Implementation of the local land-use and land-cover change model CLUE-s for Central Benin by using socio-economic and remote sensing data

Dissertation

Zur

Erlangung des Doktorgrades (Dr. rer. nat.)

der

Mathematisch-Naturwissenschaftlichen Fakultät

der

Rheinischen Friedrich-Wilhelms-Universität Bonn

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Agonlin-Houégbo/Zagnanado, Republic of Benin

Bonn, im April 2007

Angefertigt mit Genehmigung der Mathematisch-Naturwissenschaftlichen Fakultät der Rheinischen Friedrich-Wilhelms-Universität Bonn

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2. Referent: Prof. Dr. Klaus Greve
Tag der Promotion: 11. Juni 2007

This work is dedicated to:

My daughters: Solène Ayina Morênikê, and Kinède Amontcha Olayinka
May this thesis be an example to follow in your life.

My mother: Rosalie Barikissou Mitchala Orékan
Receive this thesis as a reward of your sacrifices for your children

My brothers and sisters
This thesis is a reward of your permanent support

Acknowledgments

This dissertation is the result of four years of research and would not have been possible without the help, cooperation and support of very many people.

My primary debt of gratitude goes to Prof. Dr. Gunter Menz, my first supervisor. I am indebted to him for his informed advice and effective criticisms often delivered in a most pleasant manner. I also owe Dr. Hans-Peter Thamm a debt of gratitude. Without you, this thesis would not have been achieved. You have always been there to fight for offering me better conditions for the work and always found solution to all difficulties encountered in this scientific enterprise. I am especially moved by the way we both survived the field accident we encountered. May God bless you and opens you to the whole world as a recompense for your constant availability.

I am also grateful to my colleague Michael Judex who always delivered me from complexes scientific situations. Through his permanent presence to give me ready hands, and together with Dr Thamm, I started enjoying remote sensing and GIS. Thank you for sharing your precious time with me at any time. May God give us chance to share the fruits of your sacrifices always!

I would like to express my profound gratitude to the *Deutscher Akademischer Austauschdienst* (DAAD) for its financial support.

My sincere thanks go as well to the Federal German Ministry of Education and Research (BMBF) under grant No. 01 LW 0301A and to the Ministry of Science and Research (MWF) of the federal State of Northrhine-Westfalia under grant No. 223-21200200 through GLOWA-IMPETUS project for its permanent financial support without which this studies could not be achieved.

A word of thanks to the other members of the Panel – Prof. Dr. Klaus Greve, Prof. Dr. Barbara Reichert, Prof. Dr. Brice Sinsin, and Prof. Dr. Heiner Goldbach, who have accepted to judge this my humble work.

My thanks are also due to my colleagues of IMPETUS, of *Remote Sensing and Research Group* (RSRG), and of *Zentrum für Fernerkundung der Landoberfläche* (ZFL) particularly, Dr. E. van der Akker, Dr. M. Doevenspeck, Dr. V. Mulindabigwi, Dr. U. Singer, Dr. J. Adanguidi, Dr. A. Bako, Dr, S. Giertz, Dr. K. Hadjer, D. Zhixin, O. Schmitz, B. Schoettker, J. Borgwardt, J. Röhrig, D. Klein, P. Poete, T. Drey, T.

Dobrzeniecki, B. Konermann-krüger, Dr. K. Voß, Dr. M. Braun, E. Götz, A. Waidosch, A. Vater, etc for helping and/or sharing experiences with me.

My stay and work in Bonn were facilitated through the cooperation of Dr. L. Sintondji, Dr. A. Kadanga, Dr. G. Dagbenombakin, Dr. S. Oloni, Dr. J.-P. Bognonkpè, F. A. Adégbola, D. Ogoun, M. Nadohou, K. Akandé, U. Engelhardt, H. Humpert, and many others who made my stay in Germany very pleasant.

My warm thanks to the staff in Cotonou, especially the graceful C. Mensah and A. Preu.

I am sincerely grateful to all my assistants François, Lamidi, and Issifou.

I am grateful to Prof. Dr. Ir. Brice Sinsin, my supervisor in Benin. In spite of your multiple professional activities and solicitude from many Ph.D. students and international organizations, you accepted to advice and guide me.

I am grateful to Dr. M. K. Afanuh for reading this thesis in spite your multiple occupations.

I am most grateful to Dr. Jean Cossi Houndagba. Your simplicity, humility, understanding and wisdom are always a guide for your colleagues and assistants under your responsibility within our common "*Laboratoire de Biogéographie et d'Expertise Environnementale*". I also thank all my friends of the Laboratory of Biogeography (LABEE) especially Dr. F. C. Tchibozo, Dr. B. Tenté, J. Gnélé, J. B. Vodounou, N. Agoïnnon with whom I share deep times of thought. My sincere gratitude goes also to Dr. E. Bokonon-Ganta. Finally I thank the head and all the other lecturers of the Department of Geography, especially Prof. Michel Boko who initiated the pluridisciplinary doctoral studies ''*Espaces, Sociétés et Développement du Monde Négro-Africain*''.

I would like to thank Dr. Vincent Joseph Mama, the former Director of *Centre National de Télédétection et de Surveillance du couvert forestier* (CENATEL) sincerely. Many thanks go to all my colleagues within UNC Benin especially G. Agbahungba, C. Agli, P. Assigbè, P. Adégbola, Dr. I. Mouinou, M. Hounsou, N. Taïwo, for your permanent advice and to all my friends in CENATEL with whom I shared some pleasant times.

My deepest gratitude is due to my loving and dear wife Estelle Tchégnonhou and our daughters Solène Ayina Morênikê, and Kinède Amontcha Olayinka. I say congratulations for accepting to endure all the sacrifices and to always stay alone while I am away during these four years study period. This thesis is a recompense of your patience.

A dept of gratitude is due to all my brothers and sisters especially to Cyriaque, Hilaire, Emile, Irène Orékan as well as my nephews Tadé, Sègun, Arèmou, Owolabi and all the others for your permanent moral and prayerful assistance to my person and to the members of my family while I am away from Benin.

Above all, I would thank my regretted father Rigobert Orékan and my uncle Rainier Orékan for showing me the way of education.

I would finally say a big thank you to all people near and far who in diverse ways contributed to the success of this work. The merits are yours while I take full responsibilities of the weaknesses in this piece of work.

Summary

Implementation of the local land-use and land-cover change model CLUE-s for Central Benin by using socio-economic and remote sensing data

Within the last decades wide areas in West Africa are subjected to serious land-use and land-cover changes (LUCC). The detection of the changes, the understanding of the underlying processes as well as modeling of scenarios for future development is a precondition for the set up of sustainable land-use planning schemes. In this thesis the implementation of the local LUCC model CLUE-s is demonstrated for a savanna environment in central Benin. The study was performed in the framework of the *Integrated approach to the efficient management of scarce water resources in West Africa* (IMPETUS) project. The study area has a size of around 900 km². The population density is quite low (11 persons/km²) but it is subjected to migration and the population growth is very high (up to 13 % for some villages). Land-use is mainly slash-and-burn agriculture. Uncontrolled forest logging and practice of vegetation fires are frequent.

The degree of LUCC was derived from multitemporal LANDSAT images. Between 1991 and 2000 deforestation of 8 % was observed; 20% of Woodland savanna and 5 % of Shrub savanna had been transformed respectively into Shrub savanna and farmland.

In order to explain and to model present and future LUCC, the underlying processes have been analysed with geostatistics and through the integration of socio-economic factors. Due to the insufficient availability of official data, I undertook an own survey, and 188 households had been questioned. It turned out that the socalled drivers to describe the relevant land-use changes can be divided in two broad categories: proximate causes (e.g. accessibility, agriculture expansion) and underlying causes (demographic factors and socio-economic conditions).

To implement the spatial explicit statistic-dynamic CLUE-s model, different input parameters were used: the results from the socio-economic analyses as well as datasets describing the geographical situation like land-use and land-cover and distances (e.g. distance to settlements). The calibration of the model was performed using historical data describing the land-use and land-cover patterns between 1991 and 2000.

Different scenarios for future development of the boundary conditions were defined according to the findings of the IMPETUS project. The outcome of the base line scenario (“*business as usual*”) predicts that there will be some forests left in 2025 while the scenario (“*environmental damage*”) assuming an increase of 6 % a year of agricultural area results in nearly complete deforestation of the area in 2020. The resulting spatial pattern of the predicted changes shows strong changes along the main road Oubérou-Kikélé, where most of the immigrant farmers settle. This tendency will be maintained as long as the population increases. The spatial locations of areas subjected to strong deforestation are clearly indicated.

The validation process based on multiple resolution technique shows the ability of the CLUE-s model to predict the land-use changes at the local level. However further results can be achieved with improved datasets (e.g. detailed crops and land-use statistics, historical land-use, sound population census) which remain the principal constraint faced in the study area. Meanwhile, the results are valuable for assessing the land-use changes at local level and useful for setting up a Decision Support System (DSS) for the purpose of sustainable land-use management.

Zusammenfassung

Innerhalb der letzten Jahrzehnte vollzogen sich in Westafrika tief greifende Veränderungen der Landnutzung und der Landbedeckung (LUCC). Die Erkennung dieser Veränderungen, das Verstehen der steuerndne Prozesse ebenso wie die Modellierung zukünftiger Entwicklungen über Szenarien sind für die Erstellung von Planungsgrundlagen für eine nachhaltige Landnutzung unerlässlich. In der vorliegenden Arbeit wird im Rahmen des ***I****ntegrativen* ***M****anagement-***P****rojekts für einen* ***E****ffizienten und* ***T****ragfähigen* ***U****mgang mit* ***S****üßwasser in Westafrika* (IMPETUS) ein lokales LUCC-Modell für ein Savannengebiet in Zentralbenin vorgestellt. Der Untersuchungsraum hat eine Größe von ca. 900 km². Die Bevölkerungsdichte ist mit 11 Einwohner/km² zwar eher gering, allerdings führen Wanderungen in das Gebiet zu einem sehr hohen Bevölkerungswachstum, welches in einigen Dörfern 13% beträgt. Die dominierende Landnutzungsform ist Landwirtschaft durch Brandrodung.

Die Veränderungen der Landnutzung und Landbedeckung wurden aus multitemporalen LANDSAT-Szenen abgeleitet. Zwischen 1991 und 2000 wurden 8% Entwaldung beobachtet; 20% Baumsavanne und 5% Strauchsavanne wurden in Strauchsavanne bzw. landwirtschaftliche Nutzflächen umgewandelt. Um diesen Wandel erklären zu können, wurden die wesentlichen Prozesse mittels Geostatistik und der Integration von sozioökonomischen Faktoren analysiert. Aufgrund unzureichend verfügbarer offizieller Daten wurden dafür eigene Befragungen durchgeführt, wobei 188 Haushalte befragt wurden. Es stellte sich heraus, dass die treibenden Kräfte zur Beschreibung der Landnutzungs- und Landbedeckungsveränderungen in direkte (z.B. Zugänglichkeit, landwirtschaftliche Expansion) und indirekte sachen (demographische Faktoren und sozioökonomische Bedingungen) unterteilt werden können.

Für die LUCC-Modellierung wurde das räumlich explizit arbeitende statistisch-dynamische CLUE-s Modell verwendet. Als Eingabeparameter wurden die Ergebnisse der sozioökonomischen Analysen sowie räumliche Daten, wie Veränderungen der Landnutzung und Landbedeckung sowie Entfernungen (Entfernungen zu Siedlungen oder Strassen) verwendet. Für die Modellkalibrierung wurden historische Daten, die Veränderungsmuster der Landnutzung und -bedeckung zwischen 1991 und 2000 beschreiben, eingesetzt.

Außerdem wurden basierend auf den Projektergebnissen Rahmenbedingungen für Zukunftsszenarien definiert und berechnet. Das Ergebnis des Basisszenarios („business as usual“) prognostiziert für 2025 ein Bestehen der Wälder wohingegen das Szenario („environmental damage“), basierend auf einer jährliche Zuwachsrate landwirtschaftlicher Nutzflächen von 6%, eine fast komplette Vernichtung der Wälder schon für 2020 vorhersagt. Die räumliche Analyse zeigt, dass sich die Veränderungen vor allem endlang der Hauptstrasse zwischen den Dörfern Ouberou und Kikele, die durch Ansiedlung eingewanderter Bauern gekennzeichnet ist, vollziehen werden. Diese Tendenz wird, solange wie die Bevölkerung weiter wächst, bestehen bleiben. Gebiete, die durch starke Entwaldung gekennzeichnet sind, können räumlich klar abgebildet werden.

Die Validierung durch eine „multiple resolution technique“ belegt die Eignung des CLUE-s Modells, Landnutzungsveränderungen auf lokaler Ebene vorauszusagen. Allerdings stellte die bestehende Datengrundlage für das Untersuchungsgebiet die wesentliche Einschränkung für diese Arbeit dar, so dass verbesserte Datensätze (z.B. detaillierte Statistiken zur Anbaufrüchten und Landnutzung, historische Daten zur Landnutzung, solide Bevölkerungszahlen) die Aussagefähigkeit erweitern würde. Nichtsdestotrotz konnten die Veränderungen auf lokaler Ebene mit den verwendeten Daten und Methoden gut abgebildet werden, so dass die Ergebnisse für den Aufbau eines Entscheidungsunterstützungssystem (DSS) mit dem Ziel eines nachhaltigen Landnutzungsmanagements verwendet werden können.

Résumé

Implémentation du modèle local CLUE-s aux transformations spatiales dans le Centre Bénin aux moyens de données socio-économiques et de télédétection

De vastes superficies ont subi de profondes transformations spatiales au cours de ces dernières décennies en Afrique de l'Ouest. La détection de ces dynamiques spatiales, la compréhension du processus de changement de même que la modélisation des scénarii sont autant de conditions requises pour la mise en place d'un plan d'aménagement aux fins d'une utilisation durable des ressources naturelles. Cette thèse présente l'application du modèle CLUE-s à la dynamique de l'occupation du sol et de l'utilisation des terres à l'échelle locale en région de savane dans le Centre Bénin. L'étude est réalisée dans le cadre du projet "*Approche intégrée pour la gestion efficiente des ressources hydriques limitées en Afrique de l'Ouest et au Maroc*" (IMPETUS). Le secteur d'étude couvre une superficie d'environ 900 km². Bien que la densité de population y soit faible (11 hab./km²), le secteur connaît une forte immigration et un fort taux de croissance de population (parfois supérieur à 13 % pour certains villages). L'agriculture itinérante sur-brûlis est le principal système agricole pratiqué dans le secteur. L'exploitation incontrôlée des forêts et la pratique de feux de végétation y sont courantes.

La dynamique de l'occupation du sol dérive de l'exploitation des images multi-temporelles LANDSAT. Entre 1991 et 2000, 8 % des forêts ont été dévastées; 20 % de savane boisée et 5 % de savane arbustive ont été converties respectivement en savane arbustive et en champs.

L'explication du processus qui sous-tend ce changement est faite aux moyens d'analyses géostatistiques et des facteurs socio-économiques explicatifs. Par manque de données socio-économiques officielles, une enquête socio-économique, niveau ménage a été effectuée; elle a porté sur 188 ménages agricoles. Les facteurs explicatifs de la dynamique de l'occupation du sol sont classés en deux catégories: les causes endogènes liées aux activités humaines (ex : accessibilité, expansion de l'agriculture) et les causes exogènes (facteurs démographiques et les conditions socio-économiques).

Pour modéliser la dynamique de l'occupation et de l'utilisation du sol, le modèle statistique, spatial et explicite, CLUE-s a été implémenté. Les résultats des analyses socio-économiques ainsi que les données géographiques telles que l'occupation du sol et les distances (distance aux habitations, voies) ont été les principaux paramètres d'entrée. Le calibrage du modèle a été mis en œuvre par l'utilisation de données historiques décrivant l'occupation du sol entre 1991 et 2000.

Les scénarii de développement futur définis se sont inspirés des résultats obtenus par le projet IMPETUS. Le premier scénario ("*business as usual*") présage encore de l'existence de couverts forestiers d'ici à 2025 alors que le scénario 2 ("*environmental damage*") qui suppose un accroissement annuel de 6 % des terres agricoles présage d'une déforestation complète du secteur d'étude à l'horizon 2020. Le résultat de cette modélisation montre que les changements spatiaux s'opèrent davantage le long de la voie principale Oubérou-Kikélé où la majorité des migrants s'installent d'année en année. A terme, cette tendance sera maintenue tant que la population croîtra. La localisation spatiale des aires affectées par la déforestation est aussi clairement indiquée par le modèle.

La validation du modèle s’est inspirée de la récente technique de résolution multiple. Cette technique a démontré l’habileté du modèle CLUE-s à prédire la dynamique spatiale au niveau local. Cependant les résultats obtenus ici peuvent être améliorés par la mise à disposition de données statistiques affinées (ex : statistiques sur les cultures, occupation et utilisation du sol dans les villages, recensement exhaustif des populations locales) dont l’absence constitue la principale contrainte de cette étude. Néanmoins, les résultats obtenus constituent une référence pour l’évaluation de la dynamique spatiale de l’occupation et de l’utilisation du sol au niveau local. Ils peuvent par ailleurs être valorisés dans la mise en place de système d’aide à la décision en vue d’une gestion durable des plans d’aménagement.

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1 RELEVANCE OF LUCC MODELING IN DYNAMIC SAVANNA ECOSYSTEMS (INTRODUCTION)

1.1 Background of the study

1.1.1 Global situation of LUCC

Attempting to understand the state of the environment around has always been a necessity and useful to avoid unfavorable consequences of land-use changes and to preserve sustainable natural resource management for every human generation. Many scientists stressed that land-use and land-cover change (LUCC) emerged as a central issue in the broader debate of global change; and that change, has its origins in the concerns for human-induced impacts on the environment and their implications for climate change (Gimblet, 2006; Schneider & Pontius, 2001; Lambin and Geist, 2002). The key indicators of these changes are such concentrations of carbone dioxyde (CO_2) in the atmosphere, nitrogene fixation, emission of greenhouses gases, conversion, fragmentation of natural vegetation and loss of biological diversity (IGBP, 2001). Land-use change can trigger soil degradation and soil erosion, which changes watershed properties and may cause flooding at local scales (Bruijnzeel, 2004, Chomitz & Kamari, 1998). Furthermore, unsustainable land-use practices can affect soil properties causing loss of agricultural productivity with associated effects for local livelihoods and food security.

Focusing on biological diversity, the United Nations Food and Agriculture Organization (FAO) noticed that 15 to 20 millions hectares of forest disappear every year in developing countries while West Africa loses more than two third of its wooded surface (FAO, 2000). Equally, FAO predicts a further 30 per cent loss of vegetation in Tropical Africa and the Sahel zone by 2025 (GLOWA-IMPETUS, 2005) and this may affect the climate in West Africa. Actually, deforestation is the primary cause of global environmental change in tropical regions such as in Africa (Roy Chowdhury, 2006; Geist & Lambin, 2002). In addition “proximate and underlying” factors, extension of infrastructure, agriculture expansion, wood extraction, demographic, economic, technological, policy, institutional, cultural, environmental, and biophysical factors are targeted as well.

The abovementioned changes do not affect all regions in the world in a similar way. Some areas experience large changes with a high impact while other areas are hardly affected (Overmass, 2006). From a geographical perspective, many LUCC studies have been carried out on different scales ranging from household (unit of production) to regional level via national level (LUCC, 1997). The present studies assess the land-use changes at a local level in the Upper Ouémé Catchment in Benin.

Through the following sections, this introduction gives an overview of land-use changes and the importance of modelling these changes especially in the framework of GLOWA-IMPETUS project. Research objectives and questions are portrayed as well as the outline of the thesis.

1.1.2 Land-Use/Land-Cover Changes (LUCC) in Benin

Bénin loses almost 100,000 hectares of its natural vegetation every year, as a result of clearings for cultivation (MECCAGPDPE-PNUD, 2000; Mama & Houndagba, 1991). FAO already estimated a loss of nearly 70, 000 hectares of the forest cover between 1990 and 2000, i.e. a yearly loss of 2.3 % of the forest cover (FAO, 2000). And this tendency is increasingly changing, showing a regressive evolution of forest ecosystems (CENATEL & PGRN, 1995). Disturbance in vegetation in Central Benin can be inserted in the national context where the total forest cover has decreased from 29% in 1970s to 12% in 2000 (MEHU, 2000).

Vegetation cover has temporal and spatial dynamics, principally due to human impacts in the Upper Ouémé Catchment (Menz *et al.*, 2002). The period of drought experienced since 1970s has caused large numbers of farmers of the northern Benin to migrate away from their depleted, eroded land to the less-populated south area (GLOWA-IMPETUS, 2005). In addition to that so-called “cropland colonization” of massive migrant people in the catchment, pressure on natural resources is reinforced by a strong demographic growth of nearly 3% (RGPH3, 2002). Some other anthropogenic factors, that is, human activities relative to slash-and-burn agriculture, abusive forest exploitations, extension of cattle breeding, hunting and practices of vegetation fires can be noticed as well (IMPETUS, 2005; Kok, 2004; Houinato *et al.*, 2001; MECCAGPDPE-PNUD, 2000; Adjinda & Hounton, 1997, Mama & Houndagba, 1991).

By the means of remote sensing, the land-use change assessment based on satellite images showed that agricultural land in the Upper Ouémé Catchment has doubled between 1986 and 2001. During the same period, forty (40) per cent reduction in dense coverage was recorded (GLOWA-IMPETUS, 2005). Important hot spots of the observed changes are located in the southern catchment area along the road Wari-Maro to Kikélé where many migrant villages are developed during the recent last years.

For a better understanding of these changes, it is important to analyse the dynamics as well as the driving factors and the actors during the past, and the present. Based on that process understanding it is possible to estimate how land-cover will change in the future (Lambin & Gesit, 1997) in order to remedy the unfavourable consequences on hydrological cycle in this region of Benin. Therefore, a development on land-use change modeling is discussed in a separate modeling chapter. Meanwhile a general overview of models and modeling approaches is given in the next chapter.

1.2 Research in the frame of GLOWA-IMPETUS

The GLOWA (*Globaler Wandel des Wasserkreislaufes*) Global Change in the Hydrological Cycle is a research program which serves as a pilot project for the integrated research approach that involves various research disciplines. It studies the water cycle of different climatic zones. The aim of GLOWA (www.glowa.org) is to develop simulation-tools and instruments which will allow to develop and to realize strategies for sustainable and future-oriented water management at regional level, while taking into account global environment changes and the socio-economic framework conditions (GLOWA-IMPETUS, 2005). The program is sponsored by German Federal Ministry of Education and Research (BMBF).

1.2.1 Description and aims of IMPETUS Project

GLOWA-IMPETUS (***I****ntegratives* ***M****anagement* ***P****rojekt für den* ***e****ffizienten und* ***t****ragfähigen* ***U****mgang mit der Resource* ***S****üßwasser*) is one of the five cluster projects of GLOWA launched five yeas ago. IMPETUS (http://www.impetus.uni-koeln.de), an "Integrated approach to the efficient management of scarce water resources in West Africa" is a cooperative, interdisciplinary and integrative project. The different components of hydrological cycle (**Figure 1.2.1**) and their interactions are investigated in two river catchments in West Africa (the Ouémé River in Benin) and in the Northwest Africa (the Wadi Drâa in South-East of Morocco).

IMPETUS Benin - subproject A - focuses on the hydrological cycle of the Ouémé catchment and socio-economic implications (**Figure 1.2.2**). The aim of the work packet A3 is to investigate the functional relationship between spatio-temporal vegetation dynamics and the hydrological cycle. Based on the outcome, models are applied or developed to create scenarios for future development. As developed earlier in the previous lines, the Upper Ouémé Catchment in Bénin is subjected to strong changes in land-use/land-cover due to population growth and migration as well as a change in the climatic conditions. This can lead to a shortage of arable land, uncertain food supply and conflicts. This change of the land-use/land-cover has some impacts on the hydrological system as well. Therefore, the main goal of the work packet 3-1 is to set up scenarios for the land-use/land-cover under different boundary conditions with LUCC models. The outcome will constitute an important source of information and tools for decision makers for sustainable land planning and management.

Figure 1.2.1: Conceptual framework of hydrological cycle research in the interdisciplinary IMPETUS research Community

Source: IMPETUS, 2001

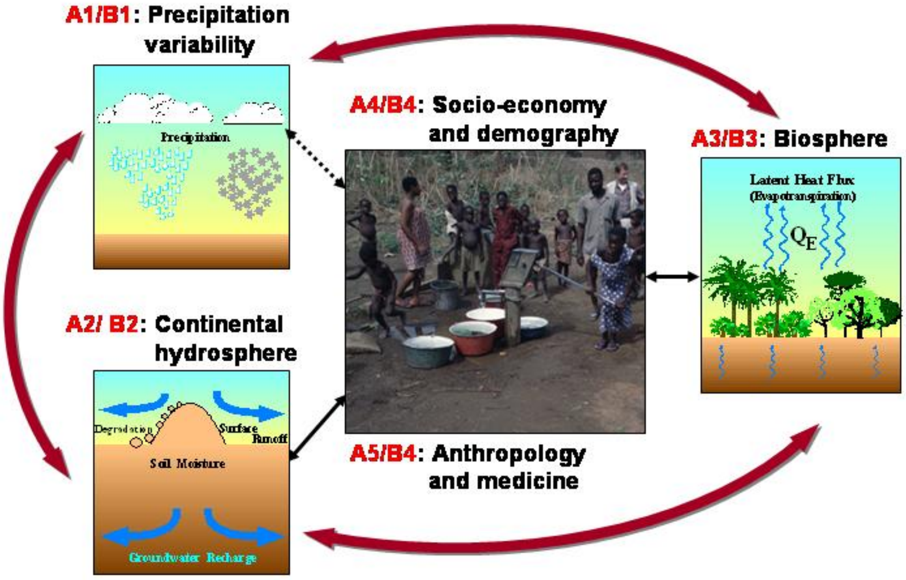

Figure 1.2.2: Multidisciplinary approach of the IMPETUS project

Source: Courtesy by Speth & Christoph. IMPETUS, 2001)

The present research is to be seen in the frame of this work packet A3 which has the following goals:

- assessment of the land-use / land-cover changes (LUCC) in different spatial and temporal changes from remote sensing images
- gaining process understanding by interpreting the LUCC in regard of the socio-economic conditions with statistic analyses
- setting up and calibration of LUCC models in different spatial scales
- derivation of scenarios of the future pattern of land-use / land-cover patterns
- computation of the agricultural potential under different boundary conditions
- development of decision support systems tools to estimate the impact of infrastructure measures on the land-use / land-cover

To achieve these goals, a number of LUCC models have been tested and a model chain was constituted (**Figure 1.2.3**). Due to the fact that sound information as input parameters for land-use modeling in developing countries is not guaranteed, the model chain is constituted of different models in different spatial resolutions (Thamm *et al.*, 2005) ranging from local to sub-national levels. The regional scale uses a resolution of 90 m x 90 m while the local scale (the present study) works in a spatial resolution of 30 m x 30 m. The local study focuses on modeling LUCC along Wari-Maro – Kikélé road in regard to socio-economic factors. More details concerning local scale modeling are given in the modeling chapter. The objectives of this study on local scale are presented below.

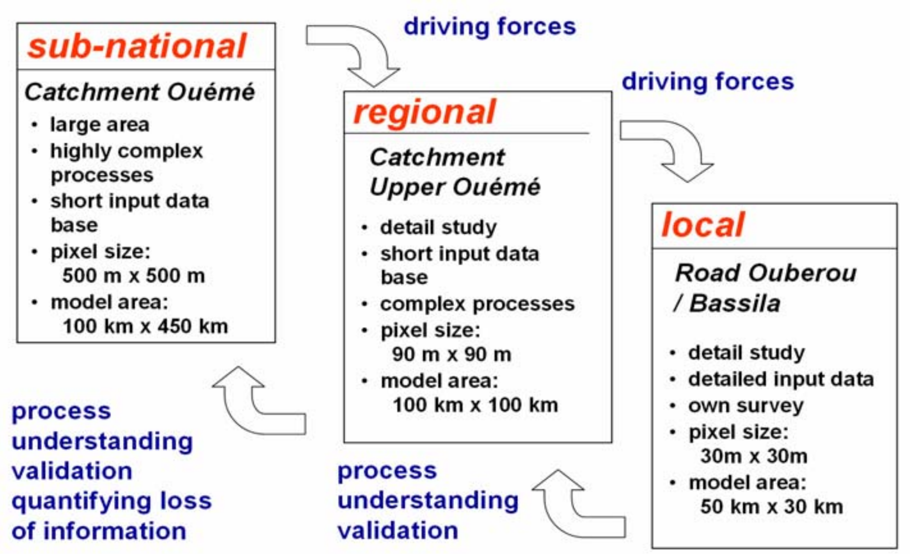

Figure 1.2.3: Scheme of the model chain to compute scenarios of future land-use and land-cover
Source: Thamm *et al.*, 2005(b)

1.2.2 Objectives of the study

1.2.2.1 General objectives

The overall objective of this research is to assess vegetation cover dynamics by modeling land-use and land-cover changes in the Southern Ouémé Catchment

1.2.2.2 Specific objectives

The specific objectives of the study are:

- linking socio-economic and remote sensed data to detect and quantify the changes in land-use and land-cover changes during the last two decades;
- simulating and locating the land-use and land-cover changes during the period 1991 to 2025;
- determining the main drivers that contribute to explain land-use and land-cover changes at local scale along the road Wari-Maro and Kikélé
- analysing how to make the simulation results useful for actors and decision makers in setting up land-use planning for a sustainable development

To reach these objectives, the following research questions are discussed

1.2.3 Research questions

- Can one provide a better understanding of land-use and land-cover changes by linking census and remote sensing data?
- What are the relationships between population increase and land-use change in this area, considering the influence of socio-economic factors?
- Where are the locations affected by changes in this study area?
- At what rate do land-cover changes advance?
- What biophysical variables explain land-use and land-cover changes in this sector?
- How can land-use and land-cover modeling help to provide a Decision Support System for a sustainable land management to the decision makers?

1.3 Organization of the thesis

Chapter 2 reviews shortly the LUCC modeling approaches. It describes the land-use and land-cover changes in general and defines some key concepts often used in LUCC studies. An emphasis is put on the driving forces of LUCC and the deforestation in tropical regions. Finally it gives an overview on different approaches in linking socio-economic and remote sensing information in LUCC modeling. The case of local area data gathering is described as a challenge. Chapter 3 introduces the study area location in the Upper Ouémé catchment, the biophysical and its socio-economic characteristics. The role played by settlements and agricultural land-use system in local LUCC are also described. In chapter 4, methods for remote sensing data collection and processing techniques, the socio-economic survey and creation of other datasets are discussed. The land-use change detection technique is fully described in Chapter 5 as well as the link of agricultural land and forest availability to population. Chapter 6 presents the characteristics of the population, the spatial organization of the study area, and finally sort out the link between socioeconomics and agricultural land-use as seen by the farmers. The relevant causes of LUCC are then indicated. The modeling approach of the CLUE-s and the resulting output as well as the validation technique and the scenario definition are detailed in Chapter 7. A comparison of link outputs, simulated results and model performance to external results from such linking and diverse applications of CLUE-s model is a part of the content of the final chapter 8. The later highlights the main summaries which are outcomes of this study with suggestions.

The following flowchart (**Figure 1.3.1**) shows the overall structure of the methodological approach of this my humble work. It comprises four main parts: Remote sensing data collection and analysis, Socio-economic data analysis, creation of additional data sets, and finally the modeling approach which could result in setting up a Decision support system in the future.

The next chapter reviews some relevant literature which includes the definition of basic terminologies used in LUCC studies. An overview on some tropical LUCC modeling approaches, their drivers, and finally the link between remote sensed and socio-economic data are highlighted.

