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# Dynamics of the Inland Valley Occupation in the Oti Watershed in Benin: Diagnosis and Prospective Analysis

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**Abstract:** The use of inland valley has highly increased in number and area over the last three decades because of their soils fertility and their hydromorphic character. The present research analyzes the dynamics of the occupation and use of inland valley in the south of the Oti watershed in Benin and their future by the years 2030 and 2050. It is based on a combinative approach which integrates spatial Remote Sensing, Geographical Information Systems and Land Use Change Model incorporated in Idrisi Selva software. Landsat TM images of 1988, ETM$^+$ of 2000 and OLI TIRS of 2015 were used for land cover information extraction. The projections' period was made based on the observed socioeconomic conditions in the study area. The 1988 to 2015 change detection indicates that plant formation (woodlands and savanna) characterized by the inventoried inland valley evolved toward the anthropogenic formations (mosaic of crops, fallows and bare soils). The annual rate of change is estimated at -0,83 %) for the first period and -1,6 % for the second period. The anthropogenic procedure was strongly observed from 1988 to 2015 with a global annual regression of 0,38 % which leads to an extension of the agricultural areas. Considering the three topographic sectors between the period of 1988 and 2015, about 22,01 % of the Atacora massif inland valley, 44,88 % of the wavy interfluves and 30,41 % of the low altitude sector are occupied by crops. This evolutionary trend of agricultural areas comes from the prominent role of the agriculture in the economy of the Oti watershed. By 2030 and 2050, we will probably witness a significant extension of agricultural areas which could respectively go from 105 461,63 hectare in 2015 to 115987 hectare in 2030 and 144182 hectare in 2050.

**Keywords:** Oti Watershed, Inland Valley, Land Cover Dynamics, Regression

## Introduction

Climate change has contributed to the greatest famines in sub-Saharan countries Since the 1970s (Diello, 2007). They are in combination with anthropogenic actions which caused poor agricultural performance and degradation of natural resources (Grouziz, 1986 ; Ouédraogo, 1998 ; Kabré, 2008).

In West Africa, the changes observed have had repercussions on water systems and huge socio-economic impacts which may constitute a constraint for the integrated management of available water resources. (Vissin, 2007 ; Totin, 2010). The progressive decrease in surface water resources in West Africa at the level of the main basins has reached 40 to 60% and is greater than that of rainfall (15% to 30%) depending on the area. (Afouda *et al.*, 2007).

The Oti watershed in northwest of Benin is not on the sidelines of these new hydro-climatic data with all their consequences on the livelihoods and on the land use model. (Idiéti, 2012). To this, must be added the rapid growth of the population which has lead to a great pressure on resources because of the positive interaction between this demographic growth and the demand for seeded areas. (Soubérou, 2013). The environmental interest that followed is reflected in a regressive evolution of forest areas and an uncontrolled extension of agricultural areas especially the hydromorphic zones, and particularly


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the inland valley. (Djihinto, 1997 ; FAO, 2007 ; Ouorou Barré, 2014). Temporarily flooded areas, these inland valley have particular hydrological and pedological characteristics that make them areas with high agricultural potential (Assigbé and Mama, 1993). These characteristics make these inland valley receivers of strategic agricultural lands that help the population to solve the issue of agricultural land's decrease upstream of the inland valley and the time-space irregularities of precipitation (Mahaman and Windmeijer, 1995).

Thus, inland valley development has accelerated in recent years because of farmers who have oriented agricultural activities more towards hydromorphic zones (Houndagba et al., 2007, Oloukoi and Mama, 2009) which show obvious socio-economic opportunities (rice production and other vegetable products) (Oloukoi et al., 2013). This new agricultural dynamics is reflected in a significant regression of natural plant formations in favor of anthropogenic formations. However, it is important to remember that no work has oriented the analysis towards the prospective dynamics of occupation and land use in the inland valley. And this is at least at the scale of a watershed in northwest of Benin despite the modern tools offered by Remote Sensing and the Geographic Information System (GIS).

For a better understanding of current and future interest of inland valley exploitation, it is important to identify the sites affected by the changes observed. Then, calculate their evolution rates and simulate the possible changes in the future, based on the results obtained and the socio-economic and biophysical information in south of the Oti watershed.

**Geographical scope of the study**

The study area is a portion of the Volta river basin (BHV) that extends over the territory of the Republic of Benin. This portion is precisely located in the Oti watershed (WHYCOS, 2006). Located in the north-west of Benin, it straddles the Atacora and Donga departments and occupies 47.20% of its total area of the Oti watershed in Benin (Figure 1). It is between 09 ° 19'6 " and 10 ° 54'8 " north latitude on the one hand and 0 ° 45'34 " and 1 ° 41'48 " east longitude on the other hand. Administratively, we can see the entire townships of Boukoumbé, Cobli, Ouaké and a part of the Municipalities of Bassila, Copargo, Djougou, Kouandé, Material, Natitingou, Tanguiéta and Toucountouna (Picture 1).

