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Modelling the dynamics of land cover by 2050 in the north-western Atacora (Benin, West Africa)

Pocoun Damè Kombienou [1,*], Ousséni Arouna [2,3] and Ismaëla Imorou Toko [3]

[1] *National Institute of Agricultural Research of Benin (NIARB), Cotonou, Benin.*

[2] *Laboratory of Geosciences, Environment and Applications, National University of Sciences, Technologies, Engineering and Mathematics, Abomey, Benin.*

[3] *Cartography Laboratory (LaCarto), University of Abomey-Calavi, Abomey-Calavi, Benin.*

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Abstract

In the north-western Atacora region, the rugged terrain limits access to agricultural land and creates a particular dynamic of land cover. The objective of this research is to simulate land cover in the 2050s in the mountainous area of northwestern Atacora in Benin. Landsat 5 TM images from 1988 and Landsat 8 OLI-TIRS from 2020 are the main data used. Supervised classification and modelling were performed with Idrisi Selva software. The annual regression rate is 18.30 % and the projection to 2050 predicts the disappearance of dense dry forests and a reduction of forest galleries and woodlands in favour of field and fallow mosaics (56.03 %) and tree and shrub savannas (25.23 %).

Keywords: Atacora; Dynamics; Land Cover; Modelling; Vegetation

1. Introduction

The evolution of natural formations is increasingly critical due to deforestation, overgrazing, overexploitation of fodder resources, wildfires and cultivation techniques [1; 2]. In Benin, the destruction of natural resources is progressing at a rather worrying rate. In 1991, it was estimated that an average of 100000 hectares of natural vegetation were destroyed annually for cultivation [3]. Cultivation practices lead to the destruction of natural vegetation types [4]. Producers have not found a balance between their production systems and the exploitation of space. Thus, their environment remains the main agent of the regressive evolution of vegetation types through agricultural activities and forestry operations [5]. Vegetation types are subject to permanent pressures linked to anthropic activities [6].

Producers therefore occupy the mountain slopes of the Atacora chain, which are their last resort and which are increasingly subject to natural and anthropogenic degradation [7]. Areas sown to cotton have increased from 340 hectares in 1993 to 31,647 hectares in 2013 in the northwestern region of Atacora, an average increase of 3.131 hectares per year [8]. Benin's agriculture is made up of about 400000 small farms whose average surface area varies between 0.5 and 2 hectares. In general, the agricultural production of these small farms is growing at the same rate as the population, i.e. 3% per year [9]. The vegetation of north-west Benin is characterised by its fragility and its advanced state of degradation. It undergoes continuous regression, resulting from the actions it experiences, notably clearing, fires due to late vegetation fire practices, overgrazing and the increase in cultivable areas [10]. Slopes and wind facilitate the spread of fire, especially during the dry season from November to May [11]. Land cover in northwestern Atacora is strongly characterised by a mosaic of crops and fallow land, saxicolous tree and shrub savannahs and settlements in the valleys. Gradually, the rural landscape has been shaped naturally by the needs of soil cultivation. Cereal crops occupy a large part of the land in Benin and indeed in West Africa.

* Corresponding author: Pocoun Damè Kombienou

Institut National des Recherches Agricoles du Bénin (INRAB), 01BP 884, Cotonou, Benin.

As far as the Atacora chain is concerned, the particularity of its mega-biodiversity gives it an important place in Benin and therefore requires appropriate measures for its sustainable management [12]. The area is under strong pressure on natural plant resources, especially forest resources, due to human activities, particularly agricultural activities. This justifies the choice of the theme: ''Modelling the dynamics of land cover by 2050 in the north-west of Atacora (Benin)''. The aim of this research is to analyze the future of vegetation and other land-use units with regard to the recent evolution of agricultural areas, its current state and the factors of change by 2050 in northwestern Benin.

2. Material and methods

2.1. Study area

The study area is located in the northwestern part of the Republic of Benin between 9°50'59'' and 12°22'11'' North latitude and between 0°58'38'' and 3°13'20'' East longitude (Fig. 1). This area has a surface area of approximately 15076 sq.km, and is home to an estimated population of 480835 inhabitants in 2013 [13]. There are generally two types of seasons in the Atacora region: the dry season and the rainy season. The dry season comprises two periods, the harmattan period (November to February), the hot season (March to April) and the rainy season, which runs from May to October.

