial-temporal dynamics of land cover categories

The difference between the areas of each land cover category in 2000 and 2019 gives an indication of the change. During these dates, the areas of land use units shall be developed. Some types have declined for some and others have increased *(Cf. Table 1)*. This phenomenon explains the existence of dynamics in the middle between these dates.

Table 1: Change in area in km2 between 2000 and 2019

Category	Area 2000 (km^2)	Area 2019 (km^2)	Rate of change (%)	Annual rate of expansion (%)	Speed of change
Forest of sclerophyll	108.17	76.18	-29.58	-1.85	-1.68
Shrub savanna	450.85	490.29	8.75	0.44	2.08
Bare soil and cultivation	5.00	15.38	207.86	5.92	0.55

Source: Landsat ETM+ 2000 and OLI&TIRS 2019 image processing

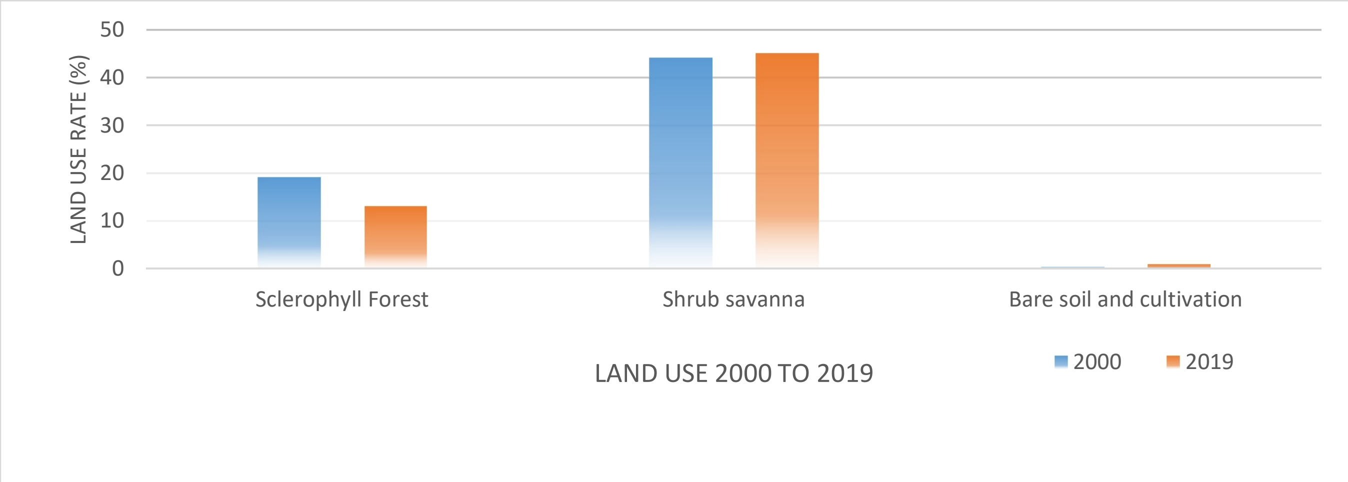


Figure 1: Change in land cover in the Itasy region between 2000 and 2019

It appears from the reading of Table 1 that the area of shrub savannahs and bare soils and crops has expanded considerably during this period with a rate of change of 8.75% and 207.86%, respectively, and an annual spatial expansion rate of 0.44% and 5.92% respectively. While sclerophyll forests have seen their areas decline with a rate of change of -29.58% and an annual average rate of expansion of -1.85%.

With regard to the dynamics of the sclerophyll forest, this study highlights the phenomenon of deforestation during nineteen years with a loss of nearly 32 km2 of tapia forest. This deforestation is the result of the combination of various socio-economic factors, forest management policies that are not adequate for nature conservation. There is also an increase of about 10 km2 of land planted with agriculture and bare land. This is due to the rapid growth of tanety crops during this period. The structure and texture of these soils, the cultivation techniques and the excessive use of inputs lead to a decrease in soil fertility and rapid exhaustion. Elsewhere, this increase in culture on tanety is linked to the population growth that brave deforestation.