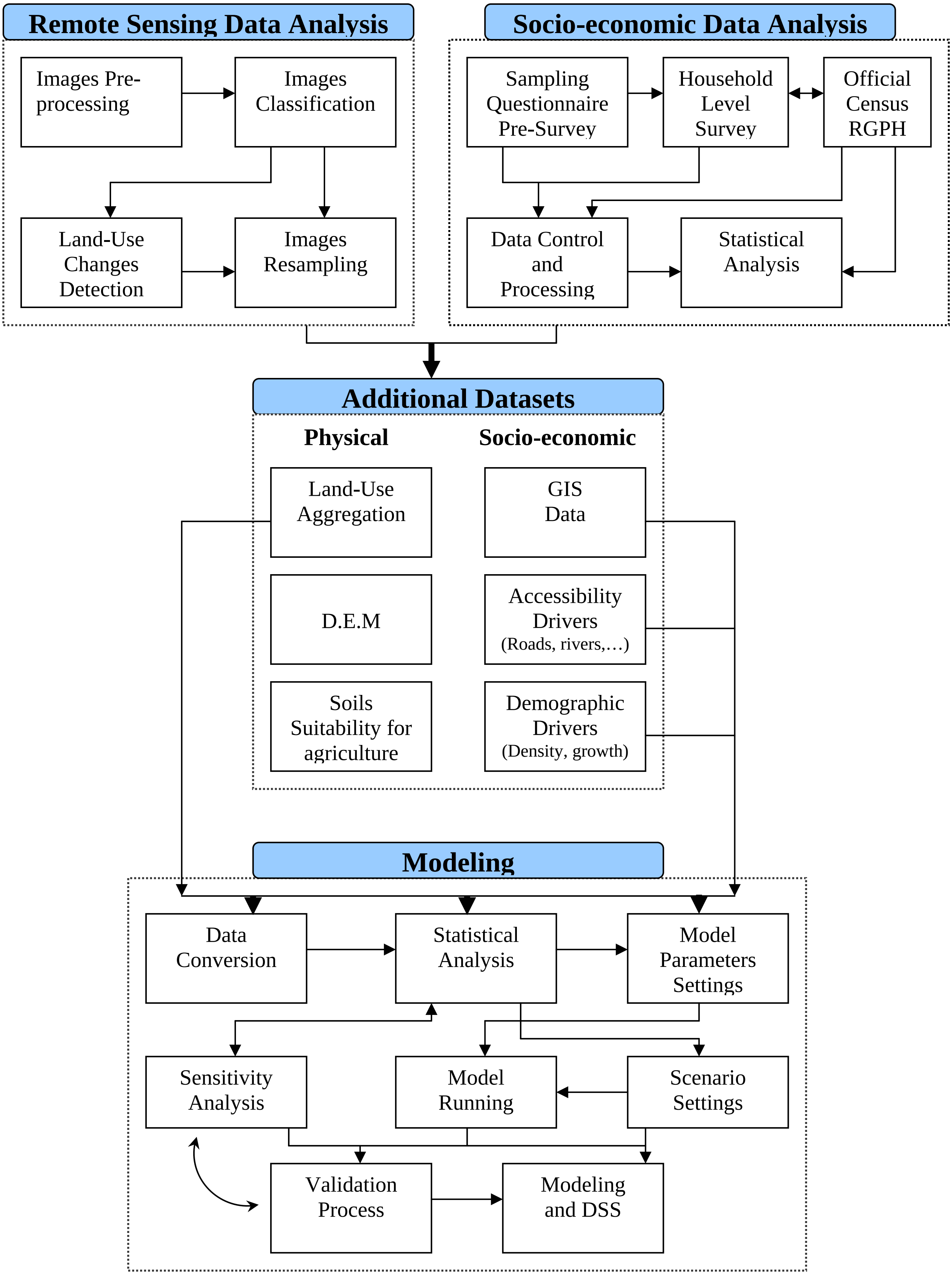

Figure 1.3.1: Flowchart of the work structure and main modeling steps

2 LAND-USE AND LAND-COVER CHANGE MODELING – A REVIEW

The aim of this chapter is to provide a brief general review of the land-use and land-cover change modeling. For this purpose, different types of models, modeling approaches and land-use change driving forces discussed among literature are presented. An overview of linking socio-economics and remote sensing in LUCC modeling studies is given as well as the challenge in local modeling data gathering for this specific research. Above all, the chapter starts to provide some definitions and clarifications of some key selected concepts often developed in LUCC modeling studies.

2.1 Definitions and Clarifications

This section gives some important definitions and clarifications of basic terminologies often used in land-use/-cover change studies. The definitions are important since they facilitate information exchange among scientists (Braimoh, 2004), improve understanding of existing classifications and their legends (Di Gregorio, 2005) and finally the land-use/-cover change studies by a broad readership. The selected terms are: Land, land-cover, land-cover change, land-use, land-use change, desertification, deforestation, driving forces, and modeling.

2.1.1 Land

As stated by Briassoulis (2000) and the Food and Agriculture Organization (FAO) in the documentation for the Convention to Combat Desertification (FAO, 1995; cited UN 1994) Land is defined in a holistic way as "a delineable area of the earth’s terrestrial surface, encompassing all attributes of the biosphere immediately above or below this surface, including those of the near-surface climate, the soil and terrain forms, the surface hydrology (including shallow lakes, rivers, marshes, and swamps), the near-surface sedimentary layers and associated groundwater reserve, the plant and animal populations, the human settlement pattern and physical results of past and present human activity (terracing, water storage or drainage structures, roads, buildings, etc.)". The same author concluded on a variety of definitions of land by arguing that it is worth noting that all definitions of land, although in general similar, differ as to the priority given to the attributes that characterize land.

2.1.2 Land-cover

Land-cover refers to the observed (bio) physical cover on the earth's surface and immediate subsurface (Turner *et al.* 1995). It includes vegetation, water (surface water, ground water), desert, ice, soil, topography and human-made structures such as mine exposure and settlement (IGBP/IHDP-LUCC and IGBP-DIS, 1997; Di Gregorio, 2005). When focusing on a very pure and strict sense, land-cover consists exclusively in the description of vegetation and man-made features.

2.1.3 Land-use

Land-use is the intended employment and management underlying human exploitation of a land-cover. It is characterized by the arrangements, activities and input people undertake in a certain land-cover type to produce, change or maintain it (IGBP/IHDP-LUCC and IGBP-DIS, 1997; Di Gregorio, 2005). Consequently, there is a link between land-cover and human activities in the environment because contemporary land-cover is changed mostly by human use (Allen and Barnes 1985; Turner II *et al.*, 1990; Whitby, 1992 quoted by Turner *et al.*, 1995).

2.1.4 Distinction between land-cover and land-use

It comes out from the above definitions that land-use and land-cover are not the same although they may overlap (Briassoulis, 2000). The distinction is schematically depicted in the following table (**Table 2.1.1**). Finally, it can be stated that the term *land-cover* is meant by the physical, chemical, or biological categorization of the terrestrial surface, e.g. grassland, forest, or concrete, whereas *land-use* refers to the human purposes that are associated with that cover, e.g. raising cattle, recreation, or urban living (Meyer and Turner, 1994).

Table 2.1.1: Types of land-cover and associated types of land-use
Source: Adapted from Briassoulis (2000)

Types of land-cover	**Types of land-use**
Forest	Natural forest Timber production Recreation Temporal pasture in Benin Mixed use-timber production and recreation
Grassland	Natural area Pastures Recreation Mixed use-pastures and recreation
Agricultural land	Cropland-annual crops Orchards, groves-perennial crops Recreation/tourism Mixed uses
Built-up Land	City Village Archaeological site Industrial area Second home development Commercial area Transportation Mixed uses

2.1.5 Land-cover and Land-use changes

Numerous researches conducted over the last decades helped to improve the understanding, the causes, and the predictive model of the land-use and land-cover changes (LUCC) concepts as they have been adopted under the auspices of the Land-Use and Land-Cover Change (LUCC) project of the International Geosphere-Biosphere Programme (IGBP) and International Human Dimensions Programme on Global Environmental Change (IHDP) (Lambin, Geist, and Lepers, 2003; LUCC-IGBP-IHDP, 1997).

In the case of land-cover changes, two types of change can be distinguished from the literature: conversion and modification (Lambin, Geist, and Lepers, 2003; Turner *et al.*, 1995). Land-cover conversion consists of change from one cover type to another (i.e. the complete replacement of one cover type by another) while Land-cover modification involves alterations of structure or function without a total change from one type to another; it could involve changes in productivity, biomass, or phenology (Skole, 1994).

In a similar way, land-use change may involve either conversion from one type of use to another i.e. changes in the pattern of land uses in an area or modification of a certain type of land-use. Modification of a particular land-use may involve changes in the intensity of this use as well as alterations of its characteristic qualities/attributes for instance changes of suburban forests from their natural state to recreation uses (the area of land remaining unchanged).

Land-cover/Land-use conversion takes place through many pathways such as deforestation, desertification, agricultural intensification, etc. Below more attention is given to the two first terminologies: desertification and deforestation.

2.1.6 Desertification

Desertification is one of major environmental impacts caused by uncontrolled land-use/land-cover changes that contribute negatively to the achievement of long term sustainability as they reduce the natural, economic, human, and social capital available to future generations. In its original form, desertification was firstly referred to as human-induced process of degradation that transformed tropical forest into savanna, and savanna into desert-like regions (Aubreville, 1949 quoted by Smith and Koala, 1999). Since then, many other scientists defined the term as a process and resulting condition of land degradation which leads to a drastic reduction of land productivity (e.g.: Briassoulis, 2000; Thomas, 1997). Key characteristics are degradation of natural vegetation cover, deterioration in soil quality, decreasing water availability, and increased soil erosion from wind and water (Hellden, 1991). Specific activities leading to desertification include clearing and cultivation of low-rainfall areas where such cultivation is not sustainable, overgrazing of rangelands, clearing of woody plant species for fuelwood and building materials. The phenomenon is prevalent in arid, semi-arid and dry subhumid areas. It is caused by various factors including natural (dry climate, low rainfall, water shortage) as well as anthropogenic factors (overgrazing, deforestation, fires, and intensive cultivation) (FAO, 1995).

2.1.7 Deforestation

Although there is no clear definition of “deforestation” (Geist and Lambin, 2001) the term is often used to describe situation of complete long-term removal of tree cover (Kaimowitz and Angelsen, 1998). Deforestation occurs when forest is converted to another land cover or when the tree canopy cover falls below a minimum percentage threshold – 10% for the United Nations (U.N.) Food and Agriculture Organization (F.A.O) (Lambin, Geist, and Lepers, 2003). The term can thus be viewed as a process of destroying forests (the removal of trees) by human beings and their replacement by agricultural systems (Roy Chowdhury, 2006; Carr, 2004; Lambin *et al.*, 2003). It sometimes relates to cases of biomass loss, shortened fallow length and other types of forest degradation. Finally, deforestation can be summarized to be not only forest conversion but also different types of degradation. Walker (1987) states that deforestation results from complex socio-economic processes and in many situations it is impossible to isolate a single cause. Therefore a diversity of causes of deforestation can be referred as driving forces (Geist and Lambin, 2002) that constitute the aim of the next sections.

2.2 Land-cover / Land-use changes and their driving forces

This section aims to give a broad overview of the diverse categories of driving forces of land-use changes with regards to selected case studies of LUCC in tropical regions. In addition, the selective case of tropical deforestation is assessed in order to clarifying the understanding of local factors that drive LUCC in our specific study area which faces as well these changes.

2.2.1 Categories of driving forces

"What drives/causes land-use change?" has always been one of the most common research questions in land-use change studies. To this question, driving forces can be simply defined as causes or factors responsible for LUCC (Braimoh, 2004). A precise meaning of the "drivers" or "determinants" or "driving forces" of land-use change is not always clear (Briassoulis, 2000). Therefore, two principal distinctions are made regarding the origins of the drivers of land-use/-cover change on one hand, and the factors and processes that contribute to land-use change and, through certain human actions, cause land-cover and environmental change on the other hand.

Concerning the first distinction, two main categories are almost distinguished: bio-physical and socio-economic drivers. The *bio-physical drivers* include characteristics and processes of the natural environment (weather and climate variations, landform, topography, and geomorphologic processes, volcanic eruptions, plant succession, soil types and processes, drainage patterns, availability of natural resources) while *socio-economic drivers* comprise demographic, social, economic, political and institutional factors and processes (population and population change, industrial structure and change, technology and technological change, the family, the market, various public sector bodies and the related policies and rules, values, community organization and norms, property regime).

In the second distinction, characterized as semantic, three broad forces are distinguished and cited by Briassoulis (ibid*): human driving forces*, *human mitigating forces* and *proximate driving forces* developed by several authors (Turner *et al.*, 1995; Moser, 1996; Kates *et al.*, 1990; Turner and Meyer, 1994; Verburg *et al.*-).

On the other hand, Lambin (2004), took into account a variability that exists in the land-cover types, the physical environments, the socio-economic activities and the cultural contexts associated with land-use change to distinguish four categories of driving forces of land-use changes. These are factors that:

(1) affect the demands that will be placed on the land, i.e. population and affluence;

(2) control the intensity of exploitation of the land: through technology;

(3) are related to access to or control over land resources: the political economy; and

(4) create the incentives that motivate individual decision-makers: the political structure, attitudes and values (Turner *et al.,* 1995).

Therefore, the author suggested for identifying the causes of land-use change to first understanding how these different factors interact in specific environmental, historical and social contexts to produce different uses of the land (ibid.).

The next subsections focus specifically on the forces that drive respectively LUCC and deforestation in Tropical regions as one of the main component of global environment.

2.2.2 Driving forces of LUCC in Tropical regions

The development of land-use change models to generate projections requires, first, a good understanding of the major causes of these changes in different geographical and historical contexts (Lambin, Geist, and Lepers, 2003; Lambin and Geist, 2002). Numerous drivers of change have been identified from selective land-use changes studies that focus on the tropical regions: Mertens and Lambin *et al.*, 2000; Geist and Lambin, 2001; Serneels and Lambin, 2001; Verburg and Veldkamp, 2001; Soepboer, 2001; Willemen, 2002; and Engelsman, 2002. The most cited drivers in selected case studies corresponding to six different tropical countries (included regions) can be summarized as follow (**Table 2.2.1**). The six case studies were selected based only on geographical location to which are referred the numbers 1 to 6.

1)	Serneels and Lambin, 2001	Kenya
2)	Mertens and Lambin *et al.*, 2000	Cameroun
3)	Gobin *et al.*, 2002	Nigeria
4)	Braimoh, 2004	Ghana
5)	Verburg and Veldkamp, 2001	China
6)	Verburg and Veldkamp, 2004	Philippines

Table 2.2.1: Some land-use change drivers extracted from selected case studies in Tropical Regions

Driver	**Case study references**					
	1	**2**	**3**	**4**	**5**	**6**
Demography						
Population density	x			x	x	x
Urban population					x	
Labour force density					x	
Agricultural labour force density					x	
Economy and infrastructure						
Distance to city (or towns)	x	x			x	
Distance to river (or river)			x		x	
Distance to stream			x			
Distance to road (or road)	x	x	x	x		
Distance to water	x			x		
Distance to forest/non forest		x				x
Market accessibility (or distance to market)			x	x		x
Distance to settlements			x			
Illiteracy					x	
Income					x	
Climate						
Range in precipitation				x		
Total precipitation				x		
Average temperature (temperature)					x	
Agro-climatic zone	x					
Geomorphology						
Mean altitude (or altitude/elevation)	x			x	x	x
Mean slope (or slope)				x	x	x
Aspect				x		
Soil						
Land tenure (or land status)	x			x		x
Suitability for agriculture (aptitude)	x	x		x		

The table shows that demography and accessibility are the most dominant drivers: 66% and 50% of the case studies cited these drivers as explanatory factors of land-use changes in their respective study areas. This observation is confirmed by Lambin and Geist, 2002) who stressed that the relevant drivers are: population growth, change in population structure and migration; intensification of agriculture, seeking an increased productivity; improvement of accessibility; changes in life styles and rural-urban interactions; demands for energy, products and amenities (consumption patterns, tourism); extreme events and variability in biophysical conditions; macro-economic drivers; national policy measures and directives, opening to external economy and economic integration; external drivers ('globalisation', trade regimes, international agreements), etc. By summarizing, they (ibid.) come to the conclusion that migration in its various forms is a very dynamic force which is more and more recognised as being the most important among the three basic demographic variables (fertility, mortality, migration). Further more, for better explaining (and modeling) land-use changes, scientists need to understand the interactions among driving forces of land-use change. Therefore, in another study, Lambin, Geist and Lepers (2003) found out that land-use change in Tropical Regions is driven by a combination of four high-level fundamental causes:

1- resource scarcity leading to an increase in the pressure of production on resources
2- changing opportunities created by markets,
3- outside policy intervention,
4- loss of adaptive capacity and increased vulnerability, and
5- changes in social organization, in resource access, and in attitudes.

And finally conclude with some interconnections between various drivers and land-use change. These interrelations can be summarized through the following equation:

Land-use = f (pressures, opportunities, policies, vulnerability, and social organization)

with

Pressures = f (population or resource users, labour availability, quantity of resources, and sensitivity of resources);

opportunities = f (market prices, production costs, transportation costs, and technology);

policies = f (subsidies, taxes, property rights, infrastructure, and governance);

vulnerability = f (exposure to external perturbations, sensitivity, and coping capacity);

and

social organization = f (resource access, income distribution, household features, and urban-rural interactions)

with the functions f having forms that account for strong interactions between causes of land-use change.

Understand these interactions could result in improving modeling of the changes in land-cover in Tropical Regions.

2.2.3 Driving forces of tropical deforestation

As considered in above sections, a number of drivers of land-use changes can be distinguished. Lambin (2004) showed that deforestation results from slash-and-burn cultivation, either by landless migrants or traditional shifting cultivators (Lambin *et al.*, 2001), government-sponsored resettlement schemes, fuel wood gathering and charcoal production, conversion of forested areas for cattle ranching, inefficient commercial logging operations, provision of infrastructure, and large-scale, uncontrolled forest fires of an exceptional nature.

By classifying the causes of deforestation, Geist and Lambin (2001) distinguished three categories of drivers namely: proximate, underlying and other causes.

Proximate causes are defined as human activities (land uses) that directly affect the environment and thus constitute proximate sources of changes. They are seen to operate at the local level (i.e. test sites). Proximate causes are grouped into three broad classes: agricultural expansion (e.g.: expansion of cropped land and pasture), wood extraction (e.g.: fuelwood extraction, charcoal production) and expansion of infrastructure (e.g.: settlements, transport, public services). For Lambin (idid), proximate causes of deforestation are generally thought to be driven by a combination of underlying driving forces such as population growth, poverty, land hunger, shifting cultivation in large tracts of forest (Carr, 2004; Lambin *et al.*, 2001), inequitable social conditions, property-rights regimes, inappropriate technology, international trade relations, economic pressures, etc.

Underlying driving forces (or social processes) are seen as complex of social, political, economic, technological, and cultural variables that constitute initial conditions in the human-environmental relations that are structural (or systemic) in nature. Explanations collected from literature result in five classes of drivers:

1) demographic factors (human population dynamics or population pressure),
2) economic factors (commercialisation, development, economic growth or change),
3) technological factors (technological change or progress),
4) policy and institutional factors (change or impact of political-economic institutions, institutional change), and
5) complex of socio-political or cultural factors (values, public attitudes, beliefs, household behaviour).

Other causes category is composed of pre-disposing environmental factors (land characteristics such as soil quality, topography, features of the biophysical environment), biophysical drivers and social trigger events.

In regard to the above development, it comes out that there are some relations depicted between different drivers. The relative importance of each cause varies widely in space and time (Lambin, 2004).

It comes out from the above developments that either LUCC or deforestation drivers are multiple and diverse. The factors can be distinguished according to space, time and the use of the land cover.

The land-use changes that occur in our local study area may be consistent component of this tropical deforestation. Once the process understanding is achieved, it helps to derive the driving forces of these changes. In the modeling approach, these changes are taken into account for better assessment of the future landscape in the study area. Socio-economic data are combined with remote sensed data for this purpose. The next section gives a brief overview on LUCC studies that link socio-economics with remote sensing data for modeling LUCC. The importance of such method is shortly examined. More details on the modeling approaches are tackled in the modeling chapter.

2.3 Linking Socioeconomics and Remote Sensing data in LUCC modeling

Today, there is an increasing interest in making scientific progress through the use of remotely sensed data in social science research (Rindfuss and Stern, 1998). Remotely sensed data (aerial photographs or satellite images) are put to various socially useful purposes, including making crop forecasts, predicting severe storms, planning land development, etc. This section attempts to point out linkages between remotely sensed data and socioeconomic data in the frame of a study that aims to determine how socioeconomic factors may drive land-use changes at the local level.

Many authors have shown importance of remotely sensed data in social sciences. Lesschen *et al.* (2005) assert that the most familiar data source for LUCC research is maps, often derived from remote sensing information. From these maps numerous visible variables that are of great interest to the social scientists can be in turn derived. For instance, many social scientists find visible human artifacts such as buildings, crops, roads which can explain what underlies some social phenomenon for better understanding human-environment interactions. Therefore, one can set out what can remote sensing do for social science and vice versa.

On one hand, remote sensing tool can help in measuring the context of social phenomena, context seen as a variety of entities including political or administrative units, a school, ethnical group, etc. The context can be measured in various ways: censuses can provide measures of demographic or socioeconomic characteristics, individual context like ethnicity, biophysical context within which people work, live and play, and numerous aspects of contexts ranging from land-cover to soil moisture to weather. Another usefulness described in the same way (Rindfuss and Stern, 1998) concerns measuring social phenomena and their effects; providing additional measures for social sciences such as geographical features or other indicators from ground-based sources; making connexions across levels of analysis; and providing time-series data on socially relevant phenomena (e.g. Land-cover data coming from Landsat TM can help to achieve images from different years or time periods providing different socially relevant phenomena from various periods).

On other hand, social science can help essentially to validate and interpret remotely sensed observations i.e. for validating remote observations against data collected on the ground. For instance, some social activities are used to define some land-use units during classification. An example is forest classified as park land or productive agroforestry. These kinds of specifications require collaboration between remote sensing specialists and social scientists for a consensus definition that takes into account knowledge of the two concerned specialists. Another example set by Lesschen *et al.* (2005) shows other sources of data such as questionnaires that are frequently used by sociologists. Note that, questionnaires are especially useful to obtain management-related data e.g. crop rotations and can also give insight into the driving factors of land-use change.

It can be pointed out from previous development that a collaboration between remote sensing specialists and social scientists is required for better understanding and controlling human impacts on biophysical environment, as well as anticipating or modeling and responding to environmental impacts on humanity. Such understanding depends on better knowledge of linkages between remote sensing and social science. This is important since many multidisciplinary projects focus more attention on global environmental problems in different domains that affect land-use and land-cover changes.

Additional issues are discussed through the literature on some specific points relative to remotely sensed data and social science. Lesschen *et al.* (2005) assert that although it may be difficult to adequately represent land-cover types on a map, some social events such as farming systems that include livestock are even more difficult to map (Thornton *et al.* 2003). They also observe that if satellite images help to collect time-series data, on the social survey side most household surveys are carried out only once, to detect changes in land-use and driving factors. Therefore, for obtaining temporal depth data, a survey with a longer timespan should be applied. One issue occurred about the methodological approach to apply in such case. Two methods are suggested for this purpose: cross-sectional or longitudinal design. Cross-sectional designs are supposed to be easier to administer because it is not necessary to follow over time sample households, which might move away from the study area or change in size, composition or character. But cross-sectional designs suffer from lack of comparability between sampled households at two time points, especially if the sample size is not large enough. In a longitudinal design in turn, repeated visits to the same household may affect the quality of household responses.

In any case, gathering input data for better analysis has always been important as well as a challenge in developing countries where available sound information is a problem.

2.4 Challenges in data gathering

In most of land-use and land-cover change studies, remotely sensed data have been proven to be one of the best techniques for monitoring forest clearing, shifting cultivation, and land-use conversion patterns (Skole and Tucker, 1993; Cao and Lam, 1997; Turner *et al.*, 1995; McCraken et al., 2002; Entwisle *et al.*, 1998; Geoghegan et al., 2001). This can therefore be identified as a technique that can be partnered with socio-economic surveys on the ground and population censuses to lead to a better understanding of land-use/-cover dynamics and the factors that bring them about. The following issue focuses on the challenge taken up in necessary data-gathering for the methodological approach applied in this study. To achieve this point, a review of selected studies and projects carried out and the lessons that can be deduced is given.

Codjoe (2004) stated on some extensive studies on the human dimensions of global change undertaken by the Land-Use/-Cover Change (LUCC) project of the International Geosphere-Biosphere Program and the International Human Dimension Program on Global Environmental Change and showed their indirect linkages between information embedded within spatial imagery and the core themes of the social sciences as highlighted by several authors in the literature. From the following selected case-studies and in other regions in the world: the Nang Rong District of Thailand (Entwisle *et al.,* 1998; Rindfuss *et al.*, 1996), the Amazon Region study (Moran *et al.*, 1998; Skole and Tucker, 1993) and the Peten Region of

Guatemala (Schwartz, 1990), it can be pointed out that the combination of socio-economic surveys and the use of satellite imagery for land-use/-cover studies have been carried out. Some extensive studies located in Africa (Guyer and Lambin, 1993; Mertens and Lambin and Geist, 2002; Mertens *et al.*, 2000) showed some interests in combining remotely sensed data and socio-economic data as well.

From the previous section, it can be noticed that merging the satellite and census data into a single data could be the most challenging aspect of a study since there isn't yet a common approach to sort the relations between remotely sensed data and socio-economic data. Most of the studies reviewed used multi-temporal remote sensing data as well as time series socio-economic surveys or longitudinal household surveys for the analysis. The present study considers only one point in time due to resource and time constraints. Nevertheless, a total of 188 households in four villages were questioned for the household survey. The difference with most of other studies carried out in the review lies in three points:

1) the approach in this study considers a cross-sectional method and a very local scale study that concerns some few villages (for instance Mertens *et al.* (2000) used survey data covering 552 households in 33 villages in a province of Cameroon while Codjoe (2004) surveyed 504 households in 21 villages);

2) use of two questionnaires administrated to a total of 188 farmer households (native and migrants);

3) the final specific issue of this study to be mentioned and which is common to most of so called "developing countries" especially tropical countries is that census data are often only available (or not) for limited points in time (Verburg *et al.*, 2000). Thus analysis is especially constrained by lack of data. One does not typically find detailed crop, forest or socio-economic surveys. Official statistics are often underfunded and data collection for agricultural and natural resource statistics can be sporadic. Therefore, the socio-economic data collected in the frame of this study come to take up a challenge in data-gathering.

In addition to remote sensing data, the socio-economic data were used to explore the land-use changes on household level. Some of the resulting outputs are input for modeling the future land-use. This topic is briefly examined in the next section.

2.5 Modeling land-use changes

This section starts to provide the reasons that underlie the land-use changes modeling and guide the implementation of the CLUE-s model. Some existing different types of models and modeling approaches are then highlighted.

2.5.1 Why modeling?

By observing a priori the environment in the future, it is necessary to make some assumptions on land-use changes and draw the future situation of the landscape, based on scenarios. Models are used in land change science to help improve our understanding of the dynamics of land-use, to make predictions and/or evaluate scenarios for use in assessment activities (Brown *et al.*, 2004). In detail, modeling land-use changes will help to answer one of the following questions (Lambin, 2004):

- which socio-economic and biophysical variables contribute to explain land-use changes and why?
- which locations are affected by land-use changes – where?
- at what rate do land-use and land-cover change progress – when?

Finally the modeling output can help actors and decisions makers to set up land-use planning for a sustainable development.

The present study aims to adapt a model describing a spatially complex process of interactions between socioeconomic and remotely sensed data in the southern part of Upper Oueme Catchment which faces profound land-use changes. The CLUE, especially the CLUE-s model is suitable for this purpose in order to value the spatial impact of the abovementioned transformations on the environment.

This topic aims to highlight an overview of models, and some modeling approaches. It helps to understand the general pattern of a variety of LUCC models. Additional details for the CLUE-s modeling approach are given in the modeling chapter.

2.5.2 Types of models

Models can be classified in two top-level model types (Mulligan and Wainwright, 2004): physical (or hardware) and mathematical models.

Physical models are scaled-down versions of real-world situations. They are used when mathematical models would be too complex, too uncertain or not possible because of lack of knowledge.

Mathematical models are more common and represent states and rates of change according to formally expressed mathematical rules. Mathematical models can be separated into three types: empirical, conceptual and physically based models. Empirical models describe behaviour between variables on the basis of observations alone and say nothing of process. By the means of simplest mathematical function, which adequately fits the observed relationship between variables, empirical models have high predictive power but low explanatory depth. Conceptual models explain the same behaviour based on preconceived notions of how the system works in addition to the parameter values, which describe the relationship between the variables. And finally physically based models are supposed to be derived deductively from established principles and produce results that are consistent; but they only do one of these rarely both.

Finally, since there are no universally accepted typologies of models, a summary of the potential means of classifying models is given in the following table (**Table 2.5.1**).

Table 2.5.1: Potential types of classifying models
Source: Mulligan and Wainwright, 2004

Types	**Models**
Conceptual	Empirical – Conceptual – Physically based - or Mixed
Integration	Analytical – Numerical – or Mixed
Mathematical	Deterministic – Stochastic – or Mixed
Spatial	Lumped – Semi-distributed – Distributed – GIS – 2D – 3D – or Mixed
Temporal	Static – Dynamic – or Mixed

These means may be used according to the discipline or situation to which the type of model is applied for. The next section deals with the LUCC modeling in general and the CLUE-s modeling approaches.

2.5.3 LUCC modeling approaches

Literally hundreds of models of LUCC have been described in the literature (Brown *et al.*, 2006). Many of these land-use/land-cover changes studies have been based on the use of models. Different modeling approaches have been adopted for this purpose and they differ from the points of view of the modelers. The modeling approach classifications also vary depending either on the issue or goals (land-use conversion, intensification, management, etc.) or the discipline (geography, natural science, economics, urban planning, regional science, geographic information science, etc.). Below is given a brief general overview of LUCC modeling approaches from different scientists (Lambin *et al.*, 2000; Lambin, 2004; Irwin and Geoghegan, 2001; Kaimowitz and Angelsen, 1998).

The first author focused its classification on the main questions to which most the LUCC modeling should reply: (1) which environmental and cultural variables contribute most to an explanation of land-cover changes — why?, (2) which locations are affected by land-cover changes — where?, and (3) at what rate do land-cover changes progress — when? Five broad categories of models are thus distinguished. These are: empirical-statistical, stochastic, optimization, dynamic (process-based) simulation, and integrated models.

In general, empirical-statistical models that use regression models are intrinsically not spatial. Spatial, statistical models result in a combination of geographic information systems (GIS) and multivariate statistical models (Lambin, 2004). Spatial empirical model aims to quantify the relationships between variables using empirical data and statistical methods; then project and display cartographically the future land-use patterns that result from the continuation of current land-use. The model is built to describe the relationship between the dependent variable, e.g. the binary variable forested/deforested, and the independent landscape variables (Chomitz and Gray, 1996; Mertens and Lambin *et al.*, 2000). The CLUE model is an example of advanced statistical land-use change (Veldkamp and Fresco, 1996) which simulates land-use conversions based on regression model. The main characteristics of each of mentioned models are presented in the following table (**Table 2.5.2**).

Irwin and Geoghegan (2001) made a synthesis of non-economic and economic, spatially explicit or non explicit, models of land-use change from existing literatures in the environmental science and geography. Two broad classes are distinguished: spatially explicit, non economic and economic models of land-use changes. The table (**Table 2.5.3**) below summarizes the characteristics and advantage/disadvantage of each class of model.