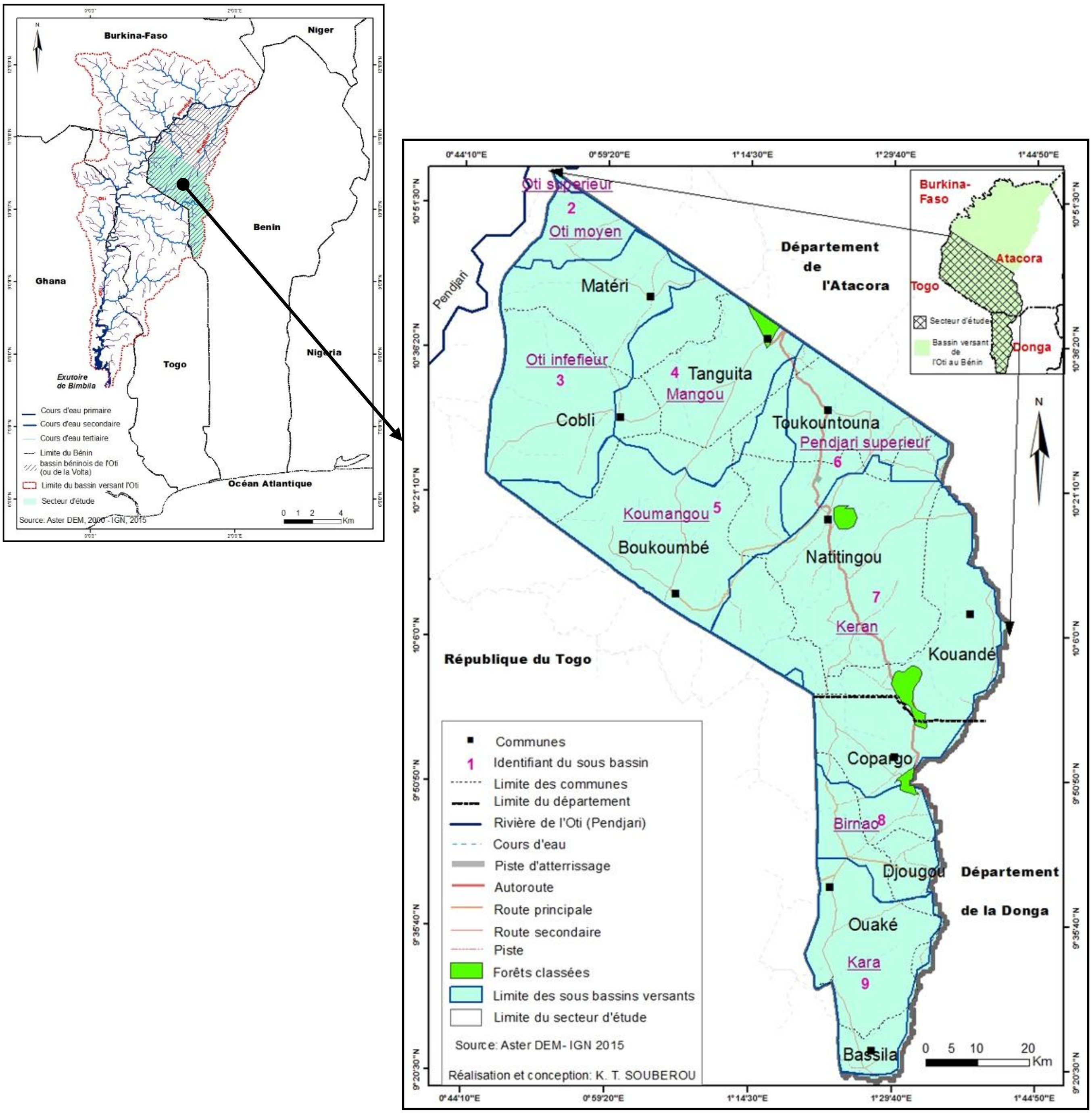
Strongly linked to the geological structure, the geomorphology reveals the presence of a large number of wetlands due to the orography. Three large morphological units are part of them. It is the Atacora mountain range, the peneplain and the plain of Gourma. The terrain is rugged with altitudes ranging from 118 to 667 m (Digital Elevation Model of the Study Environment, ASTER DEM, 2007).

The climate is of Sudanese and Guinean-Sudanese type, which integrates with that of West Africa (Adjanohoun et al., 1989). It is characterized by two great seasons: a rainy season (May to October) and a dry season (November to April). The annual rainfall is between 967 and 1255 mm. The number of rainy days in the north-west varies from 60 to 70 days (Ouorou Barré, 2014). The average temperature is about 27, 35 ° with an annual temperature range of about 18 ° C (Idiéti, 2012). Ouorou Barré, 2014).

Given these climatic factors, especially the rainfalls, the study area is well watered and the hydrographic network is dense. Nine sub-watersheds are identified in the southern part of the Oti watershed in Benin. These are the water resources management units (Birnao, Kara, Kéran, Koumangou, Mangou, Lower Oti, Middle Oti, Upper Oti and Pendjari) drained by the tributaries of the Pendjari River (which becomes Oti in Togo) and then some other tributaries of Oti (Kéran and Kara) which start down the Atacora mountain range.

Three (03) large edaphic sets are encountered in the study area. These are crude mineral soils, tropical ferruginous soils and ferralitic soils (Ouorou Barre, 2014). On the other hand, the landscape is marked by the presence of a various range of plant formations, in particular dense forests, gallery forests, woodlands, wooded savannahs, treed savannas, shrubby savannahs, mosaic of crops and fallows. This vegetation is becoming increasingly degraded as a result of agricultural and human pressures (Image Processing Landsat OLI TIRS, 2015).

The population, estimated at 723,762 inhabitants according to the RGPH 4 (INSAE, 2014), shows a socio-cultural diversity made up of 32 ethnic groups that live together and work for the development of the Oti watershed in Benin. This strong social heterogeneity of the population is still in search of fertile land for agriculture (main activity). They all take part in the valuation of the inland valley which constitute a stopgap to climate variability. It should be noted that the number of farm households increased from 38041 in 1992 (RGPH2) to 63781 in 2002 (RGPH3) and 93272 in 2013 (RGPH4). Thus, the number of agricultural households has increased significantly in the last two decades (1992 to 2013) due to the expansion of households and consequently a multiplication of the family labor.




Picture 1: Geographic and administrative location of the study environment

**Methodological approach**

**Used data**

The data used in this study are acquired over a three-year period for time-space analysis of the inland valley use and occupation. These are Landsat TM (Thematic Mapper) images from 1988, ETM + (Enhance Thematic Mapper) from 2000 and OLI (Operational Land Imager) from 2015. These data were obtained by downloading from the websites of the University of Maryland as part of the Global Land Cover Facility project (GLCF, http://glcfapp.glcf.umd.edu:8080/esdi/) and United States Geological Survey (USGS, http://earthexplorer.usgs.gov/).

The field information (GPS points of the different land use units) and the existing maps were considered to release the large units of the occupation and use of the inland valley.

**Data processing and results analysis**

The downloaded Landsat images (TM, ETM +, OLI TIRS) were processed (geometric and radiometric image correction, color composition and visual interpretation) and then classified into the Idrisi software environment to retrieve information on the occupation of the inland valley. After the process of image supervised classification, the results were improved with fieldwork and the analysis of the dynamics of the inland valley occupation was based on the change detection approach to compare the different land-use classes from 1988 to 2000 and 2000 to 2015. Detecting changes involves identifying differences in the states of an object or phenomenon through observation at different time periods (Hountondji, 2008). Oloukoi, 2012, Tohozin, 2016). She uses the GIS approach through the determination of the transition matrix and visual interpretation to understand the different types of conversion between these occupation units. Thus, changes in land use were assessed on the basis of the rate of the annual change of the inland valley occupation which shows the proportion of each land-use unit that annually changes. This is the annual average rate of spatial expansion between 1988 and 2000 on the one hand and between 2000 and 2015 on the other hand. It is calculated from the formula (Puyravaud, 2003, Schulz et al., 2010, Oloukoi et al., 2014, Tohozin, 2016) as follows:

**T = (1 / (t 2 -t 1)) x ln (S 2 / S 1);** with **T**, the annual change rate, **t1** the year of departure and **t2** the year of arrival, **S1** the area size at the date **t1** and **S2**, the area size at the date **t2**, ln the natural logarithm**.**