In addition, according to the surveys carried out in the municipality of Soamahamanina and Arivonimamo II, this area has experienced a wide production of charcoal. This activity therefore encourages deforestation. This has resulted in the withdrawal of the Forest Administration, leaving open access to over-logging.

3.3. Change Evaluation

According to the image processing, all categories of land use have changed. Each category has experienced loss and gain (Cf Map 4). Shrub savannahs and bare soils gain respectively 5318.98ha and 2133.83 ha and loss respectively of 3571.59 ha and 482.16 ha. These results show that deforestation and crop fields increase. For sclerophyll forests, there was a gain of 2023.28 ha and a loss of 5422.34 ha (Cf. Table 2)

Table 2: Occupancy Category Gain and Loss Evaluation

Category	Gain (ha)	Loss (ha)
Sclerophyll Forest	2023.28	5422.34
Shrub savanna	5318.98	3571.59
Bare soil and cultivation	2133.83	482.16

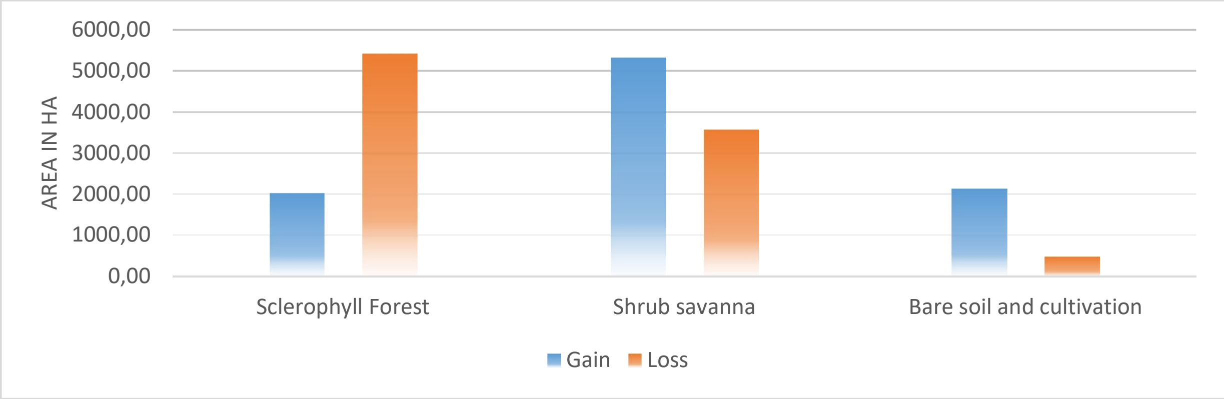
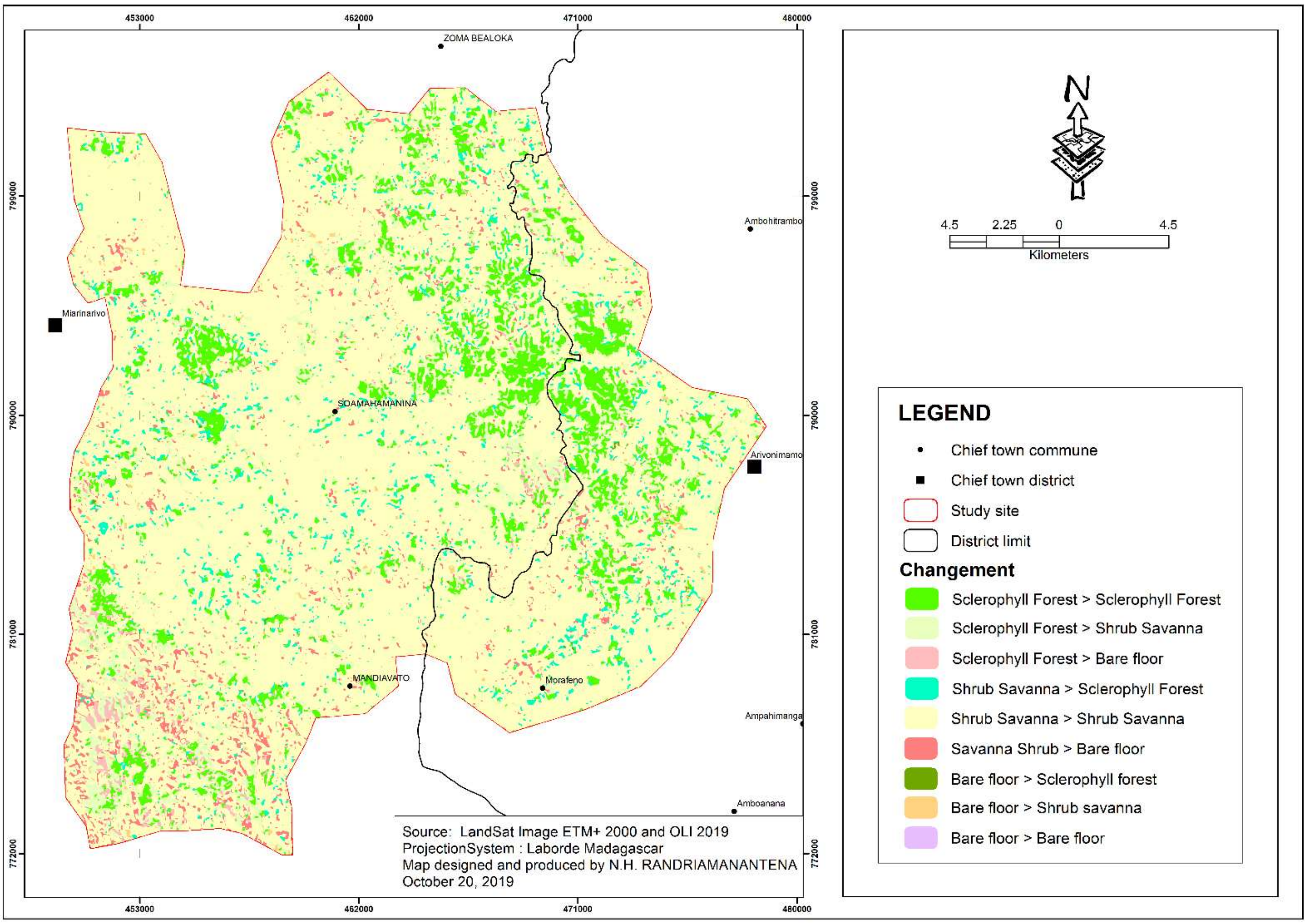