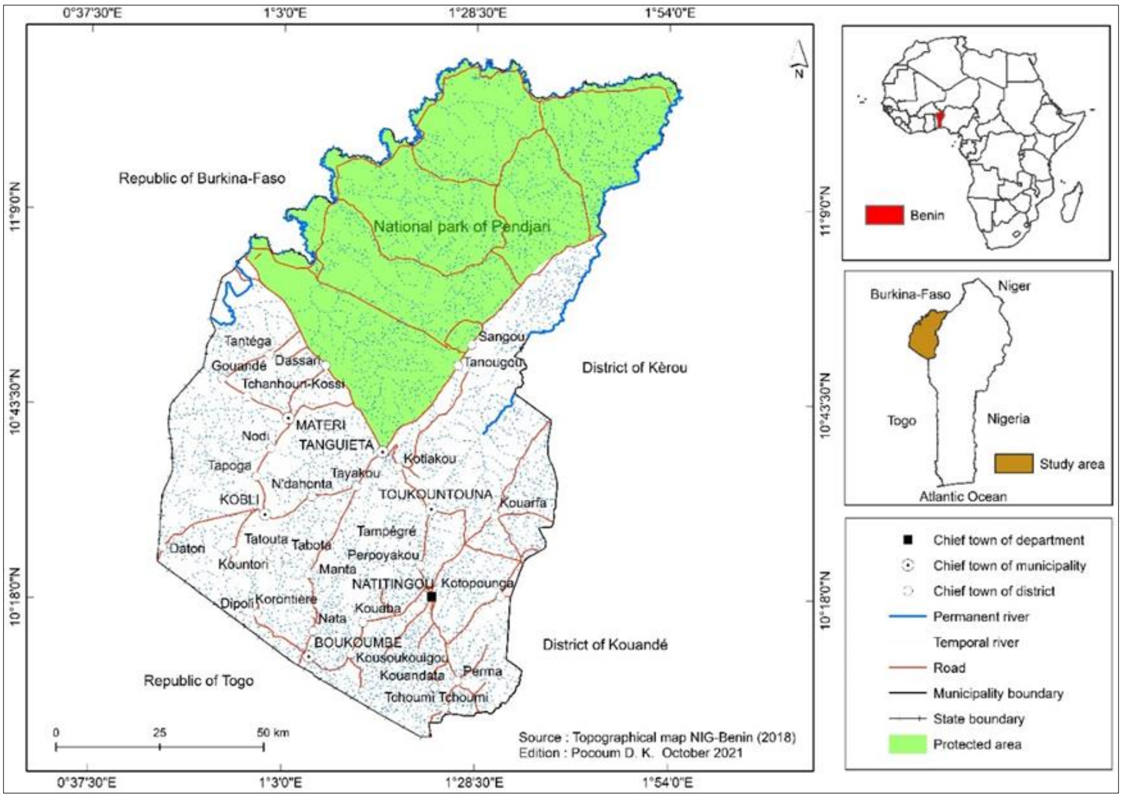


Figure 1 Location of the study area

2.2. Methods

2.2.1. Input data of modelling land cover dynamics to 2050

Two types of data were used. The first type consists of two Landsat satellite images of the study area :

- a Landsat 5 TM satellite image in Geotiff format, dated 13/01/1988, with a spatial resolution of 30 m, obtained from the GLCF/USA website
- A Landsat 8 OLI-TIRS image in Geotiff format, dated 09/12/2020, with a spatial resolution of 30 m, obtained from the EarthExplorer-USGS.GOV/USA website.

Both images were taken during the dry season when the research area is not covered by clouds. The images taken during sunny periods show a very good contrast between the different details, especially those related to vegetation and other aspects.

The second category of data, known as complementary data, consists of a topographic map at 1/50000 published by the National Geographic Institute (IGN) of Benin in 2018.

2.3. Data processing method

2.3.1. Multi-spectral maximum likelihood classification

Pixel-based classification is a process of grouping pixels in an image into a limited number of classes. If the pixel satisfies a set of criteria, it is assigned to the class that matches these criteria. Supervised classification was chosen because of the knowledge of the research area. In this case, training plots (ROI) which are homogeneous groupings of characteristic pixels (samples) of a given land cover were delimited. On the training plots, the software (IDRISI Selva) classified each image according to the parametric algorithm Maximum Likelihood. This is a very commonly used algorithm as it is generally the most efficient. Its use assumes that the distributions of the reflectance values of the training plots are normal. This classification algorithm calculates a multidimensional probability function that determines the probability of each pixel belonging to one of the categories corresponding to the spectral signatures. The advantage of this algorithm is that it provides a certainty index related to this choice for each pixel, in addition to the class to which it has been assigned. To obtain a classification with less confusion, it is recommended to take a maximum of training areas per class. When constructing the training plots, the number of samples selected was limited to 10 for each class.

2.4. Evaluation of the classification

A classification is not complete without an assessment of its accuracy. Indeed, one cannot use remotely sensed data with certainty if one does not know the statistical level of error associated with it. The evaluation of the results of a classification is done by comparing the classified image with reference data (aerial photographs, maps or field surveys). These evaluation areas were surveyed with the same care as the training areas. The values of the classified image were compared with those of the terrain in a double entry table commonly called a contingency matrix or confusion matrix. The number of areas in the table is plotted according to their membership of the different classes in the classified image (in rows) and in the field (in columns). The well classified areas are located on the diagonal of the matrix and the errors outside. There are two types of errors: errors of omission and errors of confusion (or ''commission''). An error of omission is an observation that should have been classified in B, but was "forgotten" and classified in another class. An error of confusion is an observation that is classified as a B when it should have been classified in another class, there is confusion.

In the present research, field surveys were used for this validation. Thus, the confusion matrices of the 1988 and 2020 classification were calculated from the spectral signatures in the IDRISI Selva software.

2.5. Errors of commission and omission and indices of class purity, map validity and classification accuracy

The confusion matrices were used to calculate errors of omission (EO), errors of commission (EC), class purity indices (CPI) and map validity indices (CVI). The omission errors (in column) were obtained by taking the ratio (of the number of well classified pixels in each land cover unit) and the total number of pixels in the said unit. While the errors of commission (in rows) were also obtained by the same procedure, but here at row level. The map validity indices were obtained by subtracting the omission errors from 100%. The class purity indices are obtained by subtracting the errors of commission from 100%. The accuracy index (I) of the classification of the images of these two periods was calculated from the values of each confusion matrix, using the following formula [14 ; 15 ; 16]:

$$\boldsymbol{I} = \sum_{\boldsymbol{i=1}}^{\boldsymbol{k}} (\boldsymbol{x_i})/\boldsymbol{X} \dots \dots .. (1)$$

with $\boldsymbol{x_i}$: Number of observations on the diagonal for class *i*; X: Total number of observations for all classes.