Table 2.5.2: Categories of land-use changes (after Lambin, 2004; Lambin *et al.*, 2001)

Model category	**Main characteristic**	**Modeling approach**
Empirical-statistical (Chomitz and Gray, 1996; Mertens and Lambin et al., 2000, Veldkamp and Fresco, 1996)	Identify explicit causes of land-use changes Analyses of possible exogenous contributions to empirically-derived rates of changes Predict the pattern of land-use changes Do not establish a causal relationship Regression models are not spatial and perform poorly outside the study area Can not be used for a wide-range of extrapolations Spatial statistical models combine GIS and multivariate statistical models to predict and display future land-use pattern based on formulated assumptions (scenarios)	Multiple linear regression techniques Spatial statistical (GIS-based) models
Stochastic (Thornton and White *et al.*, 1997; Jones,1998; Wu, 1998)	Stochastically describe processes that move in a sequence of steps through a set of states (i.e. an amount of land covered by various types of land-use) Consist mainly of transition probability models (e.g. Markov chains) Advantage of Markov chain analysis lies in its mathematical and operational simplicity Probabilities of transitions are defined for changes from one land-use category to another Only current land-use information is required Can predict when land-use takes place in the short term under a strict assumption of stationarity of the process Can be used when no information on driving forces and mechanisms of land-use changes is available Other forms: spatial diffusion and Cellular automata models	Transition probability models
Optimization (Kaimowitz and Angelsen, 1998; Irwin and Geoghegan, 2001)	Mainly applied in economics Uses a general equilibrium models either at the micro-economic level (farm) or at the macro-economic scale Any parcel of land, given its attributes and its location, is modeled as being used in the way that earns the highest rent Investigate the influence of various policy measures on land allocation choices Can't be used for prediction because of unpredictable fluctuations of prices and demand factors, and to the role of noneconomic factors driving changes Other forms: Agent-based and behavioural models	Linear programming Land rent theory of von Thünen and Ricardo

Table 2.5.2: Categories of land-use changes (after Lambin, 2004; Lambin *et al.*, 2001) (Continued)

Model category	**Main characteristic**	**Modeling approach**
Dynamic (process-based) simulation (Stephenne and Lambin, 2001)	Patterns of land-cover changes in time and space are depicted by the interaction of biophysical and socio-economic processes. Emphasize the interactions among all components forming a system. Condense and aggregate complex ecosystems into a small number of differential equations in a stylized manner. Simulation models are based on an a priori understanding of the driving forces of changes in a system. Process-based models can be parameterized based on local observations of decision-making (difficult to deal with scale issue)	Behavioural models and dynamic simulation models Dynamic spatial simulation models
Integrated/Hybrid (Wassenaar *et al.*,1999)	Combine the best elements of different modeling techniques in ways that are most appropriate in answering specific questions Provide useful insights into complex land-use systems since they are developed within the framework of multidisciplinary research teams	Vary according to combined models

In addition to the last classification, other more details are given by Kaimowitz and Angelsen (1998) on economic models of tropical deforestation, resulting from 150 papers. The models were classified into three main categories (analytical, simulation including programming and empirical or spatial regression) at micro, meso and macro scales representing different levels of analysis i.e. household and firm, regional, and national level.

Table 2.5.3: Categories of non-economic and economic models of land-use changes
Source: Kaimowitz and Angelsen (1998)

Categories of models	**Spatially explicit, non-economic models**		
	Characteristics	Advantages	Disadvantages
Simulation (Cellular automata: CA)	C A is a mathematical models in which the behaviour of a system is generated by a set of deterministic or probabilistic rules that determine the discrete state of a cell based on the states of neighbouring cells	Explicitly spatial	Simulation often yield complex and highly structured patterns
(Simulation models of urban growth) (White *et al.*, 1997)	Mainly used by geographers, based on cellular automata models approach to analyse the process of urban growth.	Instructive and offer practical approach to understand interaction among individual agents to determine regional patterns of urbanization	Absence of an economic foundation Not very useful for planning and policymaking
Estimation (Empirical models of LUCC) (Mertens and Lambin and Geist, 2002)	They focus on some aspects of deforestation that is derived from remotely sensed data (dependent variables). Explanatory variables are deducted from diverse sources: - remote sensing and GIS (e.g. distance measures) - spatial biophysical (e.g. soil, slope, elevation) - socio-economic (e.g. population, distance to urban center, distance to the roads, distance to the water, family size, income, education level, wealth, ability to bear risk)	Well outcome concerning LUCC Attempt to identify spatially the location of changes and explicitly the proximate causes of land-cover changes based on multivariate analyses. Multiple Linear Regression techniques are used (Multiple Logistic Regression ; Multinominal Logit Model for LUCC Trajectories)	Less successful to explain human behaviour that leads the outcome of LUC Some external features that explain temporal dynamics are often omitted (e.g. timber prices, subsidies, land tenure…)
Hybrid (Veldkamp and Fresco, 1997)	Hybrid model combines estimation and simulation models. Simulation model uses the parameters from the estimation model to predict the spatial pattern of land-use/-cover change that could occur under different exogenously imposed scenarios e.g. Markov, LUCAS, CLUE models	- Sophisticated for treatment of ecological relationships that affect or result LUCC - Very simple	Less successful to explain human behaviour that leads the outcome of LUC Some external features that explain temporal dynamics are often omitted (e.g. timber prices, subsidies, land tenure…)

Table 2.5.3: Categories of non-economic and economic models of land-use changes (Continued)

Categories of models	**Economic models of land-use change**		
	Characteristics	Advantages	Disadvantages
Non-spatially explicit (Micro-economic models) (Regional economic models)	Use mainly economic theories		Do not offer a satisfactory approach to explain the spatial economic process of LUC at the parcel level
Spatially explicit models	Often focused on simple model deforestation Shows how economic theory can be applied to motivating the variables that are included in the LU conversion model and identifying potential endogeneity problems.	Demonstrate the benefits of incorporating economic theory into the LUC models	There is no explicit model of price formation and the policy that affect land-use No direct link between the unit of observation and the decision-maker

It comes out from the above descriptions that the models vary in their temporal and spatial nature (local, regional) and modeling techniques on the one hand and differ from the objectives assigned to each other (e.g. explaining, predicting) on the other hand. For instance, the stochastic or simulation model (other form is Cellular automata) operates at a broader scale (e.g. 1 km^2) while the optimization model, applied in economics, is suitable for modeling a parcel of land with given attributes and location, but can not be used for prediction. The dynamic (process-based) simulation model in turn is most useful for forest management (pattern of land-cover changes) where decisions are usually made annually or periodically.

Based on these resulting remarks and in addition to the reasons described above (sections 1.2.1 and 2.5.1) for modeling land-use change in the very local area (30m x 30m pixel resolution), the empirical-statistical and spatial models (described earlier) fit better to this study than the previous models. The selected category of model has the advantage to locate spatially and explicitly the changes and their drivers based on multivariate analysis. In addition and for particular needs, the best elements of different abovementioned models approaches can be combined as hybrid or integrated models.

After reviewing some of the relevant literature that relates to LUCC modeling, the study area will be geographically presented through its main biophysical, socio-economic, demographic features as well as the development of new settlements and agricultural land use system in this area.

3 UPPER OUEME CATCHMENT – THE STUDY AREA

3.1 Location

3.1.1 Location of Ouémé Catchment Area

With 510 km, the Ouémé is the longest river in Bénin and the main water vein. The Ouémé river basin stretches over 46,500 km² and reaches from the Atacora Chain in the north western part of Benin to the Gulf of Guinea along the Atlantic Ocean. It consists of two main basins: the "Upper Ouémé Catchment" which is part of Dahomeyen pediplain and the "Lower Ouémé Catchment" situated on the coastal sediments. An area of about 100 km x 100 km is selected within Ouémé Catchment for the purpose of GLOWA-IMPETUS investigations. The Upper Ouémé Catchment is located between latitude 9° to 10° N and between longitude 1°30 to 2°30 E in Central Benin, a West-African country in the south of the Sahara. This region is characterized by a typical pediplain landscape with flat relief and inselbergs in a context of bio-geographically important "Dahomey Gap" where dry forest and grasslands interest the Guinea-Congo rain forest. It belongs to the transition zone between northern Guinea Zone and the southern Soudanian climate zone. In 2002, the population of the Upper Ouémé Catchment was estimated at 577,318 inhabitants with an annual population growth of 4.6% between 1992 and 2002. The main income source in this region is dominated by agricultural production which plays an important role in people revenue of this catchment. Slash-and-burn is the generalized farming method. Agricultural activities are conducted without fertilizer, and agricultural machines are scarcely used. Due to intense pressures of population growth on agricultural land, it is almost impossible for farmers to observe appropriate fallow length. Therefore dramatic land-use and land-cover changes are recorded within the last 20 years in the catchment. The area along the road Wari-Maro to Kikélé serves as an area of investigation because of its strong LUCC.

3.1.2 Location of study area within Ouémé Catchment Area

The study area of about 920 km² is located in the southern area of the Ouémé Catchment (**Figure 3.1.1**). It stretches between the villages Wari-Maro and Kikélé along the main road of Oubérou-Kikélé. This study area globally lies between latitudes 9° to 9°20' N on the one hand and between longitudes 1°38' to 2°20' E on the other hand. This sector is shared by two administrative territories of Tchaourou and Bassila District (*Districts*[1]) with respectively four

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[1] *District* (former S*ous-préfecture*) is an administrative unit under *Département* according to the new administrative boundaries reform as a result of decentralisation of political government in 2000. *Sub-District* and *Village* are the following levels under *District.*

main native (autochtonomous) villages along the main road: Wari-Maro (under Tchaourou) and Dogué, Igbomacro and Kikélé (under Bassila).

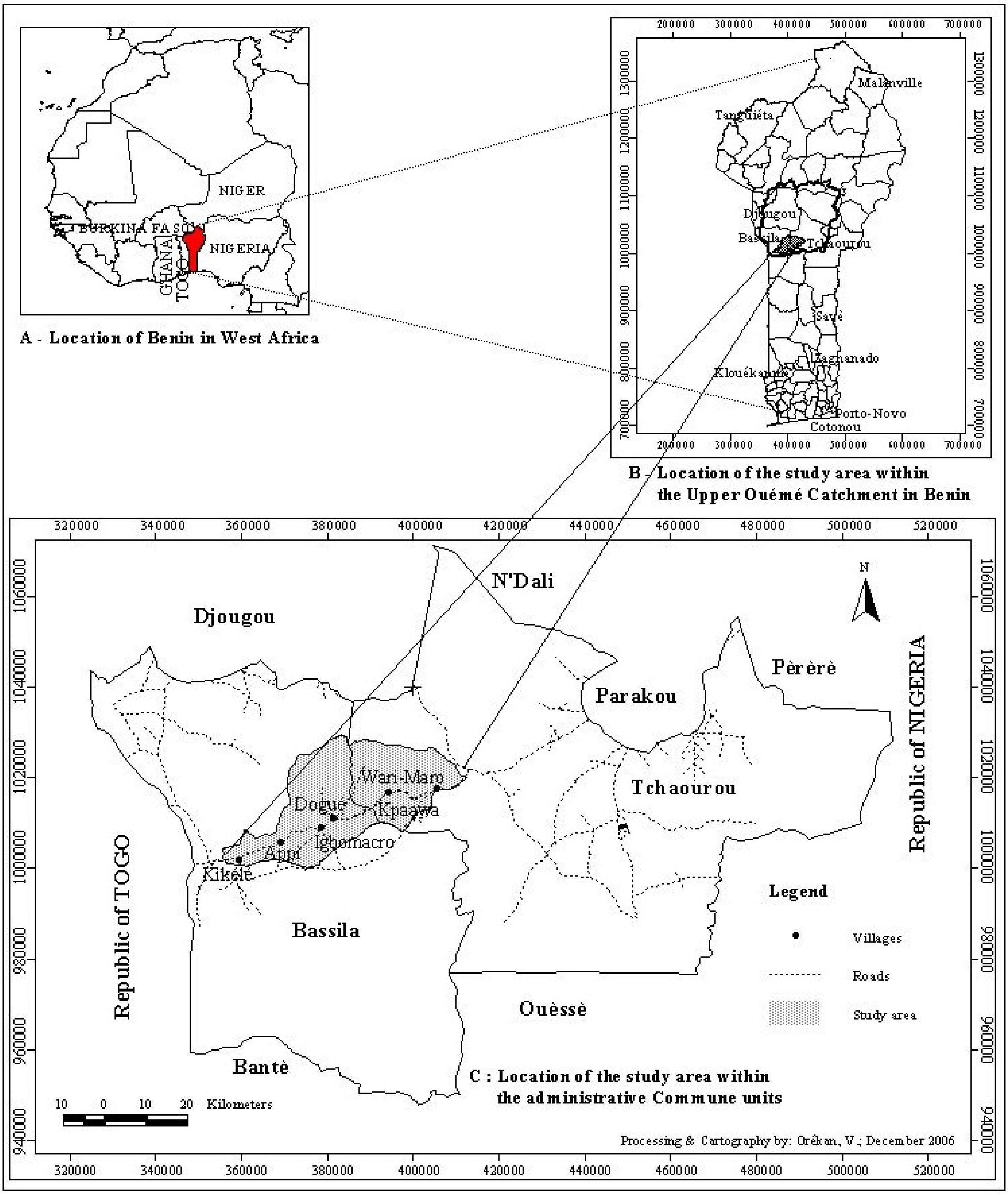

Figure 3.1.1: Location of the study in Upper Ouémé Catchment in Bénin, West-Africa

The first belongs to Beterou Sub-District (*Sub-District*) and the three other villages to Bassila Sub-District. Bassila, the main town in the District of Bassila is located at less than 10 kilometers from Kikélé, the last village in the South East of the study area. Wari-Maro, the second village after Ouberou (close to the asphalt road on the way to Parakou, the main regional capital) is at about 80 kilometers to Wari-Maro. The relief is characterized by a landscape with flat relief and inselbergs like *Soubakperou* (620m the maximum altitude in the study area) in Wari-Maro, *Goubouna* (609 m) in the north of Kikélé and *Igbéré Kouano* (445 m) in the north of Dogué village.

3.2 Biophysical environment

3.2.1 Climate

The area is located in a transitional climatic zone where the rainy season (April to October) alternates with one dry season (November to March). Like the regional climatic situation, the local climate is also subjected to a period of drought experienced since the 1970s in Benin. The figure below (**Figure 3.2.1**) shows an increase in temperature (up to 27°C) since 1980 while only a few years ago the same region gained more precipitation during the same period. The characteristics of this local climate are based on data collected from *Benin Meteorological Services* (ASECNA).

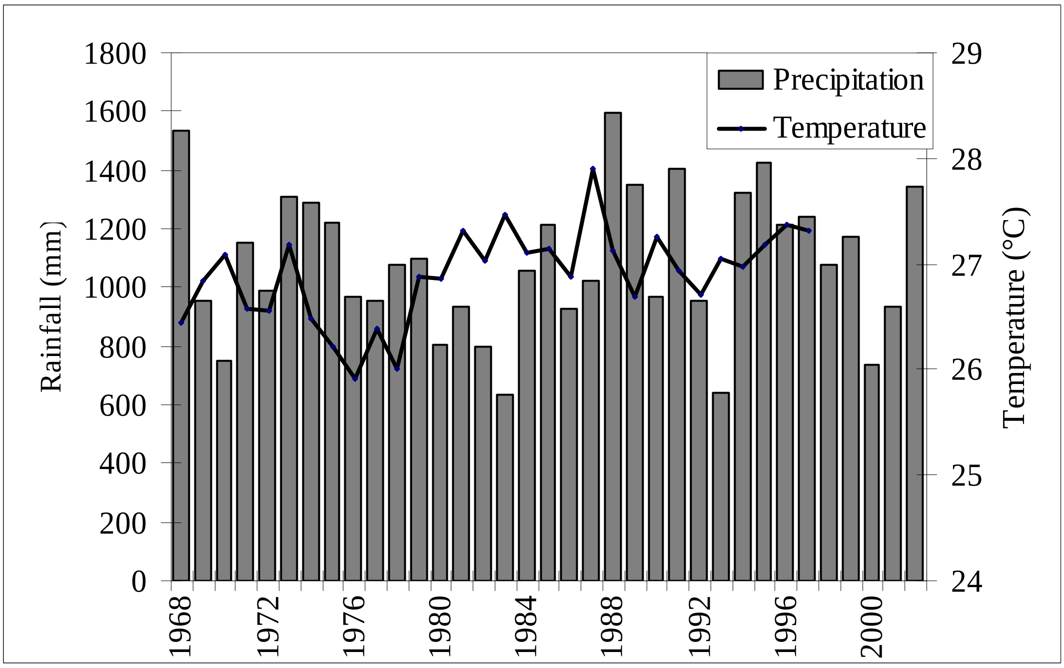

Figure 3.2.1: Annual average of rainfall (*Station of Beterou*) and temperature *(Station of Parakou*) between 1968 and 2002

Source: WMO/ASECNA, Benin Meteorological Services

The climate is generally characterized by a high temperature (mean temperature above 25°C) all the year round. It is similar to the central Benin climate which is marked by *''Harmattan''* (Orékan, 2000). *Harmattan* also called North East Trade Winds (NETW) is a seasonal wind which blows from Sahara desert and brings the dry season while the South West Monsoon Winds (SWMW) brings moisture. The NETW is generally characterized by a relative high temperature during the noon (up to 36°C) and fresh weather early in the morning and during the night (less than 21°C). The convergence of the two air masses, known as inter-tropical convergence zone (ITCZ), is closely connected to weather variability (Walker, 1962). In general, the average temperatures measured by the Synoptic Station of Parakou state about 27°C from 1994 to 1997. The monthly average minimum temperatures range between 19 and 23°C while the maximum stretch between 29 and 36°C. The highest temperatures occur during the months of February-March while the lowest are observed during July-August (**Figure 3.2.2**).

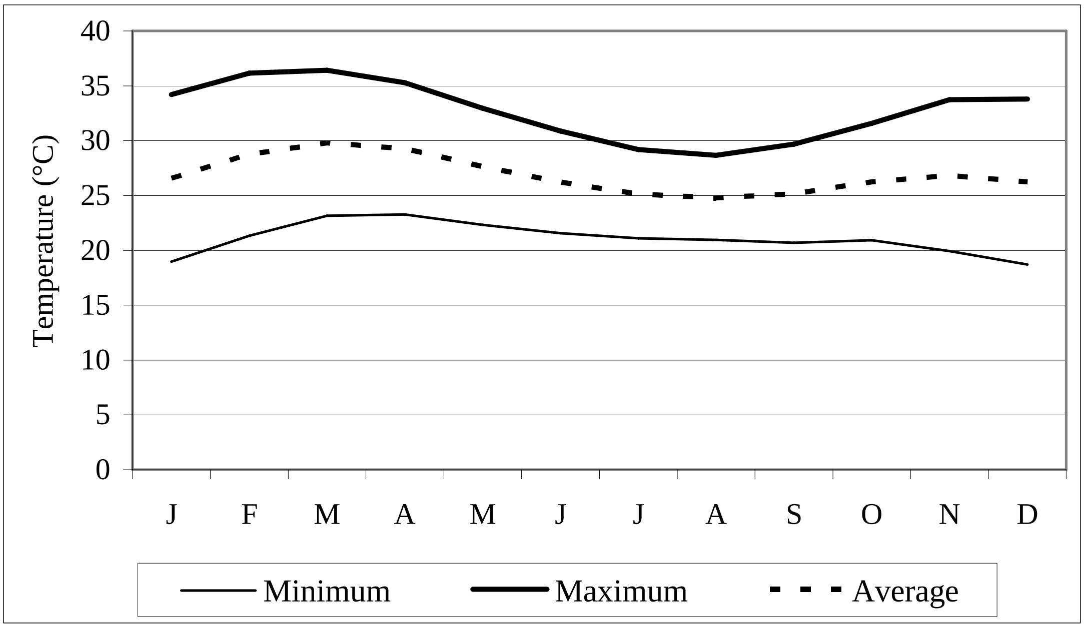

Figure 3.2.2: Monthly average temperature between 1968 and 2002

Source: WMO/ASECNA, Benin Meteorological Services, Station of Parakou

The average rainfall of the whole Ouémé Catchment ranges from 1,100 to 1,300 mm depending on location and observation length. In Beterou climatic zone, the region that covers the study area, it has been recorded 736 and 1345 mm respectively in 2000 and in 2002 (**Figure 3.2.1**). Most of the rains in the area are recorded during the rainy season especially during the months of August-September (with an average of 197 mm per month). During the dry season period, the maximum rainfall recorded averages 10 mm (**Figure 3.2.3**).

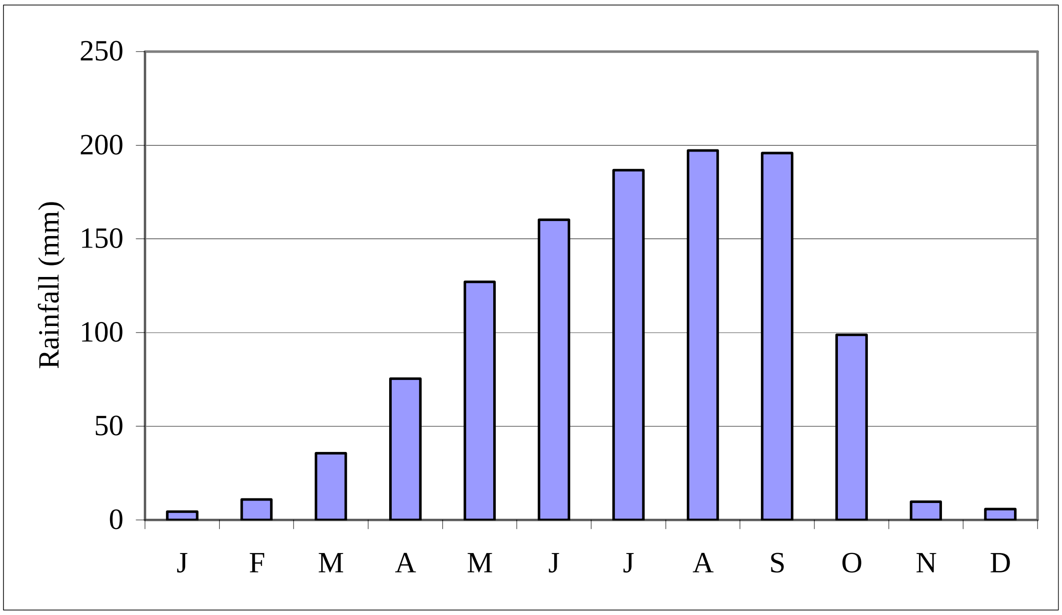

Figure 3.2.3: Monthly average rainfall between 1968 and 2002

Source: ASECNA, *Benin Meteorological Services, Station of Beterou*

During the rainy season in March recharge of soil water deposits begins and the consumption of soil water begins with the end of the rainy season in October-November, when evapotranspiration exceeds precipitation (Giertz, 2004 quoted by Orthmann, 2005; and Sintondji, 2005).

3.2.2 Geology and soils

The geological map of Benin (**Figure 3.2.4**) shows the west part of the study area dominated mainly by Precambrian chrystalline basement (migmatite, gneiss, granite) called Dahoméen in the west and lateritic consolidated soil layer on the east. The first is constituted of granular metamorphic rocks that can be regrouped in five main types: granite, gneiss, granito-gneiss, embrechites and quartzites (Houinato, 2001).

According to Faure and Dubroeucq (1977), *ferruginization* and *ferralitization* are the two main processes that characterize tropical soils. *Ferruginization* is the main process that consists in soil alteration (leaching) which makes the stratums of soils more distinguishable. The local soils are dominated by the ferruginous soil group named *sols ferrugineux tropicaux lessivés*[2].

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[2] The soil group *sols ferrugineux tropicaux lessivés* is constituted of different categories (*sols ferrugineux tropicaux lessivés indurés*, *sols ferrugineux tropicaux lessivés sans concretions*, *sols ferrugineux tropicaux lessivés à concretions* and *sols ferrugineux tropicaux peu lessivés*)

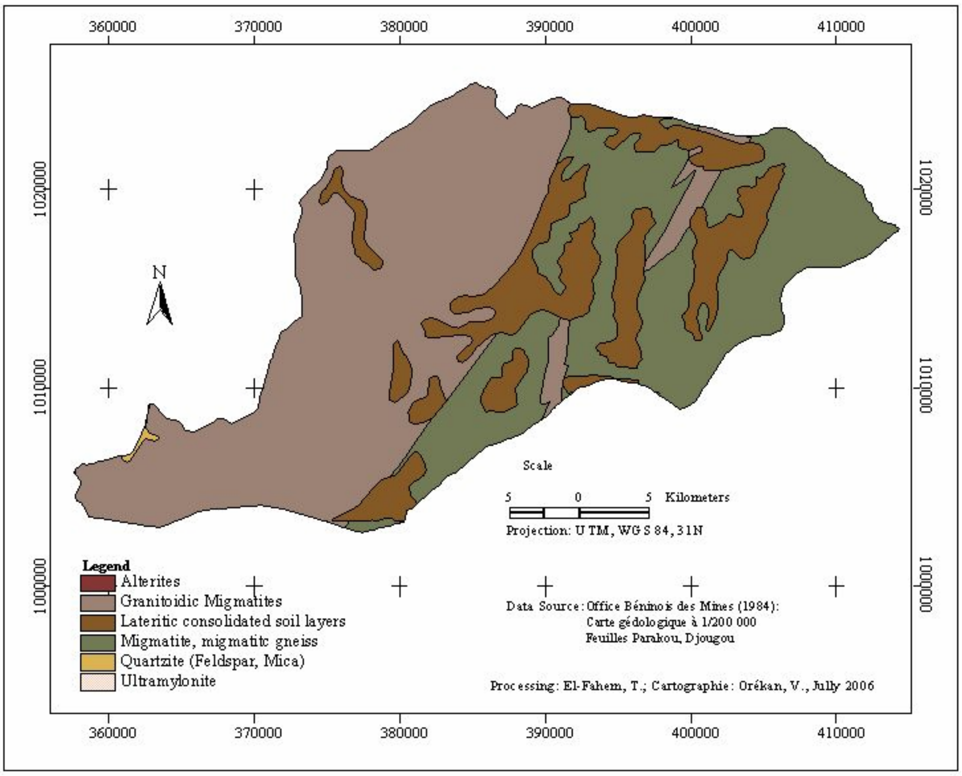

Figure 3.2.4: Geological map of the southern Upper Oueme Catchment

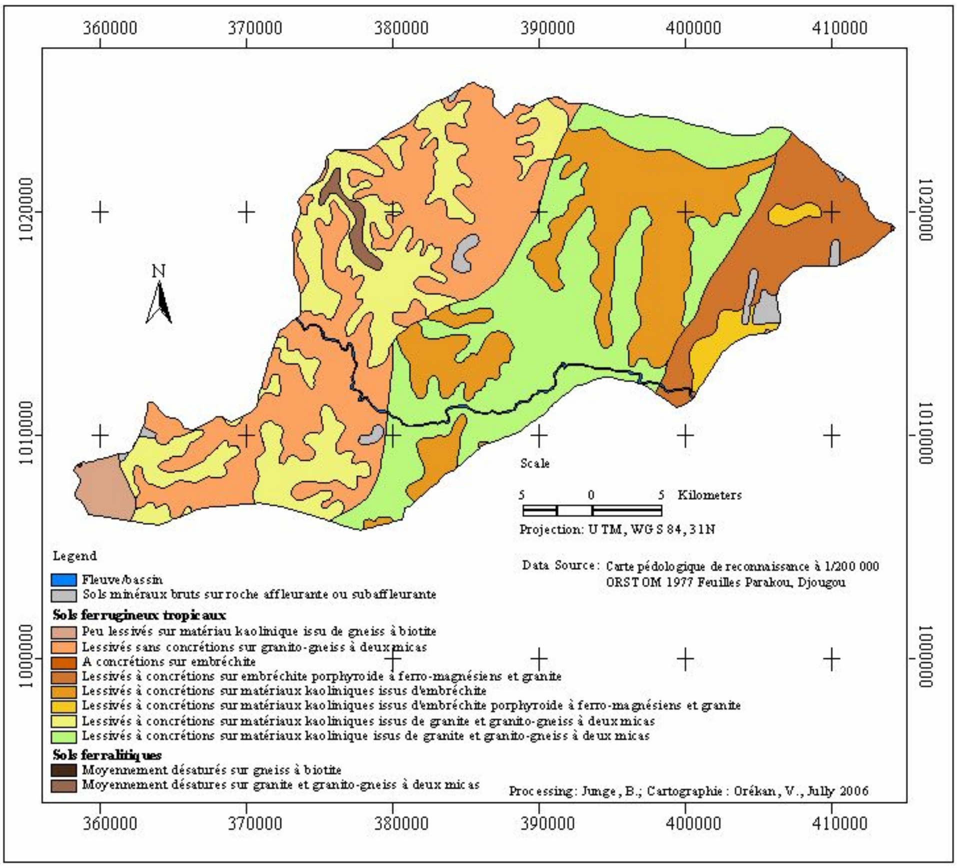

Figure 3.2.5: Soil map of the southern Upper Oueme Catchment

These soils are characterized by low fertility, quick depletion and are only suitable for reuse after a certain period of fallow. The second process, *ferralitization* is based on a series of chemical processes (hydrolysis, dissolution, drainage, oxidation) that alter the primary minerals of the rocks by producing quartz, kaolinite and oxyhydroxydes of iron. The combination of these processes confers to the stratums B their reddish colour, a character of friability and low exchange capacity and saturation rate (Houinato, 2001). Referring to the same previous authors, the group of *ferrallitiques* and *ferrugineux* soils is generally found on plateaus in this area of the study. They conclude that these types of soils are always fresh with very poor chemical qualities.

Furthermore, according to Junge (2004) and the “World Reference Base for Soil Resources” (FAO-ISRIC-ISSS, 1998) and “Classification des sols” (CPCS, 1967) quoted by Orthmann (2005), a classification of the soils in regards of their location on the landscape is made. Thus, the Albi-Petric Plinthosols (*Sols ferrugineux tropicaux lessivés indurés*) are developed on watersheds and lower slopes. The Endoskeleti-Albic Acrisols (*Sols ferrugineux tropicaux lessivés à concretions*) are characteristics of the upper and middle slopes. Finally, the Gleysols (*sols hydromorphes*) are developed in inland valley (bas-fonds). The soil map on the previous page shows more details of different soils that are present in the Upper Ouémé Catchment (**Figure 3.2.5**).

3.2.3 Hydrology

Terou and *Aguimo* are the two permanent rivers that stretch on three sub-catchments (Terou Igbomacro, Terou Wanou and Aguimo). The two rivers’ network has a number of tributaries estimated to 500 to 1000 (IMPETUS, 2005). All the rivers flow from north-west to south-east.

In addition to wells, rivers and waterholes serve as sources of drinking water for approximately 80% of the population of the study area, especially in the isolated settlements (camps) and in the farmers’ fields. Even in some villages supplied with pumps, local populations prefer drinking well water to pump water just because the first is supposed to be sweeter than the latter according to them. Twenty percent (20%) of the citizens are supplied with potable water from pipes.

3.2.4 Vegetation

The classification of LANDSAT satellite image 2000 (IMPETUS, 2005), shows a local natural vegetation dominated by forests and savanna types that constitute respectively 25 and 69 percent of the landscape in the study area. Forests with low human impact include gallery forest at the riversides, dense and opened forest islands dominated by species such *Isoberlinia doka*, *Pterocarpus erinaceus*, *Anogeissus leïocarpus*, *Vitellaria paradoxa*, *Parkia biglobosa*, *Burkea africana*, *Nauklea latifolia*, *Daniella oliveri*. As in the Upper Ouémé Catchment, more dense formations of woodlands and dry deciduous forest are often found on hilltops (Orthmann, 2005) in the study area as well. Apart from the hilltops, grass savanna occurs in the temporarily inundated depression (*Bas-fonds*); and finally in-between these two sides other savanna types (*savane boisée, arborée, arbustive*) are observed. The settlements and agricultural areas account for only 5 % and others (rock and water) 1%. Generally, agricultural areas are hidden by savanna cover type; therefore, some agricultural areas are easily distinguished on the landscape in the study area. An example of cropland is shown by the picture (12) cropland in Figure 4.2.1 and some sample-photos of land-cover types.