Figure 2 : Change land cover between 2000 et 2000



Map 4: Change in Land Use Category Map

Going from reading the map that tapia forests in the southwestern part of the study area are almost converted into shrub savannahs and bare soils. This explains the dominance of deforestation, the overexploitation of the forest in this area. On the other hand, there is a regeneration of this type of forest on the rest of the study site. In addition, it is clear that each category of occupation has changed (Cf. Table 3).

Table 3: Change in land cover categories

Change	Area (ha)
Sclerophyll Forest > Sclerophyll Forest	5389.74
Sclerophyll Forest > Shrub Savanna	4884.60
Sclerophyll Forest > Bare floor	537.74
Shrub Savanna > Sclerophyll Forest	1975.50
Shrub Savanna > Shrub Savanna	41433.34
Savanna Shrub > Bare floor	1596.09
Bare floor > Sclerophyll forest	47.78
Bare floor > Shrub savanna	434.37
Bare floor > Bare floor	2.32

According to Table 3, 5389.74 ha of sclerophyll forests has been stable, 4884.60 ha is transformed into shrub savannahs and 537.74 ha into bare soil or crops. As regards shrub savannahs, there is a conversion for the latter of which 1975.5 ha is converted into forests and 1596.09 to bare soil. Most of the area of shrub savannah remains stable at 41433.34 ha. 2.32 ha of bare soil does not change while 434.37 ha is replaced by shrub savannah and 47.78 ha in forest. This situation interprets the increase in land needs of the local population and the population explosion.