If I ≥ 0.9 (i.e. 90%), then the interpretation is correct [15].

For this research, the results of this index obtained are 91% for 1988 and 95% for 2020 *respectively.*

2.6. Statistical analyses of state changes

2.6.1. Transition matrix

The development of the transition matrix was inspired by the work of [17]. It allows us to highlight the different forms of conversion that the vegetation formations underwent between two snapshots. It consists of X rows and Y columns. The number of rows in the matrix indicates the number of vegetation formations at time t0; the number Y of columns in the matrix is the number of vegetation classes converted at time t1 and the diagonal contains the areas of vegetation formations that remained unchanged. The transformations are therefore carried out from the rows to the columns. The areas of these different vegetation classes were calculated from the intersection of the vegetation maps of two dates using the Tabulate Area function in the ArcToolbox of ArcGIS 9.3.

2.6.2. Annual average rate of spatial expansion

The annual average rate of spatial expansion expresses the proportion of each natural vegetation unit that changes annually. This annual rate (Ta) is calculated from the following formula:

$$Ta = (\mathrm{S2} - \mathrm{S1})\ \mathrm{x} \frac{100}{\mathrm{S1\ x\ (t2 - t1)}} \dots \dots \dots \dots (2)$$

With S1 is the area of a vegetation unit at date t1, S2 is the area of the same vegetation unit at date t2 and t is the number of years between t1 and t2.

2.6.3. Conversion rate

The conversion rate of a vegetation class is the degree to which that vegetation class has changed by converting to other classes. It is therefore the amount of change observed in a vegetation class between two dates t0 and t1. It thus measures the degree of conversion of a vegetation formation into other land-use units. It is obtained from the transition matrix according to the formula :

$$\mathrm{Tc} = (\textstyle\sum \mathrm{ST} - \mathrm{Ss})/(\textstyle\sum \mathrm{ST}) \dots \dots .(3)$$

WithTC the conversion rate, ST the areas of land-use units resulting from the conversion of a vegetation formation, Ss the area of the same vegetation formation remaining stable at date t1.

2.6.4. Intensity and speed of change between 1988 and 2020

In the present research, two analysis programs (Pontius Matrix 22 and intensity analysis 02.xlms) by [18], were used to measure (%) intensities of change by time intervals, categories and transitions between land cover categories.

The first program used the transition matrix from 1988 to 2020 to generate a graph showing the said intensities by time intervals. The graph shows the intensity and rate of change of land cover units between 1988 and 2020. At this level, the state of speed of change is determined by the vertical blue dashed line, called the uniform area line. If the graph is to the left of this line, or the changes would stop if the disturbances did not continue, the change is said to be slow (or dormant). But if it is to the right of this line, the change is fast (or active).

The second programme, using the transition matrix, also generated statistics for the changes in time intervals between each land cover category and the others. The same is true for losses and gains during transitions between units.

2.7. Predictive land-use modelling

Spatial modelling of vegetation evolution requires the use of software capable of taking into account the analysis of non-linear evolutionary trends by integrating change factors [17]. It aims to determine how formations will look in physiognomic terms.

2.7.1. Principle of predictive modelling

There are several modelling methods and tools, among the most widely used and/or disseminated are: CA_MARKOV on [19 ; 20 ; 21], Land Change Modeler used in ArcGIS [17] and Land Change Modeler available on [19]. In this research, the IDRISI Selva Land Change Modeler (LCM) was used.

The literature review of works based on simulation tools [22 ; 23 ; 24 ; 25]. This is broken down into four stages in the operation of the models:

- a non-spatial procedure that estimates the quantities of each transition;
- a spatial procedure that determines the probability of changes.
- a spatial component that distributes the changes in space;
- possibly a spatial module that reproduces the characteristics of the landscape.

2.7.2. Modelling inputs

The 1988 and 2020 vegetation maps were the basic inputs. The variables used are: distance to protected areas, distance to water courses and water points were taken into account.

2.7.3. Estimating the amount of change

With Land Change Modeler (LCM), the amount of change is calculated using the Markov chain, synthesised in the form of a transition matrix, usually obtained by comparing land cover and land cover maps at two different dates [17]. The transition matrix between 1988 and 2020 obtained by superimposing the two land cover maps, indicates the area (or number of pixels) for each transition. This matrix was transformed into a transition probability matrix that allowed the projection to 2050. The number of iterations obtained is 10000 with an accuracy of 89%. The annual transition probabilities are obtained by a simple linear correction of the transition probabilities. This correction consists of reducing the highest probabilities (probabilities greater than or equal to those of the permanence transitions) in proportion to the error and modifying the other probability values so that the sum of the columns is equal to 1.

2.7.4. Assessment of the probability of change

The probability of change depends on the distribution of biophysical and socio-economic variables that influence LULCC. The most commonly used variables are slope, distance to roads and settlements, soil types. The probability of occurrence of a given transition type (LULCX to LULCY) can be defined through two slightly different approaches: the determination of the suitability of a site for a type of land cover and occupation or the calculation of the probability of transition types. The LCM model calculates the probability of each transition. These data, rendered in the form of maps, are produced from the relationship between the explanatory variables and the transitions observed between 1988 and 2020. This map illustrates the importance and location of these transitions. Thus, it will be used to draw up the predictive map.