3.3 Socioeconomics and demographic features

3.3.1 Demography

The following development is based on population statistics derived from the three official population censuses of Bénin namely *Recensement Général de la Population et de l'Habitat* (RGPH). These censuses took place respectively in 1979, 1992 and 2002. The statistics derived from these censuses indicate that in 2002 a population of 9,700 inhabitants live in all the villages of the study area in the Southern Region of Ouémé Catchment (**Table 3.3.1**). The population for the three villages of Bassila *District* (i.e. Dogué, Igbomacro, and Kikélé) represents 9% of the entire *District* in 2002 and 4% in 1992. The single village of Wari-Maro counts for 3% of the entire Tchaourou *District* in 2002 and 1 % in 1992. It results that Wari-Maro village has a record high in population in 10 years than the other villages[3].

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[3] Bassila and Tchaourou Districts have respectively from 1992 to 2002 a population of 46,416 to 71,511 on one hand and 66,382 to 106,852 inhabitants (INSAE Benin, RGPH1, 2, 3)

Table 3.3.1: Distribution of population in the study area: 1979, 1992 and 2002

Source: INSAE Benin, RGPH 1, 2, 3

Year **Villages**	**1979**		**1992**		**2002**	
	Population	Household	Population	Household	Population*	Household*
Wari-Maro	459	70	887	132	3034	196
Dogué	235	43	1017	113	1809	168
Igbomacro	326	64	851	137	1298	204
Kikélé	1005	125	1701	213	3559	317
Total	**2025**	**302**	**4456**	**595**	**9700**	**885**

**Total population and households number for 2002 are estimated based on annual growth rates of 4.87% (Bassila) and 4.86 (Tchaourou)(RGPH3, 2002) using the formula*

$P_n = P_0(1+r)^{n-\alpha}$

with P_n *= estimated population,* P_o *= population of reference, n = estimation year and α = reference year and r = annual growth rate*

Population growth rate varies in the two Sub-Districts (*Districts*). It is more than 13% in Tchaourou, especially in Wari-Maro while it ranges from 4 to 7% in the villages that belong to Bassila for the year 2002 compared to 1992 (**Table 3.3.2**).

Table 3.3.2: Population growth per village in the study area: 1979 to 2002

Source: INSAE Benin, RGPH 1, 2, 3

Growth Rate **Villages**	**Population Growth Rate (%)**		
	1979-1992	1979-2002	1992-2002
Wari-Maro	5.2	8.56	13.09
Dogué	11.93	9.28	5.93
Igbomacro	7.66	6.19	4.31
Kikélé	4.13	5.65	7.66

The population growth rate (r) was estimated based on the following formula:

$$r = \left(\frac{P_n}{P_o}\right)^{1/n} - 1$$

where P_n is the recent population, P_o the population of reference and n the Time interval.

Average population density varies from 2 to 11 persons/km² respectively from1979 to 2002. The highest population density is always observed in Kikélé village where the density has increased three times within 23 years. This density has increased from 9 to 33 persons/km² from 1979 to 2002. During the same time interval, Wari-Maro has multiplied its population density by 8, Dogué by 7 and Igbomacro has doubled its density (**Table 3.3.3**).

Table 3.3.3: Population density (Inhab./km²) per village in the study area: 1979 to 2002
Source: INSAE Benin, RGPH 1, 2, 3

	Area (km²)	1979	1992	2002
Wari-Maro	379	1	2	8
Dogué	273	1	4	7
Igbomacro	158	2	5	8
Kikélé	109	9	16	33
Average	919	2	5	11

At the household level, the population data processed were collected during the survey organized during the dry season (2003). The results of this survey show a clear increase in population per household. The most important is recorded in Wari-Maro where the population per household passed from 7 to 16 respectively according to official census and local census. It is followed by Dogué with 11 people per household. Both villages have the same average number of active people per household and same number of native active people as well. On the contrary, Wari-Maro records more active migrants than Dogué (6 versus 3) in 2003. This difference may contribute to explaining the creation of several new settlements along the road Wari-Maro to Kikélé especially on Wari-Maro land. Finally Igbomacro and Kikélé have less people and same average active per household whereas the number of active natives and migrants are different. On the whole, in 2003, when considering the entire population of the study area, within 10 people in a household, half is active and more than a half belongs to the native group (**Table 3.3.4**).

Table 3.3.4: Population and active per household (Inhab.) per village in the study area
Source: INSAE Benin, RGPH 1, 2, 3 and own survey, 2003

	Population per household			Active per household*		
Villages	1979	1992	2003*	Average	Native	Migrant
Wari-Maro	7	7	16	5	6	6
Dogué	5	9	11	5	6	3
Igbomacro	5	6	8	4	6	3
Kikélé	8	8	6	4	5	4
Average	6	7	10	5	6	4

** Population per household for 2003 and Active per household are derived from our own census in the target villages. See 3.4 for more details on census approaches.*

Within these two household types, the average number of children per household is 6 and 5 women or men constitute each household. Kikélé, the most densely populated village also dominates all the other villages by the number of children and women per household (**Table 3.3.5**).

The demographic situation of the hamlets and camps, which are settlements under administrative village units, is more complicated since most of these settlements are often dynamic. This is described in more details in the following paragraphs that focus on migration and settlements.

Table 3.3.5: Population and sex (Inhab.) per village in the study area
Source: Own survey, 2003

Village	Male	Female	Child
Wari-Maro(48)	5	4	4
Dogué(40)	5	4	5
Igbomakro(40)	4	5	5
Kikélé (60)	5	7	8
Average (188)	5	5	6

Wari-Maro(48): Village (respondent)

3.3.2 Migration and Settlements

The old[4] villages in the study area are populated mainly by the Nago ethnic group: Wari-Maro, Dogué, Igbomacro and Kikélé. Among these four villages, Wari-Maro remains the one which has experimented and is still experiencing the migration phenomena. Originally, this village was founded by migrants coming from diverse directions around the XVIIth century (Iroko, 2002). As a matter of fact, Wari-Maro was already considered as a meeting point of several migratory waves (Iroko, 2002) since originally Naa Adoh (who belongs to the sociocultural group of the Nago) and Oru Gbéguru (who belongs to the Batombu), are the first two founders, and settlers of Wari and Maro. These two originally different camps constitute the Wari-Maro village (Iroko, 2002)[5]. Camps refer to individual or communal dwellings whose houses are often (made more or less) temporally, in comparison to permanent housings in villages. This type of settlement can be distinguished through the following additional characteristics:

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[4] Our investigation on the field indicated that the four so called administrative villages were created during the 15th century (Kikeke and Wari-Maro) and 16th century (Dogue and Igbomacro)

[5] *"C'est l'adjonction des deux mots « Wari! » et Maro issus l'un du nago et l'autre du batombu, qui donna naissance au toponyme de la localité initialement composée des deux campements de base."* (Iroko, 2002)

- camps are often isolate, grouped and/or often close to a village; they can be assigned hamlets i.e. a suburb of the village;

- often occupied by migrant ethnical group or isolate native people for the purpose of exploiting farm or for specific reasons;

- unstable because of transhumant settlers;

- activity (agriculture for non transhumance and breeding for others);

- geographical location (migrant settlers are often established deeper in savanna areas taking benefit of the pasture, while migrant farmers are closed to villages);

- camps' women often stay at home for market purpose (selling cheese or fruits crop or taking care for the children, harvest, etc.) or house-farm exploitation.

Nowadays, the phenomenon of migration still continues and is even stretched to the other surrounding villages especially Dogué and Igbomacro. In fact, as mentioned previously, Wari-Maro witnesses great dynamic migratory movements due to the arrival of newcomers from the north western part of Benin, densely populated and facing a high soil and natural environment degradation on one hand and to the phenomenon of cross-border transhumance of cattle breeders from the surrounding countries, namely Nigeria and Niger, on the other hand (Doevenspeck, 2004(a)). Only the village of Kikélé is still not dominated by migrants. In these three so-called "migrant" villages, the migrants, named allochthonous, belong to various socio-cultural groups. According to our recent investigations in 2003, about twenty socio-cultural groups dominated by the Yom (34%), Lokpa (18%) and Peul (18%) ethnic groups are settled in this area. Within the group "Other" (17%), one can distinguish the Gourma, Betamaribe, Taneka, Berba, Boufale, Pila-Pila, etc. classes (**Table 3.3.6**).

Table 3.3.6: Socio-cultural groups in the study area

Source: Own survey, 2003

Socio-cultural Group	% (number)
Yom	34 (44)
Lokpa	18 (23)
Peul	18 (23)
Waama	5 (7)
Kabyè	5 (7)
Ditamari	3 (4)
Others	17 (20)
Total	100 (128)

This situation is confirmed when comparing the whole population sample. It was recorded 57% versus 44% respectively for migrants (128) and natives (98) surveyed population. The migration phenomenon was reinforced with the building of the new road Oubérou-Bassila in 1997. Therefore, new settlements were created each year. It is obvious to observe these created settlements by migrants along this main road. Based on the criteria of population size, the famous created settlements are classified as follow: Kpawa, Etou, Gbaagba which are all located on the territory of Wari-Maro village. Almost two hundreds (200) settlements have been recorded during the period 2002 and 2004 in the study area. And the increase in their number is encouraged by the instability of local political regulation of the land tenure.

3.3.3 Land tenure

In the northern region of Benin in general, and in the study area in particular, it is observed by everyone that no piece of land is sold nor bought (De Haan, 1997). The “unlimited” character of land does not allow these kinds of transaction. Therefore the so-called migrant villages have an easy access to desired portions of land since land tenure and ownership are not well regulated by local institutions such as the village land lord (*chef de terre*) due to the local political instability and uncontrolled organizations of migrants. Any migrant can be given a parcel of land by simply contacting the first comer who plays the role of the village land lord in the area of the settler. Nevertheless, the land belongs anyway to the natives and some fundamental local traditional rules are followed by most settlers. Even the migrants are not allowed to plant fruit trees, they may have benefit of the usufruct right on a plot of land. Households present directly or via the first comer, gifts including a part of the harvest to the village chief in recognition of his authority. After having occupied the land, the migrant becomes in turn an owner to the next migrants (late comers) to whom he attributes a plot of land closed to his settlement or around the one obtained originally from the head. Thus both the number of settlers and the settlements increase. This process undergoes the development of settlements and farming land that has several visible changes on landscape due to the specific agricultural land-use of the migrants.

3.4 Settlements and agricultural land-use system

The economy of Benin is dependent on subsistence agriculture and regional trade (Cellule macroéconomique de la Présidence de la République du Bénin, 1995). Agriculture remains the main occupation of the majority of people and accounts for 36% of the GDP (estimation for 2001). According to INSAE (2002), it employs 49% of the rural labour force that comprises farmers, breeders and fishers. Similarly, the major land-use in the study area is agriculture[6]. The next development focuses on settlements and their influence on spatial organization of agriculture and then the cropping and farming systems.

3.4.1 Settlements and spatial organization of agriculture

The spatial organization of agriculture in the southern area of Ouémé Catchment is influenced by the settlements configuration and the agricultural land-use system of dominant ethnic groups.

Apart from the main native villages and other new comers (allochthonous) hamlets closed to the main road that crosses the study area, there are some camps scattered all over the region, surrounding some villages or away from the villages or hamlets, deeper in the savanna. In Borgou and Alibori Districts and in the study area as well, the Bariba ethnic groups live in closed villages with their surrounding fields. Increase in settlements, pressure on the land and higher animal density in the surroundings of a village often force younger and more dynamic farmers to search for fertile land further away (Brüntrup, 1997). Some small rainy-season camps near the fields are established when the distance to the fields becomes too time-consuming (Brüntrup, 1997). Such kinds of camps often make up the nucleus of a new hamlet and/or later new villages.

Peul (Fulani) farmers live dispersed (**Figure 3.4.1**A) and displace their camp usually every 5-10 years. However, some sedentarised Peul settlements stay at the same place for generations. Some displacements of Peul lead to resettlement in new villages or inside a territory of the Bariba village with whom the Peul have some ancient relationships. Remote Peul farms are often not accessible by vehicle (Brüntrup, 1997).

The Gando ethnic group occupy an intermediate position. They are not as mobile as Peul farmers. Therefore, they can stay in or near a village when they focus their activity on animal husbandry. But they live in separate quarters in a village or in camp groups (Brüntrup, 1997).

Below are some samples of native and migrant settlement configurations. The **Figures 3.4.1**A, B and D are aerial photographs taken with a Drone experienced by IMPETUS in the Upper Ouémé Catchment through Remote Sensing Research Group by Dr. Hans-Peter

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[6] In Dogué, agriculture employs 95% of the population (Wotto, 2003)

Thamm in 2004-2005 (see Thamm and Judex, 2006). **Figure 3.4.1**C shows an image taken with a camera during the fieldworks.

A: Dogué, a native's village located along the main road Wari-Maro to Kikélé

B: Kpawa, a migrants' village located along the main road Wari-Maro to Kikélé

C: Peul temporary settlement located deeper in savanna on Dogué Land

D: A migrant's settlement with closed fields around Kpawa hamlet

Figure 3.4.1: Spatial organization of native and migrant settlements
Source: Photos made by Orékan (in 2002) and Thamm (2004-2005)

To avoid long walks, most farmers prefer the nearest fields to their home concession (**Figure 3.4.1**D) either in the autochthonous villages or migrant (allochthonous) camps or hamlets (**Figure 3.4.1**A,B). But that tends to decline soil fertility because of over exploitation. Therefore, most of the fields in the region are located at 1 to 4 km distance from the concession (**Table 3.4.1**). This confirms the obviousness that soil fertility increases as the distance from the centre of village or hamlets to the farm increases (Brüntrup, 1997). The fields surrounding the concession are often cultivated by elder person, the eldest brothers of a family or by women. For the latter, these fields permit a better reconciliation of fields and household work (Brüntrup, 1997). More often, the increase in settlements and thus in the labour population brings about decline in soil and will lead to more cropped lands, depending on the agricultural land-use systems.

Table 3.4.1: Allotment and distribution of farming systems per type of household
Source: Own survey, 2003

	Native	Migrant
Average distance* to fields (km)	4(96)	3(92)
Average cropped areas (ha)	5.2(94)	3.2(58)
Average number of fields	10(89)	3(28)

** Distance between fields and village of the farmer*;
4(96): 4 average distance to field and (96) the number of farmers

3.4.2 Cropping and farming systems

Agriculture in the study area is essentially based on shifting cultivation. The latter comprises the cultivation of staple grains (cereals and vegetables), vegetables, root and tuber crops, as well as cattle and poultry breeding.

The crops cultivated are functions of the quantity and the distribution of rainfall. Due to the fact that the region records two main seasons (wet and dry) per year, only annual crops that are able to complete their life cycles during the rainy season, are cultivated without irrigation (Duadze, 2004).

The cereals include maize, sorghum, millet, and rice, while the legumes include groundnuts and beans. The root and tuber crops are yams and cassava. Most of the crops are primarily produced and harvested for subsistence needs. Nevertheless, a part of the harvest is sometimes sold in order to purchase additional household needs. In the valley bottom (“*bas-fond*”), rice is grown while the other crops are grown on the uplands. Farming systems in the southern Upper Ouémé Catchment are also characterized by the growing of cashew plantations and cotton production as well (Mulindabigwi & Janssens, 2003).

After the farming season in November, herds of cattle are let loose to graze the crop residues and stubble of the crops. Therefore, during the long dry season, a large transhumance phenomenon usually marked by an influx of Peul herdsmen coming from the surrounding countries mainly from Nigeria to graze their cattle far away from their place of origin is observed (more than 20 kilometres (Duadze, 2004, Wotto, 2003). At the end of the dry season, during April-May, all the herds of cattle are back to the camps.

The farms are largely smallholdings of approximately one hectare or more (sometimes less) and are usually mixed cropping or monocropping Systems (Duadze, 2004, Braimoh, 2004). All cropped areas together by farmers may range from 3 to 5 hectares respectively, for both migrants and native people (Table 6.4 in Appendix 2).

The type of crops grown in the study area are the same throughout the Upper Ouémé Catchment, but the land is often rotated, in that a farmer cultivates a given plot of land for a couple of years and then abandons it under the traditional bush fallow system for a new one when he notices a decline in the fertility of the soil (Wills, 1962). The farm landscape is thus a mosaic of cultivated land, fallow regrowth (at various stages of growth) and natural vegetation (Sakyi-Dawson, 2000). In the bush fallow farming System, availability of land for farming is not a problem and the farmer relies on natural regrowth fallow to restore the fertility of the soil (Wills, 1962).

The length of a normal fallow period (that is the period it takes the farmer to return to cultivate the fallowed land again) ranges between 2 and 25 years and depends on the availability of land, and the type of household (allochthonous or autochthonous). During the field survey, the average fallow age of between 7 and 12 years respectively according to migrant and native people is declared by the farmers (own survey, 2003)[7].

The more secured the tenure and the larger the size of holding (> 2 ha), the more diverse the cropping pattern, and the more likely it is for a farmer to practice crop rotation (Braimoh, 2004). Therefore, the number of fields in fallow vary with migrants or native farmers and ranges from 3 to 10 fields. One can observe a variability in cropping pattern within autochthonous than migrants since natives have more allotment than migrant’s (**Table 3.4.1**).

Finally, the farming system in the study area is characterized by low external input. The most important input in the agricultural production process is labour. Most of the farming activities are carried out by the farmer and his family members. Another source of labour available to farmers includes exchange labour. It is an arrangement between farmers to work on each other's farms for the same amount of time without financial compensation (Braimoh, 2004).

Once the theories which underlie the LUCC modelling reviewed, and the study area and its challenges for researcher presented, the next chapter will focus on the specific data and methods used in this study.

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[7] 33 of 128 migrant farmers that is 26% of surveyed farmers versus 95 of 96 native farmers that is 99% of surveyed farmers were concerned about that study.

4 DATA AND METHODS

This chapter gives an overview on socio-economic and remote sensed data collection and the methods applied for data processing as well as the modeling approach and geographical dataset creation.

4.1 Socio-economic survey

The socio-economic data were collected from two main sources: official censuses of 1979, 1992, and 2002 (INSAE-RGPH, 1988; 1994; and 2003) and our own survey: i.e. interview. The latter was carried out on household level which can be defined as a group of persons sharing one housing unit with the objective of securing their common needs (Overmass & Verburg, 2005; Schlauderer, 1997).

The aim of this survey is to figure out the characteristics of land-use and agricultural perspectives as perceived by the farmers. Thus, all information regarding the land-use, land tenure, accessibility, etc. was obtained through questioning the respondents. Therefore, in this part of the research (and due to time limitations), location of the fields and their mapping was not necessary. This is contrary to studies that map the fields by using information to link data from other sources, like maps or images to the fields (Overmass & Verburg, 2005). Nevertheless, these socio-economic data are supposed to help to better appreciate the effect of household practices on land-use/land-cover change in the study area. Especially, this socio-economic study was designed to elucidate the factors associated with the increase/decrease of cropped areas by households over the period covered by remote sensed images (Braimoh, 2004). Moreover, migration and the demographic household impact on land-use are of importance.

The population sampling derived from official population census and estimation[1]. More details on the official census source are figured out in the demographic part of the chapter on the Study area. The next development focuses on the questionnaire design and survey technique, followed by the processing approach.

4.1.1 Questionnaire design and survey technique

To collect data at household level, socioeconomic survey were carried out between January and April 2003 in the villages along Oubérou-Kikélé axis, the main road of the study area and in some neighboring hamlets and camps. The target population was farmer’s households

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[1] Population statistics from the last official census (RGPH 2002) was missing for the village Dogué and Igbomacro. Therefore, they were estimated

which have agricultural activity as the main occupation. Therefore, the dry season was chosen since the farmers are more available during this time-period. Two complementarily structured questionnaires were used for this purpose: one focused on both migrant and native farmers and the second, especially on the migrant farmers. The aim of choosing two questionnaires was guided by the following reasons:

1) the first questionnaire of one (1) page was designed to collect data about farmers in the main administrative villages settled by both autochthonous and allochthonmous;

2) the second (five (5) pages) questionnaire was designed for collecting data about farmers in the surrounding hamlets and camps that are supposed to be settled only by migrants, named allochthonmous. Therefore, some additional information related to migrants was collected through the second questionnaire;

3) both questionnaires are complementary since both include common questions that allowed collection of information relative either to migrants or native farmers;

4) the farmers in general have different agricultural practices and property rights that influence the land-use. This needed to be understood for better analyses the geographical pattern of the landscapes in the area;

The selection of variables to be incorporated in the questionnaires was based on theories through literature exploitation, and knowledge of the area. Some of the theories that were considered while constructing the questionnaires are the relationship between land-use and accessibility (Overmass and Verburg, 2005, Chomitz and Gray, 1996), household structure and its effect on land cultivation, e.g. Chayanov's theory of demographic differentiation and land-use (Perez and Walker, 2002; Walker *et al.*, 2002). An excerpt (from Perez & Walker, 2002) of this theory is provided in Appendix 1 (Doc.4.1). The aim was to construct a questionnaire containing variables that could possibly have an influence on land-use decisions of farmers in the area.

The questionnaires administered to the household head comprises many sections that are: (1) land-use (different crops, cropped area size in 2002, 2003, and 2004, crops' periods of cultivation, fallow, charcoal production); (2) land tenure (property rights); (3) bush fires (period, actors, causes, consequences, traditional policy of fires); (5) transhumance (origin and consequences); (5) resource management (orchards management, size, revenue); (6) markets and production organization (markets, cash crops, prices of firewood and charcoal); (7) perspectives (infrastructures, individual agricultural projects), and accessibility i.e. the distances from household unit and field to diverse locations (market, water spot, road, village). Except the accessibility, the second questionnaire assembles all these parameters while the first one contains in addition the land-use, the perspectives and additional specific questions related to migrants or to native farmers. The type of household (migrant or native), the demographic characteristics of the household are the main information components of the identification part of each questionnaire. More details can be found in the two questionnaires (see Appendix 1; Doc.4.2 and Doc.4.3).

For the completion of the survey, a contact with the main village authority (village head: *chef de village,* counsellor: *Conseiller*) or a representative person such as the eldest of the hamlet, was first established. Some explanations are given on the objectives, the reasons and the procedures of the survey. The surveyor-assistants are introduced as well. This contact helped to set atmosphere of confidence during the interviews. Further more, one guide was designated by the head or eldest of the village to follow the assistants to the households where possible. The selection of farmers was made in an equal geographical distribution within the village. The presence of an influential member of the local government is sometimes of importance and reassures the households who may want to answer our questions. This aspect was also very important knowing that, in the villages, conflicts may exist among the people (between native and migrant for instance).

A month before the official start of the survey; the questionnaires were pre-tested in four different administrative villages in order to adapt them to the understanding of the villagers. During the test-interview, the questionnaires, written in French, were translated by two local interpreters/field assistants into local languages. These last vary according to the spoken language of the surveyed farmers. Due to the language constraints, the assistants work more often in the villages in which they are able to speak their language (*nago* and *dendi*) in order to be perfectly understood by villagers and surveyed farmers. By doing so, it helps to avoid misinterpretation which questionnaires interpretation causes. About twenty socio-cultural groups are present in the study area (own field survey, 2003). And it is often difficult to find people speaking multiple languages and able to translate from French to other languages and to interpret into French as well, without any transformation. Therefore, some additional assistants were identified in each specific surveyed area to help to overcome this problem. They were used for administering the questionnaires that the number is defined by sampling.

4.1.2 Sampling methods

The selection of households to be interviewed was based on a combination of stratified and random sampling. This approach used the available population data with the official censuses from 1979, 1992 and 2002 (**Table 3.3.1**). The sample was stratified according to the four (4) main villages that belong to two administrative zones: Districts (Bassila and Tchaourou), and Sub-Districts (Bassila and Beterou) respectively the second and third level of administrative units. The villages (level 4) in turn, encompass several hamlets and migrants' settlements (camps) under study (**Figure 4.1.1**). In all the villages and hamlets, households are surveyed randomly by following an equal geographical distribution of the households' samples over the specific settlement; and the whole study area as well. This sampling approach was chosen based on the following reasons:

- due to time and budget limitation, it was not possible to organize a census of households within each village or hamlet since there is no reliable list of households which could help to choose randomly a list of farmers to surveyor at random;
- to avoid repetition of surveyed farmers;
- to avoid concentration of surveyed farmers in a particular area of each village or hamlet.

In addition to this random choice, the farmers should meet the criteria of being farmers, being adult (man or woman), of more than fifteen (15) years old, head of household, and living alone or together with his family. The age of the farmers were easy to estimate by the assistant-interviewers since they are experienced, familiar with farmers and belong to the same class.

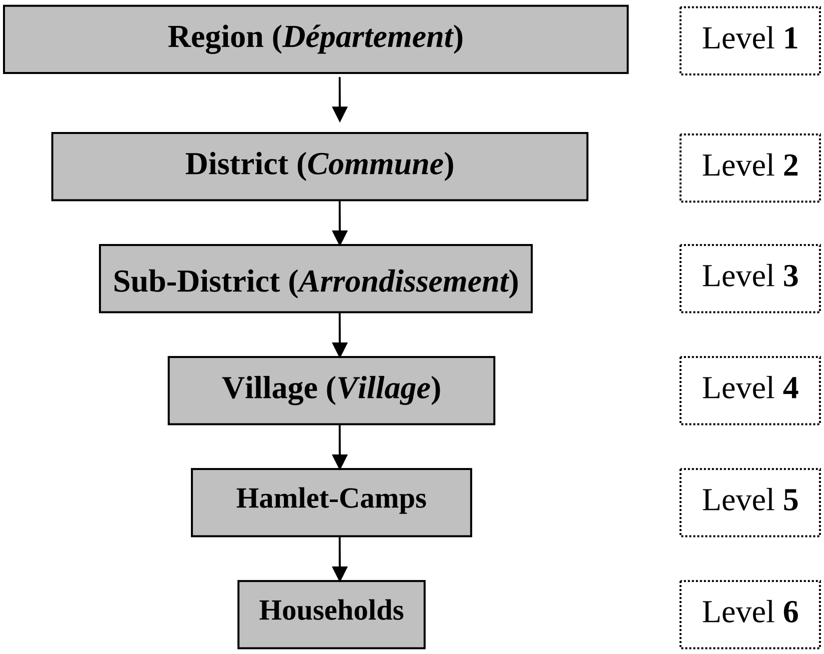

Figure 4.1.1: Administrative organization tree in the study area

From a total of 885 households in the four villages, hamlets and isolated camps, a sample of hundred eighty eight (188) households, that is 21.24% of the total households was interviewed (**Table 4.1.1**). The number of households per locality ranges from five (5) households in small villages to forty (40) in the biggest ones.

Table 4.1.1: Distribution of surveyed households in the study area

Village	**Hamlet**	**Number of surveyed households**		
		Per locality	**Expected per village**	**Corrected per village**
Doguè	Doguè Adjimon Kônin	20 15 05	36 (21.43)	40 (23.81)
Igbomakoro	Igbomakoro	40	43 (21.08)	40 (19.61)
Kikélé	Kikélé Api Kikélé-Lokpa	35 09 16	67 (21.13)	60 (18.93)
Wari-Maro	Etou Kpawa Samba Wari-Maro	05 15 08 20	42 (21.43)	48 (24.49)
Total		188	188 (21.24)*	188

* 188 (21.24): number of households (sampling rate in %)

The sampling rate was based on equation $N = M \times t$
with N, the number of household to survey; M, the total number of households and t, the sampling rate.

The sampling rate of each village was determined as well according to each specific total number of households. Based on expert knowledge of the study area, the expected number of households per village, defined according to the official statistics, was replaced with a corrected value (**Table 4.1.1**). This was done according to population size of hamlets whose statistics were not available with the census[2]. This replacement was initiated against the standard rule of sampling in order to focus more questionnaires on the villages or their environment that are supposed to be populated by migrants (Wari-Maro and Dogue), to the detriment of others (Kikélé and Igbomacro). Therefore, the corrected sampling rates for

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[2] The same sampling rate of nearly 22% can not be defined and applied to all hamlets and camps because the official census statistics are available only at village level.

different village range from 18.93% to 24.49%. The global sampling rate remains although the same.

4.1.3 Data Processing

This part of the study focuses on the data processing method. It starts from the database set up, quality control and ends with statistical analysis. A special attention is given to data verification and error control.

4.1.3.1 Data control, error correction and database set up

During the survey, the data control and error corrections started parallel with information collection. The data control consists mainly in reviewing all the registered and filled questionnaires each day or couple of days. Recorded answers through the questionnaires were checked and corrected if necessary after discussing the topic with the interviewer. Completion of ambiguous answers was sometime made after several meetings with respondents. For instance, due to errors from exaggeration, unsuitable or wrong answers, some modalities such as cropped area, age of household head and some open questions, accessibility (i.e. distances to diverse locations) are often discussed together with either interviewer or respondents. After more explanations for better understanding of questions, final answers were obtained. Nevertheless, some respondents stay "*closed*" and prefer not to give the right information. In these cases, additional information was required from the nearby household to confirm or reject his answers. The questionnaires were definitely retained afterwards. On the contrary, some farmers disappear after the interview; so it was impossible to meet them in time for further discussion.

After quality control (acceptable questionnaires without unfilled questions for processing) and error checks were achieved, the data entry begun. All the questionnaires were first codified. Then the variables were created according to the collected answers either from closed or open questions. Notice that the final categories of answers from open questions are the summary of diverse modalities of answers. Based on the aforementioned steps, a database was built with ACCESS and SPSS packages for the two questionnaire types. Transfer to SPSS and sometime EXCEL helped for statistical calculation and analysis.

Finally, the missing values in the database were replaced by an average value in similar nearby groups (Schlauderer, 1997). During data exploration, the cases of outliers are examined, retained or rejected if they are justified. The excluded cases were then mentioned if necessary before the statistical analysis start.

4.1.3.2 Statistical analysis

Once all the information entered in the database, the data and errors control checked, some descriptive and quantitative statistics were derived from the data exploration. With the help of statistical tools, some key statistical analyses were established with the purpose of elucidating the main household level drivers of land-use change.

Before hand, a test of Kendall (Dagnelie, 1998) was run to point out the main crops practiced by each farmer and the relation between the cropping systems and land-use changes. Secondly, a Principal Component Analysis (Palm, 1998; Philippeau, 1992) was run to sort out the relevant socio-economic variables that affect the land-use changes in the study area according to farmers' responses. Thirdly, a linear regression was used to assess the relation between specific variables and other socio-economic variables. Finally a correlation between agricultural area derived from remote sensing data and demographic parameters (population density and population growth) derived from censuses was run for better assessing the link between the land-use changes and population increase in the study area.

4.2 Remote sensing data collection and processing

In addition to socio-economic data, remote sensed data were collected and processed as well. Researches carried out in the frame of modeling land-use and land-cover change are focused on LANDSAT (Earth Observing System image series) and ASTER (Advanced Spaceborne Thermal Emission and Reflectance Radiometer) satellites images utilization. Two LANDSAT images and a subset image of ASTER were selected because of the limited availability of cloud-free images in tropical regions. The LANDSAT images were processed and classified based on several field campaigns conducted by the *Remote Sensing Research Group (RSRG)* team within the Upper Ouémé Catchment in the frame of IMPETUS project. The final classification results were accurately assessed and a change detection based on suitable method was conducted. Furthermore, our knowledge of the study area and experiences acquired during the field campaigns helped us to classify the ASTER subset image for the modeling purpose.

4.2.1 Data sources and pre-processing

Satellite images taken on board of LANDSAT 5 of Thematic Mapper (TM) on 13.12.1991 and LANDSAT 7 Enhanced Thematic Mapper Plus (ETM7+) on 26.10.2000, with a ground resolution[3] of 30m x 30m, are the mainly used remote sensed data. Two scenes of 180km x

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[3] The resolution of cell-size in the source image of LANDSAT is 28.5 m

180km, each identified by paths/rows (192/53 and 192/54), cover the Upper Ouémé Catchment which is about 100km x 100km. Both scene images were acquired by IMPETUS project and were processed by *Remote Sensing Research Group*. Only the second scene (192/54) covers the southern part of the Upper Ouémé Catchment. In this region is located the study area. In addition to the LANDSAT scenes, a subset image of ASTER of October 2003, covering only tree villages (Kikélé, Igbomacro, and Dogué) was also used particularly for validation purposes, the remaining area being cloudy. Due to the difficulty to identify clearly different land-cover types on the three-band ASTER image of VNIR (Visible and Near InfraRed), with spatial resolution of 15 m, it was combined to the six-band image of SWIR (Short Wave InfraRed) with spatial resolution of 30 m. In this procedure, the first ASTER image was resampled from 15 m resolution to 30 m resolution that fits the second image and the LANDSAT images. By extending the first image, additional bands of the SWIR helped to better distinguish different land-cover types. The images were pre-processed using one of the two common geometric correction procedures, often used by scientists to make the digital remote sensor data of value (Jensen, 1996): image-to-image registration. Thus the images were co-registered to a master scene LANDSAT 7 ETM+ from 13.12.2001 as reference. Using the nearest neighbor resampling, a root mean square error of the first-order polynomial function of less than 0.6 pixels was achieved. In addition to a radiometric calibration, an atmospheric correction with COST Model (Chavez, 1988) has been applied for basic atmospheric correction and transformation to ground reflectance for the two LANDSAT images.

