American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)

ISSN (Print) 2313-4410, ISSN (Online) 2313-4402

http://asrjetsjournal.org/

Modeling of Environmental Dynamics Using the SpaCelle Software in the Department of Alibori in Benin (West Africa)

Sabi Séko M. Orou Seko[a]*, Euloge Ogouwale[b], Brice Tente[c]

[a,b]*Laboratoire Pierre PAGNEY : Climat, Eau, Ecosystèmes et Développement (Université d'Abomey-Calavi 01 BP 526, Cotonou 01)*

[c]*Laboratoire de Biogéographie et d'Expertise Environnementale*

[a]*Email: sabiseko1@gmail.com*

Abstract

The natural resources are under heavy anthropogenic pressures caused by an ever increasing demand for the satisfaction of the needs of the population. The aim of this study was to assess future environmental changes taking into account the current land-use dynamics in the Alibori Department. The establishment and the diachronic analysis of the dynamics of the occupation of the grounds, the characterization of the vegetation and the environment of the classified forests from phytoecological surveys, socio-economic surveys, impact assessment methods and predictive modeling carried out under SpaCelle were the main methods used. The assessment of land-use dynamics revealed that the surfaces of woodlands and woodland savannas increased from 35.43 % to 7.29 km^2 from 1990 to 2015. On the other hand, the areas of mosaics of crops and fallows passed from 13.36% to 35.22% from 1990 to 2015. The population growth and the agricultural practices that are not very respectful of the environment were the main factors in this degradation of the vegetation cover. The predictive modeling carried out under SpaCelle from the development of the scenarios makes it possible to deduce that with the scenario of "environmental stability", the area occupied by mosaics of crops and fallows will be 56.56 % against 74.36 % for the scenario of "tendency towards catastrophe" in 2050.

Keywords: Alibori department; dynamics; land use; modeling.

---

* Corresponding author.

1. Introduction

The vegetation cover is constantly subject to increasing degradation despite its undeniable role in the balance of living beings. To this end, the threats that weigh more and more on natural vegetation formations in Benin are linked to the demographic growth and the introduction of industrial crops, which consumes a lot of space [1]. The growing population of cities is above all one of the main causes of this pressure on vegetation cover in Benin [2]. With population growth leading to increased demand for natural resources, there is unfortunately a mismatch between harvesting of wood resources and their rate of renewal [3]. Thus, the development of livestock and agriculture, especially the increase in livestock and the extension of the areas exploited have led to a degradation of natural resources, particularly plant formations [4]. Unlike industrialized countries and highly urbanized countries, apart from the problems of coastal erosion and garbage; the main cause of environmental degradation in Benin is still agriculture [5].

Moreover, many agricultural and forestry operations badly managed by farmers promote environmental degradation [6]. For this purpose, in the cotton zones of Benin (like Alibori which is the basin of the white gold of the country), Slash-and-burn cotton is the most important agricultural practice that forces farmers to clear several hectares each year [1]. Speaking of the most important environmental disturbance factors are agriculture, grazing and wildfires [7, 8, 9]. These factors associated with others cause a loss of about 70 000 ha in the period from 1990 to 2000, an annual loss of 2.3% of Benin's forest cover [10].

However, farmers are primarily responsible, but also the principal victims of environmental degradation [11]. On top of that, the problems of environmental degradation are taken more into account when promoting the technological progress needed to sustainably increase yields and reduce pressures on fragile ecosystems, as in the case of cotton cultivation [12].

Considering all these factors, the Republic of Benin has ratified the Rio de Janeiro Convention on the Conservation of Biodiversity [13]. But the question is whether this has a positive impact on the protection of the environment is a guarantee of sustainable development. The department of Alibori, which constitutes the study area (Figure 1), is the cotton basin in Benin and in turn is subject to a drastic regression of its vegetation cover.

The department of Alibori has a surface of 26 242 km² (23 % of the own territory). It is limited to the East by the Federal Republic of Nigeria, to North by Burkina-Faso and Niger, to the South by the department of Borgou and to the West by the department of Atacora. It comprises six (06) communes: Banikoara, Gogounou, Ségbana, Kandi, Malanville and Karimama and have a total of 229 villages.

The climate is Sudanese with an average temperature of 28°C. The average annual rainfall is of the order of 900 mm. The area has a unimodal rainfall pattern with a rainy season from May to October and a dry season from November to April. The main economic activities are agriculture, livestock and fishing.