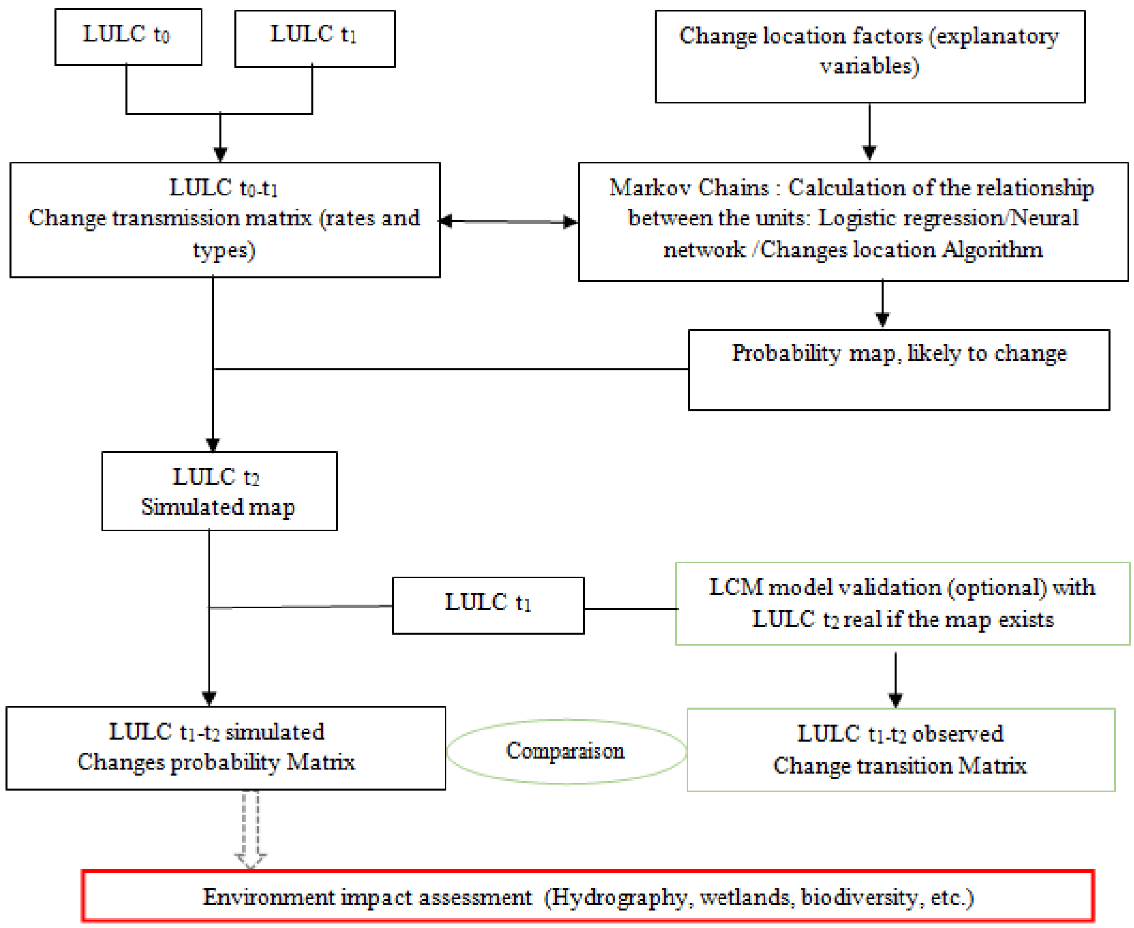
The Indicator **R** helped to characterize the evolution of the inland valley land use units through the three topographic altitude levels existing in the study area and reflects the temporal speed of the observed changes. Showed as a percentage, a negative result indicates a phenomenon of savanization or anthropisation whereas a positive result reflects afforestation (Vigneau, 2013). Its formula is**:** $\mathbf{R= [((S_2 / S_1) \times (1/ (t_2 - t_1)) - 1] \times 100}$

**Projection model description of the dynamics of the land use of the used inland valley**

In order to meet the challenges of sustainable development which requires a glimpse of future changes, the prospective approach has become unavoidable (Hubert-Moy, 2006, Houet et al., 2008). Thanks to the past analysis and current dynamics, it was about building a base of the relevant hypotheses for the explanation of the future (Godet, 1986).

The Land Change Modeler (LCM) model incorporated into the Idrisi Selva software was explored to implement the socio-economic scenario based on the Markov chain and external data. This software offers great flexibility thanks to the programming tools (predefined operations) available for the execution of a multitude of commands (tasks) in its graphical environment. It has been validated by several studies (Pontius et al., 2008, Eastman 2009, Mas et al., 2011 and Vigneau 2013) with interesting and reliable results which favors its use in this article.

LCM is a probabilistic model with a discrete event that is one that does not evolve continuously over time but with discrete time steps (Coquillard and Hill, 1997). As a prospective model, it shows the landscape and its organization in a future temporal dimension (projected time t). Thus, two maps of the land use and use of the inland valley (LULC) at known times $t_0$ (previous) and $t_1$ (current) were highlighted for a comparative analysis in order to determine the transitions, to quantify the concerned area for each type of transition and locate the changes. On the basis of the transitions matrix of obtained, the future potential changes are calculated at a time $t_1$ + ... n. The model was calibrated by factors that explain the changes that have occurred (socio-economic and biophysical factors that have contributed to the evolution of the land use inland valley units until 2015). Each type of transition can be explained with known quantifiable and mappable factors (maps of slopes, expansion of the agricultural areas, population progress, etc.). The model will then combine the different factors by attributing to them more or less strong weights to explain the transitions it has detected between the two maps provided at the beginning (Figure 2). Thanks to the linking and the combination of the explanatory factors and the changes that occurred between the two original land use maps, the model will first carry out via a statistical method (logistic regression or neural network) probability maps to changes (susceptibility maps to changes). Then, the prospective land-use map at a given date $t_1$ + ... n will be used based on the previously identified changes to simulate the next one. Finally, the last step is the evaluation of the simulation. According to Vigneau (2013), this is an optional step but it helps to give more credibility to the reliability of the simulations.




