

Simulation of the Dynamics of Land Cover and Land Use in the Lobo River Watershed Upstream of Nibéhibé (Center-West of Côte d'Ivoire)

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Abstract

From medium-resolution satellite images (Landsat TM, ETM+ and OLI), the spatial dynamics of land cover and land use are highlighted. The objective of this study is to quantify the evolution of land use in the watershed of the Lobo River upstream of Nibéhibé between 1986 and 2019 in order to analyze the impacts of human activities on the landscape. The study method was based, on the one hand, on the processing of satellite images, for the analysis of the dynamics of land use and, on the other hand, on the CA-Markov model, for the prediction of land use by 2050. It emerged from this study that the land use maps produced made it possible to highlight the spatio-temporal dynamics of land use on the basin. For the period from 1986 to 2019, there is a decrease in the area of forests in favor of built-bare ground and crops and fallows. A land use scenario for the years 2019 and 2050 was simulated with an accuracy of 87.11%. The regressive trend in forests seems to continue in the future with current land use practices.

Keywords

Satellite Image, Land Cover and Land Use, Space-Time Modeling, Lobo

1. Introduction

The lands of the world are undergoing profound spatial changes. In West Africa and particularly in Côte d'Ivoire, these spatial changes which result in the degradation of the vegetation cover are increasing day by day.

Like the developing countries, Côte d'Ivoire has an economy heavily dependent on the agricultural and forestry sector, leading to a rapid decrease in forest areas [1]. In addition, studies carried out on the evolution of this forest cover

show that Côte d'Ivoire experienced the highest deforestation rate in the tropics in the twentieth century [2]. In fact, forest areas have decreased from around 14 million hectares in 1912 to nearly 2 million hectares in 2000 [2] [3]. Thus, the vegetation cover of the Center-West area has not escaped this deforestation.

In the area of Lobo River watershed studied here, stripping of land for agriculture has become increasingly important in recent years [4]. Resources are under strong anthropogenic pressures because of the population explosion and a purely extensive cropping system. The increased expansion of cultivation areas and agglomerations leads to a gradual reduction in the extent of wooded areas and a destabilization of the soil structure [5]. Crop rotation and fallow also have major disturbances on these precariously balanced ecological systems. Changes in land use thus have a direct impact on land cover and on the landscape configuration of this environment.

For several decades, the modeling and projection of land use change has established itself as a relevant decision support tool. It allows the analysis of territorial planning policies in order to assess and anticipate their environmental impacts [6]. The originality of this research lies in the fact that the land use dynamics modeling will make it possible to follow the evolutionary trend of the landscape and to find acceptable rules to preserve natural resources, like forest and water resources. Therefore, we can wonder about the spatial translation of this degradation of the landscapes. The objective of this study is to assess the land use dynamics of the Lobo River Watershed upstream of Nibéhibé, in order to predict their future changes. More specifically, it will be a question of simulating changes in land use by 2050.

To simulate changes in land cover and land use, several models are used. Among the most widely used, mention may be made of the combination of cellular automata model (CA) and Markov model (CA-MARKOV). The work of [7] shows that the CA-MARKOV combination integrates the stochastic function of Markov Method with the stochastic spatial characteristic of Technology CA. CA-MARKOV a powerful tool that has enabled several authors including [8] [9] [10] to simulate land cover and land use changes.

To conduct such a study, it is important to use reliable quantitative and qualitative data. Under these conditions, satellite imagery and geographic information systems (GIS) present themselves as an opportunity for this study. Indeed, satellite imagery, thanks to its synoptic view, makes it possible to understand and map dynamic phenomena such as land use. As for GIS, they make it possible to organize and better structure information. In view of the prediction of land use of the Lobo river watershed upstream of Nibéhibé, the use of models is necessary. Under these conditions, CA-Markov model appears to be useful tools for this study.