The following table (**Table 4.2.1**) summarizes the characteristics of the used remote sensing data and their sources as well. The processing of the satellite images was followed by their classification after several ground truths. The classification result presented in this study derived from the master classification of the whole Upper Ouémé Catchment.

Table 4.2.1: Image sources and characteristics

Sensor	Date	Resolution (m)	Identification Path/Row	Acquisition source
LANDSAT5 TM	13.12.1991	30	192/54	IMPETUS/RSRG
LANDSAT7 ETM+	26.10.2000	30	192/54	IMPETUS/RSRG
LANDSAT7 ETM+*	13.12.2001	30	192/54	IMPETUS/RSRG
ASTER VNIR 3 bands	19.10.2003	15	192/54	IMPETUS/RSRG
ASTER SWIR 6 bands		30	192/54	

* The 2001 LANDSAT image was used specifically as reference for the images regi-stration

4.2.2 Classification of images

The classification of the two multispectral LANDSAT scenes and ASTER subset used the maximum likelihood algorithm based on more than 600 ground control points collected during GPS-assisted field campaigns and nearly two hundred training samples in total for all classes. The field campaigns were carried out between 2002 and 2004, during the dry season. The acquisition date of the end of the rainy season (October) enables us to get nearly cloud free images in which the vegetation is not too much affected by bush fires. On the contrary, the 1991 image, acquired in dry season (December), and the ASTER subset show respectively many burned, and cloudy areas for which no information about the underlying land-cover is extractable. Thus no land-cover class could be assigned. Therefore only the three-village-subset image was classified. Furthermore, the classification of 1991 image was improved by using the classification from the 26.10.2000 for the areas which had been burned in the 1991 image (i.e. by replacing some of the burned areas with data from the classification from 26.10.2000). The assumption is that natural succession of savanna areas is slow in nine (9) years, so that it is possible to take data from another classification. With the help of a change detection analysis, all areas with no change are selected with the exception of those areas which are cultivated in 2000 (Drey, 2003). These selected areas in the 1991 classification are replaced by data from the classification of 2000. If a pixel was burned in 1991 and the classification of 2000 indicates a farm in that pixel, no replacement was made, so that some burned areas still remain with no land-cover information. All that improvement was made with 3x3 median filter data using ERDAS IMAGINE® 8.7 package.

Spectral separation of fields and inselbergs is very difficult and sometimes not possible. Therefore inselberg pixels are often misclassified as field. With the integration of a digital elevation model (DEM) it was possible to eliminate these false classifications. The DEM data from the SRTM[4] Mission (http://www2.jpl.nasa.gov/srtm/) was used with an xy resolution of 90 m. These data were resampled to 28.5m for better pixel matching. From the elevation data, the slope value in degree was extracted. With the following condition the false pixels are eliminated: If slope is greater than four (4) degree and pixel is field, then replace with inselberg class.

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[4] The NASA Shuttle Radar Topographic Mission (SRTM) has provided digital elevation data (DEMs) for over 80% of the globe. The SRTM data is available as 3 arc second (approx. 90m resolution) DEMs. (Source: http://srtm.csi.cgiar.org).

The classification scheme based on land-cover/-use key interpretation of IMPETUS in Table 4.1 (Appendix 1) was used to assign pixels to land-cover classes. Thus, the final classification results in fourteen classes (without "no information" class) which are: *Forêt dense*, *Forêt claire*, *Savane boisée*, *Savane arborée*, *Savane arbustive*, *Savane saxicole*, *Savane herbeuse*, Water, *Bas-Fond*, Urban, Village, Cropland, Inselberg, Degraded Areas/Sparse Vegetation, and No information. These land-use classes are described in **Table 4.2.2**.

Table 4.2.2: The land-use and land-cover classification scheme of the Upper Oueme Catchment

N°	Land-cover class	Description
1	Forêt dense sèche* (Dense dry forest)	Dry forest consisted of isolated patches of vegetation populated mainly by trees (15 to 20m) and riparian vegetation along rivers and with closed canopy
2	Forêt claire* (Open forest)	Woodland or open forest; characterized by light canopy (50%-75%) with permanent grass stratum
3	Savane boisée* (High savanna)	Savanna woodland is made of trees and shrubs, forms 20% - 50% canopy
4	Savane arborée* (Open savanna)	Tree savanna made of trees and shrubs scattered from 2% - 20% canopy
5	Savane arbustive* (Shrub savanna)	Shrub savanna of canopy 20% - 50% with bushes, no trees. Formations of grasses at least 80 cm high from a continuous lower stratum. Usually burns annually
6	Savane saxicole* ("saxicol" savanna)	Mainly bushes and shrubs developing on rock or inselberg
7	Savane herbeuse* (Grass savanna)	Grass savanna essentially, trees and shrubs generally absent and form less than 2 % canopy
8	Water	Rivers, lakes, reservoirs
9	Bas-fond	Wetland, temporally swamp, no trees or bushes
10	Urban	Settlement dense
11	Village	Settlement sparse
12	Cropland	Agricultural lands with crops, harvested agricultural land
13	Inselberg	Inselbergs, bare surface, career, sandy area
14	Degraded areas	Degraded/lateritic surfaces

* Some of the vegetation types are expressed here in the French language classification scheme as used in Benin.

Source: the vegetation types classification scheme uses here the French names based on canopy recovery % and classification schemes from diverse sources: Akoègninou (2004), UNESCO/FAO (1977), YANGAMBI (1956), and other characteristics from Orthmann (2005)

Samples of different land-use\land-cover types are shown below (**Figure 4.2.1**) and a comparative scheme of some vegetation types (Woodland to Shrub savanna) to their pictures can be found in Figure 4.1 (Appendix 1).

Figure 4.2.1: Some sample-photos of land-cover types in the study area

The pictures are referred to the number assigned to each land-cover type in table 4.2.2 (e.g.: (4) Tree savanna shows a sample picture of the Tree savanna type which is numbered 4 in the table 4.2.2.

4.2.3 Change detection method

This method subsection gives an overview on change detection applied to highlight the changes in the study area. But it is necessary to define what “change detection” means. According to Singh (1989), Change Detection can be defined as “[…] the process of identifying differences in the state of an object or phenomenon by observing it at different times”. Land-cover change, as a phenomenon, often focus on conversions from land-cover type into another (between-class change) and transformations within a given land-cover type (within-class change). Most remote sensing change detection studies focus on the first type of land-cover change (Yuan *et al.* 1998).

Among the existing remote sensing techniques for assessing land-cover change, “Principal Component Analysis” (PCA) and “Change Vector Analysis” (CVA) (Jensen 1996; Lunetta & Elvidge 1998) were applied. PCA is a “powerful data transformation technique for information extraction in remote sensing for the analysis of multispectral and multidimensional data” (Lillesand & Kieffer, 1979 cited by Lunetta 1998). CVA, as also a “powerful tool to analyse successive years of remotely sensed indicators … derived from high temporal resolution data” is based on change vector (vector difference between successive time-trajectories) that can be used to compare the differences in time-trajectory of biophysical indicator (Lunetta 1998). The described methods were applied respectively by Thamm *et al.* (2001) to two LANDSAT ETM 7 images from December 1999 and December 2000, and Thamm *et al.* (2004) to LANDSAT images from 13.12.1991 (TM), 26.10.2000 (ETM+), and 16.12.2001 (ETM+). The PCA was achieved to investigate changes in spatial patterns of the vegetation along Bétérou - Bassila axis while the second method was applied to assess the “dramatic change in LUCC within the last decades” (Thamm *et al.* 2002) in the Catchment of the Upper Oueme in Benin.

As results, the first study reveals a strong deforestation along Bétérou - Bassila axis during the study time-period. The changes are materialized by red spots on the image below (**Figure 4.2.2**). It is obvious that most of the changes happen along the road-axis, where most of the settlements in the study area are located. Some degraded natural vegetation areas are figured out by these spots as well.

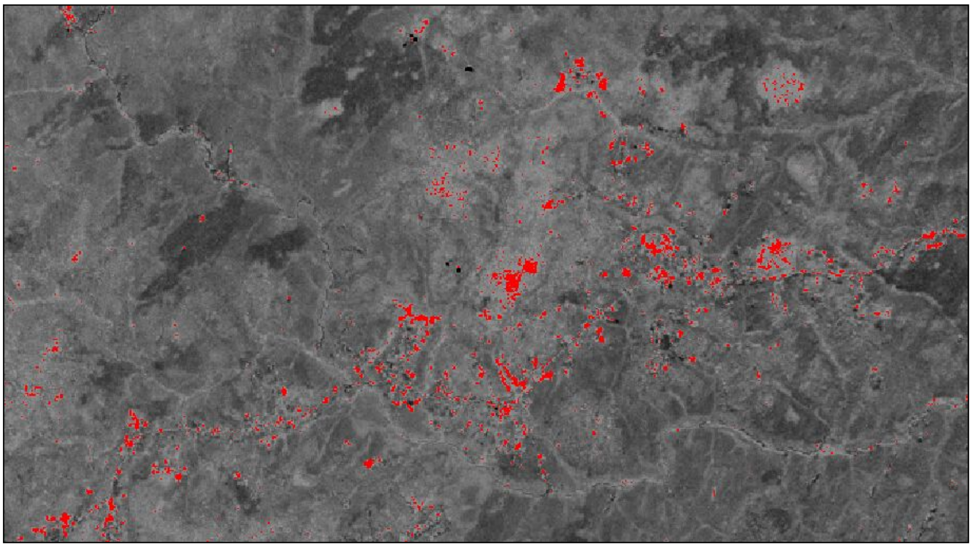

Figure 4.2.2: Subset of image showing deforestation (in red colour) between Dec. 1999 and Dec. 2000 along Bétérou-Bassila axis

According to the second study, several changes occurred from 1991 to 2001, whereas some areas remained unchanged. Among the changes registered, we can list: vegetation to settlements/field (6.28%), vegetation to burned areas (18.68%), vegetation to degraded vegetation (7.48%); and as unchanged vegetation (36.71%). Further details can be seen in the following table (**Table 4.2.3**).

Table 4.2.3: Legend of the classification of PCs for December 1991 and 2001

Class name		Percentage (%)
Land-use/Land-cover 1991	Land-use/Land-cover 2001	
Burned	Burned	4.90
Vegetation	Burned	18.68
Vegetation	Settlement/Field	6.28
Burned	Vegetation /Field	10.13
Vegetation	Degraded Vegetation	7.48
Field	Burned Vegetation	4.76
Unchanged (settlement/Roads/Inselbergs)		11.07
Unchanged Vegetation		36.71

Source: Extract from Thamm *et al.* (2004)

These two studies confirm several changes occurring in the study area. As mentioned in the study area presentation, most changes are related to increase in human activities and settlements.

For the better understanding of the trend, the rate, and the nature of these changes during 1991 and 2000, the two images were compared. Some threshold values were then defined to assess the main changes with regards to transition (conversion) to less (loss) or more (gain) vegetation within the period of a decade. The results achieved from the field campaigns may also help to confirm or reject these changes.

4.2.4 Field campaigns

Prior to image classification and surveys, a reconnaissance of the study area was carried out to develop an image-environment mental model of the study area on the one hand and to assist in developing appropriate land-use and land-cover classification on the other. The identification of the potential land-cover/land-use classes and the thematic content that a classification can or should incorporate is required. In fact a classification should be the thematic interpretation of the landscape (Jensen, 1996). For the establishment of such interpretation, factors that influence and determine the appearance of objects or phenomena need to be identified and understood. For this purpose, field observations are necessary for a supervised and knowledge based classification approach (Richards and Jia, 1999). If the thematic content, and thus a classification scheme, is defined, field data can be obtained and assigned for the classification purposes. For this reason a set of intensive ground truth was organized during 2000 (October - November), 2001 (March-April), 2002 (February-April) and 2003 (January) to localize different land-cover and land-use types in order to refine the aforementioned classification.

In parallel to the ground truth data collection, a survey of camps and isolated hamlets was organized. The villages were excluded because there were already surveyed and their coordinates known. In addition, during each subsequent field check, all the new settlements were recorded with the help of assistants-interviewers and/or guides. Each settlement was located precisely with GPS (*Global Positioning System*), and some complementary information regarding the camp, for instance year of installation, population of household, socio-cultural group, main activity, birth origin, etc. were recorded. It is worth to mention that due to instability of household head, information is sometimes collected from his wife. The wife (s) is (are) generally designed to stay at home for specific reasons mentioned in chapter three. Some wives never answer the questions because of language constraint or just to preserve security of the household[5].

During the fields check, GPS points were collected in January 2004 to mark the village boundaries in the study area. These points were allocated with the help of resource-persons who are knowledgeable to recognize them. Inquiry is often preceded by a deep discussion between the head of the village, the elders, hunters and some old people who still remember the precise locations of the village boundaries. After discussion, the selected guide-assistant collects the consensual ideas about the points to collect on the field. These points often referred to natural pieces of evidence (rock, river bed, forest) or historic places or human acts such as a road. The collected data were finally digitized with ArcView GIS tools. For data improvement, and based on expert knowledge of the potential conflicting situation[6], discussions with native scientists from these villages helped to delete some confusing or

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[5] Women are not often authorized in a household to reply to foreign people without their husbands' consent

[6] Administrative village boundaries are subject to current discussions, even conflicts among certain villages. Therefore, the pioneer boundaries used in this study are determinant for scientific purpose since there are no official village limits till now.

overlapping information. The results were then aggregated to constitute the limits of the four villages, which remain the reference in administrative village borders for this study.

4.2.5 Accuracy assessment

The performance of the classification was tested with ground control points obtained during field campaigns. The ground truth data consisting of about 600 points were compared to the defined units of land-use and land-cover within the land-cover classification. The results show that more than 80% of the land-cover was correctly classified (Thamm *et al.*, 2005a & b).

4.3 Creation of other datasets

Land-use/land-cover reclassification, Digital Elevation Model and Soil suitability are the distinctive topics to which this subsection is designed. These data were created for the modeling purpose.

4.3.1 Reclassification of Land-use/Land-cover

Prior to the reclassification of the original land-use/land-cover, the classification has been improved by filling the gaps in the classified image from 1991. The objective was to release or fill in the black empty gaps in the image that are observable only at fine resolution. A low-pass function of ERDAS IMAGINE was applied to a subset fitting with the study area extent. The model was run with the original source classification with a mean focal filter (3x3 matrix) which has been increased up to 7x7 matrix even more until the gaps were filled up entirely. At each following step, the source classification input is replaced by the previous result to which another low-pass or custom matrix is applied. Finally, a colour function was then applied to the final result to get the new classification image in pseudocolour.

For the purpose of land-use/land-cover change modeling, the original classification, fifteen classes at a resolution of 28.5 m cell size, was recoded to three (3) classes and resampled to 32 m cell size. Thus the configuration of the new reclassification is shown in **Table 4.3.1**

Table 4.3.1: Land-cover classes in original and new classification

Original classification		**Reclassification**	
Old code	**Class name**	**New code**	**New class name**
1	Forêt dense	1	Forest
2	Forêt Claire	1	Forest
3	Savane boisée	1	Forest
4	Savane arborée	1	Forest
5	Savane arbustive	2	Savanna and agricultural area
6	Savane saxicole	1	Forest
7	Savane herbeuse	1	Forest
8	Water	3	Others
9	Bas-fond	1	Forest
10	Settlement dense	2	Savanna and agricultural area
11	Settlement sparse	2	Savanna and agricultural area
12	Fields	2	Savanna and agricultural area
13	Degraded veg. (inselberg)	3	Others
14	Fallow (heavy degraded veg)	2	Savanna and agricultural area
15	No information		

The first class recoded 1 called "Forest" refers to natural vegetation, including natural forest (dense dry forest and woodland included gallery forest), and savanna types (i.e. savane boisée, savane arborée, savane saxicole, savane herbeuse and bas-fond) that are not much influenced by human activities. The second class named "Savanna and agricultural area" (quoted later Agriculture) comprises mainly some humanized area such as shrub savanna, fields, fallow and settlements.

The last category "Others" regrouped other classes (water, inselbergs and bare lands).

4.3.2 Digital Elevation Model and soil suitability

4.3.2.1 Digital Elevation Model (DEM)

The Shuttle Radar Topography Mission (SRTM) data sets result from collaboration among the National Aeronautics and Space Administration (NASA), the National Imagery and Mapping Agency (NIMA), and the German and Italian space agencies as well, to generate a near-global digital elevation model (DEM) of the Earth using radar interferometry[7]. A subset based on the study area extend was derived from these datasets as topographical variable

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[7] This data is currently distributed free of charge by USGS and is available for download from the National Map Seamless Data Distribution System, or the USGS ftp site. Additional SRTM partners (JPL, NASA, NGA, DLR and ASI) and processing information can be found on http://www2.jpl.nasa.gov/srtm/links.html

where all elevations are in meters (**Figure 4.3.1**). SRTM-3 data are divided into one by one degree latitude and longitude tiles in "geographic" projection. Their individual rasterized cells are about 90 meters in extent. From this resolution, the original image was resampled to 32m for the purpose of modeling. The topography of the study area shows very little difference in altitudes. In a wide part, the altitudes vary between 300 and 350 m asl.. The west and north-west areas’ altitudes range between 400 and 450 m asl.. The most dominant pick is situated in the area of Wari-Maro where is located a prominent isolated inselberg named *Soubakperou* (south-east) with 566 m asl. A remarkable point is the river basin with low altitudes less than 300 m asl..

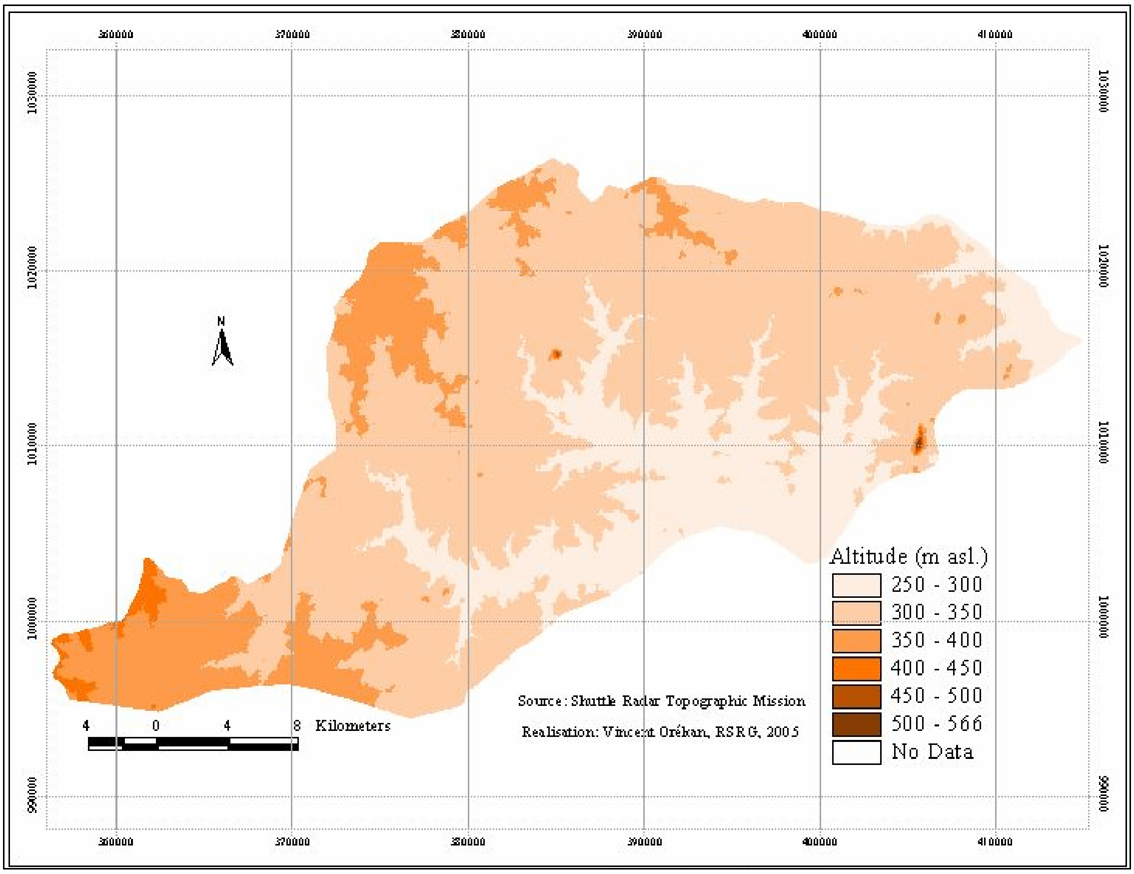

Figure 4.3.1: Digital elevation model of the study area

4.3.2.2 Soil suitability

In the framework of IMPETUS project, a previous soil map of the Upper Ouémé Catchment 1:200.000 was extracted from the soil map for Benin which was elaborated by ORSTOM (Faure and Dubroeucq, 1977 quoted by IMPETUS (2005); Junge, 2004). In addition, a map of soil suitability for agricultural use was produced based on the previous map[8]. Five main categories of soils were distinguished from the subset of our study area:

1) not suitable for agricultural use
2) very low suitability (exception: rice)
3) low suitability
4) good suitable
5) very good suitable

The most dominant category in the study area refers to suitable soils for agriculture in general. Categories 2 and 3 are more frequent than category 1. Good suitability soils for agriculture (e.g. Endoskeleti-Albic *Acrisols* or *sols ferrugineux tropicaux lessivés à concretions sur embréchite porphyroide à ferro-magnésien et granite*) are located in the east area while the very good suitability soils (e.g. *sols ferrugineux tropicaux lessivés sans concretions sur granite-gneiss à deux micas*) are situated in the west of the study area.

4.3.3 Other geographical datasets

Because accessibility and population density are the main triggers for the land-use changes in the area, it was necessary to create additional datasets.

4.3.3.1 Accessibility variables

Two types of accessibility variables are considered: stable and dynamic. Distance to roads, distance to streams, and distance to forests are supposed stable while distance to settlements is dynamic.

Concerning the roads, two categories of tracks can be distinguished apart from the main road axis Oubérou-Kikélé:

- i) the first category of tracks is constituted of minor roads or "*field-roads*" i.e. adjacent small paths to the main road Ouberou-Kikele. They are mostly used by farmers or by bicycles to reach the fields or isolated camps. Particularly to the camps, the tracks are not often visible. Therefore some of these tracks were constructed based on GPS points collected during the fieldwork;

- ii) the second category of tracks was completed with delineated roads from the recent satellite image. They are larger than the first ones because they are practised by trucks for timber transportation through savanna.

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[8] Some additional ongoing improvements of this map (not published) are under a Ph.D. thesis of Claudia Hiepe under the umbrella of IMPETUS project

Both categories of tracks are assumed stable since there is no additional information about their history and no reliable prediction can be made in this sense. In addition to the previous reason, sacred forests and streams are also assumed to be stable since they are not dynamic in nature. The sacred forests are always well protected in most of the villages.

Geographic Information System (GIS) tools were used to determine either stable or dynamic variables based on features such as points (settlements and forests) or lines (roads and streams). The resulting grid theme contains a Euclidean distance (the straight line distance between two points) which is calculated between each of the output cells that doesn't contain a feature, to the closest feature.

The previously described process is used for constructing the stable variables. These three features are considered stable since they were not subject to (or face little) change in time and space during the time period of the study.

By contrast to the previous distances, distance to settlements consists of a dynamic variable due to the rapid increase in settlements in the study area. Therefore distances to settlements vary according to population density which results from settlements density year by year. A high dynamic is induced by the number of settlements that varies in time and space. Due to very small area size of settlements, especially hamlets, and their closeness to each other, data were aggregated based on the following conditions:

- spatial configuration (location in the same area);
- ethnical similarity (dominant common language);
- year of establishment (nearly the same time period of installation within the settlement);
- membership of the aggregated settlement (not being isolated from the community: most of the migrant people prefer living together).

Finally, one camp or hamlet with its coordinates is selected to represent the whole aggregated settlements. Then distance to settlements is calculated for each group of settlements per year. Thus distance to settlement varies from 1991 to 2004 (the final year for data collection). For the following years, i.e. from 2005 to 2025, the distances remain the same as for the 2004, since the number of settlements is theoretically assumed to be constant.

Once calculated, all the previous variables (Land-cover, DEM, Soil suitability, Accessibility variables) and population density (discussed in next section) were used for the model calibration process. The following table (**Table 4.3.2**) describes the different variables used to calibrate the model, especially the dynamic distances and population densities. In turn, some created datasets, especially some geographical variables and population density are mapped in the following figure (**Figure 4.3.2, a, b, c and d**).

Table 4.3.2: Description of variables used for model calibration

N°	Variable name	Description	Type	Observation
	Land-use/cover	*Area surface used per class(ha)*		
0	Forest	Natural vegetation		Dense forest, woodland, gallery forest and savanna types
1	Agriculture	Agricultural areas		Shrub savanna, farms, fallow and settlements
2	Others	Other uses (Water, inselbergs, bare lands)		
	Geographic data	Euclidian distance (m)		
0	Distance to roads	Distance to main and secondary roads, including tracks to camps	Stable	All mainly practiced roads are considered
1	Distance to streams	Distance to rivers and streams	Stable	Temporary and permanent rivers
2	Distance to forests	Distance to small islands of closed forest, named "*forêts sacrées*"	Stable	
3	Distance to settlements	Distance to settlement (1991 to 2025)	Dynamic	Distance to settlement from 2005 on remains the same for 2004
	Demography	*Persons/km²*		
4	Population density	Population density (1991 to 2025)	Dynamic	Population density from 2005 on remains the same for 2004
	Biophysical data			
5	SRTM DEM	Digital Elevation Model (Altitude)		
6	Soilsuit	Soil suitability (low suitable, suitable, very suitable)		Categories of soils suitability for agriculture

4.3.3.2 Population density

For the purpose of model running, a population density map was created for each year. The settlement population statistics estimation and the segmentation of the study time period for the centroid distance determination are of importance.

The process of estimating the population of the settlement consists in fives steps:

1) determination of average population per hamlet or camp based on socio-economic surveys, using both questionnaires;

2) calculation of average population per hamlet or camp based on available household population within the surveyed camps and hamlets;

3) assign calculated values to settlements that lack information on household population but for which the number of huts is known;

4) aggregate the settlement to others with regard to its spatial distribution (see the aforementioned criteria for settlement aggregation) and apply the growth rate of the village to which it belongs for determining the population of this settlement.

5) the same process (1 to 4) is repeated for each settlement or group of settlements according to its spatio-temporal distribution on the one hand an its membership to the prominent socio-cultural group on the other hand.

Once the population statistics are available, population density can be calculated. This is done by using ArcView GIS tools. A kernel density method based on radius distance is used. The radius determines the distance to search for points from each cell in the output grid theme. This density distributes the measured quantity of an input point theme throughout a landscape to produce a continuous surface. Finally, the output density values will be the occurrences of the measured quantity per specified area unit (here in meter).

Due to the fact that human habitation acts over a larger distance (Soepboer, 2001), the assumption made for the radius definition is that the anthropological influence extent on environment (especially agricultural influence) varies with the increase/decrease of settlements with its population. Several considerations are taken into account for this purpose:

- the average distance expressed by farmers from the survey for the recent years, nearby the survey's year (2003) is 4 km. Therefore the average distance during 2001 to 2005 is estimated to five (5) kilometers[9];

- for the earlier years, i.e. from 1991 to 1994, some theories from literature (Overmas and Verburg, 2005; Chomitz and Gray, 1996) figured out that villager-farmers often prefer having land nearby their house because of accessibility and safety reasons. And this was obvious in the past of this study area which was less populated than nowadays, when considering official census statistics and literature as well (Iroko, 2002). Therefore, the farms were as well closer to the houses as the distances to the settlements nowadays. The maximum length of this distance was estimated to 2.5 kilometers. This distance has increased to half a kilometer during 1995 and 1997 and was supposed to increase at the same rate from 2005 to 2025.

We also note here that:

- in 1997, the new main road Ouberou-Kikélé of the study area was built. This leads to the creation of new settlements and thus new tracks to have access to their agricultural lands.

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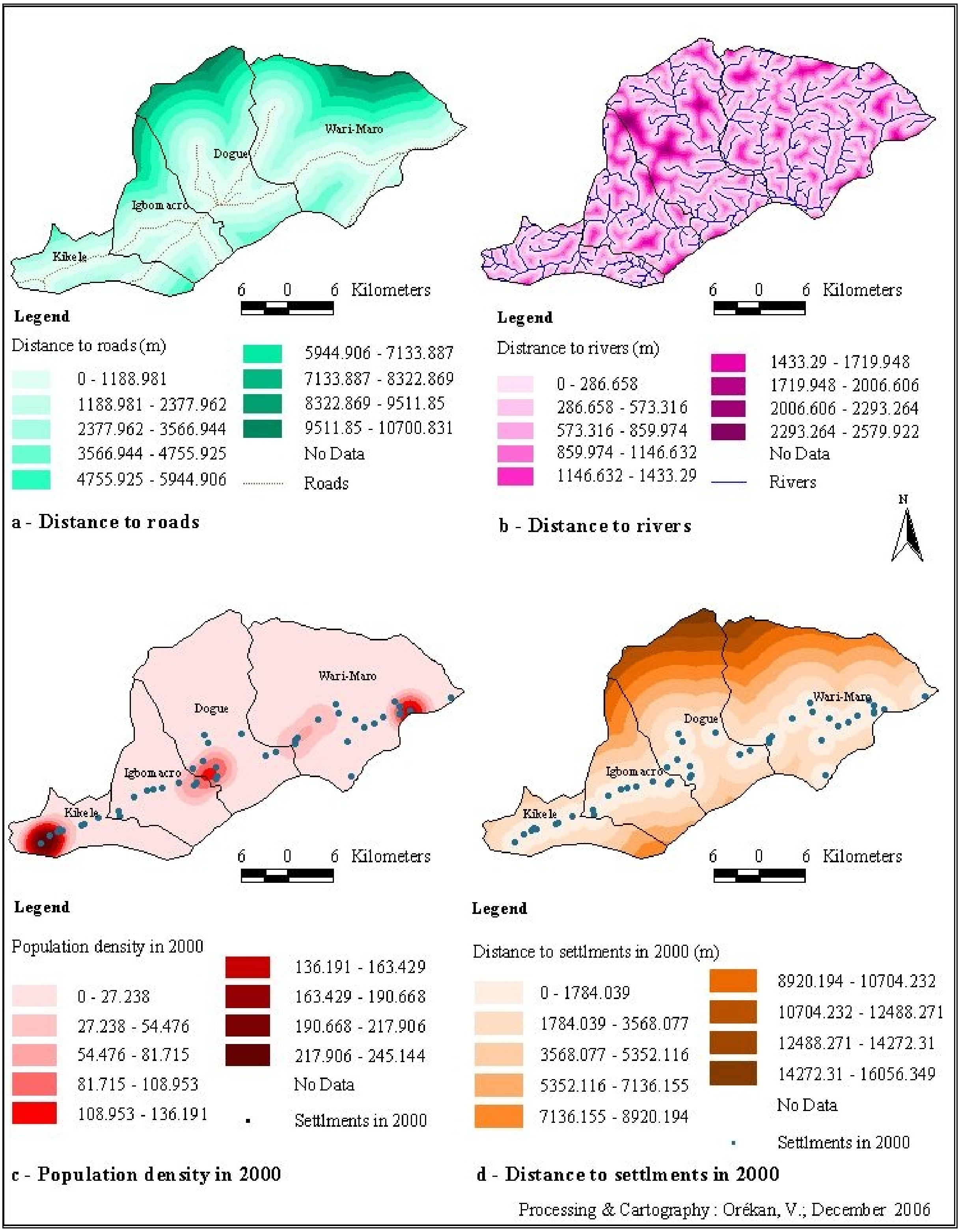
[9] Average distance of five (5) instead of four (4) kilometers was retained in consideration of the idea that farmer's distances estimate is more longer than their really thought.