Picture 2: Spatial Simulation procedure of the Land Use and land Use Dynamics in the Southern of Oti watershed by the LCM Model

The modelling of the occupation and use of the inland valley in the south of the Oti watershed from 1988 to 2000 and 2000-2015 was taken into account for a simulation of the spatial dynamics at 2030 and 2050. Spatial simulation by the year 2050 was done because FAO (1997) prospected global agriculture over the year 2080 and predicted fertility stabilization faced with climate change in developing countries at that period. In addition, the time required for climate adaptation dictates that the 2050 time should not be too close to the base year of the projections. This scenario is based on assumptions from the work previously done (Orekan 2007, Arouna 2012, Oloukoi 2012, Boko 2012, Ouorou Barré 2014). Changes in the inland valley occupation depend on biophysical and socio-economic factors. Thus, the following assumptions were considered :

- the increasing population progress has led to a severe degradation of natural resources and a disruption of environmental stability (Sounon et al., 2007);;
- Populations use degrading techniques in the environment (animal traction, slash-and-burn farming techniques, soil conservation techniques and the restoration of soil fertility, uncontrolled deforestation, reduction of fallow periods, etc.);
- The enthusiasm of the rural population towards low wet areas is strong and their development constitutes a strategy of adaptation to climate variability (Soubérou, 2013).

These basic considerations made it possible to highlight future trends in the different units of the occupation and land use of the inland valley in order to propose measures of sustainability, especially in this context of climate change.

## Results

### The dynamics of the occupation of inland valley in the south of Oti pond in Benin

Four (4) units constitute the inland valley land use after the classification of the three (03) explored satellite images (1988, 2000 and 2015) and a superposition of the map results of the potential inland valley areas in the south of the Oti watershed. These are gallery forests, woodlands and wooded savannas, treed and shrub savannahs and the mosaic of crops and fallows. The evolution of these different occupation units was analyzed successively from 1988 to 2000 and from 2000 to 2015. Table I presents the transformations carried out within the vegetation cover characterized by conversions of the occupation units among themselves.

Table 1: Transition matrix of the inland valley land-use units between 1988-2000 and 2000-2015 (hectare)

| Classes | | Fcsb | Fg | Mcj | Saa |
|---|---|---|---|---|---|
| **1988** | Fcsb | **17662,31** | 0 | 954,97 | 2056,45 |
| | Fg | 0 | **6500,5** | 562,33 | 685 |
| | Mcj | 0 | 0 | **32701,45** | 14214,71 |
| | Saa | 1424,62 | 0 | 37604,04 | **245528,54** |
| | | **2000** | | | |
| Classes | | Fcsb | Fg | Mcj | Saa |
| **2000** | Fcsb | **14084,01** | 0 | 1067,9 | 5521,12 |
| | Fg | 0 | **6176,43** | 743 | 828,40225 |
| | Mcj | 0 | 0 | **46124,59** | 791,57 |
| | Saa | 222,61 | 0 | 57526,04 | 226808,55 |
| | | **2015** | | | |

**Caption :** Fg: gallery Forest; Fcsb: woodland and wooded savanna; Mcj; Mosaic of crops and fallows; Saa: Treed and shrub savanna

From the analysis of the information in Table I, it should be noted that between 1988 and 2000, nearly 2056 hectare of woodlands and wooded savannas were transformed into tree and shrub savannas. Then, the latter, about 37604 hectares was transformed in the mosaic of crops and fallows. The changes in the occupation units continued and were observed between 2000 and 2015 in the same way. During this period, nearly 59,337 hectare of plant formations (forests and savannahs) experienced a transition to these anthropogenic formations (mosaic of crops and fallows and bare soils). However, the opposite was very insignificant. Moreover, an average stability of nearly 0.75% of the area of the four occupation units is observed during the two periods (areas in bold) despite the different transitions (gallery forests, woodland and wooded savannas> tree and shrub savannas> mosaic of crops and fallows in terms of the present amount of biomass)

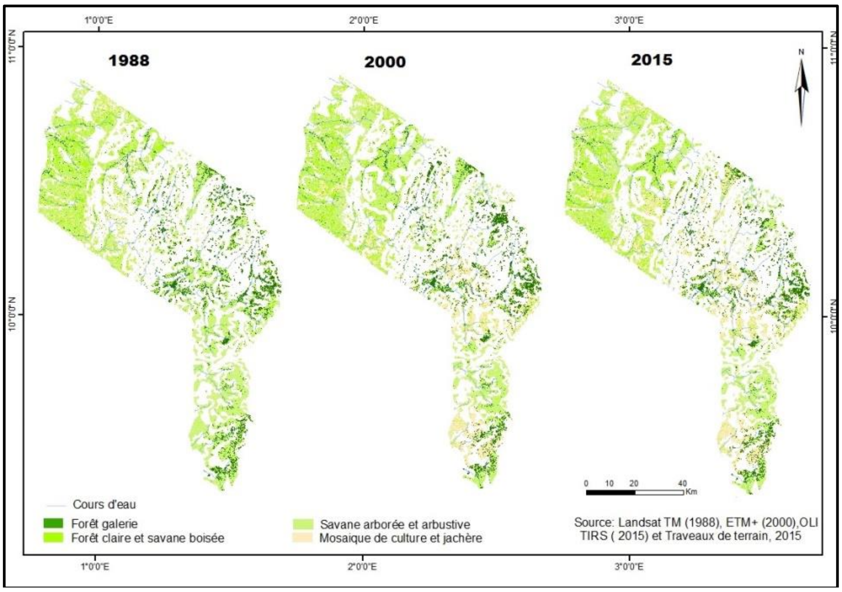
A global analysis of the available potential helped to evaluate the evolution of the areas of the different land use units in the two time intervals of the study (Table II).

Table II : Evolution of the inland valley occupation in the south of the Oti watershed between 1988-2000 and 2000-2015

| **Classes** | **Areas** | | | | | | **Change rate** | |
|---|---|---|---|---|---|---|---|---|
| | **1988** | | **2000** | | **2015** | | | |
| | ha | % | Ha | % | ha | % | 1988-2000 | 2000-2015 |
| Fcsb | 20673,73 | 5,74 | 19086,93 | 5,30 | 14306,62 | 3,97 | -0,31 | -3,81 |
| Fg | 7747,83 | 2,15 | 6500,5 | 1,82 | 6176,73 | 1,72 | -0,77 | -0,59 |
| Mcj | 46916,16 | 13,04 | 71822,79 | 19,95 | 105461,63 | 29,31 | 3,48 | 3,92 |
| Saa | 284557,2 | 79,07 | 262484,7 | 72,93 | 233949,94 | 65 | -1,57 | -1,12 |
| Total | | | 359894,92 | | | | 0,83 | -1,6 |
| Moyenne | | | | | | | -0,38 | |

**Caption:** Fg: gallery Forest; Fcsb: woodland and wooded savanna; Mcj; Mosaic of crops and fallows; Saa: Treed and shrub savanna

The analysis in Table II shows a gradual evolution of the fields and fallows mosaics of (3.48%) between 1988 and 2000, (3.92%) between 2000 and 2015 as shown in Picture 3. On the other hand, the other units area is reduced mostly that of the tree and shrub savannas with respectively a change rate of (- 1,57%) and (1,12). The average of the annual change rate is estimated at (-0.83%) for the first period and (-1.6) for the second period.