2. Study Area

The Lobo River Watershed upstream of Nibéhibé is located in the center-west of the Côte d'Ivoire between 6°45' and 7°55' North latitude and between 6°15' and

6°55' West longitude. The Lobo River is one of the main tributaries of the Sassandra River. It has its source at an altitude of 400 m south of Séguéla [4]. The Lobo River Watershed upstream of Nibéhibé covers an area of 7280 km² and partly covers the localities of Séguéla, Vavoua, Daloa and Pélézi (Figure 1).

The Lobo River Watershed upstream of Nibéhibé is influenced by the Equatorial Climate of attenuated transition (Baoulean climate) characterized by two seasons: a rainy season from March to November and a very marked dry season from November to February. The average annual rainfall recorded over the period 1990-2015 is 1238.2 mm. The average monthly temperature trend generally varies between 24°C and 28°C, *i.e.* a thermal amplitude of 4°C [11].

The Lobo river watershed upstream of Nibéhibé is an agricultural area. Agriculture is the main activity which occupies most of the active population in the watershed [8]. The rural environment is dominated by agriculture. It is an extensive, anarchic, rainfed and manual agriculture, which compensates for its weaknesses by the permanent conquest of new lands [4] [12]. Cash crops are cocoa, coffee, rubber, cotton, cashew and food crops. In terms of food crops, maize, rice, yams, plantains, chili peppers, eggplant and cassava are the main subsistence crops of the populations (Ministry of Agriculture).

3. Materials and Methods

3.1. Materials

The material used consists of satellite images and agricultural data. The satellite images used are recorded by the TM (Thematic Mapper), ETM+ (Enhanced Thematic Mapper Plus) and OLI (Operational Land Imager) sensors of the Landsat 5, 7 and 8 satellites respectively. The study area straddles the scenes 197-55 and 198-55. The date of acquisition of the images is very important in the study of changes in the landscape from satellite data [13] [14] [15]. For this, our data was selected during the great dry season (December to February), the period during which the cloud cover rates are the lowest. In addition, this choice contributes to reducing any seasonal effects [16]. The different acquisition dates are: for TM images on 01/09/1986 and 01/16/1986; ETM+ on 01/20/2002 and 12/13/2002 and for OLI images on 02/12/2019 and 01/02/2019.

The agricultural data used in this study concerns statistics, crop production yields per hectare and the number of farmers. These data are provided by the regional directorate of the Ministry of Agriculture of Haut Sassandra. These data are used to assess the evolution of crops.

3.2. Methods

3.2.1. Satellite Image Processing

Knowledge of the study area made it possible to opt for a supervised classification. The Maximum Likelihood algorithm was chosen for the supervised classification. This method is commonly used in the literature. The validation of the classification is obtained using the confusion matrix, the overall precision and

the Kappa coefficient (Table 1, Table 2). These tables display in the diagonal, the percentage of well classified pixels and off diagonal, the percentage of misclassified pixels. The confusion matrix shows a good classification of the images.