2.7.5. Spatial change allocation procedures

Change allocation is a decision process that selects the pixels that will undergo change from the change probability maps or suitability maps. Considering that it is the sites most likely to change that actually change, LCM selects the pixels with the highest probability values. As there is usually competition between different transitions (the same site can be a candidate for different transitions), LCM uses a multi-objective assignment procedure based on the probabilities of the different land cover types and the amount of change calculated previously.

2.7.6. Simulation of spatial and temporal dynamics of land cover and land cover changes

The simple selection of pixels with a higher probability of change (without cellular automaton) does not lead to the reproduction of plausible spatial patterns. LCM tends to favour areas in direct proximity to the road for LULC 2 and those at the same altitude for LULC 3. For the LULC 2 class, the effect of using continuous variables to characterise the influence of distance to the road is very clearly observed. CLUE shows a similar result but favours LULCC to LULC 3 in altitude due to logistic regression. The use of restriction or incentive zones allows the probability of change to be adjusted for certain management policies that cannot be derived from the explanatory variables. LCM allows the use of restriction or incentive zones at one or more user-defined time step(s) during the simulation.

2.7.7. Evaluation of simulations

In general, the evaluation of the models is based on the comparison between the simulated map and a map of the actual observed situation (real map). The evaluation can concern the probability of change map(s) (also called "soft classification") or the maps of future land cover and occupancy. In the first case, the probability of change map (continuous values) is compared with the real map (categorical values). In the second case, the simulated and real maps are compared. IDRISI Selva offers a way to evaluate the results of the simulation for each case:

- the ROC (Relative Operating Characteristics) method [26 ; 27];
- the Kappa index. But the evaluation of the logistic regression analysis is usually based on an ROC analysis performed in another software.

It should be noted that the evaluation methods are all oriented towards assessing the spatial coincidence between simulated and observed changes. This approach may bias the evaluations towards an overestimation of the methods that assign the changes to the pixels with the highest values of change probabilities. This is because the reproduction of spatial patterns in the landscape is at the expense of spatial coincidence. For applications in which the simulation of spatial landscape patterns is important, it is recommended to evaluate this aspect, for example using fragmentation indices [28]. IDRISI Selva allows the calculation of different indices.

3. Results

3.1. Land cover dynamics between 1988 and 2020

Spatio-temporal changes in land cover units in northwest Atacora were assessed through the land cover maps of 1988 (Figure 2) and 2020 (Figure 3).

Examination of the 1988 land cover map in northwest Atacora allowed us to distinguish 7 land cover classes (Figure 2), consisting of gallery forests found along the main rivers and their tributaries, open forests and wooded savannahs found mainly in the Pendjari National Park, saxicolous savannahs found on the hills, and tree and shrub savannahs constituting the landscape matrix of the environment in terms of their extent. Open forests and wooded savannahs and tree and shrub savannahs dominated the landscape in 1988. Crop mosaics and fallows were poorly represented, as were plantations found only in the terroirs of Matéri. Settlements were scattered along roads and around water points (Figure 2).

In 2020, the physiognomy of the north-western Atacora region is dominated by mosaics of fields and fallows (Figure 3). The forest galleries are in tatters along the main rivers and their tributaries. The open forests and wooded savannahs are fragmented. Saxicultural savannahs have also decreased in size, leading to an increase in rocky areas. Plantations can be observed in the areas of Matéri, Tanguiéta, Kotiakou and Natitingou. Settlements are developing along roads and around water points (Figure 3).