Picture 3: Occupation and use of inland valley in the south of the Oti watershed in 1988, 2000 and 2015

The examination of Figure 3 shows an extension of cultivation and fallows areas and an increase in the area of tree and shrub savannas at the expense of gallery forests, woodlands and wooded savannas in both periods. From these results, the continuity of the processes of savanization and anthropisation in the units of occupation emerges.

In sum, from 1988 to 2015, the dynamics of the inland valley units of occupation in the south of the Oti watershed were made with an overall annual regression of (-0.38%) and led to an expansion of wooded and shrub savannas, especially mosaics of crops and fallows and the bare soils.

**Evolution of inland valley occupation units based on the morphological structure**

The analysis of the land use units' small scale helped to assess the spatial dynamics trends of inland valley' occupation in the three predefined areas (Atacora Massif, Peneplain and Plain). At the level of the three sectors, there was an extension of the mosaic unit of crops and fallows (increase in areas) during the two periods (Table III) and a reduction in the area of forest formations. This analysis confirms the processes of savanization and anthropisation that appear through the conversion of the land use classes.

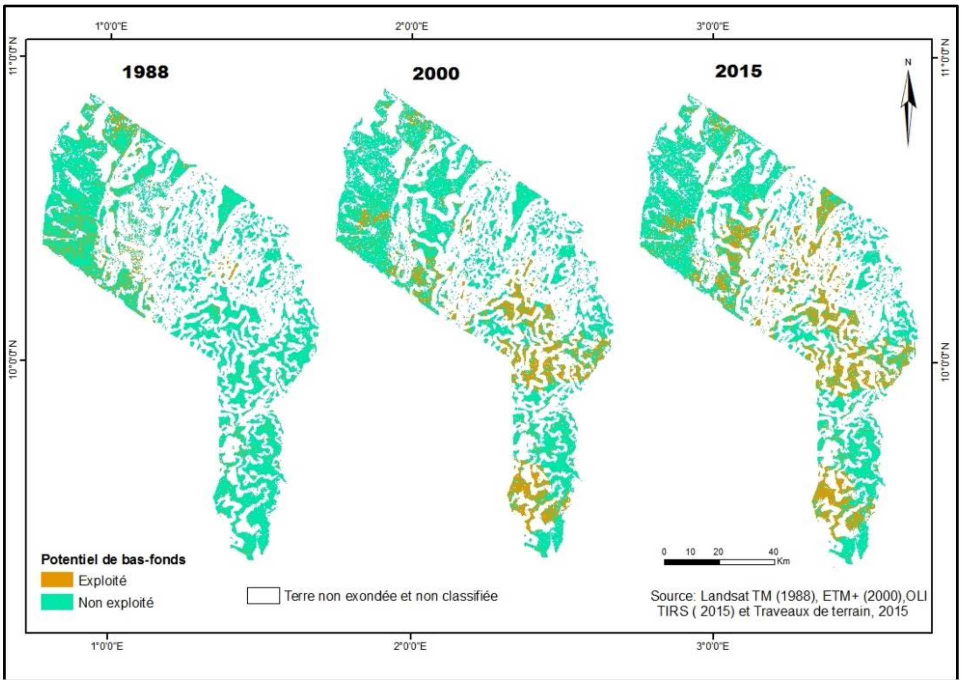
Table III : Statistics of the land occupation in the three sectors and the indicator R of the dynamics

<table>
<tr><th rowspan="2">Sectors</th><th rowspan="2">Classes</th><th colspan="3">Areas (hectare)</th><th colspan="2">Indicator R (%)</th></tr>
<tr><th>1988</th><th>2000</th><th>2015</th><th>1988-2000</th><th>2000-2015</th></tr>
<tr><td rowspan="4">The Atacora massifs</td><td>Fcsb</td><td>14857,13</td><td>11234,19</td><td>10673,67</td><td rowspan="4">-90,33</td><td rowspan="4">-98,76</td></tr>
<tr><td>Fg</td><td>1462,04</td><td>1208,06</td><td>1020,27</td></tr>
<tr><td>Mcj</td><td>4976,8</td><td>10598,54</td><td>11886,26</td></tr>
<tr><td>Saa</td><td>32688,27</td><td>30943,45</td><td>30404,04</td></tr>
<tr><td rowspan="4">The corrugated peneplain</td><td>Fcsb</td><td>17650,48</td><td>14987,68</td><td>4299,34</td><td rowspan="4">-90,51</td><td rowspan="4">-96,04</td></tr>
<tr><td>Fg</td><td>2643,47</td><td>1858,41</td><td>1491,41</td></tr>
<tr><td>Mcj</td><td>27820,64</td><td>64275,81</td><td>72700,27</td></tr>
<tr><td>Saa</td><td>113838,12</td><td>80832,81</td><td>83460,69</td></tr>
<tr><td rowspan="4">The Gourma plain</td><td>Fcsb</td><td>33312,69</td><td>28736,37</td><td>26398,82</td><td rowspan="4">-93,37</td><td rowspan="4">-99,07</td></tr>
<tr><td>Fg</td><td>5590,86</td><td>4002,15</td><td>3908,03</td></tr>
<tr><td>Mcj</td><td>1970,45</td><td>28876,72</td><td>44784,41</td></tr>
<tr><td>Saa</td><td>103083,96</td><td>82342,72</td><td>70866,7</td></tr>
</table>

**Caption:** Fg: gallery Forest; Fcsb: woodland and wooded savanna; Mcj; Mosaic of crops and fallows; Saa: Treed and shrub savanna

The R indicator shows a phenomenon of anthropisation over the whole area (Table III). Negative indicators show the impacts on the environments (degradation of forest formations) due to the human action. Since 1988, there has been an acceleration of this fact in the three sectors, such as the Atacora massif (we go from -90.33% in 1988-2000 to -98.76 between 2000-2015), the crystalline peneplain (from -90.51% in 1988-2000 to -96.04 between 2000-2015), the Gourma plain (from -93.37% in 1988-2000 to -99.07 between 2000 -2013). Thus, between 1988 and 2015, about 22.1% of the inland valley of the Atacora Massif, 44.88% of the wavy interfluves and 30.41% of the low altitude sector are occupied by crops.