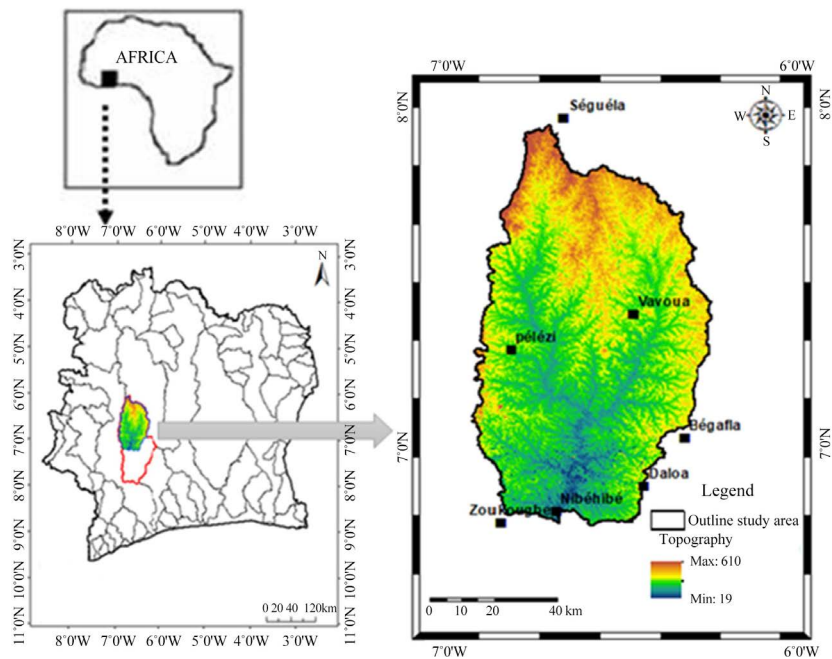


Figure 1. Presentation of the Lobo River Watershed upstream of the Hydrometric Station of Nibéhibé.

Table 1. Confusion matrix of the 1986 image classification.

Classes	Water	Forest	Degraded forest	Built-bare ground	Cultivation and fallow
Water	97.02	0	0.6	0	0
Forest	1.82	96.2	9.81	0.53	1.57
Degraded forest	1.16	3.2	89.59	0	6.09
Built-bare ground	0	0	0	98.57	0
Cultivation and fallow	0	0.6	0	0	92.57
Total	100	100	100	100	100

Overall accuracy: 94.74%; Kappa coefficient: 0.87.

Table 2. Confusion matrix for the 2019 image classification.

Classes	Water	Forest	Degraded forest	Built-bare ground	Cultivation and fallow
Water	98.64	0	2.01	0	0
Forest	0	100	0	0	0
Degraded forest	1.05	0	89.13	0	4.44
Built-bare ground	0.31	0	0.02	98.16	0
Cultivation and fallow	0	0	8.84	1.84	95.56
Total	100	100	100	100	100

Overall accuracy: 94.10%; Kappa coefficient: 0.90.

3.2.2. Analysis of the Dynamics of Land Use

Analysis of changes over the entire study period was done by post-classification comparison. It produces a change detection matrix resulting from the comparison between the pixels of two classifications between two dates [9]. From this situation, the global rate of change (T_g) and the average annual rate of spatial expansion (T_c) were calculated.

Global scale changes were determined by showing the areas of different land use units for each year. The changes have been determined between 1986 and 2019. This consisted of carrying out the ratio between the difference in areas and the initial areas for each period.

In a second step, we moved on to an in-depth analysis, evaluating the changes that took place within each land use unit taken in isolation. This analysis is done by calculating the rate of change (T_c) or average annual rate of spatial expansion, commonly used in studies of land cover change [17] [18]. These rates of change are evaluated from the formulas of Equations (1) and (2) below:

$$T_g = [(S_2 - S_1)/S_1] \times 100 \quad (1)$$

$$T_c = [(S_2/S_1)1/t - 1] \times 100 \quad (2)$$

where:

T_g = overall rate of change (%).

T_c = rate of change (%).

S_1 = area of the class at date t_1 .

S_2 = area of the class at date t_2 ($t_2 > t_1$).

t = number of years between the two dates.

Analysis of the rate of change values shows that positive values indicate “progression” and negative values “regression”. Values close to zero indicate that the class is relatively “stable”.

3.2.3. Simulation of the Dynamics of Land Use

Simulation consists of putting a model into action. In this study, the CA-Markov model was chosen for its performance and the fact that it has been successfully applied multiple times in tropical regions. According to the work of [19] [20], the CA-Markov model gave better results in the simulation of land cover compared to other models (LCM, Dinamica and CLUE-S). This model combines Markov chains, EMC and cellular automata. The method put in place is a processing chain made up of two steps, from data construction to modeling.

The first step concerns the EMC (Multicriteria Assessment): the environmental variables (road network, slopes, altitude), likely to have an effect on the dynamics of land use are identified and weighted in order to obtain decision support maps by integrating a set of measurable and mappable criteria. These maps were produced and compiled in a file.