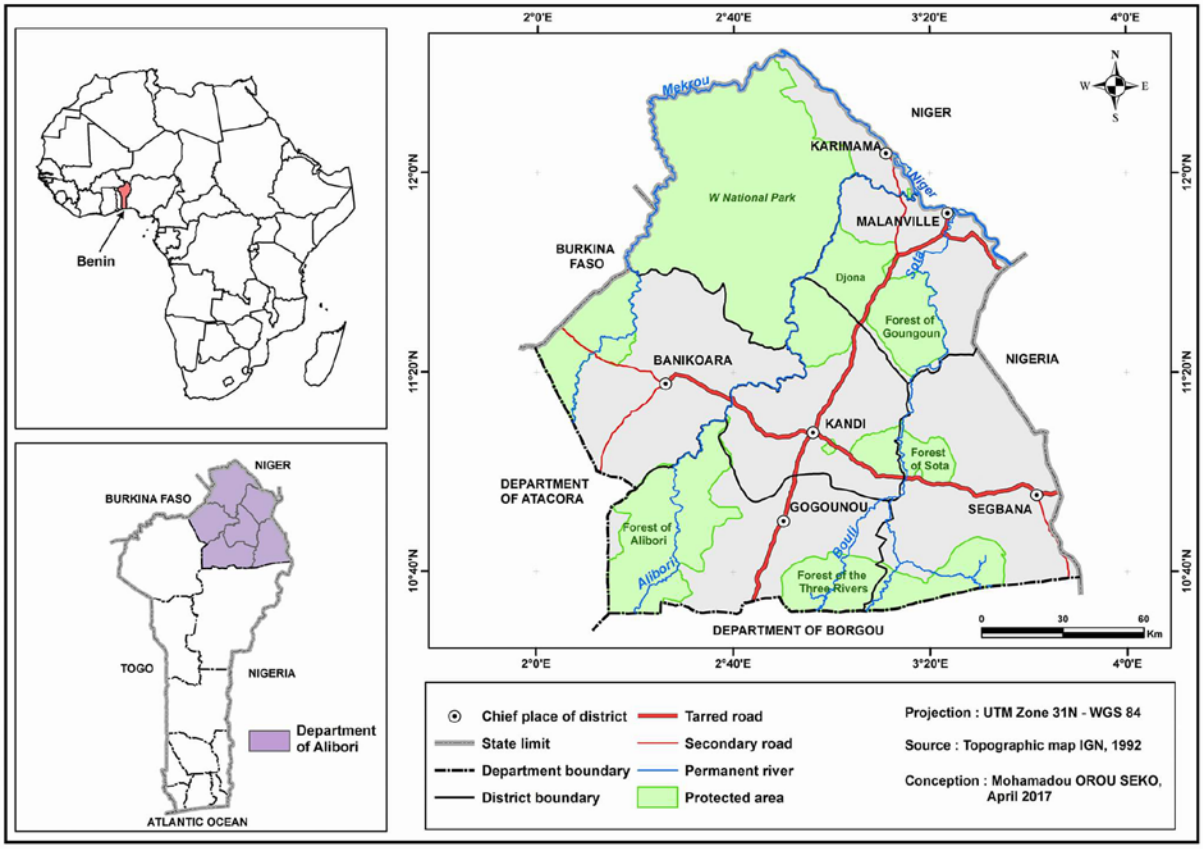

Figure 1: Geographical situation and administrative division of the Alibori department

2. Materials and Methods

The future assessment of land use units is based on the simulation of spatial changes using the SpaCelle model. The predictive model uses two land occupation maps, a current map and an earlier map. In the case of this study, these are the 1990 and 2015 land cover maps. A comparative study of these two maps made it possible to determine the transitions, to quantify the surfaces concerned by each type of transition and to locate these changes. Each type of transition can be explained by known factors, quantifiable and mappable. By linking and combining the explanatory factors and the changes that have occurred between the two original land-use maps, the SpaCelle model will use a statistical method to map probability maps to changes. These probability maps correspond to the selected transitions. The number of probability maps is a function of the number of isolated transitions. These are the first cards provided by the model. Next, the model produces a prospective land-use map for a *tn* date based on the previously completed probability maps. This step performed by a cellular automaton simulates the previously identified changes and allocates them in space.

2.1. Presentation and justification of the choice of the SpaCelle model

The methodology adopted in this study was inspired by the approaches of [14, 15, 16], for the prospective dynamics of land use in Benin. These approaches are revealed to be just and scientifically sustainable. Thus, the land use simulation approach using the SpaCelle model appears to be a major asset for a prospective dynamic of

land use. It is an approach that can be used locally, nationally and regionally.

- ***Presentation of the SpaCelle model: Definition, Data Requirements and validation***

SpaCelle is defined as the Production System of Environmental Cellular Automata [17]. This software was used for the first time in 2001 by [18] for the simulation of surface runoff.

The simulation of land use in the study area required the acquisition of the SpaCelle model Version 5.1.8, a multi-layer spatial (2D) cellular automaton, which operates on the basis of transition rules. It is software of numerical simulation of land occupation units. It makes it possible to make projections of the dynamics of land occupation at a definite horizon (2050 in this case).

The SpaCelle modeling platform makes it possible to build cellular automata by defining:

- ✓ a list of states;
- ✓ different cellular layers, of type with a grid;
- ✓ layers of networks and points vectorial;
- ✓ rules of life and rules of transition.

These four types of elements to be defined condition the accuracy, representativeness and complexity of the modeled territory and constitute the knowledge base of the modeled system.

- ***Justification of the choice of the SpaCelle model, advantages and limits***

SpaCelle is a software package the purpose of which is to answer problems on the evolution of the land use [17]. The choice of this model for the simulation of the evolution trend of the units of environmental occupations of the department of Alibori was dictated by several criteria, the most important of which are:

- ✓ the simplicity of the data required to run the model. This is the same data that was used to analyze the changes in units of occupancy. They include the same series of remote sensing images and the same in the field;
- ✓ SpaCelle is a tool for simulating the dynamics of land-use units that has been adapted and validated in several regions around the world, and the results obtained are reliable and similar to complex models such as CA_MARKOV, DINAMICA, Land Change Modeler ... [15, 14, 19, 20].

It also has limitations because it does not generate moving objects or remote action. It is then necessary to use multi-agent systems, which are a generalization of cellular automata.

- **Scenario of land-use dynamics in the Alibori department**

The scenarios developed in this study are based on assumptions of environmental stability and the tendency towards disaster [21,14].

- **Assumptions of the scenario of "environmental stability"**

The assumptions of this scenario do not take into account any forest and wetland management constraints established in the Forest Sector Foresight Study Papers for Africa [22, 21, and 23]. This scenario is based on the following assumptions:

- agriculture is mechanized with intensive low-area yields adopted by producers;
- the economic situation of the population has improved and the rate of economic growth at the national level is 12.4% [22];
- the share of fuelwood in meeting people's domestic energy needs is reduced by 50% in favor of other energy sources such as domestic gas and the use of crop residues.

- **Assumptions of the scenario "tendency towards the catastrophe"**

The purpose of the "tendency towards the catastrophe" scenario is to provide an overview of land use change in the Alibori Department if nothing changes in terms of the pace of human activities.

In this "tendency towards the catastrophe" scenario, the prospective dynamics of land use are based on socio-economic considerations, ie population dynamics and human activities. This scenario is based on three basic assumptions developed by [14]:

- the extensive nature of agricultural production involves the use of environmentally harmful methods (slash-and-burn farming, uncontrolled deforestation, reduction of fallow periods, predominant monoculture on crop rotation in general, etc.) and continuously degrades ecosystems in general and land in particular [24];
- the population is dependent on the natural resources that are the main source of energy;
- the rate of land-use dynamics remained the same as in the period from 1990 to 2015.