IV. Discussion

4.1. Land use dynamics

Analysis of the results obtained from the mapping of vegetation cover between 2000 and 2019, shows overall vegetation degradation with negative trends if mitigation measures are not taken. This phenomenon is very worrying for such an area whose economy is based mainly on the exploitation of vegetation especially the forests of Tapia which allows the rural populations to support themselves through the exploitation various wood and non-timber products.

The contribution of spatial remote sensing can be summarised in highlighting the general trend in land use dynamics. This trend reveals a strong regression of forests and savannahs to the profits of bare soils and crops on tanety. This significant degradation of the extensive forests at the study site is due to the misuse of wood for heating and cooking, as well as the emergence of agroforestry land. This is due to the fact that this period was marked by significant population growth and a purely extensive agriculture without the use of fertilisers for the soil. The reconciliation of demographic and economic variables shows an imbalance between the needs of populations and the resources available. To this end, the increase in crop area is therefore linked on the one hand to the increase in the population in the study area and to the increasing demand for agricultural land on the other.

After a long period of cultivation of land resulting from the destruction of dense forests, the use of these deforested areas can make it possible to benefit from new fertile land and to increase agricultural production. As a result, this deforestation is causing wildlife to disappear because of the considerable destruction of their natural habitats. Beyond the expansion of agricultural land, it is essential to put in place strategies for the sustainable management of the natural resources of this environment in order to strengthen food security.

4.2. Factors of degradation of sclerophyll forests

Demography, agriculture and wildfires remain the main causes of degradation of sclerophyll (tapia) forests in the Itasy region according to the results of our survey. Population pressure is causing the population to cut new land for agriculture. Thus, the internal growth of the household population implies an increase in the number of people to be fed, so that more income and agricultural products are needed. In response to this demand, farmers decide to clear new crop lands to overcome the growing burden of their households. That is why there is a strong correlation between population growth and land degradation. The main reasons for land erosion and degradation according to the respondents in the local population are agriculture and deforestation. In the former Province of Tananarive, agriculture is found to be one of the driving forces behind land cover change, according to the NEB report. Our result is therefore consistent with this situation, which concluded that agriculture remains the main factor inducing changes in vegetation cover at our study site. However, factors can vary from one area to another within the country. It is clear that charcoal production is the main activity introducing the change in vegetation cover at this study site. Implementation of buffer zone activities and improved forest administration are necessary. Considering the needs for wood and non-timber forest products expressed by the local population, it is better to invent alternative agro-activities income-generating pastorals in this area to mitigate deforestation. However, the reinforcement of protection measures must take place and the organisation of night patrols or night controls is strongly recommended. In the case of infringements, penalties provided for in the current regulations must be applied without discrimination, since local communities regard the laxity of the forester as an element of the forest.

V. Conclusion

This study provided a better understanding of the current land use in the study area, and of the evolutionary trends of the different land cover categories. Thus, we can note the regression of sclerophyll forest formations which is an endemic species in Madagascar with an amplitude of 29.58% for only 19 years from 2000 in 2019. High population growth and increased land requirements for agriculture are the main drivers of agricultural degradation. These results involve the various actors or decision-makers in charge of the management of this territory. They must urgently develop integrated and participatory management strategies at local and regional levels to preserve plant resources, ensure resilience and define sustainable agriculture strategies. Knowledge of this dynamic makes it possible to predict the future and to propose to the competent authorities tools to support decision-making that is to say to propose forms of sustainable planning and territorial planning.

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In carrying out this research, VR developed the research protocol, collected and processed the data and provided advice in the collection and processing of the data. LR participated in the proofreading of the document and the field trip. They all approved the final version of the manuscript.

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