The Gourma Plain sector is increasingly experiencing a mosaic of crops and fallows during both study periods, while the other two were stabilizing between 2000 and 2015. Consequently, anthropization would migrate more towards the low altitude sector with more hydromorphic lands, after taking place mainly in medium altitude sector (peneplain) and high altitude sector (Atacora massif). This evolutionary trend of agricultural land (Picture 4) in the Oti watershed comes from the prominent role of agriculture in the economy of the townships which constitute the study environment, It also comes from the depletion of farmland in high and medium altitudes and fallows land cultivation over a long period (0 to 5 years).




Picture 4: Evolution of agricultural lands in the southern part of the Oti watershed from 1988 to 2015

From the observation of Picture 4, there is a very active exploitation of inland valley in the last two decades. This is mainly the period (2000 to 2015) of a change in crop orientation towards the Pendjari valley due perhaps to climatic fluctuations, population explosion or degradation of uncontrolled land, unexploited land due to the use of certain agricultural practices (shifting cultivation, slash-and-burn, etc.).

In order to better assess the future proportion of agricultural land development, a prospective analysis of the inland valley occupation units in the 2030 and 2050 is conducted.

**Prospective modelling of the dynamics of the inland valley occupation and use by the years 2030 and 2050**

The projection of the spatial dynamics of the inland valley occupation is made on the basis of the trends observed within the land occupation units in 2015 and the scenario set up by means of the model "Land Change Modeler" (LCM). These achieved biophysical and socio-economic scenarios of the inland valley occupation changes in the south of the Oti watershed took into account the state of the basin during the period 2000-2015.

**Probability matrix of the changes of land use units**

Table IV presents the probability of conversion of different land-use units from past observation to grasp the reality of future changes.

Table V : Projection of the land use units proportions (in hectare and %) by the years 2030 and 2050

| Classes | Areas | | | | | |
|---|---|---|---|---|---|---|
| | 2013 | | 2030 | | 2050 | |
| | Ha | % | Ha | % | ha | % |
| Fcsb | 14306,6 | 3,97 | 14930 | 4,15 | 12194,1 | 3,39 |
| Fg | 6176,73 | 1,72 | 5864,3 | 1,63 | 5566,17 | 1,55 |
| Mcj | 105462 | 29,31 | 115987 | 32,23 | 144182 | 40,06 |
| Saa | 233950 | 65 | 223113 | 61,99 | 197952 | 55 |

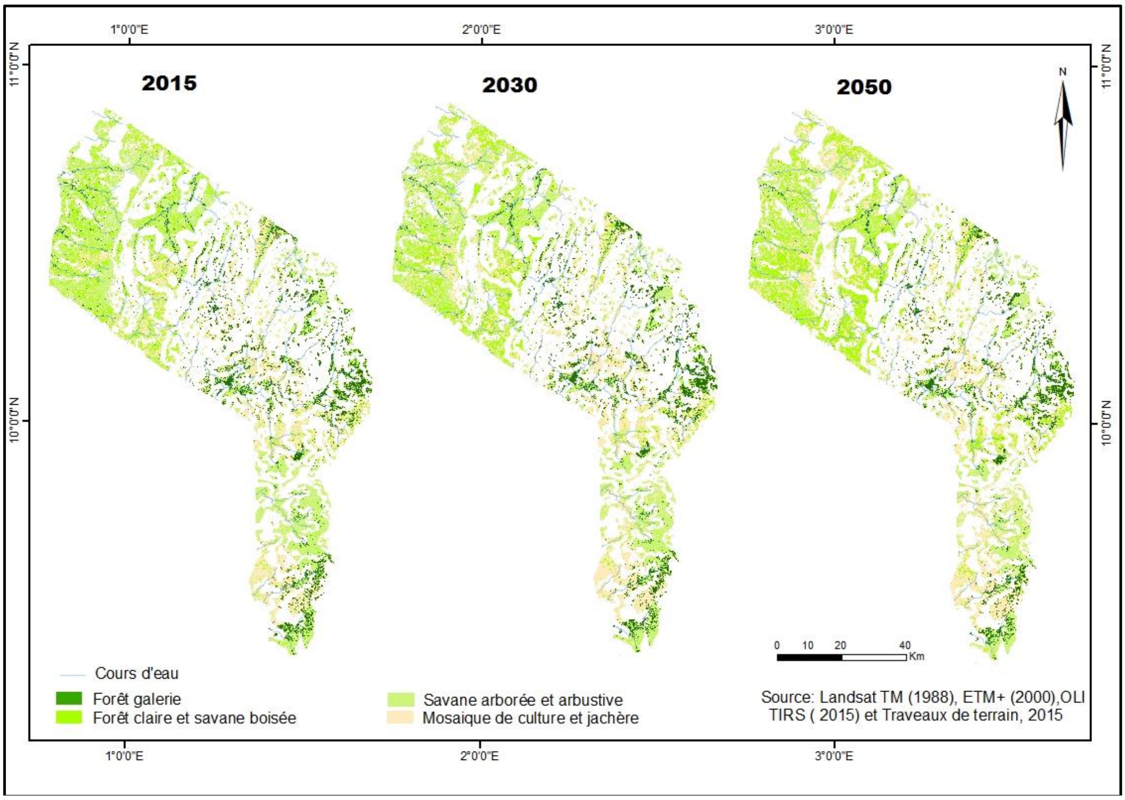
**Captions :** Fg: gallery Forest; Fcsb: woodland and wooded savanna; Mcj; Mosaic of crops and fallows; Saa: Treed and shrub savanna

Between 2015 and 2030 the probability of the evolution of the woodlands and wooded savannas class towards the other units (except gallery forests) is 0.38. On the other hand, woodlands and wooded savannah formation had 0.21 chance of becoming tree and shrub savannas and 0.32 of becoming mosaic of crops and fallows. But during the period 2030-2050, the probability of the different units to change to another is low except the woodlands and wooded savannas formation (0.13) and trees and shrubs savannas (0.36) to become respectively savannas with trees and shrubs and mosaics of crops and fallows. It should be noted that the probability of all these land use units to remain in their category is greater than 0.5 (varies between 0.53 and 0.97) therefore strong. The diagonal analysis of the probabilities indicates that between 2015 and 2030, the change speeds within the occupation classes are medium and they are low between 2030 and 2050, confirmed by off-diagonal probabilities. The average time required for the Land Change Modeler (LCM) model to reach a state (class) given that it comes from another class is short over the period 2030-2050. It may be because of the conservation measures of the reinforced forest trainings and the development policies carried out in the study areas to limit the degradation of the open and natural domains. The major transitions are made because the transfer to savannas and then to the crops' areas remains the most important for the two projected periods.