This scenario aims to get a better idea of what the future situation might be, so that it raises awareness among all those involved in sustainable development.

In sum, during the simulation, the input data or model parameters in the case of the "*environmental stability*" scenario will contribute to the achievement of results aiming at an increase in the life of forest ecosystems because human pressures on them will be reduced.

On the other hand, the input data or the model parameters in the case of the "*tendency towards the catastrophe*" scenario will lead to a reduction in the lifespan of the plant formations of the Alibori department by 2050. Indeed, the latter will undergo anthropogenic pressures causing their degradation.

3. Results

These are the results on the vegetation cover evolution between 1990 and 2015 and the projection in 2050.

3.1. State of the occupation of land in 1990 and 2015

The texts governing good environmental management began to appear in Benin from 1990. However, until today the application of these texts is still not fully effective. Nevertheless, although development and application have not automatically contributed to forest restoration, they have still helped to stem the ever-increasing advance of vegetation cover degradation (table 1).

Table 1: Surface of land use units in 1990

Units of land use	Surface 1990 (ha)	Percentage (%)
Waterbody	2500.85	0.09
Swamp	7100.98	0.26
Dense forest	8573.24	0.32
Woodland and savannah woodland	951392.05	35.43
Gallery Forest	99473.89	3.70
Tree and shrub savannahs	11890706.13	46.51
Field mosaic and Fallow	358736.69	13.36
Agglomeration	9054.02	0.33
Total	**2685037.87**	**100**

All of these units experienced changes in 2015 (table 2).

Table 2: Surface of land use units in 2015

Units of land use	Surface 2015 (ha)	Percentage (%)
Waterbody	2444.987	0.09
Swamp	5848	0.22
Dense forest	5845.249	0.22
Woodland and savannah woodland	147789.364	5.50
Gallery Forest	78003.1975	2.90
Tree and shrub savannahs	1478713.925	55.07
Field mosaic and Fallow	945751.984	35.22
Agglomeration	20641.1644	0.77
Total	**2685037.871**	**100**

At 92.45% the area of the department of Alibori is in 1990, occupied by tree and shrub savannahs at 44.04% followed by woodland and savannah woodland at 35.43%. But the intensity of the degradation of the vegetation cover is more observed at the level of the latter (Figure 2).

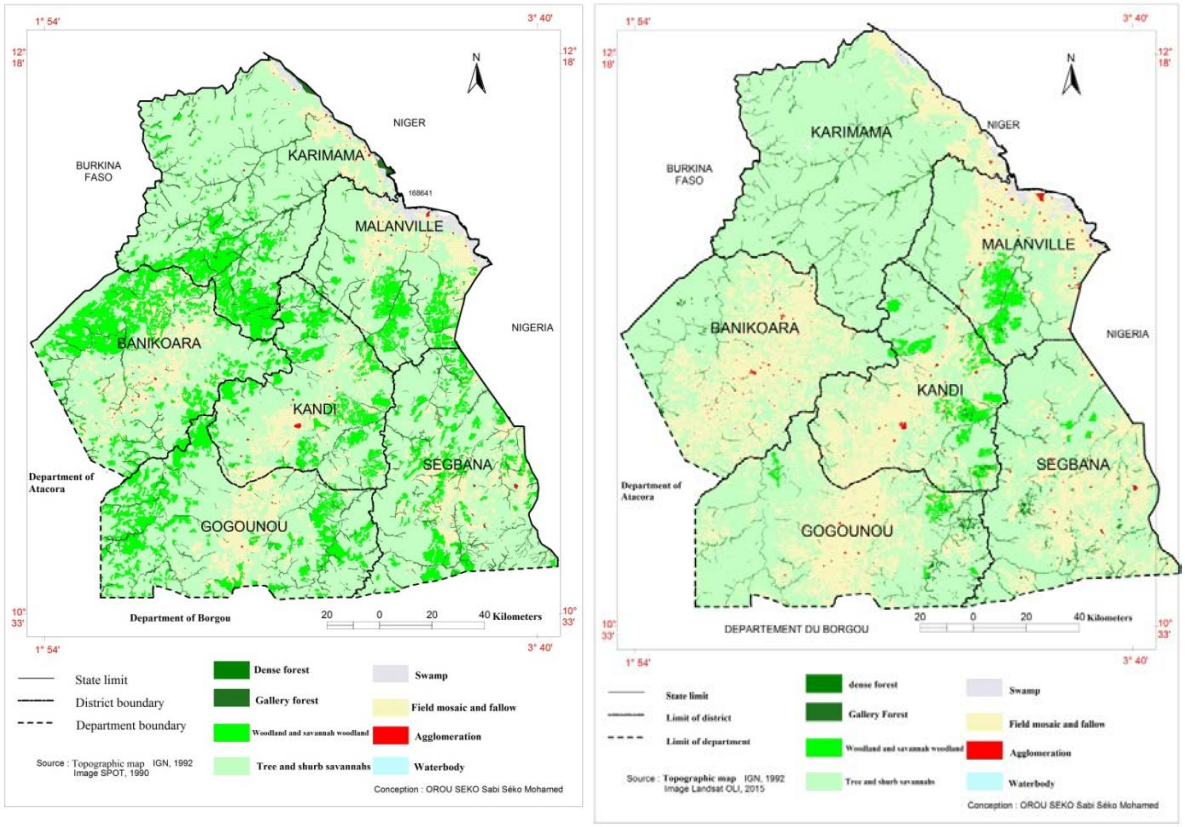

Figure 2: Land use between 1990 and 2015 in the department of Alibori

The physiognomic characteristics of the vegetation in 1990 were dominated by tree and shrub savannahs and dotted by open woodland and savannah woodland. The latter are strongly in the municipalites of Banikoara and Gogounou and continually give way to mosaics fields and fallows (Figure 3).