Processing & Cartography : Orékan, V.; December 2006

Figure 4.3.2: Spatial representation of some geographical variables and population density

Letters a, b, c and d represent the distance to roads, distance to rivers, population density (2000) and distance to settlements (2000) respectively. The boundaries of the different principal villages of the study area (Wari-Maro, Dogué, Igbomacro and Kikélé) are figured out and overlaid as well.

Therefore, the distance has increased as well from 3 km to 4 km between 1997 and 2000, and 4 km to 5 km between 2000 and 2005[10].

- From 2006 on, assumption is made that the distance-effect will increase solely to half kilometer each established period (2006-2010, 2011-2020, and 2021-2025) since the number of settlements will increase as well in the study area as in the nearby villages. Therefore, the distance among settlements and fields will reduce because creation of villages could lead to a phenomenon of conurbation. The maximum distance-effect is assumed to stabilize to 6.5 kilometers.

On the whole, the following centroide distances are fixed according to the retained segmentation of the study time-period (**Table 4.3.3**)

Figure 4.3.2 (c) shows an example of population density variable for the year 2000.

Table 4.3.3: Radius-distances (m) per time-period

N°	Time-period	Distance (m)	Observation
1	1991 to 1994	2,500	Before main road period
2	1995 to 1997	3,000	Main road building period
3	1998 to 2000	4,000	Post main road building period
4	2001 to 2005	5,000	Later period
5	2006 to 2010	5,500	Future period*
6	2011 to 2020	6,000	Future period
7	2021 to 2025	6,500	Future period

* Assumption for the future period refers to the period over the study time frame

All the above closely underlie the data collected and analysed in this piece of work. The next chapter will look closely at the land-use and land-cover changes in the study area as well as the agricultural land and forest cover availability. Finally, the outcome from linking remote sensed data to population features will help to highlight the link between population increase and forest cover decrease.

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[10] The assumption here is based on the knowledge of the field as is the reality during the fieldwork until 2005

5 LAND-USE AND LAND-COVER CHANGE

This chapter gives a historical view of the different land-use/-cover in the study area. It describes the rate of land-use change and the agricultural lands availability as well. It finally attempts to find out the relationship between agricultural land and population growth.

5.1 Land-use/cover in the study area

As a general point of view, a historical description of the land-use and land-cover in the study area needs a time-series analysis of remote sensed images. As mentioned in the methodology approach, very few cloud free images and with less burned area of the study area are available. Therefore, the historical analysis is viewed here through the two LANDSAT images of 1991 and 2000 i.e. quite a period of a decade. The resolution of the cell size is the same as the source image and its classification[1] (28.5 m). The results are essentially presented by maps, statistics and graphs.

The spatial distribution of the land-use/-cover is shown in the maps (**Figure 5.1.1** a (1991); b (2000)). In addition, from the following **Table 5.1.1** and **Figure 5.1.2**, land-cover statistics show that the savanna areas are predominantly natural vegetation (Woodland and Shrub). Variations in different classes indicate nearly 48 and 31% for Woodland savanna (SB), 17 and 25% for Shrub savanna (Sa), 24 and 25% for Woodland (FC) or open forest respectively in 1991 and 2000. It can be pointed out that there is an increase in Tree savanna (SA) and Shrub savanna while the Woodland savanna decreased. The Woodland area did vary substantially. The dry semi-deciduous forest (quoted Forêt dense (FD)) decreased from 2.6% in 1991 to 0.4% in 2000. By contrast to Forest dense, the agricultural fields increased fivefold from 1% in 1991 to 5% in 2000. This proves the high increase in agricultural areas (in pink colour) during this decade. Most of these agricultural fields are widespread along the main road axis and densely agglomerated in the west area (in Kikélé village). The few “Forêts denses” are located scattered in the landscape.

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[1] The classification map (resolution of 32 m cell size) used for he modelling is aggregated from the source image (with a resolution of 28.5 m cell size)

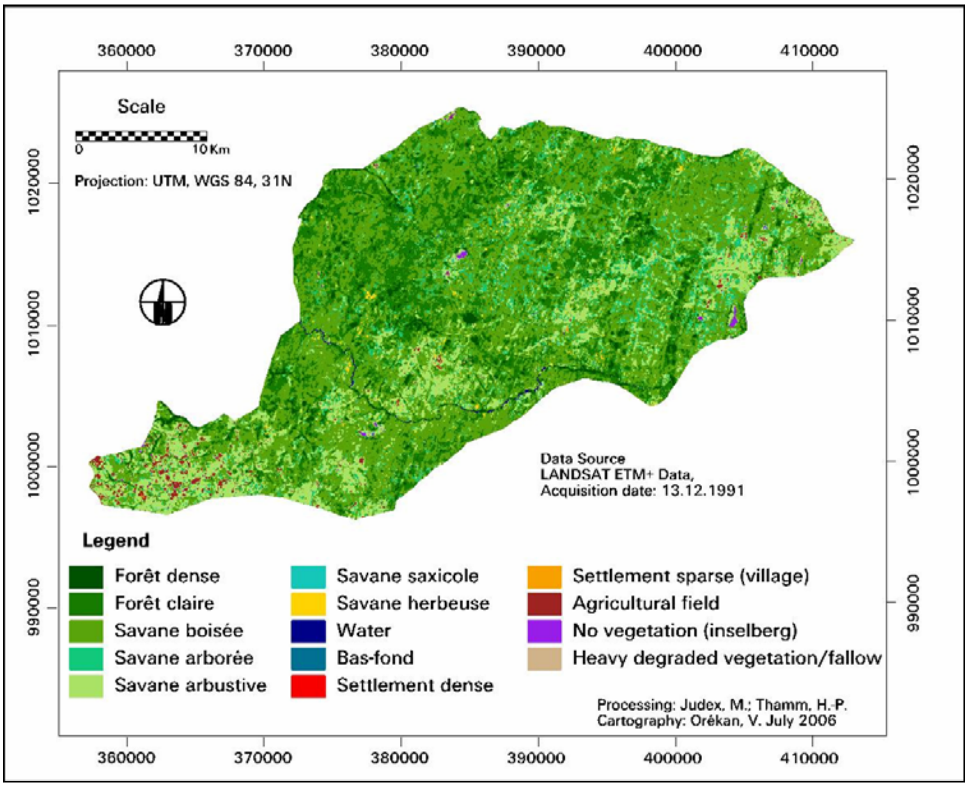


Figure 5.1.1a: Land-use classification of the southern Upper Ouémé Catchment, December 1991

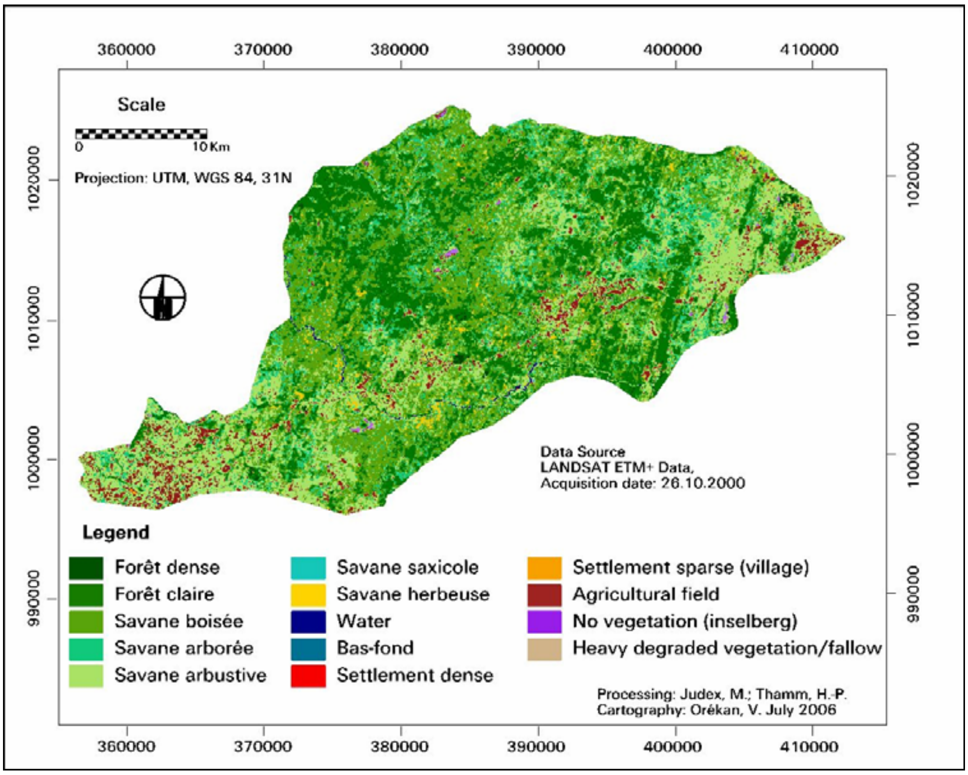


Figure 5.1.1b: Land-use classification of the southern Upper Ouémé Catchment, October 2000

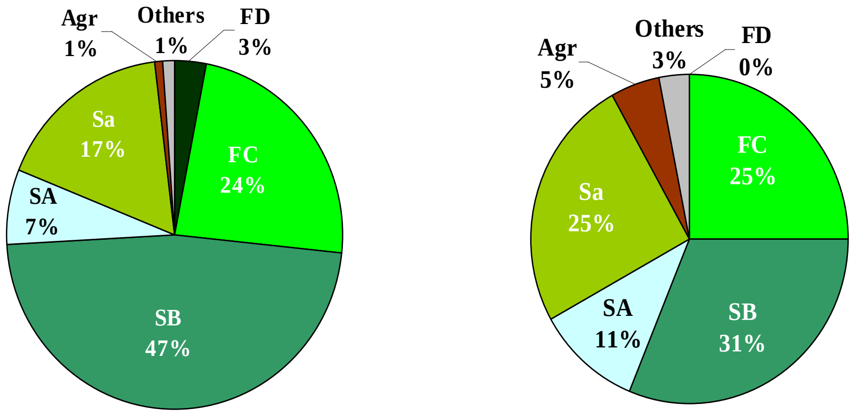
Represented by riparian forest, they are found in areas adjacent to watercourses or fresh-water bodies (Warner, 1979 quoted by Natta, 2003; Adomou, 2005).

From the two maps, changes in the landscape are described as followed.

Table 5.1.1: The land-use and land-cover in the study area: 1991 and 2000

Land-cover classes	Area in 1991		Area in 2000	
	(ha)	(%)	(ha)	(%)
Forêt dense	2356	2.6	384	0.4
Forêt claire	21819	23.7	23017	24.9
Savane boisée	44104	47.9	28648	31.1
Savane arborée	6662	7.2	10162	11
Savane arbustive	15231	16.5	23377	25.4
Savane saxicole	80	0.1	111	0.1
Savane herbeuse	447	0.5	1455	1.6
Water	138	0.1	196	0.2
Bas-fond (humide)	100	0.1	362	0.4
Settlement dense	16	0	0	0
Settlement sparse (village)	23	0	47	0
Agricultural field	942	1	4167	4.5
No vegetation (inselberg)	168	0.2	180	0.2
Heavy degraded vegetation/fallow	1	0	2	0
Total	92085	100	92108	100

Note: The difference in the total area is due to rounding errors. The number of pixels of the "No information" class is different for 1991 (N= 95470) and for 2000 (95447) while the total reveals equal pixels for the window for both images (187554)



LU/LC 1991

LU/LC 2000

Figure 5.1.2: Land-use and land-cover distribution in the study area: 1991 and 2000

Legend: Dense Forest (FD) Woodland (FC) Woodland savanna (SB)
Tree savanna (SA) Shrub savanna (Sa) Agricultural fields (Agr)
Others comprise all the remaining classes of the previous Land-Use and Land-Cover (**Table 5.1.1**)

5.2 Land-use and Land-cover change

By comparing the land-use and land-cover maps from 1991 and 2000, the result of changes in LU/LC is presented as follow (**Table 5.2.1**). Three main points discussed in detail are: the trend and annual rate of changes, the nature of changes and their location.

Trend and annual rate of changes

The details of changes in land-use and land-cover classes and the annual rate of these changes per class for the period 1991-2000 are shown in the following table (**Table 5.2.1**). The change's columns present the absolute area changes (positive or negative in ha) and the percent (%) of change[2] while the annual rate of change per land-cover/land-use is given in hectare.

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[2] The percent (%) of change can be defined as the report of the observed change per class and the absolute sum of the change multiplied by 100 (Adeniyi, 1999)

Table 5.2.1: Land-use and land-cover change statistics in the study area: 1991-2000

Land-use and land-cover	Land-use and land-cover change 1991-2000 (ha)	%	Annual rate (ha)
Forêt dense	-1954.8	-5.0	-219
Forêt claire	1176.4	3.4	133
Savane boisée	-15458.7	-44.3	-1717
Savane arborée	3484.9	9.9	389
Savane arbustive	8158.4	23.4	905
Savane saxicole	30.8	0.1	3.4
Savane herbeuse	1016.3	2.9	112
Water	59.3	0.2	6.5
Bas-fond (humide)	265.8	0.8	29
Settlement dense	-15.4	-0.1	-2
Settlement sparse (village)	23.9	0.1	3
Agricultural field	3223.2	9.2	358
No vegetation (inselberg)	13.7	0.1	1.4
Heavy degraded vegetation/fallow	0.5	0	0.1

The previous statistics show negative changes for Dense Forest (FD), Woodland savanna (SB) and Dense settlement (SetD). Shrub savanna (Sa), Tree savanna (SA) and Agricultural fields (Agr) had positive changes from 1991 to 2000.

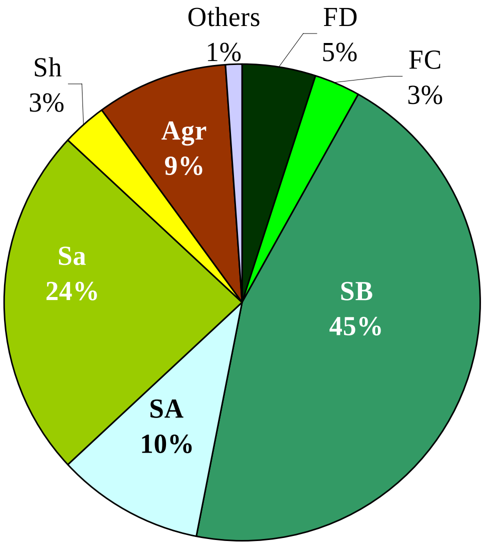

Figure 5.2.1: Trends in land-use and land-cover change in the study area: 1991 and 2000

Legend: Dense Forest (FD) Woodland (FC) Woodland savanna (SB)
Tree savanna (SA) Shrub savanna (Sa) Agricultural fields (Agr)

Within a period of nearly decade (1991-2000), the proportion of Woodland savanna and “Forêt dense” declined from 48% to 31% and from nearly 3% to 0.4% respectively (**Table 5.2.1**). By contrast, the same table shows that Shrub savanna, Tree savanna and Agricultural fields increased progressively and respectively from 17% to 25%, from 7% to 11%, and finally from 1% to nearly 5%. In total, the **Figure 5.2.1** and **Table 5.2.1** show that Woodland savanna experienced the highest absolute annual rate of changes (a drastic loss of 1717 hectares/year which corresponds to 45% of overall areas changed). This class is followed by the Shrub savanna (which observes a rate of increase of 905 hectares/year that is 24% of the total changes). The decline in Woodland can be explained by an increase in Shrub savanna associated with an increase in Agricultural areas. This last is due to an increase in demand in farming (9% of areas changed) subsequent to the high population growth.

Built-up area occupies more than double the area (mainly the village settlements) (from about 23 ha to 47 ha) within the decade, covering a new area of nearly 3% ha each year (which is equivalent to the area of Forêt dense in 1991). These statistics contrast with the reality on the field when compared to the knowledge of this statement. However, the number of settlements (mainly the “*camps*” created by migrant farmers) have increased drastically due to immigration in the study area. Differences in the realistic information with statistics derived from the remote sensed data could explain the appearance of these settlements in the study area. In fact most of the new settlements are built with local materials (essentially wood and branches covered with straws) which give less reflectance in remote sensing data collection. Therefore, they are mixed with natural vegetation so that it is hard to distinguish precisely the settled area.

On other side, the decrease in Settlement dense (-0.1%) contrasts with the real situation. The study area is a rural (only villages) and does not host any city. The amount of area attributed to that class is due to the quality (burned areas) of the satellite image of 1991.

Nature of changes

The nature of changes in this sub-section focuses on two objectives: (i) provide additional understanding of the previous sub-section which indicated the net change (being positive i.e. gain or negative i.e. loss); and (ii) to find out “W*hat is changing and to what?*” (Adeniyi, 1999; Braimoh, 2004). According to the approach followed by these authors and adopted here, the last objective takes this study to a point-by-point comparison of LU/LC classes over time. To achieve this, a matrix of confusion is built. The **Table 5.2.2** shows the statistics describing the nature of changes in land-use/land-cover from 1991 to 2000. The result can be examined through three categories: areas of LU/LC classes which remain unchanged, areas of LU/LC classes lost to other classes, and finally the areas of LU/LC classes gained by other classes. To clarify and harmonize the terminology, the two last characteristics will be named by “transition” to less vegetation and to more vegetation respectively. Thus, the “transition” word used in the following lines may be traduced as conversion from one cover type to another cover type. Furthermore, transition to less vegetation can be traduced as loss, and transition to more vegetation as gain. Details about loss and gain are given below.

During this decade, the area under study can be claimed to be unstable as 471268 ha (about 42 %) (See statistics in hectare in Appendix 2, Table 5.1) of the land faced drastic changes while 662431 ha (about 58 %) remained unchanged i.e. in the same locations (sum of statistics in grey colour in the diagonal line). For maintaining these unchanged areas, Savanna classes accounted for more percentage (71%) than other classes (28% and 1% respectively for Forest classes and the remaining classes). Dense forests accounted only for 0.2 %. This suggests that very little area of forest remains unchanged and a high amount of these forests is facing logging.

Table 5.2.2: Land-use and land-cover change matrix (%) in the study area for 1991 and 2000

	Land-use and Land-cover Classes for 2000											
1991	**FD**	**FC**	**SB**	**SA**	**Sa**	**Ss**	**Sh**	**W**	**BF**	**Set**	**Agr**	**Inselb**
FD	**0.21**	4.58	0.23	0.16	0.79	0.00	0.01	0.04	0.00	0.00	0.05	0.00
FC	0.29	**27.49**	8.35	4.04	4.43	0.01	0.15	0.08	0.13	0.00	0.85	0.01
SB	0.28	15.87	**42.98**	12.42	20.27	0.06	1.81	0.12	0.48	0.02	3.44	0.04
SA	0.02	0.40	2.96	**6.29**	4.24	0.01	0.22	0.00	0.03	0.00	0.68	0.00
Sa	0.10	0.54	2.81	1.06	**21.04**	0.05	0.47	0.01	0.03	0.02	4.99	0.13
Ss	0.00	0.00	0.00	0.00	0.06	**0.10**	0.00	0.00	0.00	0.00	0.01	0.00
Sh	0.00	0.00	0.00	0.00	0.02	0.00	**0.80**	0.00	0.00	0.00	0.01	0.00
W	0.00	0.03	0.01	0.00	0.06	0.00	0.00	**0.18**	0.00	0.00	0.00	0.00
BF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.19**	0.00	0.00	0.00
Set	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	**0.03**	0.02	0.00
Agr	0.02	0.03	0.05	0.03	1.52	0.02	0.02	0.00	0.00	0.03	**0.51**	0.03
Inselb	0.00	0.02	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.06	**0.18**

Legend: Dense Forest (FD) Woodland (FC) Woodland savanna (SB) Tree savanna (SA)
Shrub savanna (Sa) Saxicol savanna (Ss) Grassland savanna (Sh) Water (W)
Wetland (BF) Settlement (Set) Agricultural fields (Agr) Inselberg (Inselb)

Transition to less vegetation can be read from 1991 to 2000 along the rows (excluding the figure on the diagonal) and transition to more vegetation are read along the columns.

Among the areas under change, transition to less vegetation occurs faster than transition to more vegetation. The most important transition of more than 20% from Woodland savanna to Shrub savanna occurred during this decade. A synthesis (**Table 5.2.3**) from the change matrix (**Table 5.2.2**), shows the main following transitions that occur: from Woodland to Woodland savanna (8%); Shrub savanna to cropland (5%) and Dense forest to Woodland (4.6%). Timber, charcoal production and firewood collection for domestic and commercial purposes can be associated with these changes. Between 1991 and 2000, the transition of natural vegetation to cropland could be put in the order: Shrub savanna (5%) > Woodland (3%) > Woodland or Tree savanna (1%). These processes are related to increases in demand for fields (more clearings) and in logging activities within the natural vegetation (Woodlands).

Table 5.2.3: Analysis of land-use transition (%) from 1991 to 2000

Transition to less vegetation	%	Transition to more vegetation	%
FD to FC	4.58	FC to FD	0.29
FC to SB	8.35	SB to FC	15.87
SB to Sa	20.27	SA to SB	2.96
SA to Sa	4.24	Sa to SA	1.06
Sa to Agr	4.99	Agr to Sa	1.52

Legend: Dense Forest (FD) Woodland (FC) Woodland savanna (SB) Tree savanna (SA) Shrub savanna (Sa) Agricultural fields (Agr)

The transition from cropland to natural vegetation was in the order: Shrub savanna (1.5%) > Woodland savanna (0.1%) > Trees savanna (0.03%). These processes are related mainly to fallows which are rare (with low percent) in the study area.

The last synthesis (**Table 5.2.3**) shows that the overall transition to less vegetation is higher (21%) than the transition to more vegetation (16%). The increase in proportion of cropland (5% for the whole period) is higher than the transition to more vegetation. Based on knowledge of the study area, this assumes that more fields were created by local farmers, indicating consequently a high pressure on land, as this is 9% higher than overall transition to more vegetation: the conversion of natural vegetation to cropland that occurs is obvious.

Spatial location of changes

By overlaying the LU/LC images for 1991 and 2000, the location of areas of LU/LC changes can be computed and mapped. To achieve this, the original classification of 14 classes has been reduced to 12 LU/LC types. While the two settlements classes were grouped to "Settlement" (Set), Agricultural fields and Very degraded vegetation (fallow) were put together in "Agricultural fields" (Agr). The other LU/LC types remain unchanged. In the next step, the changes were computed and mapped with regards to the unchanged (stable), gained and lost areas from 1991 to 2000. ArcGIS 9.0 and ERDAS IMAGINE packages were used for this purpose. The result of the changes is shown in **Figure 5.2.2**.

Visually, the spatial distribution of the changes showed that gains in LU/LC are more grouped (patched) than losses in LU/LC. Dominantly, the losses reveal some fragmented areas which follow a diagonal line (North-West to South-East) while gains divided the area under study in a straight line (West to East).

Finally, in order to have a synoptic view of the LU/LC changes, the table 5.2.4 summarises the previous matrix of confusion to sort out the losses (dominant transition to less vegetation) and the gains (dominant transition to more vegetation). For better analyses, three (thresholds) levels of assessment of the gain and loss areas were defined: High, medium and low which correspond to less than 4%, 4% to 15%, and more than 15% respectively. Gain areas are shown in hatched symbols while loss areas are coloured. Both gain and loss symbols are assessed accordingly to the three previous levels. For example, a high (loss of 20%) less vegetation is hatched with Light Trellis pattern while a low gain (more vegetation) is coloured with green colour pattern.

As a result, the following table (**Table 5.2.4**) indicated that the transition to less vegetation from SB (Woodland savanna) to Shrub savanna (Sa) has the higher rate than the other transitions. By the same logical way, the transition to more vegetation from SB (Woodland savanna) to Woodland (FC) recorded the highest rate as well within this category. Regarding the croplands, most conversions are made from Shrub savanna (Sa) since the most important rate was recorded for this transition. It has to be noticed that most of the transitions to less vegetation have medium rate while all the transitions to more vegetation have a low rate except from Woodland savanna (SB) to Woodland (FC). This confirms the suggestion formulated above that very little vegetation is recorded by natural vegetation from human-induced areas (e.g. shrub, grasslands, and cropland). Consequently, very few fallows are found in the study area.

Table 5.2.4: Assessment of LU/LC changes from 1991 to 2000

↱ 2000 1991	FD	FC	SB	SA	Sa	Agr.
FD		▨	▤	▤	▤	
FC	🟩		▨	▨	▨	▤
SB	🟩	🟥		▨	▩	▤
SA	🟩	🟩	🟩		▨	▤
Sa	🟩	🟩	🟩	🟩		▨
Agr		🟩	🟩	🟩	🟩	

Legend

Loss	Gain	Assessment	Percentage Threshold
▩	🟥	High	More than 15%
▨	🟪	Medium	4% to 15%
▤	🟩	Low	Less than 4%

Note: Loss (transition to less vegetation) and Gain (transition to more vegetation) can be red from left to right, above (less) and below (more) the empty diagonal in white colour

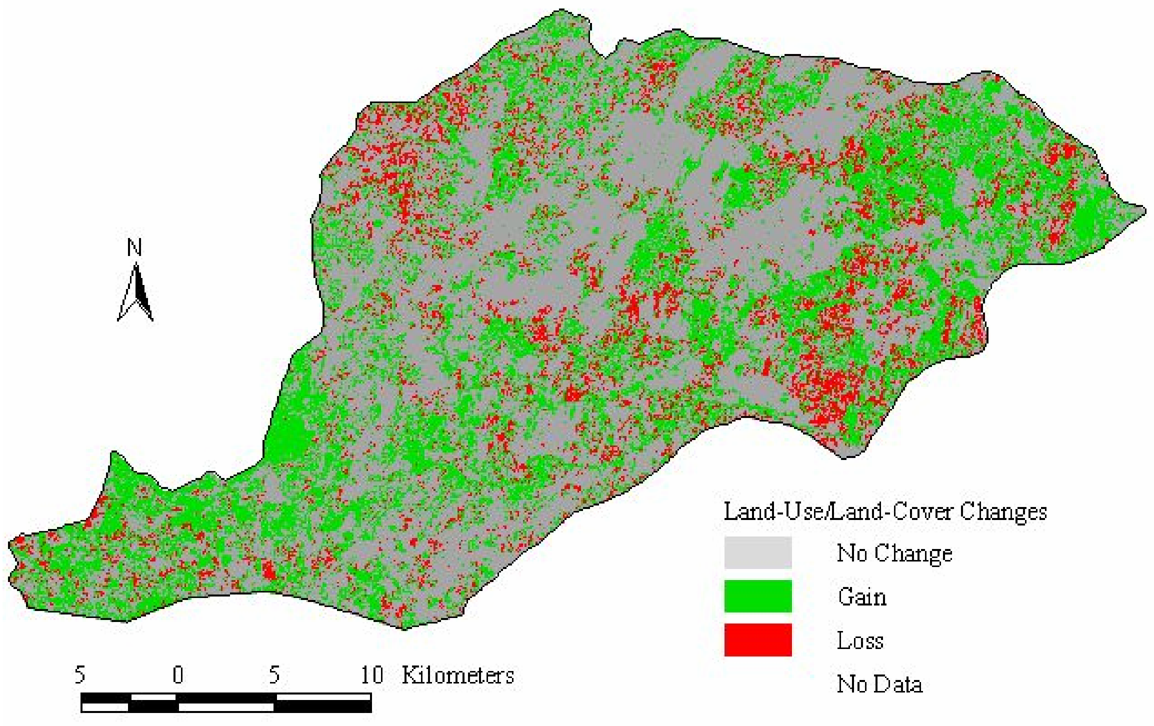

Figure 5.2.2: Land-use and land-cover changes in the study area: 1991-2000

5.3 Agricultural land and forest cover availability in the study area

Agricultural land-use and forest cover

The previous section gave a detailed overview of the LU/LC and the changes that have occurred in the study area. In this section, the agricultural areas and forest cover derived from the remote sensing database for 1991 and 2000 in order to have a look at the relationship between the agricultural land-use and population growth on the one hand and between forest cover and population density on the other hand. Finally an estimate of the agricultural land available in the study area is given. The availability of land considers all the exploitable lands except rocks (inselbergs), water, and settlements. The wetlands accounted in the statistics since they are sometimes seed by farmers - often for rice cultivation or vegetable growing (Mama *et al.*, 2000). All the other vegetation classes are supposed to be useful for agriculture since they are not yet protected. Instead the agricultural areas and forest cover described here concern only the areas derived from the classification data.

The following figure (**Figure 5.3.1**) shows the agricultural area distribution per village from 1991 to 2000. Two main observations can be made: a) agricultural areas have increased in all the villages; b) Kikélé and Wari-Maro recorded more increase than the two other villages (Igbomacro and Dogué). The first statement confirms the increase already mentioned in section 6.3 by farmers during the field survey.

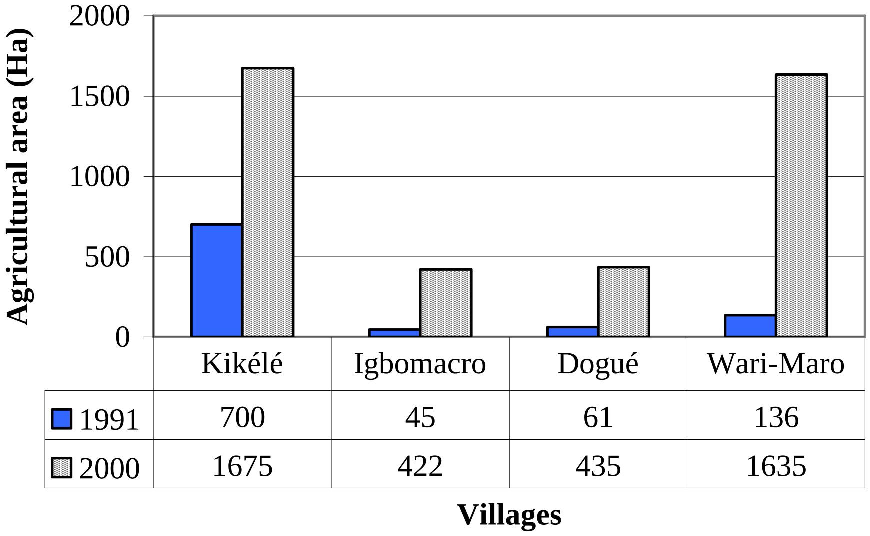

Figure 5.3.1: Distribution of agricultural area per village: 1991-2000

In the same way, it can be seen from the following figure (**Figure 5.3.2**) that the agricultural area per inhabitant has increased from 1991 to 2000. While Kikélé has a slight increase, Wari-Maro has more than quadrupled its area and Igbomacro more than six times in the same period. In comparison to allotment in the study area, average cropped area by farmer is estimated more than 3 ha per farmer as mentioned in the Study area chapter above.