The second step consisted of opening the CA-Markov module in the IDRISI software. The process first consisted of entering the base land cover image which is the last land cover image used with MARKOV (the 2002 image). Then the

Markov transition zone file name, created by MARKOV, was inserted. Then the name of the group file which lists the compatibility images of the transition has been inserted (file containing the aptitude cards). The value 5×5 was used as an adjacency filter.

3.2.4. Model Calibration and Validation

Simulating the dynamics of land use on the horizon (2050) requires first the calibration of the model previously constructed with known data. For this, the image of 2019 being the most recent, was retained. It will be the subject of a first simulation-test, calibrated by two earlier dates (1986 and 2002). The images from 1986 and 2002 are used as a basis for extrapolating the states of future land use. This is a linear extrapolation, as the simulation is based on two points in time to calibrate the model. According to [21], calibration is the estimation and adjustment of the parameters and constraints of the model in order to improve the fit between the outputs of the model and a set of data. This step is fundamental, because the quality of the results obtained will depend on the correct configuration of the model. For validation, the result of the 2019 land use simulation is compared to the 2019 land use map resulting from the classification.

4. Results and Discussion

4.1. Results

The overall evolutionary trends observed in the dynamics of land use from 1986 to 2019 are represented by **Figure 2** and **Figure 3**. Analysis of these figures indicates a decrease in the surface areas of water and forests, which respectively go from 0.63% to 0.29%; from 76.22% to 6.73%, and an increase in the areas occupied by degraded forests, built-bare ground and crops and fallows, which rose respectively from 18.73% to 26.27%; from 1.87% to 7.95% and from 2.56% to 58.76%.

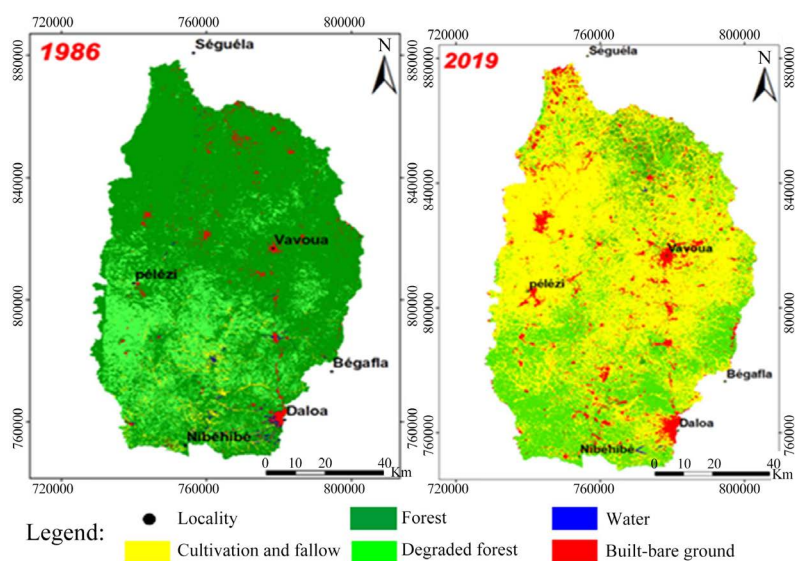


Figure 2. Land cover and land use maps from 1986 and 2019.

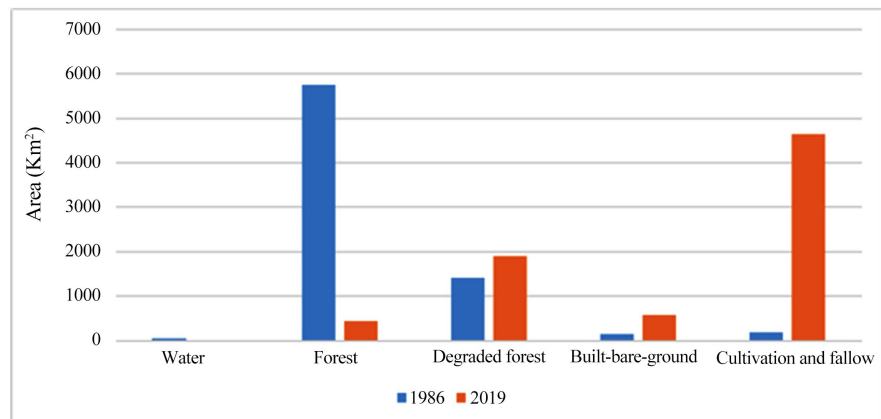


Figure 3. Global evolution of land cover and land use class areas between 1986 and 2019.