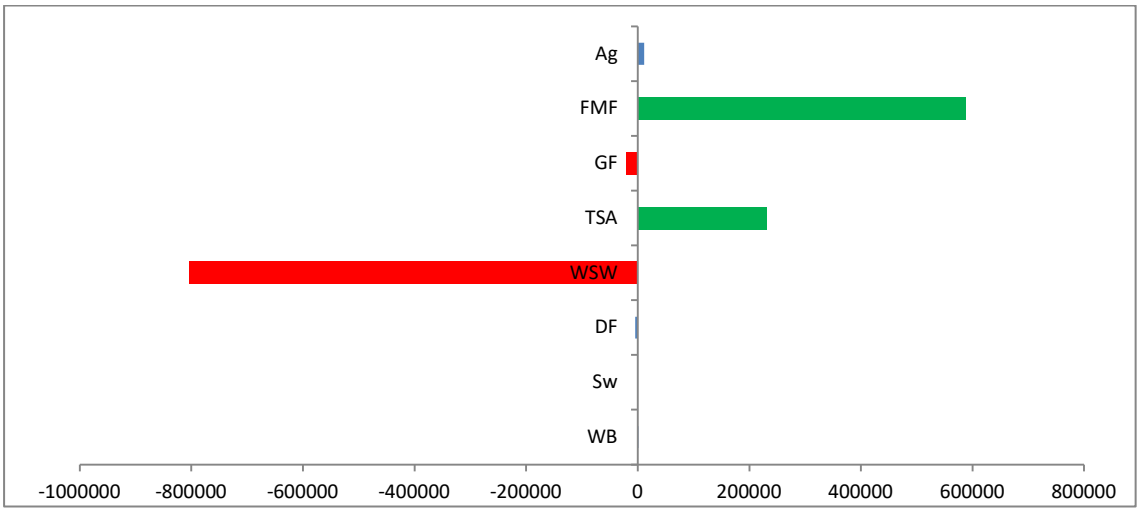

Figure 3: Assessment of evolution of vegetations formations and other land-use units between 1990 to 2015

Ag : Agglomeration, FMF : Field mosaic and Fallow, GF : Gallery Forest, TSA : Tree and shrub savannahs, WSW : Woodland and savannah woodland, DF : Dense forest, Sw : Swamp, WB : Waterbody

3.2. Evolutionary trend of land occupation in the department of Alibori by 2050

The concerns are based on the future of Alibori vegetations formations by 2050 if current pressures are maintained. The realization of the predictive map made it possible to understand the future stakes, to better appreciate them in order to rethink the modes of existence if necessary. On the basis of the assumptions made in relation to the scenario "tendency towards the catastrophe" with especially the maintenance of the bad farming practices and the strong demographic growth, it has been noted intensive degradation of the landscape units (figure 4).

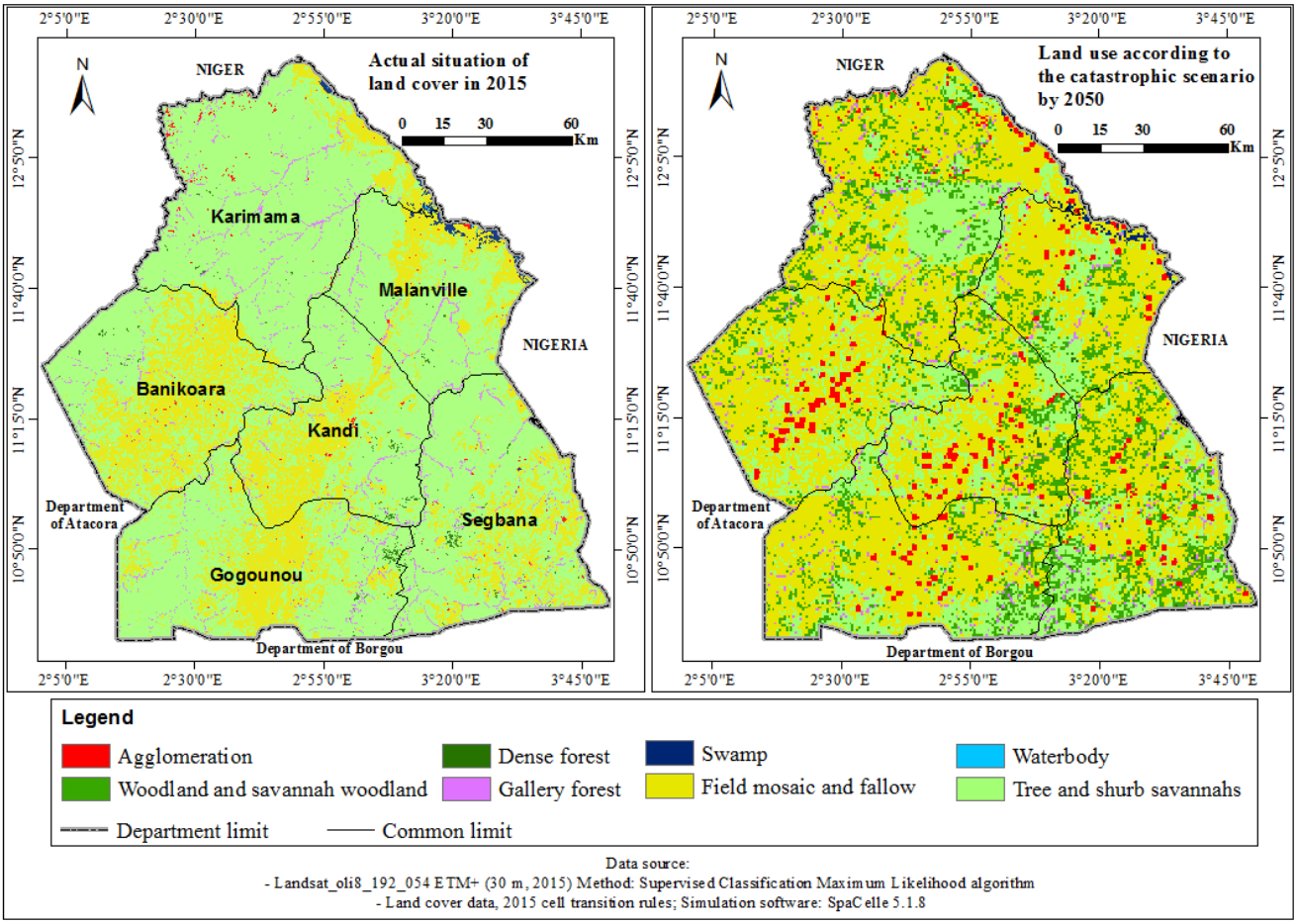

Figure 4: States occupation of land for the "catastrophe scenario" by 2050

The analysis of the figure showed that in 2050, the trend of evolution of field mosaics and fallows will consolidate further. During this same year, the regression of natural formations will gradually continue. In 2050, the phenomenon of anthropisation of the environment will increase at the expense of natural vegetations formations if the assumptions made are maintained.