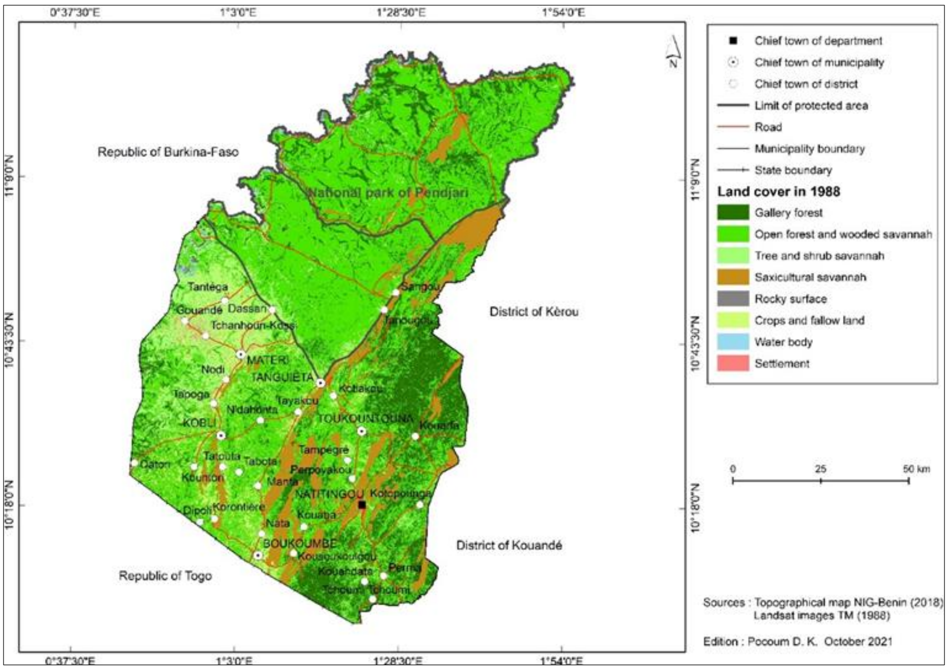


Figure 2 Land cover in northwest Atacora in 1988

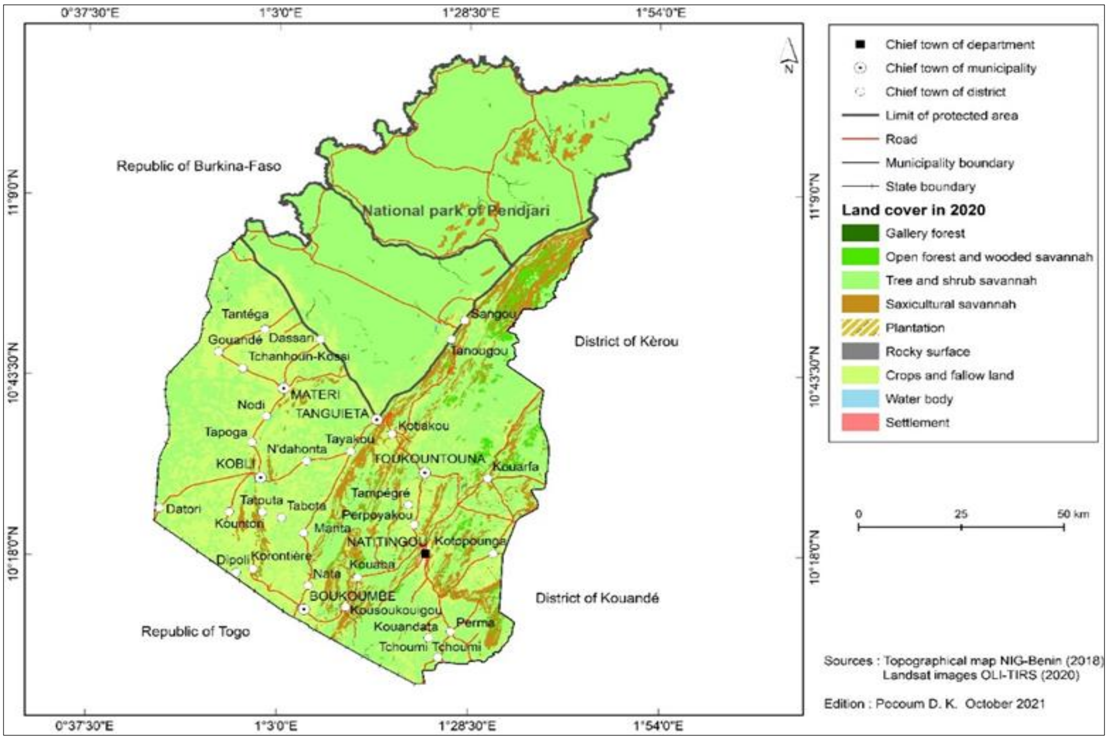


Figure 3 Land cover in northwest Atacora in 2020

The dynamics of land cover in northwest Atacora between 1988 and 2020 showed a strong anthropisation of natural ecosystems. The conversion of vegetation formations and other land cover units between 1988 and 2020 was summarised by the transition matrix (Table 1).

Table 1 Transition matrix of plant formations and other land cover units between 1988 and 2020

Units in 1988	Units in 2020									Area in 1988 (sq.km)
	FG	FCSB	SAA	SS	PE	PL	SR	MCJ	AGG	
FG	113.53	0	0	0	0	0	0	2327.69	0	2441.22
FCSB	0	274.32	4272.75	0	0	4.1243	0	1550.21	12.41	6113.82
SAA	0	0	478.84	0	0.51	6.03	0	503.83	19.73	1008.93
SS	0	0	0	954.35	0	0	1.025	0	0	955.37
PE	0	0	0	0	70.22	0	0	0	0	70.22
SR	0	0	0	0	0	0	82.77	0	0	82.77
MCJ	0	0	0	0	0	0	0	736.98	108.2	845.18
AGG	0	0	0	0	0	0	0	0	70.99	70.99
Area in 2020 (sq.km)	113.53	274.32	4751.59	954.35	70.73	10.15	83.80	5118.71	211.33	11588.49

FG: gallery forests; FCSB: open forests and wooded savannahs; SAA: tree and shrub savannahs; SS: saxicultural savannahs; SR: rocky surface; MCJ: Crops and fallows land; PE: water body; AGG: Sittlement

The area of natural forest formations (gallery forests, open forests and wooded savannahs) has decreased significantly from 8555.04 sq.km in 1988 to 387.85 sq.km in 2020 (Table 1). A significant part of these forest formations has been transformed into field and fallow mosaics (3,877.91 sq.km) and tree and shrub savannahs (4,272.75 sq.km) in 2020. In 2020, open forests and wooded savannahs are only present in village lands on marginal lands unsuitable for agriculture.

3.1.1. Gallery forest dynamics

From 1988 to 2020, the area of gallery forests was reduced by 95.12% of their original area. The transition matrix analysis showed that 2327.69 sq.km of gallery forests were converted into field and fallow mosaics (Table 1). An area of 113.52 sq.km remained unchanged between 1988 and 2020.

3.1.2. Dynamics of open forest and wooded savannah

From 1988 to 2020, the area of open forest and wooded savannahs decreased from 6113.82 sq.km to 274.32 sq.km. The conversion rate was 95.30%. The analysis of the transition matrix indicated that 274.31 sq.km of the area of this vegetation formation remained stable (Table 1); however, the remainder was transformed into tree and shrub savannahs (4,272.75 sq.km), urban areas (12.40 sq.km), crop and fallow mosaics (1,550.21 sq.km) and plantations (4.12 sq.km). Thus, open forests and wooded savannahs were only present in the village territories on marginal lands. On the other hand, in the Pendjari Biosphere Reserve, these plant formations were still present.