The rates of variation of the different classes of land cover observed over the whole of the study period (1986-2019) are shown in **Table 3**.

Analysis of this table shows that annual decreases of 12.53% and 14.93% were observed for water areas and forest areas respectively. We also note an annual average increase of 1.83% and 9.48% respectively in the areas of degraded forests and built-bare ground as well as a strong annual average increase of 21.98% in the areas of crops and fallows of the study area.

For the calibration, a transition probability matrix was produced using land cover classes between 1986 and 2002 in order to use it as a basis in the projection of land cover in 2019 (**Table 4**). The matrix indicates the probability that each category has in 2002 of migrating to another category or of remaining stable in 2019.

From the analysis of this table, we notice an overall stability with a maximum for bare buildings and crops and fallows. For the calibration of the model, the land cover map simulated in 2019 was validated by comparing it to the land cover map of 2019 resulting from the classification as shown in **Figure 4**.

The comparative analysis of the simulated land use and that observed in 2019 made it possible to develop the confusion matrix represented by **Table 5**. This analysis shows that the simulation predicted 0.19% of water surfaces, 6.09% of forest areas, 25.89% of degraded forest areas, 7.96% of built-bare ground and 59.87% of cultivated and fallow areas.

After calibrating the model and assessing its validity, it was interesting to examine the structure and trend of the change at a later date (2050). The prediction of land use in 2050 was made on the basis of the transition between land use in 2002 and 2019. The result of the land use forecast for the year 2050 is shown in **Figure 5**.

The visual analysis of the result of this simulation indicates that crops and fallow land and bare buildings will have a very high growth rate. Degraded forests will experience a strong decrease towards their disappearance. Forests and water will be disappearing as shown in **Figure 6**.

The land use simulation indicates an increase in built-bare ground and areas

of crops and fallow respectively from 7.95% to 30.27% and 58.76% to 61.50% over the period from 2019 to 2050, while water, forests and degraded forests will experience a decrease, respectively, of up to 0.05%, 1.01% and 7.17% over the same period.

4.2. Discussion

The analysis of the dynamics of land cover and land use brought out the different evolutionary processes that took place within the landscape during the period from 1986 to 2019.