The table 3 shows that in the Alibori department tree and shrub savannas will be reduced from 52.82% in 2015 to around 15.93% in 2050. Simultaneously agglomerations will extend from 0.76% in 2015 to 1% in 2050. Similarly mosaics crops and fallow could range from 35.22% to 74.36% in 2050.

Table 3: Projection of the area (in ha and in %) of the land cover units by 2050 according to the scenario of "tendency towards the catastrophe"

Units of land-use	Surfaces (ha)	Percentages (%)
Waterbody	730.91	0.03
Swamp	1532.72	0.06
Dense forest	1946.11	0.07
Woodland and savannah woodland	214200.33	7.98
Gallery Forest	15312.11	5.90
Tree and shrub savannahs	427731.01	15.93
Field mosaic and Fallow	1996530.63	74.36
Agglomeration	27054.05	1
Total	**268 503 7.87**	**100**

The various states of land occupation for scenarios of "environmental stability" and "trend towards disaster" in 2015 and by 2050, in the department of Alibori, are summarized by the figure 5.

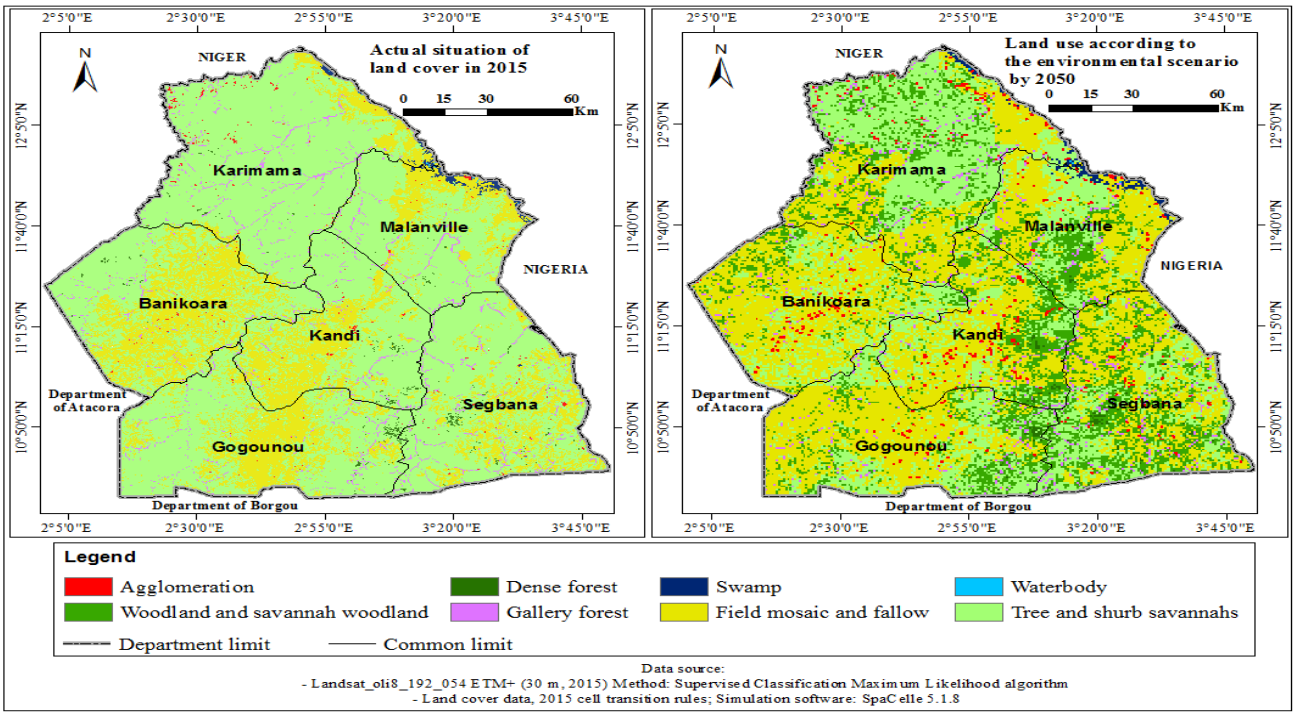

Figure 5: Land cover states for the "environmental stability by 2050" scenario

The "environmental stability" scenario aims to reduce pressures on plant resources. With this scenario, most of the land-use units of the Alibori Department, including natural formations and anthropogenic formations, have been in a state of very little regression or progression, as shown in the table. The observation of the table 4

shows that the forest and savannah woody saves 6.84% from 5.5% in 2015 to 12.34 % in 2050. The agglomerations, although in slight stability, increased from 0.76% in 2015 to 0.29% in 2050. Mosaics crops and fallow, meanwhile, will increase between 2015 and 2050 passers from 35.22 to 56.56%.

Table 4: Projected area units of land occupation in 2050 according to the scenario of "environmental stability"

Units of land use	Surfaces (ha)	Percentages (%)
Waterbody	1339.52	0.05
Swamp	3516.84	0.13
Dense forest	3628.16	0.13
Woodland and savannah woodland	331500.57	12.34
Gallery Forest	50273.07	1.87
Tree and shrub savannahs	759331.35	28.28
Field mosaic and Fallow	1518576.24	56.56
Agglomeration	16872.12	0.29
Total	**2685037.87**	**100**

3.3. Environmental dynamics in the department of Alibori

On the basis of the assumptions made with respect to the "catastrophe trend" scenario, and also considering the lifetimes of the land-use units, the analysis of this scenario makes it possible to make findings at the level of the units of occupation of the grounds. The projection based on this scenario reveals that plant formations will virtually disappear in favor of fields and fallows and agglomerations (Figure 6).