3.1.3. Dynamics of tree and shrub savannas

The conversion rate of tree and shrub savannahs between 1988 and 2020 was 9.66%. Examination of the transition matrix (Table I) showed that 503.82 sq.km of tree and shrub savannas were converted into field and fallow mosaics (503.83 sq.km) and into settlement (19.73 sq.km) and plantation (6.02 sq.km).

3.1.4. Average annual rate of spatial expansion and rate of conversion of land cover units from 1988 to 2020

The changes in the annual average rate of spatial expansion and the rate of conversion of land-use units are shown in Table 2.

Table 2 Average annual spatial expansion rate and land cover unit conversion rate from 1988 to 2020

Units	Area in 1988 (sq.km)	Area in 2020 (sq.km)	Ta (%)	Tc (%)
FG	2441.22	113.53	-2.979	95.12
FCSB	6113.82	274.32	-2.984	95.30
SAA	1008..93	4751.59	11.592	9.66
SS	955.37	954.35	-0.003	930
PE	70.22	70.73	0.022	0
PL	0.00	10.15	0	0
SR	82.77	83.80	0.038	0
MCJ	845.18	5118.71	15.801	581.11
AGG	70.99	211.33	6.178	0

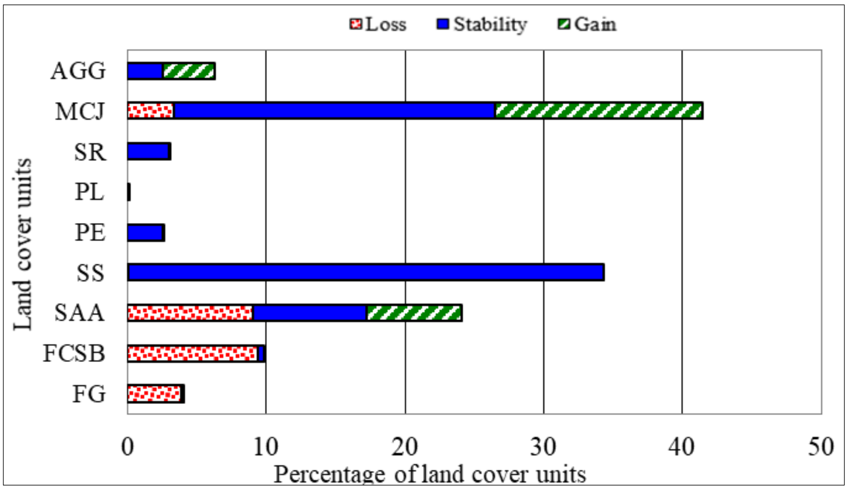
FG: gallery forests; FCSB: open forests and wooded savannahs; SAA: tree and shrub savannahs; SS: saxicultural savannahs; SR: rocky surface; MCJ: Crops and fallows land; PE: water body; AGG: Sittlement

Field and fallow mosaics expanded the most with 15.80% and a conversion of 581.11% from 1988 to 2020 (Table 2). Tree and shrub savannahs expanded by 11.59% and converted by 9.66%. Settlements expanded by 6.17%. Gallery forests and open forest and wooded savannahs show the highest rates of conversion; these formations have also experienced a regression in area with spatial expansion rates of about 2.9%.

3.2. Intensity of change per unit of land cover from 1988 to 2020

The intensity of change per unit of land cover between 1988 and 2020 is presented in Figure 4.

The intensity of change per unit of land cover is not proportional between 1988 and 2020 (Fig. 4). Crop-fallow mosaics experienced the greatest change over 41% of the study area with 15% gain, 23% stability and 3% loss. Next, tree and shrub savannahs showed 7% gain, compared to 8% stability and 9% loss, and open forest and wooded savannahs showed no gain, compared to a 9% loss and a stability of minus 1%. On the other hand, gallery forests experienced only a loss of 4% of the study area. Finally, the area of settlements was increased by 4%.

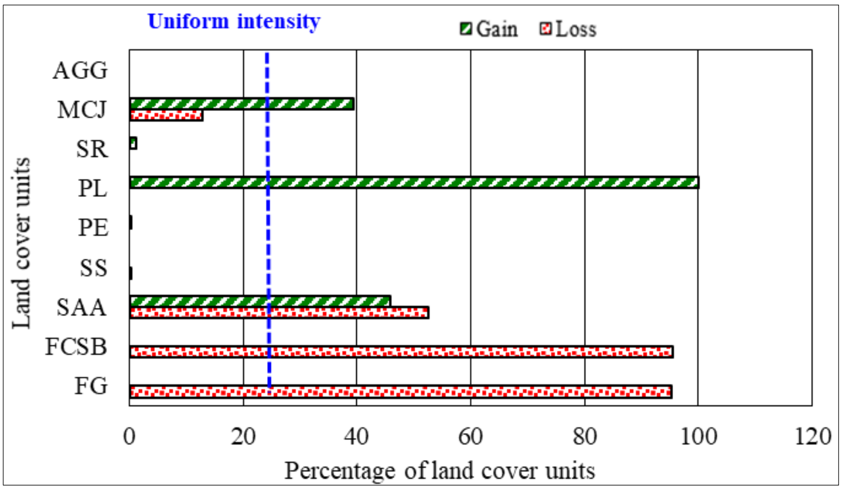


FG: gallery forests; FCSB: open forests and wooded savannahs; SAA: tree and shrub savannahs; SS: saxicultural savannahs; SR: rocky surface; MCJ: Crops and fallows land; PE: water body; AGG: Sittlement