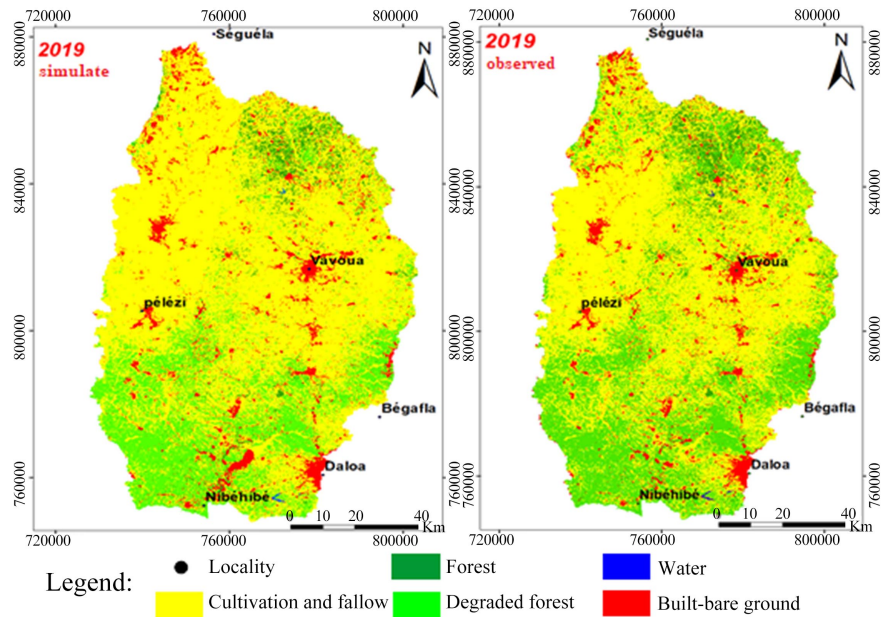


Figure 4. Simulated and observed land cover and land use maps of 2019.

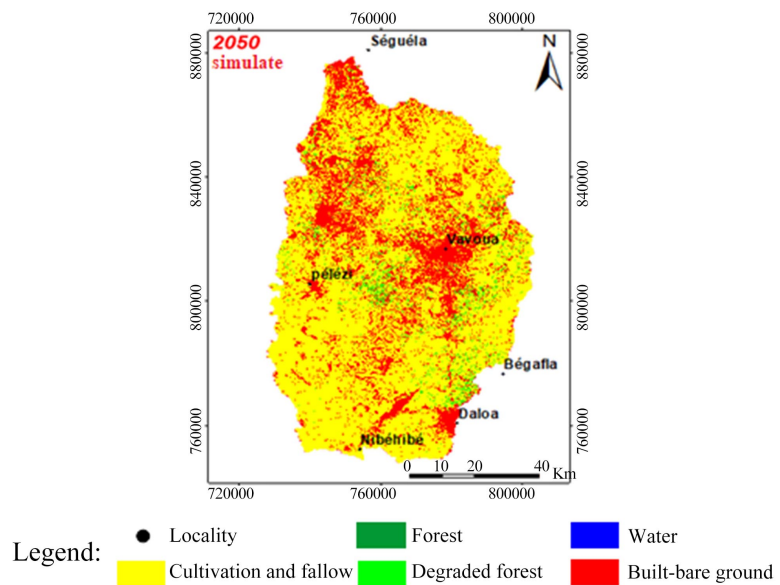


Figure 5. Simulated land cover and land use map for the year 2050.

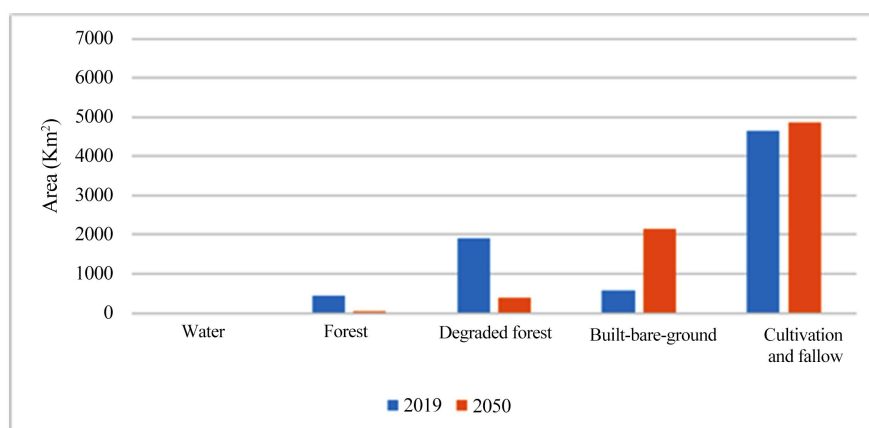


Figure 6. Evolution of areas of land cover and land use classes between 2019 and 2050.

Table 3. Rate of change of land use classes between 1986 and 2019.

Land use classes	T_g (%)	T_c (%)
Water	-92.48	-14.93
Degraded forest	33.85	1.83
Built-bare ground	310.15	9.48
Cultivation and fallow	2303.65	21.98

Table 4. Transition probability matrix for the 2019 simulation.