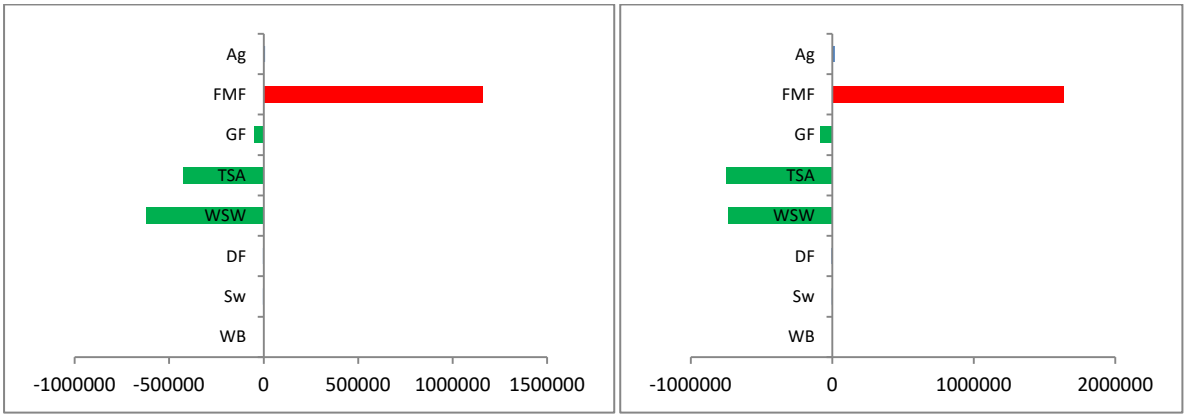

Figure 6: Landscape units of environmental and catastrophe scenarios in 2015 and 2050

Ag : Agglomeration, FMF : Field mosaic and Fallow, GF : Gallery Forest, TSA : Tree and shrub savannahs, WSW : Woodland and savannah woodland, DF : Dense forest, Sw : Swamp, WB : Waterbody

From the analysis of the figure, it appears that with the environmental stability scenario, only field mosaics and

fallow land will progress in the department of Alibori. As for the other units, there will be a dynamic but it concerns more the woodland and savannah woodland because their degree of degradation remains always considerable. On the other hand, the results developed by the scenario tending towards the catastrophe show that the phenomenon of anthropisation of the environment will increase at the expense of the natural plant formations of the department of Alibori in 2050. It should be noted an increase in agglomerations and mosaics of fields and fallow land. But, the woodlands and savannahs woodland and the tree and shrub savannahs are experiencing a meteoric decline. This challenges the consciousness of everyone, especially researchers and decision-makers, through a vast reforestation or reforestation campaign of the Alibori department.

4. Discussion

4.1. Dynamics of Land Use

The assessment of land area unit dynamics in the Alibori department was carried out over the period 1990-2015. It is characterized by an extension of human formations to the detriment of natural vegetations formations. In fact, the area of woodland and savannah woodland increased from 35.43% in 1990 to 5.5% in 2015. It is also the same for the gallery forests, which experienced a significant decrease from 3.70% in 1990 to 2.90% in 2015 despite being fully protected by Beninese forest legislation [25]. The same phenomenon was observed in tree and shrub savannahs whose area increased from 46.51 % in 1990 to 55.22 % in 2015, an increase of about 8.71 %. Overall, there is a significant reduction in forest area as well as an increase in the area of field and fallow mosaics and tree and shrub savannahs. The decrease in forest area is explained by the fact that most of them have been converted into savannahs and field mosaics and fallows.

This confirms the results of [1, 14, 26, 27, 16], concerning the regression of dense vegetation formations in favor of agricultural areas. Indeed, the work of [28] revealed a rate of deforestation of 6% between 1991 and 2000 in Upper Ouémé. In addition, [1], by studying the factors of the floristic diversity of the slopes of the Atacora massif also concluded that the natural plant formations are in regression of 3.5%. The results of this research complement those of existing work on land-use dynamics in Benin. Indeed, the work of [27] in the communes of Banikoara and Karimama (Alibori Department) show that all land tenure units have undergone changes in the form of losses and gains. Thus, outside of gallery forests, changes in the different land-use units of the study area are all active or rapid. The highest rate of change was recorded in woodland and savannahs woodland with 55% loss and only 5% gain. They are followed by tree and shrub savannahs with 13% loss and 19% gain and mosaics of fields and fallows with 11% loss and 18% gain. Finally, in gallery forests, only losses (3%) are observed and the rate of change was slow. On the other hand, only gains (18%) are observed for the agglomerations.

Unlike the work of other researchers, this research like [16] went further, insisting that in addition to the growing fields and fallows, agglomerations have also intensely contributed to the regression of the plant cover in Alibori department. Overall, the areas of anthropogenic formations and agglomerations department of Alibori have experienced a very rapid increase from 1990 to 2015 at the expense of natural forest formations.

4.2. Use and limits of the predictive modeling of the vegetation

The predictive modeling of the evolution of wood energy resources in the southern watershed was done with the SpaCelle model. This model is much more dependent on local interactions between cells than factors that influence these cells or automata. The use and adaptation of the SpaCelle model in a tropical environment raises some questions of environmental similarity because it was originally conceived in the French context. However, SpaCelle was easily tropicalized and adapted in this study thanks to its calibration on the neighborhood relations between the basic cells. Only, to make the prospective maps under SpaCelle, a problem related to the functioning of the model has been highlighted. This comes from a limit of the model to simulate the processes of change from one type of unit of occupation to another, presenting intermediate states, whereas this was the approach taken from a conceptual point of view [17, 29, 14, 15, 16].