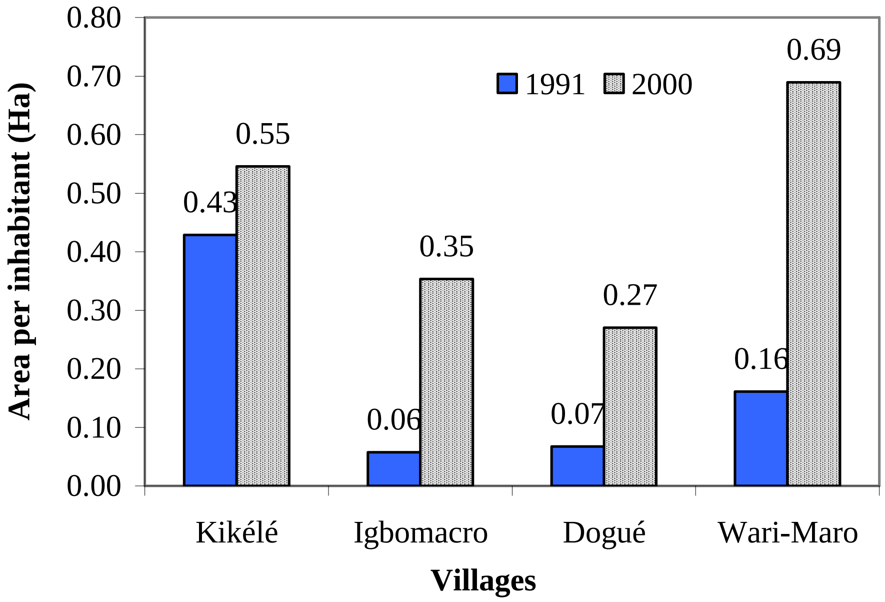

Figure 5.3.2: Distribution of agricultural area per inhabitant per village: 1991-2000

The next step focuses on setting up the relationship between the agricultural land-use and population growth on one hand and between forest cover and population density on the other hand. The population data was derived from an estimation of the population for 1991 and 2000 based on the three official censuses (**Table 5.3.1**). The data sets were correlated and the results of coefficient of correlation show that agricultural areas and population growth are more positively correlated for 1991 (0.98) than 2000 (0.92). Similarly Dense forest and population density are more negatively correlated for 1991 (-0.87) than 2000 (-0.62). This gives an indication that growth in agricultural area and forest decline have kept pace respectively with population growth and population density.

Table 5.3.1: Population, agricultural land and area per inhabitant and population density from 1991to 2000

Source: RGPH official censuses from 1979, 1992 and 2002 and Remote Sensing Data

Village	Population		Agricultural area (ha)		Area per inhabitant (ha/inhab.)		Population density (hab/km^2)	
	1991	2000	1991	2000	1991	2000	1991	2000
Kikélé	1634	3070	700	1675	0.43	0.55	15	28
Igbomacro	790	1193	45	422	0.06	0.35	5	8
Dogué	909	1612	61	435	0.07	0.27	3	6
Wari-Maro	843	2372	136	1635	0.16	0.69	2	6

Agricultural land availability

As previously described, the agricultural land availability refers to the potential of land available in the study area. The following table (**Table 5.3.2**) indicates the total available area per village and for the whole study area. The area per capita shows the land potential per inhabitant as well. It can be observed from this table that the area per capita decreased by half from 1991 to 2000 in the whole study area.

Table 5.3.2: Population, agricultural land and area per capita: 1991-2000

Source: RGPH official censuses from 1979, 1992 and 2002 and Remote Sensing Data

Village	1991		Area/capita (ha/inhab.)	2000		Area/capita (ha/inhab.)
	Area (ha)	Population		Area (ha)	Population	
Kikele	10900	1634	7	10921	3070	4
Igbomacro	15795	790	20	15752	1193	13
Dogue	27298	909	30	27269	1612	17
Warimaro	37859	843	45	37848	2372	16
Study Area	**91852**	**4176**	**22**	**91790**	**8247**	**11**

The dynamics that follows agricultural land availability and forest decline that assumes deforestation poses some real thoughts for a sustainable resources management.

5.4 Relevant outcome from linking remote sensed data to population

By correlating agricultural land and forest cover, both derived from remote sensed data with population growth and population density, it has been pointed out that agricultural areas and population growth increase simultaneously. Consequently, area of available land per capita decreases year by year (see **Table 5.3.1** and **Table 5.3.2** for more information). In contrast, a decrease in forest cover corresponds to an increase in population density especially in Kikele village where the forest cover is very low and population density very high. This relationship between agricultural areas, forest cover, population, and population density demonstrates that linking remote sensed data and socio-economic data can lead to concrete results. Therefore, demographic data can be considered as one of the main drivers of LU/LC changes in the study area.

Finally, in general it results from the previous sections that the study area faces a high deforestation rate of about 5.6% during the period 1991-2000. Two main causes can be pointed out from the previous findings: human activities and demographic factors. Among demographic factors, population growth and population density best explain forest cover variation which compensates gains in agricultural lands. This means that agricultural activities can be seen as another cause of deforestation since agriculture remains the principal activity of rural people who increase their cropped areas year by year. The increase in cropped areas has been facilitated by immigration (new additional yearly settlements), availability of fertile soils, shortening of fallow periods, and finally the new comer settlers with new agricultural practices. The slash-and-burn technique is widespread in the study area and also the cropping system contributed to important loss of forest cover.

From the above, it comes out that the land-use and land-cover changes derived from remote sensing are due mostly to human activity and demographic factors. At this stage, the study demonstrated whether linking satellite and census data „can produce robust and valuable findings" i.e. "socializing the pixel" (Livermann *et al.*, 1998). Hence it remains necessary to look closely to the link between population and agricultural land-use with regards to household survey characteristics. Thus, the next chapter will deal with population, its characteristics and agriculture to derive the land-use changes drivers based on farmer declarations during the field survey.

6 POPULATION AND AGRICULTURAL LAND-USE IN THE SOUTHERN OUÉMÉ CATCHMENT AREA

This chapter assesses the trend of population growth, the contribution of immigration to this growth from 1979 to 2002 and the main population pattern. This is done with regards to agricultural household characteristics, as well as projections for 2025, for the four different villages (Wari-Maro, Dogué, Igbomacro and Kikélé) that belong to the study area. Furthermore, it assesses the spatial organization based on settlements growth and gives an overview on the agricultural land-use. It concludes with a relationship between socio-economic factors and agricultural land-use through annual income, cropped area and finally influence of human actions in land-use changes. The relevant causes of LUCC as seen by farmers are finally summarized.

6.1 Population of the study area

The population size of the four main administrative villages from 1979 to 2002 and for 2010, 2015, 2020, and 2025 is given in table 6.1.1. Population size from 1979 to 2002 derived from official census while all the others are predicted. The following analysis focused mainly on two villages as examples: Dogué and Wari-Maro. These two villages are supposed to record the majority of migrants and Dogué is the super test site of the IMPETUS project.

As shown in table 6.1.1, the Wari-Maro village had a population of 459 in 1979, which grew to 887 in 1992 and 3,034 in 2002. The period that stretches between 1979 and 1992 on the one hand and between 1992 and 2002 on the other hand experienced respectively 93% and 242% increase in the population of Wari-Maro, compared to a 561% increase within 1979-2002. Concerning the Dogué village, the population increased from 235 in 1979 to 1,017 in 1992; and to 1,809 in 2002. By comparing the increase within the two previous periods (1979 to 1992 and 1992 to 2002), the population of Dogué experienced 332% and 77% respectively while 669% increase in population was observed between 1979 and 2002. It comes out that the population of these villages more than doubled within a period of 10 years (1992-2002) for Wari-Maro and quadrupled within 13 years (1979-1992) for Dogué. But one should notice that while Wari-Maro registered high growth of 242% within 1992-2002 Dogué village observed less with 77%. Vice versa, an opposite phenomenon was observed within 1979-1992, period where Wri-Maro registered 93% while Dogué observed 332%. Another observation reveals a great growth for Dogué compared to Wari-Maro within a period of 23 years (1979-2002) with respectively 669% and 561%. The following graph (**Figure 6.1.1**) compares the different growths of the villages within each period of observation.

Table 6.1.1: Distribution of population per village in the study area: 1979 - 2025

Source : INSAE Benin, Population Census 1979, 1992, 2002

Villages	1979	1992	2002	2010*	2015*	2020*	2025*
Wari-Maro	459	887	3034	8115	15008	27757	51335
Dogué	235	1017	1809	2869	3826	5103	6807
Igbomacro	326	851	1298	1819	2246	2774	3425
Kikélé	1005	1701	3559	6422	9289	13435	19431

* Projected figures

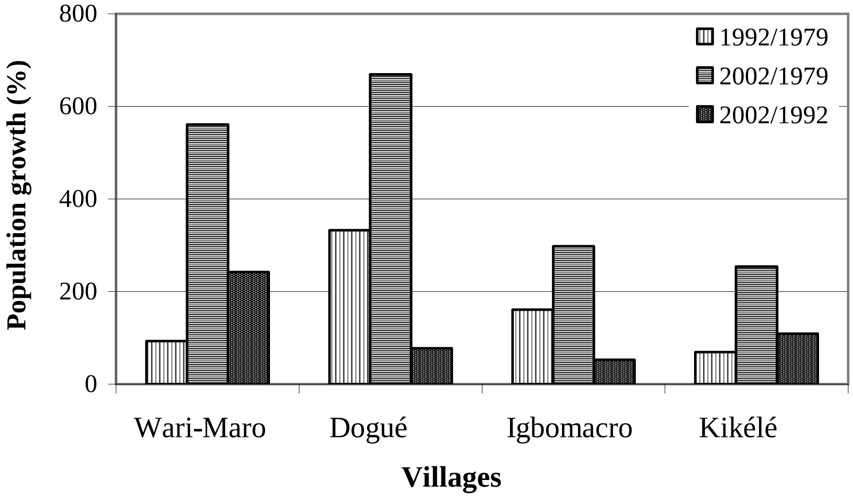

Figure 6.1.1: Population growth (%) of different villages per period: 1979-1992, 1979-2002, and 1992-2002

Source: INSAE, RGPH1, 2 and 3

From an additional perspective view, using the specific inter-censual growth rate[1] of each District during each specific period from 1979 to 2002, all things assumed to be unchanged, the population of these two villages will increase rapidly for Wari-Maro (projected to reach 51335 in 2025) while Dogué's population will grow progressively (projected to reach 6807 in 2025), representing a 1592% and 276% increase respectively for Wari-Maro and Dogué on the basis of the 2002 Benin Population and Housing Census Report (RGPH3).

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[1] The population projection is based on exponential growth rate approach developed in the chapter 3, section Socioeconomic and demographic features

6.1.1 Trends in population growth

Analysis in this paragraph is based on trends that result in official available and predicted statistics. Thus the following figure (**Figure 6.1.2**) shows the population trend for the four villages. For all the periods involved in this analysis, namely, 1979-1992, 1979-2002 and 1992-2002, there were relatively steady increases in population for all villages. All projected population put together experience higher population increase between 2002 and 2025 than within the other three periods. Among these four villages, Wari-Maro and Kikélé are higher while Dogué and Igbomacro know a steadily increasing population growth. This situation is confirmed by the annual population growth rate developed in the previous chapter (see *Socioeconomic and Demographic Features* section in chapter 3) for all the four villages.

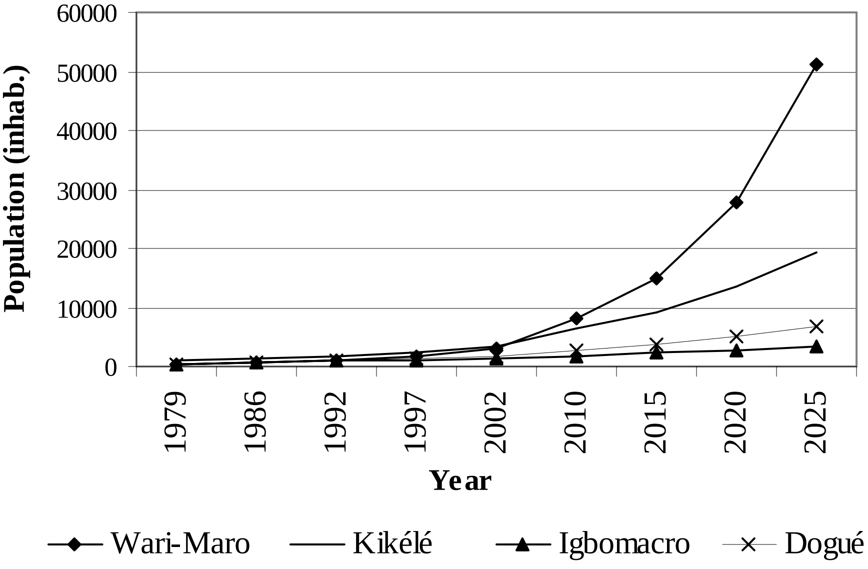

Figure 6.1.2: Trend in population growth by village: 1979-2025

6.1.2 Immigration and population growth

By comparing population census data from 1979 to 1992, the population of the study area observed an increase, passing from about 2,025 to 9,700 inhabitants (RGPH 1979 and 2002) with an annual growth rate of 12.8%. As in the Borgou province (and Donga as well), the population growth results from natural growth and immigration (de Haan, 1997).

According to the Concise Oxford Dictionary (1999) and the New Encyclopaedia Britannica (1998), migration is the act of moving from place to settle into another place or country, temporarily or permanently. Thus an immigrant is someone who intends to reside permanently in a country or region. The long term and/or permanent movement of human population in general, whether into, out of, or within countries, is regarded as migration. Finally, migration refers to all movements in physical space with the assumption more or less implicit that a change of residence or domicile is involved (Smith quoted by Bilsborrow and Okoth-Ogendo (1992)).

The study area is particularly characterized by this phenomenon of migration and finally by immigration since it is produced inside the country and specifically into the Upper Oueme Catchment region. The term of migrant or immigrant will thus be equally utilized in the text to design every person who has been settled in a region of which he is not a native. It will be opposed to native (or allochtonmous versus autochtonmous).

Since 1997, many migrants settled in the study area and contribute then greatly to the increase of the population. As figured out by the respondents during the interview, migrants are recorded in the study area since 1981 (**Figure 6.1.3**) that is before 1990 (18%). A majority of them (73%) have settled since 1997 to grow up steadily according to previous graph. This is confirmed by Doevenspeck (2004a) who carried up a detailed survey on migration within native and allochtonmous villages that surround Beterou, a Sub-District to which Wari-Maro belongs. The author statuated on the role played by migrants number in population growth. „*Le poids démographique des migrants est maximal dans l’arrondissement de Bétérou où ils constituent environ 65% de la population. […] Avec presque 6% entre 1992 et 2002, le taux d’accroissement annuel de la population de l’arrondissement de Bétérou dépasse même la moyenne communale.*” He also linked this increase in population to the extension and improvement of the road Ouberou to Bassila. „*Ces chiffres s’expliquent aussi par la rehabilitation de la piste rurale qui traverse la zone d’est en oust entre Oubérou et Bassila. Depuis l’achèvement de cette nouvelle route en 1997, le processus de colonization agricole déjà en cours s’est intensifié avec la constitution de véritables fronts pionniers.*” Another surge of migrants settled in the area in-between the two time-periods. From the Table 6.1 (Appendix 2), except the migrants interviewed from the isolated settlements, it can be pointed out that most of the migrants recorded within the administrative villages are located in Wari-Maro (27, 56%) even though the native farmers are dominant (96, 51%).

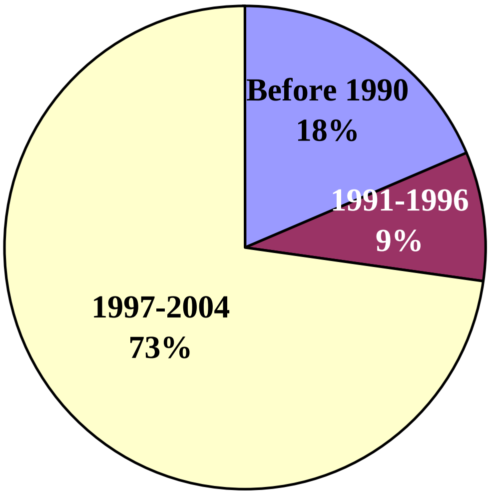

Figure 6.1.3: Distribution of migrant according to the period of installation
Source: Own survey, 2003

Regarding their origin, it can be stated out from the following table (and Table 6.2 in Appendix 2) that the allochtonmous have diverse origins. The District of Djougou, Kopargo, Natitingou, Tchaourou, Ouaké respectively remain the most dominant and cited by interviewed migrants and are some even from Togo, a country west of Benin. This statement is confirmed by respondent of both questionnaires noticed A and B in the **Table 6.1.2** respectively. The table 6.2 in Appendix 2 gives more details about the source of the localities of the migrants. Consequently, in addition to the most cited Djougou, more than fifteen (15) localities or villages are distinguishable. Among the cited localities, fifteen (15) migrants originate from Ouaké District only to which the villages of Ouaké, Badjoudè, Kpaou, Afékoukou and Kawado depend administratively.

In all, except Porto-Novo (a city located in the south of Benin at about 450 kilometres to Wari-Maro) and Togo, all the villages or localities mentioned by the migrant farmers representing their origin are located in the north east of Benin. This statement confirms the assertion that immigrants in the Upper Ouémé Catchment come from the north area of Benin where the soil conditions are no more suitable for agriculture to agricultural zones where soils are still fertile (Doevenspeck, 2004 (a); Wotto, 2003; Mama, 2002). The following map (**Figure 6.1.4**) shows the spatial distribution of the origins of about 431 migrants and transmigrants surveyed by Doevenspeck (2004) just before 2003 within the IMPETUS project. The red arrows mostly indicate the different birth origins (namely the Districts of

Djougou, Ouaké and Natitingou) that surround the study area and the neighbouring country of Togo.

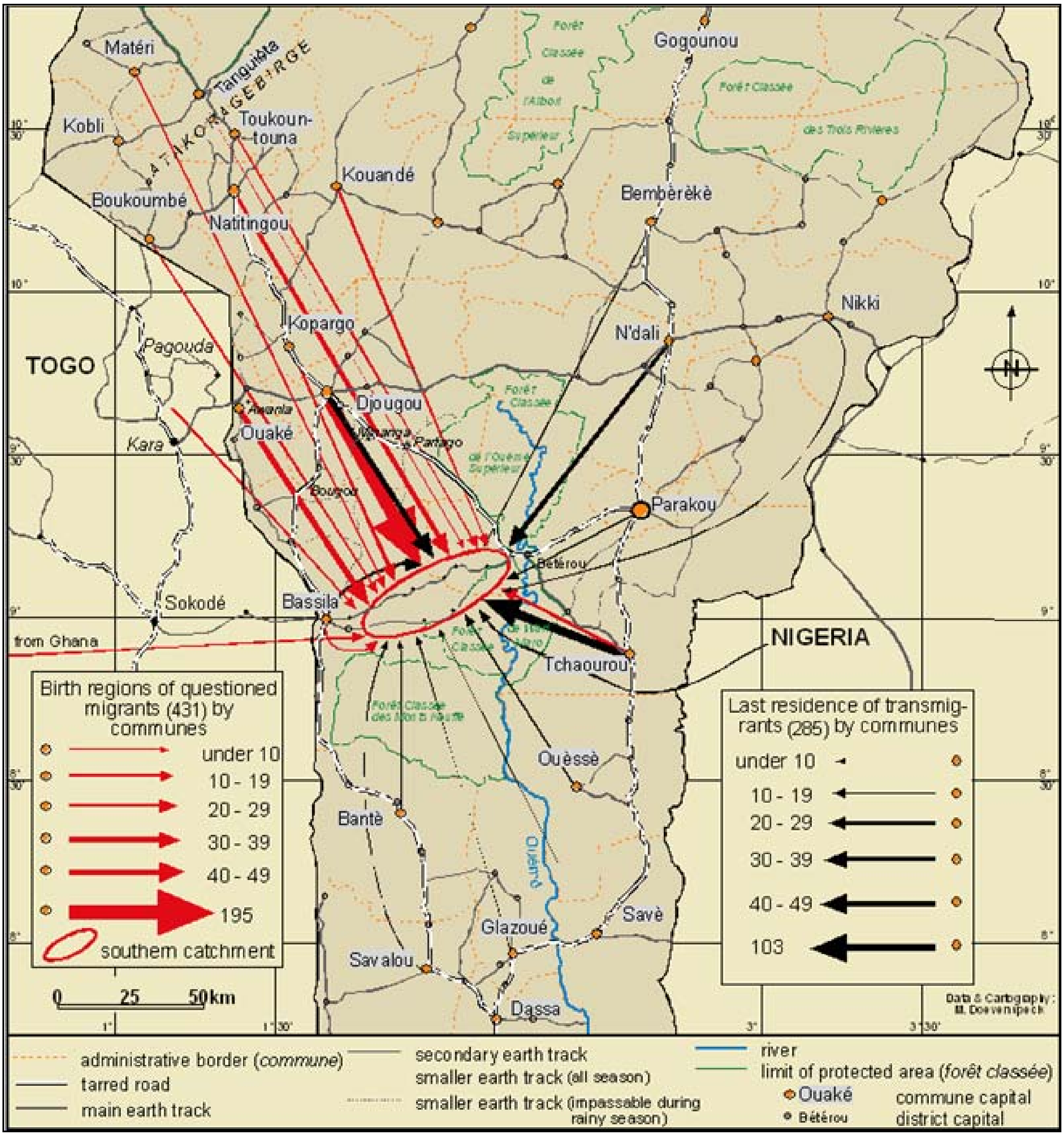

Figure 6.1.4: Birth regions of migrants and last residence of transmigrants in the southern Upper Ouémé Catchment

Source: Reproduced from Doevenspeck, M.(2004 (b) p.49) with the permission of the author

Diverse reasons trigger the migration, The main reasons that have been making migrants shift from their native place to another are shown in the next figure (**Figure 6.1.5**).

These are: need for soil fertility, land availability for cultivation, pasture, pasture and land cultivation, search for money through diverse activities like teaching, adventure, labour, etc.

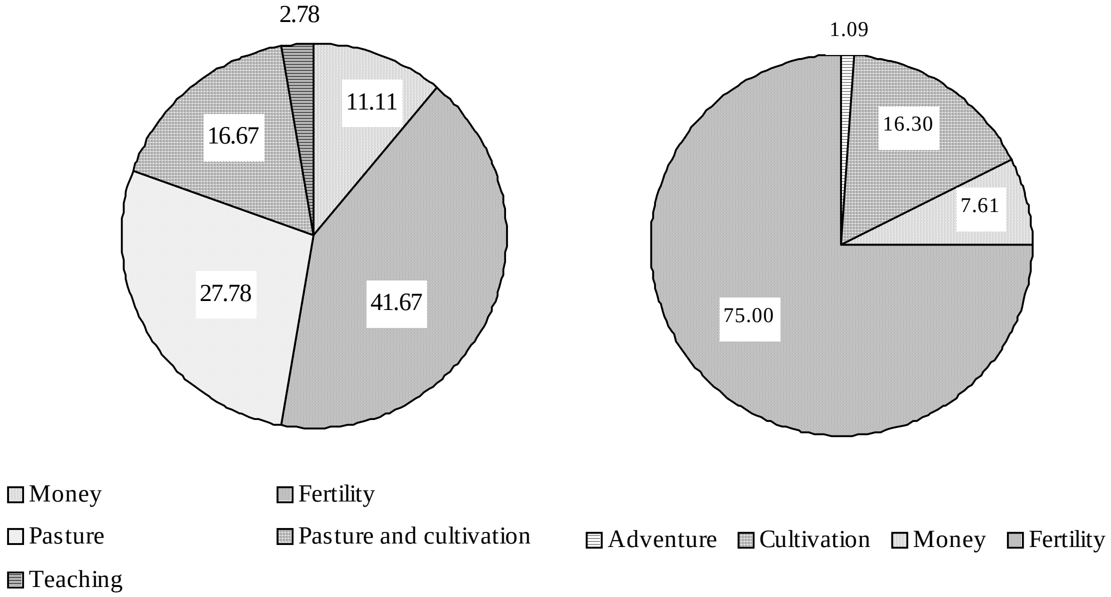

Figure 6.1.5: Reasons for migrating (%) in administrative villages (on right) and isolated settlements (on left)

The figure shows reasons for migration according to each category of surveyed farmers with regard to its location in the study area. Those located in the settlements along the main road or in administrative villages (right pie diagram) are forced to migrate especially for cultivation on available fertile land (16.30%, 75%). Other reasons reported include labour or employment opportunities in order to make money (7.61%). In the isolated settlements the main reasons indicated are either need of pasture for livestock and land cultivation (44.44%) or soil fertility (41.67%).

The reasons for migration are quite similar but there is a little difference due the different types of migrants recorded at different places in the study area. As figured out by Mama (2002), some long-term migrants who stayed in their residence for a period of more than 10 years are more stable (i.e. fixed or do not expect to return to their home place), permanent and sometimes become landlords for new migrants. They usually develop their own farming activities and build their own settlements. On the contrary temporary migrants versus sojourners or semi permanent migrants are less stable and very mobile. Therefore, their aim and activities during the stay are not similar. For instance the migrants recorded in the administrative villages have agriculture as main occupation since the lack of fertile soil forced them to migrate. By contrast, the second category of migrants often located in isolated settlements so called “*campements*” are considered as temporary migrants or sojourners or semi permanent migrants who move seasonally from their native residence with the intention of returning to their native residence or for pasture purpose. These last migrants often stay far away from the nucleus of the villages and prefer temporary settlements to permanent or definitive ones. Some of these migrants complement agriculture activity with pasture in order to create some additional (off-farm) revenue. This makes them richer (financial means) than native people.

Globally, scarcity of fertile land, pasture and other social reasons constitute the main reasons for migrations. Often most of these migrants plan a permanent stay since none of them ever declared the year or return to the native place. In some rare cases, some special events (like death of parents, annual traditional ceremonies, etc.) force them to come back temporarily to their home places (**Table 6.1.2**).

For a better understanding of these migrants, their characteristics or patterns are more developed in the next paragraphs.

Table 6.1.2: Allochtonmous District origin according to each type of questionnaire
Source: Own survey, 2003; from the two questionnaires types

District/ Country	**Questionnaire Type**		**Count**		**Percent (%)**	
			A	**B**	**A**	**B**
Bassila	A		2	1	2.2	2.8
Bembèrèkè		B		1		2.8
Boukoumbé	A	B	1	3	1.1	8.3
Djougou	A	B	48	10	52.2	27.8
Kandi	A		2		2.2	
Kobli		B		3		8.3
Kopargo	A	B	8	3	8.7	8.3
Kouandé	A		4		4.4	
Matéri	A		1		1.9	
Natitingou	A	B	8	2	8.7	5.6
Ouaké	A		11		11.9	
Parakou		B		1		2.8
Porto-Novo		B		1		2.8
Tanguiéta	A		1		1.1	
Tchaourou	A	B	1	11	1.1	30.6
Togo	A		5		5.4	
Total			**92**	**36**	**100.0**	**100.0**

A : Questionnaire of 2 pages ; B : Questionnaire of 5 pages

6.1.3 Population pattern

The official census' statistics are limited to the villages. These statistics lack some specific details relative to some parameters such as age, household numbers (migrants versus natives), literacy, etc. at the household level. For the purpose of analysis on that local level, this paragraph focuses on some population patterns derived from socio-economic interview. Thus, the relevant characteristics of the respondents are presented. These are household age, marital status, socio-cultural groups, literacy, education level, active population and children.

Household, age and marital status

From a total of 188 households interviewed, a majority group (71, 37.8%) of the farmers was aged 30-40 years (**Table 6.1.3**). The average age of the households was nearly 44 years (Table 6.3 in Appendix 2). Most of the farmers' ages vary from 30 to 50 years. The youngest and the oldest groups of farmers interviewed were 17, 9% and 13, 6.9% respectively.

When focusing only on migrants, the previous statement remains confirmed. From the following figure (**Figure 6.1.6**), most of the migrant farmers' (nearly 40%) ages are located within 30-40 years class. All the migrants together, their dominant age (30-60) represents a high percent (80.5%) while the youngest and oldest farmers cover very low percent (2, 5.6% and 5, 13.9%) respectively.

Table 6.1.3: Distribution of households' ages per category

Source: Own survey, 2003

Age classes	Frequency	Percent	Cumulative Percent
< 30	17	9.0	9.0
30 - 40	71	37.8	46.8
40 - 50	48	25.5	72.3
50 - 60	23	12.2	84.6
60 - 70	16	8.5	93.1
> 70	13	6.9	100.0
Total	**188**	**100.0**	

Apart from four singles interviewed, all the farmers surveyed were married and have their own household, given that the interview was focused mainly on the household head as one of the criteria of sampling. Among these farmers can be distinguished a variety of ethnic groups. The next paragraph gives an overview of the surveyed groups and more details on this topic can be found in the chapter on the study area.

Figure 6.1.6: Household age per category

Socio-cultural groups and education level

Based on the interview of either native or migrants it results from both questionnaire outputs that in addition to the Nagot ethnic group, the most dominant socio-cultural groups recorded among the migrants refer to five main classes: Yom (36, 39.1%), Lokpa (21, 22.8%), Peul (17, 47.2), Waama (7, 7.6%).

Concerning the education level, most of the interviewed farmers are illiterate 80% (139) of the rest, very few of them have a primary and secondary school education (41, 21.8% Primary) and (8, 4.3% Secondary). This statement confirms the general fact that farmers have very low or no education at all. This constitutes a weakness of their ability to have access to modern information for better improvement of their main activity which is agriculture.

6.2 Spatial organization

The spatial organization observed in the study area results in the anthropogenic actions that take place with the increase in the settlements. This subsection is focused on the dynamics of the settlements and their contribution to the spatial organization of the landscape in the study area.

6.2.1 Trends in the growth of settlements in the study area

During the periodic ground truths and fieldworks (2002 to 2004), several isolated settlements have been recorded according to their period of installation. Some additional data were collected as well from a specific survey in the established settlements or administrative villages and hamlets along the main road.

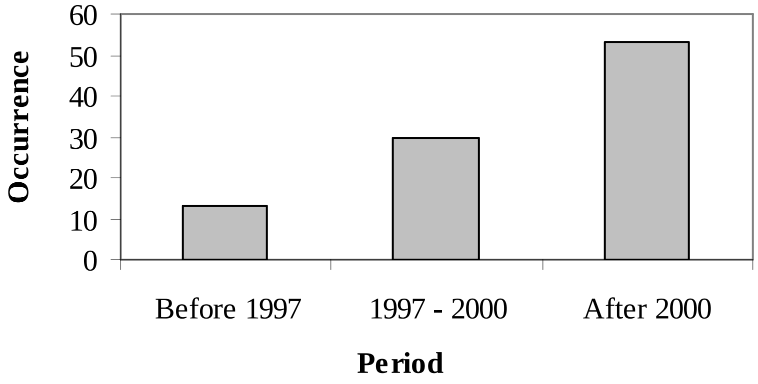

Figure 6.2.1: Settlements occurrence in the study area: before 1997 to after 2000

From these data is derived the previous figure (**Figure 6.2.1**) which shows the occurrence of settlements in regard to the different period of establishment. The figure indicates an increase in settlement year by year and period by period. Most of the settlements recorded are established after 1997 where the main road that crosses the study area has been built. From that period on, the settlements and the migrant’s population equally started growing tremendously. From the field observations and respondents, settlements have grown along the road network. In the study area, for farmers surveyed, most of their settlements are located less than 0.5 kilometre to the main road (159, 84.57%, N=188) either for migrant or native. This is confirmed by Mama (2002) in a study carried out in Tchaourou and also wthin Savè and Ouèssè, two District located under the Upper Ouémé Catchment where settlements are scattered along the main road.

The settlements are often made of huts. The number of huts per settlement varies according to the size of the household. One can distinguish between 1 and 20 huts in each settlement. The mean is 4.35 (Std. Dev. 3.6, N=75) per settlement while the settlement of 2 huts are dominant.

From the following pie diagram (**Figure 6.2.2**), it results that the Peul (48, 64%) constitute the most dominant and representative ethnic group surveyed within the settlements.

Among the Peul, four groups can be distinguished: Bariba, Gando, Haoussa and Kotocoli. The Peul group is followed by Ditamari (10, 13%) and Pila-pila (6, 8%) and other groups.