2002 1986	Water	Forest	Degraded forest	Built-bare ground	Cultivation and fallow
Water	0.3496	0.041	0.2086	0.1043	0.2966
Forest	0.0011	0.3452	0.3042	0.0104	0.2392
Degraded forest	0.0052	0.0045	0.5452	0.1367	0.3085
Built-bare ground	0.0081	0.0077	0.0172	0.623	0.3441
Cultivation and fallow	0.008	0.0071	0.0305	0.1303	0.8314

Table 5. Confusion matrix between observed and simulated land use in 2019.

2019 Simulate 2019 Observed	Water	Forest	Degraded forest	Built-bare ground	Cultivation and fallow
Water	2.299	0.01	0.05	1.23	0.81
Forest	0.1	238.18	3.82	3.82	173.91
Degraded forest	0.03	54.49	1318.1	20.3	425.62
Built-bare ground	0.01	0.18	0.68	511.04	46.94
Cultivation and fallow	0.01	4.75	53.04	86.58	4254.15
Prediction (%)	0.19	6.09	25.89	7.96	59.87

Overall accuracy: 87.11%; Kappa coefficient: 0.75.

In the Lobo River Watershed upstream of Nibéhibé, rainfall has been decreasing like the African humid tropics since 1960 as observed by [22]. This decrease in rainfall could explain the decrease in water surfaces observed in the study area, which fell from 0.63% in 1986 to 0.29% in 2019. The increase in the area of degraded forests, which went from 18.73% in 1986 to 26.27% in 2019, comes from forest deforestation. Agriculture and bush fires, practiced in an anarchic manner in the area, lead to a sharp increase in cultivation and fallow areas, which rose from 2.56% in 1986 to 58.76% in 2019 and largely contribute to the reduction of forest surfaces and depletion of flora. There is also an increase in built-bare ground which went from 1.87% in 1986 to 7.95% in 2019, due to the increase in the population as predicted by the [23]. Indeed, after one or two years of food crops, the peasants abandon the cultivated plots to colonize new, more fertile forest lands, leaving the former fallow in order to restore their fertility.

The assessment of food crops in the Vavoua zone over three years (2014, 2015 and 2016) with statistical data provided by the Ministry of Agriculture, gives evolving results in terms of cultivated area in hectares in said zone. The results obtained from this evaluation confirm those obtained in our work. The fact that the Vavoua area is heavily dominated by crops can be explained by the strong anthropogenic pressure in the production of food crops with an extensive cultivation method.

The results of the 2019 and 2050 simulations show the same trends in the evolution of land cover and land use. Built-bare ground and crops and fallows are expected to grow considerably to the detriment of forests.

The simulated land cover and land use of 2050 indicates an increasing trend in built-bare ground, crops and fallows and a decrease in forest areas. This induces an increase in agricultural land and a loss of natural vegetation. This trend could be explained by human pressures and the increase in population density. Indeed, projections made according to [23] predict a population increase of 2.7%. In densely populated regions, all available space will be converted to agriculture in the near future. This will result in a high rate of deforestation in these areas and, the small forests areas remaining will certainly be converted into agricultural land. However, the best way to slow the rapid changes in land use is to propose a method of managing bush fires and an adapted intensification of agricultural production, *i.e.* an increase in yield per unit of land area, accompanied by sustainable planning of land use.

5. Conclusions

In the light of this work, we note that the processing of the images made it possible to analyze the dynamics of land cover and land use between the years 1986, 2002 and 2019 and to predict the state of land cover and land use in 2050.

The study of the dynamics of land cover and land use has shown that the Lobo River Watershed upstream of Nibéhibé has dynamic environments undergoing strong change. The ecological balance of the forest areas has been seriously dis-

turbed by human activities. Map results indicated increasing deforestation rates. This reduction in forest areas has benefited agricultural communities which are constantly conquering new forest lands. The simulation of land cover by the CA-Markov model predicted land cover for the years 2019 and 2050 with an accuracy of 87.11%. It shows that the current trends of decrease in forest area and expansion of crops will continue in the future.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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