The analysis on the use of the SpaCelle model was inspired by that made by [16] on the dynamics of wood-energy resources and impacts on forest ecosystems in the southern supply basin of the Republic of Benin. Thus, the validation of a model is essential and consists in ensuring that the spatial and temporal representation of the simulated processes respects the trends, the change processes or even the landscape patterns as previously defined in the prospective scenarios. It aims to enhance the plausibility of the scenarios and is based on criteria, the number of which may vary according to the authors [30, 31]. Indeed, the multitude of indicators based on the comparison of a simulation with an observed situation, developed by Pontius, such as Kappa [32], the ROC curve [33], the indicators derived from Land Use and Change Change (LUCC) budgets [34] appear inappropriate when used individually. They evaluate the predictive power of a model and not its ability to correctly simulate the desired land-use processes or landscape patterns [35]. Since the SpaCelle model does not have its own evaluation tools, the validation of the simulation results requires the use of two types of methods. This is the visual validation with Google EarthPro © and the validation by calculation of the compliance rate. The combined use of these methods was therefore necessary to increase the confidence that one can have in the model to simulate prospective scenarios.

5. Conclusions and recommendations

The crop production and livestock are the main livelihood activities of the Alibori Department. They are influenced by climatic conditions of the Sahel which force producers to adopt new agricultural practices (the misuse of plant protection products and especially the increase in plantings through the adoption of new tools and production techniques) in order to hope for a good return. Since these activities are the main sources of income for agricultural households, the consequences of climatic hazards on them inevitably affect the living conditions of these households. The strategies of adaptation not rational developed by the populations to face the climatic instabilities of the department of Alibori engender an unprecedented environmental upheaval. The analysis of vegetation cover conditions from 1990 to 2015 revealed that the department of Alibori is characterized by an extension of human formations to the detriment of natural vegetation formations. The area of woodland and savannahs woodland increased from 35.43% in 1990 to 5.5% in 2015.

The results obtained from the projection made using the SpaCelle software shows that with the environmental

stability scenario, the woodland and savannah woodland is gaining 6.84%, going from 5.5% in 2015 to 12.34% in 2050. The agglomerations, although in slight stability, increased from 0.76% in 2015 to 0.29% in 2050. The field mosaics and fallow, meanwhile, will increase between 2015 and 2050 passers from 35.22 to 56.56%. On the other hand, the results developed by the scenario tending towards the catastrophe show that the tree and shrubs savannahs will be reduced from 52.82% in 2015 to around 15.93 % in 2050. Simultaneously agglomerations will extend from 0.76% in 2015 to 1% in 2050. In the same way field mosaics and fallows could extend from 35.22 to 74.36% in 2050.

It is therefore imperative:

- Implement national, departmental and local policies aimed at reversing the perilous trend of deforestation, to the benefit of both populations and the overall environmental balance.
- Initiate afforestation and reforestation campaigns
- Create local monitoring committees
- Create a young volunteer for participatory development and environmental monitoring
- Decision support tools will then be essential to make informed choices in the management of territories in order to simulate future changes in land use to anticipate the degradation of natural vegetation cover

References

[1] Tenté B. A. Recherche sur les facteurs de la diversité floristique des versants du massif de l'Atacora : secteur Perma- Toucountouna (Bénin). Thèse de Doctorat, Université d'Abomey-Calavi, 2005, p. 252.

[2] Akouéhou S. G., Alingo H., Kpomalègni C. Approvisionnement en bois-énergie des grands centres urbains de Porto-Novo et de Cotonou au Sud du Bénin : une menace pour les mesures d'adaptation aux changements climatiques. 16 colloque international en évaluation environnementale, forêt, énergie, changement climatique et évaluation environnementale : pour une gestion durable, du global au local. Version électronique, 2011, p14.

[3] Mèdjigbodo R. M-J. Impact sur la pauvreté de l'adoption des équipements alternatifs au foyer traditionnel par la ménagère au Bénin. UAC, Bénin, version électronique, 2004. 5p.

[4] Djenontin AJ. Dynamique des stratégies et des pratiques d'utilisation des parcours naturels pour l'alimentation des troupeaux bovins au Nord-Est du Bénin [Thèse de doctorat,]. [Abomey-Calavi]: Université d'Abomey-Calavi; 2010.

[5] Biaou H. S. S. Etude des possibilités d'aménagement de la forêt classée de Bassila: structure et dynamique des principaux groupements ligneux et périodicité d'exploitation. Mém.Ing.Agron. FSA, UAC, Bénin, 1999, 194 p.

[6] Mariko M. Learning from the Future: Competitive Foresight Scenarios, first ed., John Wiley & Sons Inc., New York, 1996, p. 81–108..

[7] Hahn-Hadjali K., et Thiombiano A. Perception des espèces en voie de disparition en milieu Gourmantché (est du Burkina Faso). Berichte des Sonderforschungsbereichs, Band 14, Frankfurt a.M., 2000, pp 285-297.

[8] Mama A. & Sinsin A. B. Problèmes de cohabitation entre la faune sauvage et les populations d'Alfakoara au Bénin. In Proceedings of symposium-workshop on mammal study and biodiversity. Vereniging voor Zoogdierkunde en Zoogdierbescherming (VZZ), Société pour l'Étude et la Protection des Mammifères Réseau Rongeurs et Environnement (RéRE), Bénin, 2002 , pp. 117-124..

[9] Guedou Gangbe R. Répartition spatiale et stratégies d'évolution des peuplements à ANOGEISSUS (DC.) Guill. Et Perr. Dans la forêt classée de la Lama, DEA ? Option gestion de l'environnement ; FSA/UAC,, 2005, 68 p.

[10] FAO, Global Forest Resources Assessment 2000, Main Report. FAO, Forestery paper, 2000,Vol. 140, pp. 115-120.

[11] Toko MI, Arouna O, Sinsin BA. Cartographie des changements spatio-temporels de l'occupation du sol de la forêt classée de l'Alibori Supérieur au nord-Bénin. Rev Géographie Bénin Univ D'Abomey-Calavi Bénin. 2010;(7):22–39.