Figure 4 Intensity of change per unit of land cover between 1988 and 2020

3.3. Intensity and rate of change per unit of land cover from 1988 to 2020

The intensity and rate of change of land cover units between 1988 and 2020 are presented in Figure 5



FG: gallery forests; FCSB: open forests and wooded savannahs; SAA: tree and shrub savannahs; SS: saxicultural savannahs; SR: rocky surface; MCJ: Crops and fallows land; PE: water body; AGG: Sittlement

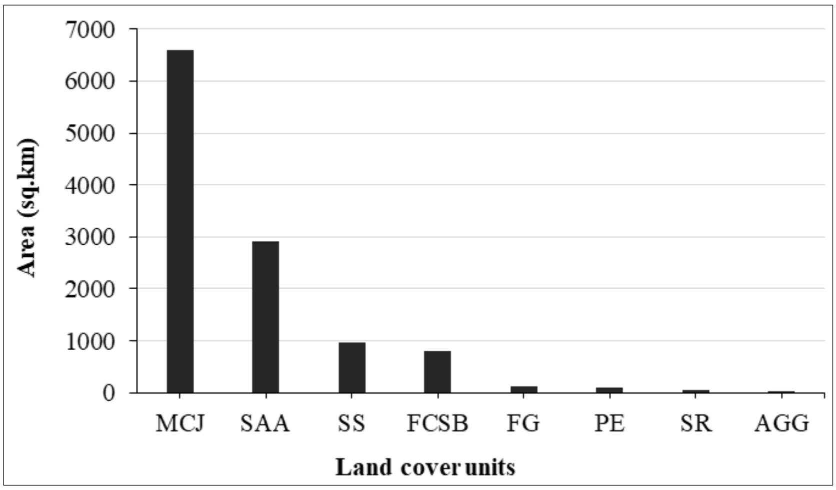
Figure 5 Intensity and speed of change of land cover units between 1988 and 2020

Changes in plantations were rapid with the greatest rate of change in terms of gain over 100% of the study area (Fig. 5). This was followed by field and fallow mosaics and shrub and tree savannahs with gains of 36% and 46% respectively. The changes noted in terms of area loss were observed in natural formations such as gallery forests and open forests and wooded savannahs. These changes are rapid with rates of 95% and 96% respectively.

3.4. Evolutionary trend of land cover units by 2050

The transition probabilities deduced from the 1988 and 2020 land cover maps were used to obtain the likely state of land cover by 2050 (Fig. 6 and 7).

In 2050, the vegetation landscape of northwest Atacora will probably be dominated by anthropogenic formations to the detriment of natural formations. More specifically, field and fallow mosaics will be the most important units with a surface area of 6,606.68 sq.km, i.e. 56.90% of the region, with an average annual spatial expansion rate of 2.29% between 2020 and 2050. Tree and shrub savannahs will follow with an area of 2905.98 sq.km (25.03%), i.e. an average annual rate of regression of 1.01%. The total disappearance of dense dry forests and a significant reduction in the area of gallery forests and open forests and wooded savannahs will also probably be observed. The analysis of evolutionary trends by considering natural and anthropogenic plant formations has made it possible to better identify the specificities (conversion rate, speed and intensity of change) of these different units.



FG: gallery forests; FCSB: open forests and wooded savannahs; SAA: tree and shrub savannahs; SS: saxicultural savannahs; SR: rocky surface; MCJ: Crops and fallows land; PE: water body; AGG: Sittlement