**Projection of the inland valley occupation from 2013 to 2030 and 2050**

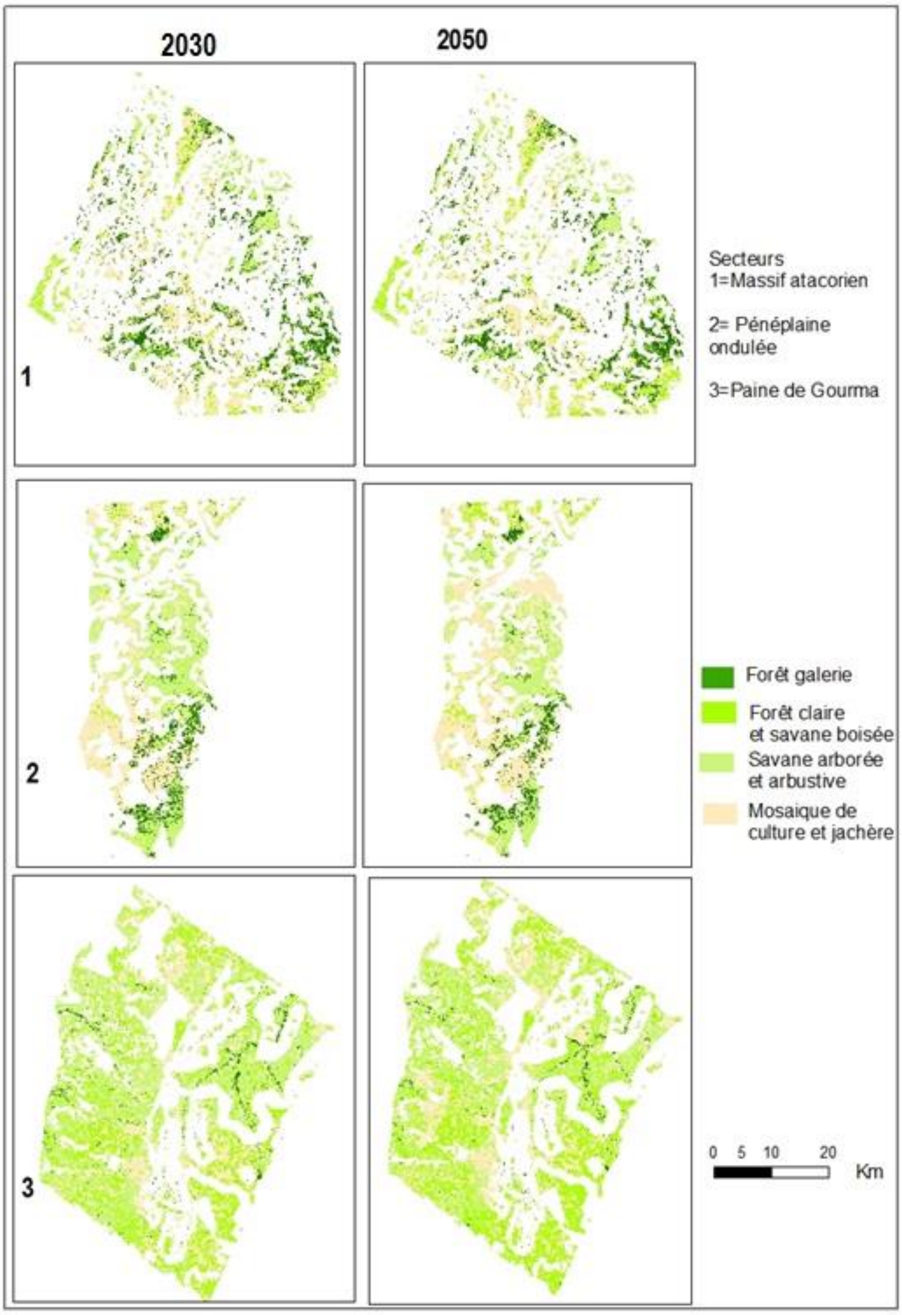
The projection based on previous trends reveals that forest formations are declining in favor of mosaic crops and fallows in 2030 and 2050 (Table V). The savannas will experience a reduction in their areas (about 4.63% in 2030 and 15.39% in 2050) while the areas of crops and fallows will continue to expand. In 2013, the mosaics of crops and fallows which accounted for 29.31%, will increase by 2.93% in 2030 and 7.83% in 2050. On the other hand, the other units will be reduced gradually. The gallery forests will increase from 1.72% in 2015 to 1.63% in 2030 then to 1.55% in 2050. The woodlands formations and wooded savannas will go from 3.97% in 2015 to 4.15% in 2030 and 3.39% in 2050.

The picture 5 shows the future status of the inland valley occupation units in the Benin portion of the Oti watershed area by the years 2030 and 2050.




Picture 5: Occupation and use of inland valley in the south of the Oti watershed in 2015, 2030 and 2050

The analysis of figure 5 announces between 2015-2030, an extension of the mosaics of crops and fallows in the south (sector of the corrugated peneplain) and in the north (sector of the plain of gourma) of the area of study and more, between 2030-2050 with a regression of wooded and shrubs savannahs especially in the center (sector of the Atacora massifs). The prediction of the future of the area in terms of the land occupation and use has shown that the next conversions will allow an increase in the areas of fields and fallows especially in the north-west part (Gourma plain) that is experiencing an increasing demographic growth (Picture 6). The occupation units of the unchanged lands in the center and south (medium and high altitude sector) are unexploited areas.

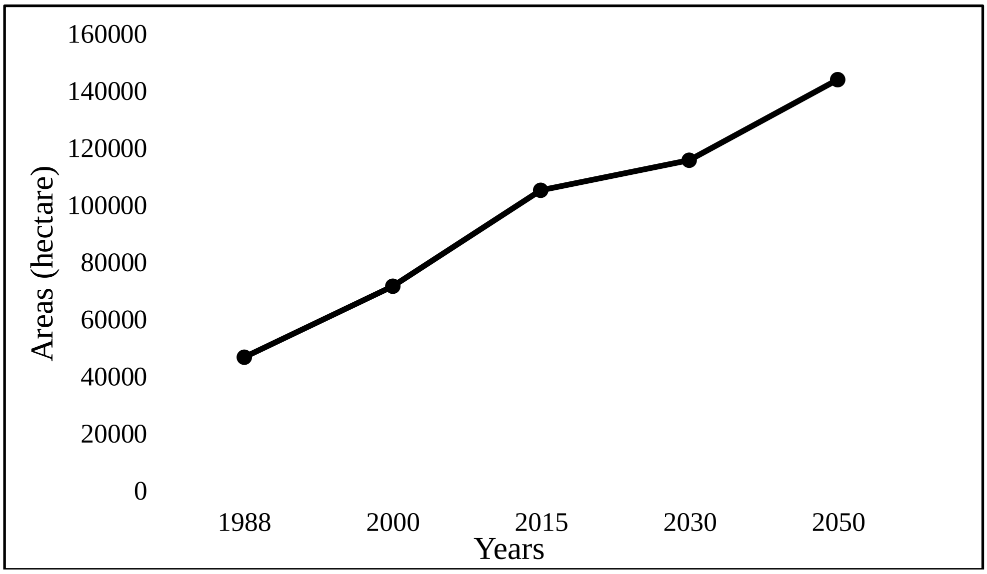



Picture 6 : Inland valley occupation and use in the three topographic units in the south of the Oti watershed in 2030 and 2050