[12] CMA/AOC: First session of the Conference on Cotton and Global Trade; 2002, pp 17-24.

[13] CENAGREF (2003) : Etude de l'impact de l'utilisation des engrais chimiques et des pesticides par les populations riveraines sur les écosystèmes (eau de surface substrat des réserves de faune) dans les complexes des aires protégées de la Pendjari et de W. CENAGREF/MAEP. 93 p.

[14] Oloukoi J. Scénario socio-économique et écologique des changements de l'occupation des terres au Bénin », VertigO - la revue électronique en sciences de l'environnement [En ligne], 2013, 13 (1), mis en ligne le 16 avril 2013, consulté le 02février 2017. URL : http://vertigo.revues.org/13267 ; DOI : 10.4000/vertigo.13267.

[15] Abdoulaye D. Dynamique de l'occupation des terres et ses incidences sur l'écoulement dans le bassin versant de l'Ouémé a l'exutoire de Bétérou (Nord-Bénin). Thèse de Doctorat Unique, Université d'Abomey-Calavi. Ecole Doctorale Pluridisciplinaire « Espace, Cultures et Développement », 2015, 253 p.

[16] Gbaguidi A. H. U. Dynamique des ressources en bois-énergie et impacts sur les écosystèmes forestiers du bassin d'approvisionnement sud de la république du Bénin. Thèse de doctorat en Géographie, UAC, 2016, 259 p.

[17] Langlois P. Le modèle SpaCell. Base de données du Groupe Modèles du GDR Libergéo, 2001, pp. 111-125.

[18] Langlois P. Les automates cellulaires pour la modélisation des systèmes spatiaux, in Y. Guermond (dir), Modélisations géographie, Déterminismes et complexités, 2005, Chap. 12, pp 321-352 (32).

[19] Langlois P., Delahaye D. RuiCells, automate cellulaire pour la simulation du ruissellement de surface. Revue internationale de géomatique, 2002, vol 12, n° 4, p. 461-487.

[20] White R., Engelen G. and Uljee I. The use of Constrained Cellular Automata for high-resolution modelling of urban land use dynamics. Environment and Planning B, 1997, 24, pp.323-343,

[21] Bénin Alafia. Des OMD au Bénin : Document de stratégies de 2000, Etudes Nationales de Perspectives à Long Terme, Bénin 2025 ALAFIA. 2001, 155 p.

[22] FOSA-Bénin. L'Etude prospective du secteur forestier en Afrique (FOSA). République du Bénin, Ministère du Développement Rural, Direction des Forêts et des Ressources Naturelles, Bénin, 2001,64 p.

[23] IMPETUS Atlas du Benin. Résultats de recherche 2000 – 2007. Troisième édition. Département de Géographie, Université de Bonn, Allemagne, 2007, 144 p.

[24] MECCAGPDPE-PNUD. Dynamique démographique, question agraire, et urbanisation au Bénin. Etudes Nationales de Perspectives à long terme. NLTPS-BENIN 2025. Ministère d'Etat Chargé de la Coordination de l'Action Gouvernementale, du Plan, du Développement et de la Promotion de l'Emploi (MECCAGPDPE), et le Programme des Nations Unies pour le Développement (PNUD), 2000, 147 p. + Annexes.

[25] Orou Séko S. S. M. Risques sanitaires liés à l'utilisation des produits phytosanitaire en coton culture dans la Commune de Banikoara. Mémoire de master en géographie, MIRD/FLASH/UAC, 2014, 99 p.

[26] Arouna O. Cartographie et modélisation prédictive des changements spatio-temporels de la végétation dans la Commune de Djidja au Bénin : implications pour l'aménagement du territoire » Laboratoire d'Ecologie Appliquée [Internet]. Thèse de Doctorat Unique, UAC. 2012 [cited 2017 Apr 6]. Available from: http://leabenin-fsauac.net/fr/mapping-and-predictive-modelling-of-time-space-changes-of-vegetation-in-the-district-of-djidja-benin-lesson-for-regional-planning/

[27] Toko Issiaka N, Arouna O, Imorou IT. Cartographie De La Dynamique Spatio-Temporelle Des Parcours Naturels Des Troupeaux Transhumants Dans Les Communes De Banikoara Et De Karimama Au Benin (Afrique De L'ouest). Eur Sci J ESJ [Internet]. 2016 [cited 2017 May 17];12(32). Available from: http://eujournal.org/index.php/esj/article/view/8394

[28] Orékan VA. Implémentation du modèle local CLUE-s aux transformations spatiales dans le Centre Bénin aux moyens de données socio-économiques et de télédétection [Thèse de doctorat,]. [Bonn, Suisse]: Université de Bonn,; 2007.

[29] Torrens P. et O'Sullivan D. Cellular automata and urban simulation: where do we go from here?, Environment and Planning B, 2001, 28 163-168.

[30] Wilson I. Mental maps of the future: an intuitive logics approach to scenarios, 1998, 95 p..

[31] Alcamo T., Henrichs T. Towards guidelines for environmental scenario analysis, Environmental Futures: The Practice of Environmental Scenario Analysis, first ed., Elsevier, Amsterdam, The Netherlands, 2009, p. 13–35.

[32] Pontius R.G., Schneider L.C. Land-cover change model validation by an ROC method for the Ipswich watershed (Massachusetts, USA), Agriculture, Ecosystems & Environment, 2001,vol. 85, p. 239–248

[33] Pontius R.G. Statistical methods to partition effects of quantity and location during comparison of categorical maps at multiple reterresutions. Photogrammetric Engineering & Remote Sensing, 2002,vol. 68, p. 1041–1049.

[34] Pontius R.G., Huffaker D., Denman K. Useful techniques of validation for spatially explicit land-change models. Ecological Modelling, 2004, vol. 179, iss. 4, p. 445-461.

[35] Brown D.G., Page S., Riolo R., Zellner M., Rand W. Path dependence and the validation of agent-based models of land use. International Journal of GeographicalInformation Science, 2005.vol. 19, iss. 2, p. 153-174.