Figure 6 Area of land cover units in northwest Atacora by 2020

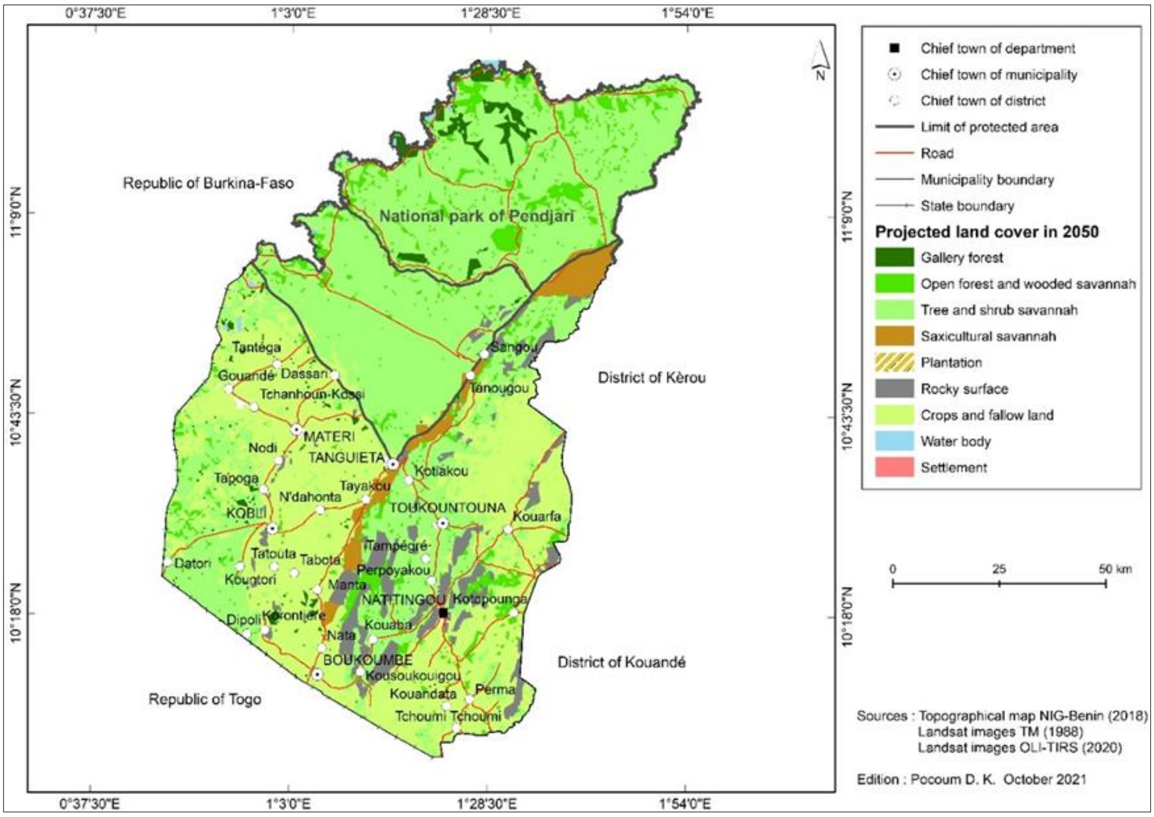


Figure 7 Prediction of land cover units in northwest Atacora by 2050

3.4.1. Evolutionary trend of natural vegetation formations up to 2050

Predictive modelling of land cover by 2050, based on the 1988 and 2020 maps and transition probabilities, suggests that tree and shrub savannahs will increase at the expense of forest formations such as gallery forests, dense dry forests and open forests if current natural resource exploitation practices are maintained. Indeed, tree and shrub savannahs could occupy 25.23% of the total area of the study area in 2050. Saxicole formations are likely to account for 8.23% of the land-use units. Open forest and wooded savannah will cover 7.01% of the total area of the study area. Forest galleries may represent 1.11% of the land-use units and will be located in places along the Pendjari River and its tributaries (Fig. 6 and 7).

3.4.2. Evolutionary trend of anthropogenic formations up to 2050

The anthropogenic formations in the 2050 horizon are likely to be, in order of importance, field and fallow mosaics and settlements (Fig. 6 and 7). Field and fallow mosaics will dominate the vegetation landscape with 56.03% of the total area of the study area. Settlements will cover 0.34% of the total area of northwest Atacora.

4. Discussion

In the research sector, the decline in vegetation cover is perceptible through the expansion of agricultural areas and the development of informal settlements. According to [17], the increase in population and the introduction of industrial crops, notably cotton, have resulted in natural vegetation formations giving way to fields and fallows. Several authors, notably [29] and [30 ; 31], have reached the same conclusion by pointing out the contribution of agricultural activities to the degradation of natural resources. These authors have estimated that slash-and-burn agriculture linked to the development of cotton cultivation is responsible for the dispersion of farmers and the multiplicity of agricultural farms that transform the physiognomy of the terroirs and protected areas.

The various changes in the natural area reflect the importance of agriculture and the various extensions of the villages. The decline in natural formations is due to the pressure of agriculture. Indeed, from 1988 to 2020, a reduction in the area of pastoral spaces was noted, notably the clear forests and wooded savannahs. This situation raises questions for the population and the authorities about the viability of agro-pastoral activities in the study area.

The study area is experiencing severe degradation of plant formations. The factors of this degradation are natural and anthropogenic. [17] has identified the role of anthropogenic activities in the degradation of ecosystems. According to these authors, agriculture is partly responsible for the degradation of natural resources. Furthermore, deforestation during cultivation has effects at several levels. The first negative impact of crop clearing is the loss of vegetation cover.

Agriculture in the study area is dominated by yam and cotton. The negative impacts of cultivation after clearing and deforestation include loss of vegetation cover, soil exposure and accelerated erosion.

All these observations are in line with those of several authors [32 : 20 ; 33;34 ; 31 ; 17 ; 6 ; 4 ; 33] for whom agriculture is the main cause of vegetation cover regression in Benin.

According to the projections and simulations, if the degradation trend continues in 2050, the dense dry forests will disappear in the study area and the landscape matrix will be dominated by mosaics of fields and fallows. This situation will result in the disappearance of habitats, which will lead to a loss of biodiversity, overexploitation of forest reserves, erosion and a drop in soil fertility, and consequently a drop in agricultural yields. This will lead to the impoverishment of the area and the rural exodus of young people to other areas [12]. Taking into account the future of the mountainous region of northwest Atacora must be a priority in natural resource conservation actions in Benin.

5. Conclusion

The dynamics of land cover in northwest Atacora between 1988 and 2020 reveal two major changes after 32 years, namely savannisation with the conversion of dense dry forests and open forests into savannah formations, and anthropisation marked by the transformation of natural formations into mosaics of crops and fallow land and into agglomerations. Predictive modelling of land cover by 2050 predicts a reinforcement of this trend with a strong progression of field and fallow mosaics to the detriment of natural vegetation formations if current practices of exploitation of natural resources are still maintained.

The mountainous region being a fragile area, rapid changes in land cover can generate ecological upheavals with unprecedented socio-economic impacts. Therefore, it is appropriate to set up an integrated management plan for this region based on the results of the present research. Such an operation is the responsibility of the local authorities at the decentralised level with the involvement of the deconcentrated authorities.

Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of interest in the manuscript, as no associate author has contributed to the manuscript.

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