The sectors (1, 2, 3) will experience a stable area of crops and fallows mosaics from 2030 to 2050 (6). The regressive trend of plant formations in sector 2 and 3 noted between 2015 and 2050 will help decision-makers to take actions in order to manage and preserve natural resources so as to anticipate the irreversible degradation and the maintenance of the regulatory role played by this basin in the hydrological cycle. The agricultural activities movement from sectors 2 and 3 to sector 1 is therefore to be planned for a rational and sustainable use.

**Analysis of the inland valley use dynamics**

Picture 7 shows the curve of the evolution of the inland valley set in crops from 1988 to 2015 and the results of the projection by the year 2030 and 2050.




**Picture 7:** Evolution of the cultivated inland valley potential in the south of the Oti watershed

The area of agricultural land has increased from 1988 to 2015 (Picture 7) and is respectively 46 916.16 hectare (1988), 71 822.79 hectare (2000) and 105 461, 63 hectare (2015) with an overall change indicator (-93.44). The considered twenty-seven years of study coincide with the periods of enhancement of the inland valley in Benin (periods of characterization and the policy of the inland valley' hydro-agricultural development "1980 to 2015" during which the government and the National and international NGOs give priority to inland valley' lands by establishing the infrastructures that can be controlled and monitored by farmers for agricultural intensification). The average annual growth of cultivated areas over these three decades has increased by 2.30%.

At present, the development of the inland valley' agricultural resources is a priority for the rural economy. On the basis of the changes obtained between 1988 and 2015 and probabilities, the area of inland valley to be exploited will increase from 105461, 63 hectare (2015) to 115987 (2030) and 144182 (2050). More than 40% of the inland valley of the study area will be converted into agricultural land in 2050 according to the prediction made. There will be a remarkable increase in the cultivated areas in the inland valley over the next thirty-five years following the diachronic and prospective analysis carried out. What are the fundamental reasons for these observed changes in the inland valley' land use?

**Discussion**

The analysis of the occupation dynamics and the inland valley' land use from 1988 to 2015 showed an extension of crops and fallows areas and an increase in the area of wooded and shrubby savannas at the expense of the gallery forest formations, degraded woodlands and wooded savannas during the two periods. This analysis is confirmed by the general results on the time-space analyses of the land occupation (Oloukoi 2012, Ogouwalé 2013, Abdoulaye 2015) concerning the disappearance of dense plant formations in favor of agricultural areas. It is important to note that the resolution of the image used did not help to have full access to the land use details which implies that for safety measures we explore for the future studies more improved resolution images than those of the Landsat series. This is a match with Oloukoi's (2012) analyses which show that the classification of Landsats data used in his research presents some uncertainties in terms of planimetric accuracy. Considering the three sectors (low, medium and high altitudes) of the inland valley' characterization, the same evolutionary tendency of the crops and fallows' areas has been noted with the depletion of arable lands at high and medium altitudes and the orientation of crops towards the low altitude sector. The results support those of Albergel et al. (1993) who finds a migration of farmers from areas subject to degradation of the natural environment and drought to more fertile and wetter areas. The use of the Land Change Modeler (LCM) model for simulating the future occupation of the inland valley through the previous observed dynamics helped to predict the future of the Oti watershed part. Indeed, this scenario provides for an extension of agricultural areas in 2030 and 2050 and has shown that the next conversions will be more in the plain of Gourma.

This upward trend in crops and fallows mosaics areas is mainly due to the agricultural potential (availability of water, presence of permanent moisture, soil fertility, etc.) that the inland valley have for high agricultural production (Thenkabail, 2013). It is therefore important to understand that the decrease in rainfall causes a concentration of the various crops in the inland valley where the soil moisture content is higher than on the uplands (Albergel et al., 1993). This analysis is confirmed by Dembele (2010) who believes in his study that the popularity of inland valley development is emphasized by the population growth, the persistence of the climate deterioration and the market satisfaction (economic factor). So the enhancement of the inland valley is a response to the land pressure on highlands; a way of securing or increasing the agricultural production and a means for the efficient management of natural resources. Similarly for Konaté (2009), population growth, drought and lack of water infrastructure are the main reasons that farmers and development organizations are interested in inland valley farming in the basin. The results of the factors generating the dynamics of the occupation and use of the inland valley complement those existing but reveal that the increasing evolution of the population and the variation of the climate parameters have led the farmers to modify their agricultural practices such as the reduction of the fallows' periods and the intensive exploitation of plateau over the last three decades. All this have contributed to the degradation of the land, and consequently to the agricultural change towards the inland valley.

## Conclusion

Between 1988 and 2000, the dynamics of the land's use in the inland valley in the south of the Oti watershed evolved from plant formations (woodlands and savannas) to anthropogenic formations (mosaics of crops and fallows and bare soils). Those changes (transitions) in the occupation units continued between 2000 and 2015. It was noted that a gradual evolution of field and fallows mosaics respectively 3.48% between 1988 and 2000, (3.92%) between 2000 and 2015 and a reduction in the area of the other units especially tree and shrub savanna with a respective rate of change of -1.57% and 1.12%. The average annual rate of change is estimated at -0.83% for the first period and -1.6% for the second period. The anthropisation process was strongly noticed from 1988 to 2015 with an overall annual regression of -0.38% which led to an extension of the wooded and shrub savannahs and especially the mosaics of crops and fallows, agricultural areas and consequently the inland valley. It is important to remember that the inland valley have been exploited in recent decades in a very active way.

Simulations made on the basis of this trend in order to assess the behavior of land occupation units in the future revealed that forest formations are still in decline in favor of mosaics of fallows and crops in 2030 and 2050. Consequently, there's an increase in the farming areas in the inland valley. Considering the average annual growth of the cultivated areas over the three decades being raised to 2.30%, we will witness a remarkable extension of agricultural areas the next thirty-five years. The regressive trend of plant formations between 2015 and 2050 will help the decision-makers to take actions in order to manage and conserve natural resources so as to anticipate the irreversible degradation and the maintenance of the regulatory role played by this basin in the hydrological cycle.

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