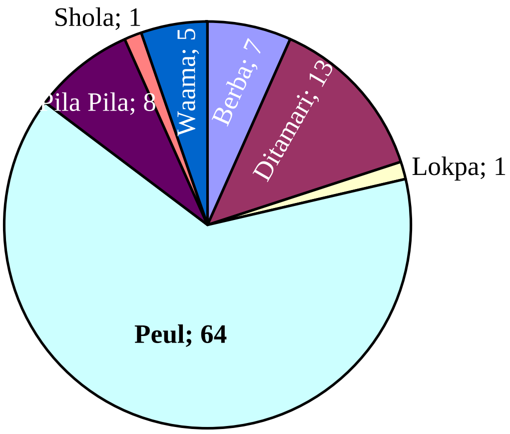

Figure 6.2.2: Dominant ethnic groups (%) recorded in the settlements

In all it is obvious that the process of land occupation is closely linked with the road network which facilitates transport of means, goods and the people as well. Therefore, the road network plays an important role for economic development of each area concerned as stated by many authors (Overmass & Verburg, 2005; Mertens & Lambin et al., 2000; Chomitz & Gray, 1996). The ethnic characteristic of the settlement influences the spatial organization.

6.2.2 Settlement types

According to the Cambridge dictionary (2003), a settlement may refer to any location where people live (hamlet, village, town or city) and can constitute an initial step in the colonization of open lands, or the resulting communities. This paragraph focuses on the spatial organization of the isolate settlements and an overview on native society for describing their spatial organization. Settlers are defined as people who have migrated from the land of their birth to live permanently in different geographic regions or colonies. The previous mentioned dictionary asserts that in agricultural history of some settlements, settlers are pioneers or colonists.

In the study area, according to the survey results, the settlements are populated by a variety of ethnic groups. The new settlements are dominated by Peul ethnic groups within the immigrant community. Below is given a brief description of the spatial organization of the Peul's farm as related by Bierschenk (1996)

The Peul’s farms are generally very uniform in their spatial organization either at the farm (named *wuro*) or in their huts. The central pivot around which the spatial arrangement of the farm is remarkable is the shea or “*karité*”[2] tree which is always located in west and then represents the west limit of the farm. This tree is always significant in the installation of every Peul for whom It is a sign of welfare or well being for the settlement. The surrounding area of the *karité* is often devoted to the woman (or women) and her (or their) activities. There is the barn and the required tools for pounding the grains. Just on the opposite side (east) is located the reception room where all the males pass the day. In-between the *karité* and the reception room are found the herd. The round kitchen and sleeping rooms (huts are nearly ca 4m) made with straws are located in the north and south of the farm. In their position, the cattle are often transferred to another place for a better manuring during the night especially within the rainy season. During the dry season, the herd pasture in the adjoining fields or far away from their place.

The Peul, generally named “*fulbe*” are considered nomads and cattle breeders. But they are also sedentary since they associate other agricultural activities to cattle breeding (Bierschenk, 1996). In addition to the breeding, they have some fields around the farm (an average of 2 ha of fields surround each Peul farm). Thus, sorghum and maize fields are often mixed around the farm. Some of them (who stay longer than others) practise yam and sometimes cotton. The **Figure 6.2.3** is a sketch of spatial configuration of a typical Peul farm.

As defined above, hamlet may regroup some farms. Within the immigrant people’s hamlet constitutes the great residential unit. The hamlets therefore regroup in general nearly 15 farms, similar (in size and in appearance) and close to each other. No immigrant hamlet ever contained some socio-economic infrastructures such as market, meeting room, mosque, etc. These infrastructures can only be found in the villages to which these hamlets or “*campements*” are closed to, especially *agricultural farmers’ villages*. In these villages can be found some ethnic groups like *Baatombu* (or Bariba) and *Boo* (or Boko) according to Bierschenk (1996). One or two hamlets are often attached to an *agricultural farmers’ village* within a distance of more than a kilometre at least. Most of the Peul visit the market of this village every market day. The market day is an opportunity for the elder Peuls to meet in small groups for discussion, entertainment or shopping. For the women as well, they get their revenue by selling the cheese made from milk extracted from the cattle. Finally, the market place offers an occasion for girls and boys to develop some relationships.

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[2] Shea tree (Karité) is a small tropical African tree bearing oily nuts. Scientific designation is *Vitellaria paradoxa* or *Butyrospermum parkii*.

Finally, in their spatial organization, the Peul group associate subsistence agriculture to the livestock farming and *karité* (*Butyrospermum parkii*) and *néré* (*Parkia biglobosa)* seeds gathering that appears to be a specific complex production system with a high economic autonomy.

Now, what about the characteristics of the native landscape spatial organization?
It is obvious to notice that the native people constitute the most dominant farmers in the study area. On the contrary, the land owners have easy access to land and no limitation in its utilization. Nevertheless, the spatial organization is quite similar. Nagot people constitute the main ethic group in the administrative villages and influence this organization.

Administrative villages are divided into quarters or hamlets. Here, the settlement is agglomerate with some grouped concessions. In each concession are grouped different households that belong to the same family. Sometimes one or few concessions compose a quarter or hamlet.

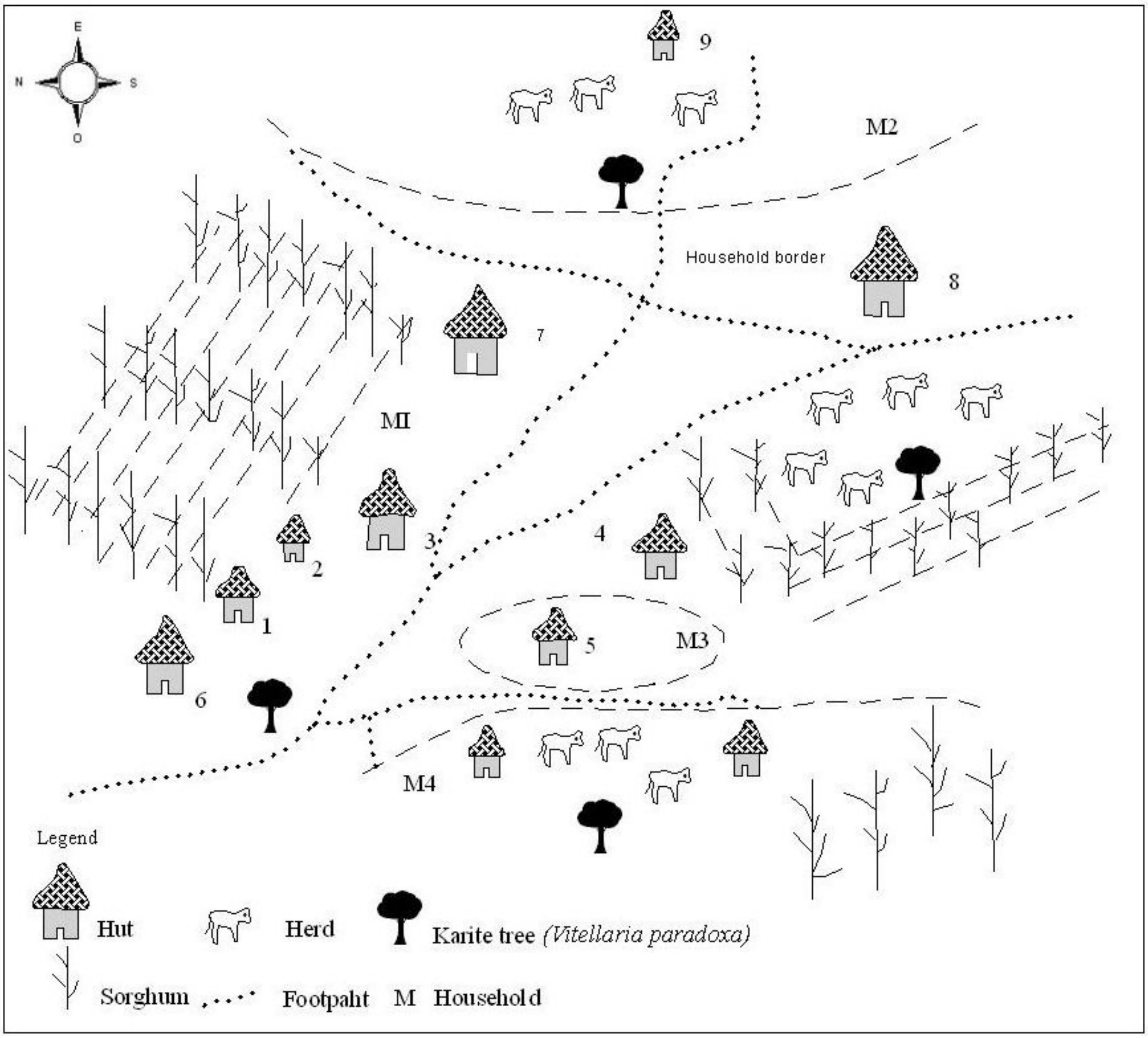

Figure 6.2.3: Sketch of typical Peul farm in the study area
Source: Own drawing, adapted from Bierschenk & Le Meur (1997)

Autochtonmous fields are often located far away from the village (more than 3 kilometres) as declared by most of the native farmers surveyed (48, 50%, n=188). Nevertheless, some surrounding fields (or compound farming) are located within the homestead of the farmers (10, 5.3%, n=188).

In general, the native spatial organization presents a series of irregular rings of landscapes as developed by Pélissier (1996) quoted by Mama (2002): around the village is a ring of plantations or orchard or fallow, followed by orchard and intensive shifting cultivation. In the next ring is observed an extensive shifting cultivation followed finally by bush and grazing land.

On the other hand, in the migrant’s settlement (as indicated above), each village provides itself with socioeconomic infrastructures such as market, mosque, church, health centre, etc.

6.3 Agricultural land-use in the study area

Agricultural land-use as presented in the following figure shows an increase in cropped area from year 1 to year 3 in all the village units (**Figure 6.3.1**). These results are based on all the interviewed farmers who declared their cropped area from 2002 to 2004. The aim of this question was to estimate the total cropped area by each household for all crops together each year. Therefore the year before and after 2003 that is the years 2002 to 2004 were chosen. Farmers from Dogué and Igbomacro are supposed to crop more area (3.6 to 4.5 ha and 3.6 to 4.2 ha respectively in Dogué and Igbomacro from 2002 to 2004) than Kikélé and Wari-Maro (2.16 ha to 2.77 ha in Kikélé). The next figure (**Figure 6.3.2**) shows a more important increase with the native farmers than migrants’ farmers. This statement can be explained by the fact that native farmers have easy access to land while migrants’ farmers are limited.

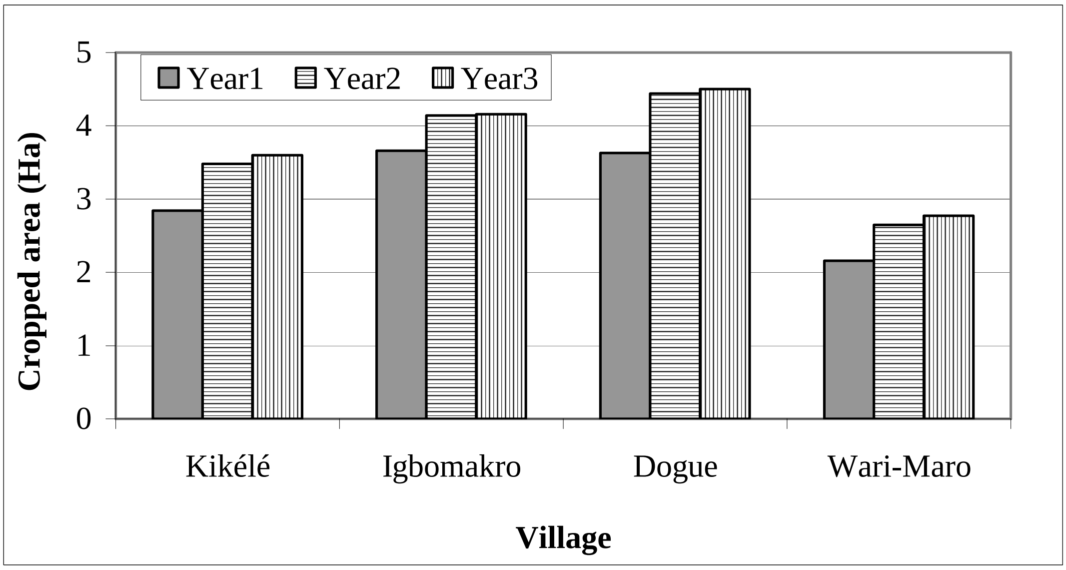

Figure 6.3.1: Cropped area per household, year and village
Source: Own survey, 2003

The estimates from farmers always consider essentially annual crops produced each year. Due to difficulty to separate crops in association, some cropped areas may include both annual and young plantations (e.g. plantations of age less than 5 years).Cashew plantation for example is often associated to other crops such as yam, cassava, maize, sorghum, groundnut, as quoted by Mulindabigwi (2005). Over to five years, cashew plantation can be distinguished homogenously, not associated with other crops. Therefore, cropped areas from peasants may be over or underestimated statistically with regards to some cases of mixture of crops (annual and permanent).

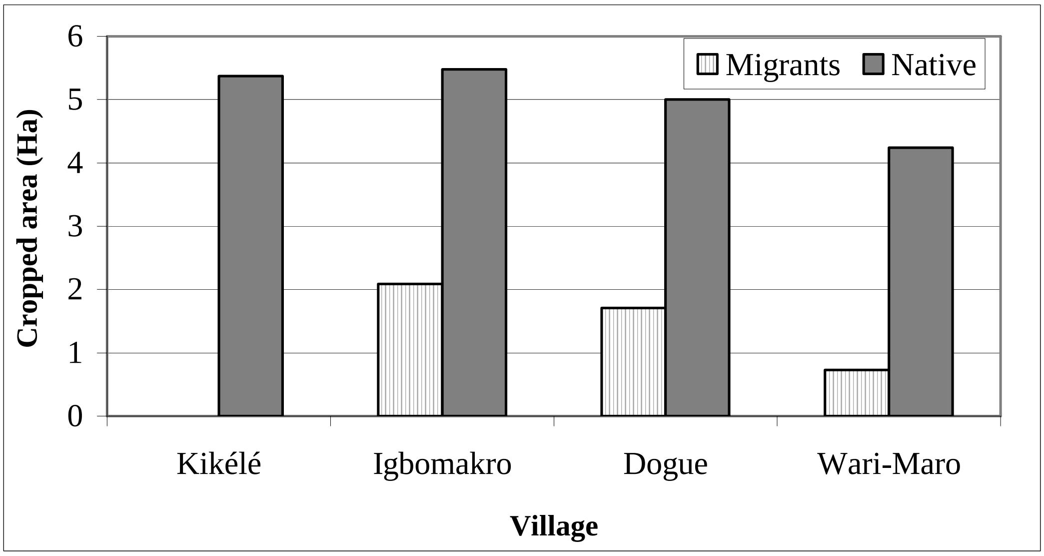

Figure 6.3.2: Cropped area per person and village (natives versus migrants)
Source: Own survey, 2003

For a better understanding of the cropping systems and to point out the relation between these cropping systems and land-use changes, the crops practiced by each farmer need to be known. For this purpose, a concordance test of Kendall was run (Dagnelie, 1998). According to the same previous author, Kendall's W is a normalization of the Friedman statistic and it is interpretable as the coefficient of concordance, which is a measure of agreement among raters (Dagnelie, 1998). Each case is a judge or rater and each variable is an item or person being judged. For each variable, the sum of ranks is computed. Kendall's W ranges between 0 (no agreement) and 1 (complete agreement)

The test can be explained as follow:

Let’s suppose a classification of data made by q experts. For each couple of experts, a coefficient of concordance of Spearman is calculated. It will then be retained $\frac{q(q-1)}{2}$ correlation coefficients of Spearman. By naming $\overline{\gamma_s}$ the arithmetic mean of $\frac{q(q-1)}{2}$ correlation coefficients of Spearman, the coefficient of concordance (W) of Kendall can be expressed through the following equation:

$$W = \left[1 + (q-1)\bar{r}_S\right] / q$$

As this parameter always ranges between 0 and 1, the more the values are closed to 0 the better is the discordance in the classification while the closer values to 1, the better is the concordance within the classification. Thus, the coefficient of concordance of Kendall helps in evaluating the degree of concordance that exists in a classification established in a form of rank of two or more experts or panel of judges. It also helps to test the significance. In this specific case study, it can be defined as following.

In the term of a classification made by surveyed farmers regarding the crops practiced, the Kendall concordance test is run in order to test the concordance of the classification made by farmers themselves. From the results presented in the following tables, it can be seen that there is a significant difference with a threshold of 1%. It can be deduced from the previous results that the classification made by farmers is extremely consistent Therefore, the results can be adopted. Thus, based on the results compiled in the following table (**Table 6.3.1**), among all crops put together, the main crops practiced by all the farmers in the study area are summarized to: yam (*Discorea* spp.), maize (*Zea mais*) and cassava (*Manihot esculenta*). Sorghum and cashew crops occupy respectively the 4th and 5th position.

By comparing native versus migrants, it results from the previous test of Kendall that yam, maize and sorghum are more practiced crops by migrants while native farmers prefer yam, cassava and maize. The following table (**Table 6.3.2**) summarizes the same test results for the four different villages. It emerges that all the surveyed farmers practice yam and maize in the first and second position in all the villages of the study area. They are followed by cassava and cashew in the 3rd and 4th position and finally sorghum, bean and rice depending on the position within the village.

Table 6.3.1: Hierarchical classification of main crops practiced by all the farmers: Result of concordance test of Kendall

Source: Own survey, 2003

Crop	Mean Rank	Order	Test Statistics	
Yam	1.93	1	N	188
Maize	3.40	2	Kendall's W	0.63
Cassava	5.28	3	Chi-Square	2127.2
Sorghum	6.06	4	df	18
Cashew	9.09	5	Asymp. Sig.	0,00
Bean	9.70	6		
Rice	10.99	7		
Sesame	11.01	8		
Peanut	11.39	9		
Cotton	11.96	10		
Tomato	11.97	11		
Pepper	11.98	12		
Soya	12.14	13		
Cocoa	12.17	14		
Kola	12.17	15		
Oil palm	12.18	16		
Cane	12.18	17		
Ananas	12.19	18		
Orange	12.19	19		

Table 6.3.2: Classification of five main crops practiced by farmers per village: concordance test of Kendall

Source: Own survey, 2003

Crop	Kikele	Igbomacro	Dogué	Wari-Maro
Yam	1	1	1	1
Maize	2	2	2	2
Cassava	3	3	3	4
Sorghum	4	4		3
Cashew	5	5	5	
Bean			4	
Rice				5

As a result it can be stated that yam remains the main crop practiced by farmers either native or migrants. As declared by many farmers and confirmed by Bell *et al.* (2000) and De Haan (1997), this crop characterizes a cropping system which needs a permanent clearing of land. They indicated in addition that concrete and satisfied yields are only obtained when yam crop is practiced on new clearing of lands that are supposed fertile. In addition, it can be seen from the following table (**Table 6.3.3**) and graph (**Figure 6.3.3**) that the cropped area of these three crops, especially the first one, is increasing. On the one hand in all cases, none of the average cropped areas (per crop) is more than 1.5 ha. The average size of all assembled fields never exceeds 5 ha as well. On the other hand, the graph shows a clear increase in yam, cassava and maize crops quoted respectively Y, C and M from the first year to the third (1, 2 and 3) that represent 2002, 2003 and 2004.

The increase in cropped area especially for yam crop is a great signal for land-use change due mainly to the clearings that often affect the land-cover and which are specific (mostly) to the migrant's cropping system. Such behavior can help to hypothesize a significant relationship between agricultural land-use and socio-economics.

Table 6.3.3: Average cropped area per household, per crop and per year (ha)
Source: Own survey, 2003

Crop	N	Mean (Ha)	Std. Deviation
Yam	151	1.28	1.30
Cassava	131	1.29	1.05
Maize	133	1.06	.67
All crops for year1	124	4.56	2.35
All crops for year2	126	5.39	2.83
All crops for year3	126	5.51	2.93
All crops for each year	126	4.62	2.60
Valid N (listwise)	107		

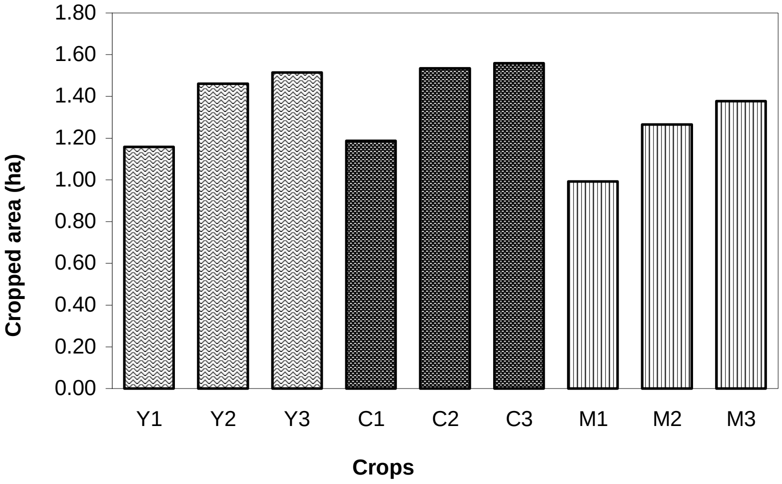

Figure 6.3.3: Cropped area development per crop: 2002-2004

Source: Own survey, 2003

Letters Y1, C2, M3 on x axis define the average cropped area respectively for Yam during year 1, for Cassava during year 2, and for Maize during year 3

6.4 Relationship between socioeconomics and agricultural land-use in the study area

This section examines the relationship between socio-economic aspects and agricultural land-use. The first of the four main subsections exposes the factors such as demographic factors that are supposed to influence land-use in the study area. The second subsection focuses on the relationship between socio-economic parameters and household annual income. The third section then deals with the relationship between these factors and cropped area. In the last section are discussed human acts influences on LUCC.

6.4.1 Influence of socioeconomic factors on land-use

Land-use/-cover changes (LUCC) are often influenced by several factors among which the socio-economic factors play a great role (Lambin & Geist, 2002). As stated by Verburg *et al.* (2004), land-use change can be described by the complex interaction of behavioural and structural factors associated with other variables such as demand, capacity, social relations and nature of environment. To point out the relevant socio-economic variables that affect land-use in the study area, a Principal Component Analysis (PCA) has been computed. For this purpose the analyses were focused on the variables derived from socio-economic survey on household. Below are firstly defined the PCA's objectives, principle, and the input parameters, then its interest and the results are finally presented.

Principal Component Analysis (PCA): Objectives and Principle

The Principal Components Analysis is one of the seven useful methods of factor extraction in the Factor Analysis method[3]. Factor Analysis method is primarily used for data reduction or structure detection. The purpose of data reduction is to remove redundant (highly correlated) variables from the data file, perhaps replacing the entire data file with a smaller number of uncorrelated variables (SPSS®, 2003; Palm, 1998; Philippeau, 1992; SAS INSTITUTE INC, 1989). This method attempts to identify underlying variables, or factors, that explain the pattern of correlations within a set of observed variables.

For Data reduction, the principal components method of extraction begins by finding a linear combination of variables (a component) that accounts for as much variation in the original variables as possible. It then finds another component that accounts for as much of the remaining variation as possible and is uncorrelated with the previous component, continuing in this way until there are as many components as original variables. Usually, a few components will account for most of the variation, and these components can be used to replace the original variables. For this case-study, the variables involved in these analyses are relative to four broad parameters:

- demographic parameters such as age, household status (migrant or native), education level, literacy, mean population and active population per household;
- crops and fields information such as crops, cropped area a year, crops sale, income, fields in fallow, duration of fallow, charcoal production;
- distances estimate with regards to distances of house to market, house to water, house to farm, house to main road, farm to water, farm to main road, farm to market, farm to village
- finally some perspectives for improving land management (need of energy, water, market, road).

In the following table (**Table 6.4.1**) is given the complete list of all the variables used to compute the PCA analysis. This table shows in total 25 variables used. Among these last, fifteen (15) are continuous, eight (8) are binary and two (2) are ordinal.

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[3] In addition to Principal components, unweighted least squares, generalized least squares, maximum likelihood, principal axis factoring, alpha factoring, and image factoring are available methods (SPSS®, 2003)

Table 6.4.1: Description of variables used for Principal Component Analysis computation

Letters in bold characters indicate the selected relevant variables that appearin the Component Matrix

Variables	**Label description**	**Type**	**Value**
AGE[l]	Household age (year)	Continuous	Real value
HOUSEHST[d]	Household-status	Binary	1=Native, 0=Migrant
AREACSEY[f]	Average area (ha) of all crops per year	Continuous	Real value
YAM[k] SORGHUM[i]	Dominant crop per household	Ordinal	1=Yam, 2=Maize, 3=Cassava, 4=Sorghum
FIELDFAL	Number of fallow of the farmer	Continuous	Real value
AGEFALO	Duration of fallow per farmer (year)	Continuous	Real value
CHACOLPR[m]	Charcoal production or not	Binary	1=Yes, 0=No
CROPSALE	Are the crops produced well sold or not	Binary	1=Yes, 0=No
INCOME[o]	Farmers income (FCFA)	Continuous	Real value
HMARKET	Distance of house to market (Km)	Continuous	Real value
HWATER	Distance of house to water (Km)	Continuous	Real value
HMEANFAR[b]	Distance of house to farm (Km)	Continuous	Real value
HMAINROD	Distance of house to main road (Km)	Continuous	Real value
FWATER	Distance of farm to water (Km)	Continuous	Real value
FMAINROA[e]	Distance of farm to main road (Km)	Continuous	Real value
FMARKET[c]	Distance of farm to market (Km)	Continuous	Real value
FVILAGE[a]	Distance of farm to village (Km)	Continuous	Real value
ENERGY	Need of energy	Binary	1=Yes, 0=No
WATER	Need of water	Binary	1= Yes, 0= No
MARKET	Need of market	Binary	1= Yes, 0=No
ROADS	Need of roads	Binary	1= Yes, 0=No
EDUC[j]	Education level of household head	Ordinal	0=Illiterate, 1=Primary, 2=Secondary
LITRCY[n]	Literate or not	Binary	1=Literate, 0=Not literate
HACT[g]	Household active population (inhab.)	Continuous	Real value
HPOP[h]	Household population (mean)	Continuous	Real value

In order to remove the effects due to differences in means and to unit choice, all the variables have been standardized i.e. centered and reduced. The standardization is given by the equation: $x_{ij} = (y_{ij} - \bar{y}_j)/\hat{\sigma}_j \quad (i = 1, \ldots, n; \quad j = 1, \ldots, p)$

where, y_j is the initial variable, $\bar{y}_j$ its arithmetic mean and $\hat{\sigma}_j$ its Standard deviation estimate, and x_j the reduced variable of the column *j*; *n* the number of individuals/observations and p the number of columns/variables.

Interest of Principal Component Analysis

PCA is very useful to detect the structure of data that describe the driving factors of LUCC (Lesschen *et al.*, 2005). In the frame of PCA, two tests are made. These tests indicate the suitability of the data input for factor analysis: The Kaiser-Meyer-Olkin Measure of Sampling Adequacy and Bartlett's Test of Sphericity. The first is a statistic which indicates the proportion of variance in the input variables which is common variance, i.e. which might be caused by underlying factors (SPSS®, 2003). The following table (**Table 6.4.2**) shows the results of these two tests.

Table 6.4.2: KMO and Bartlett's Test for PCA

Test		Value
Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.725
Bartlett's Test of Sphericity:	Approx. Chi-Square	1312.284
	df	105
	Sig.	.000

The previous table indicates for the Bartlett's Test of Sphericity a very small value (less than 0.05) which indicates that there are probably significant relationships among the input variables. The same table shows as well a KMO test’s result that is more than 0.6, a high value which generally indicates that a factor analysis may be useful with the data. Therefore, it comes out that the PCA results are of importance and can then be accepted. These results are compiled in the following table (**Table 6.4.3**).

Results of Principal Component Analysis

After run the PCA, the following resulting table (**Table 6.4.3**) gives eigenvalues, variance explained, and cumulative variance explained. Two additional panels of information conclude this table.

From this table, the first panel gives values based on initial eigenvalues. For the initial solution, there are as many components or factors as there are variables. Here are listed the fifteen (15) variables (components) that represent the 15 factors selected from the whole variable list after the PCA is run. The following panel shows the Extraction Sums of Squared Loadings group that gives information regarding the extracted factors or components. From the 15 variables indicated in the first column, only the first four (4) components are extracted. These four components account for 62% of the variance. The last panel indicates the results in the "Rotation Sums of Squared Loadings". By comparing the two last panels, it can be observed that the variance accounted by the rotated factors or components and those reported for the extraction are different. But the Cumulative % for the set of factors or components is the same (62 % for the last component).

Table 6.4.3: PCA results: total variance explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.814	25.427	25.427	3.814	25.427	25.427	3.185	21.235	21.235
2	2.604	17.361	42.788	2.604	17.361	42.788	2.333	15.554	36.789
3	1.741	11.609	54.397	1.741	11.609	54.397	2.246	14.976	51.764
4	1.144	7.625	62.022	1.144	7.625	62.022	1.539	10.257	62.022
5	.980	6.531	68.553						
6	.909	6.059	74.611						
7	.797	5.312	79.923						
8	.721	4.808	84.731						
9	.638	4.252	88.983						
10	.517	3.446	92.428						
11	.373	2.488	94.916						
12	.320	2.135	97.051						
13	.245	1.635	98.686						
14	.147	.983	99.670						
15	4.956E-02	.330	100.000						

Extraction Method: Principal Component Analysis.

Based on the previous explanations, it can be concluded that the four (4) first axes that represent the four variables account (or explain) for about 62% of information contained within the initial 15 variables. Each of these components explains more than one initial variable. The scores obtained by each variable are given within the table of the component matrix (**Table 6.4.4**). The scores of the initial variables are shown in comparison to each of the 4 components extracted.

Principal Component Analysis: Analysis of the components extracted

By focusing on the first factors plan i.e. for a two-factor solution, a two-dimensional plot can be deduced. A three-dimensional factor loading plot can be deduced as well for the first three factors. While the **Figure 6.4.1** shows the two first components of the bi-dimension plan, **Figure 6.4.2** represents the variables in the first rotated factor space. By analyzing the previous table, **Figures 6.4.1** and **6.4.2**, the following remarks can be noticed:

Table 6.4.4: The Component Matrix of the PCA

Factor	Component			
	1	2	3	4
FVILAGE	0.752	-0.577	-0.002	0.081
HMEANFAR	0.751	-0.555	0.005	0.061
FMARKET	0.646	-0.523	0.015	0.096
HOUSEHST	0.644	0.456	0.294	-0.220
FMAINROA	0.602	-0.577	0.066	0.035
AREACSEY	0.577	0.486	0.207	0.026
HACT	0.552	0.549	-0.324	0.380
HPOP	0.524	0.495	-0.343	0.408
SORGHUM	0.453	0.367	0.410	-0.123
EDUC	-0.181	-0.021	0.591	0.436
YAM	-0.045	0.038	0.480	0.078
AGE	0.351	0.385	-0.395	-0.101
CHACOLPR	-0.300	-0.243	-0.320	0.220
LITRCY	-0.246	0.052	0.476	0.562
INCOME	-0.257	-0.137	-0.389	0.421

Extraction Method: Principal Component Analysis.

- three groups of variables globally appear especially when the analysis refers basically to the first plot. The first group of variables is constituted of HMEANFAR, HMAINROA, FMARKET and FVILLAGE. This group of variable influences more the first factor axis which can be named "*distances axis*". This group of variables is mainly opposed to the variables INCOME, LITRCY, EDUC and CHACOLPR;

- the second group of variables assembles the variables INCOME, LITRCY, EDUC and CHACOLPR that oppose the first group of variables traduces a correlation between the level of education, the income and charcoal production. In other words, the households whose head is more educated are those who are more involved in charcoal production and generate high revenue;

- the third group of variables gathers HOUSEHST, SORGHUM, AGE, HPOP, AREACSEY and HACT. This classification indicated that native households have more croplands than migrants, the correlation being high between HOUSEHST and AREACSEY. As well there is a high correlation between SORGHUM, AGE, HACT and AREACSEY. This traduces that the native households are more involved in sorghum production, have a great size of active population for agriculture and consequently have to provide a living for more people;

- Finally, the third group of variables which tend to oppose to the second group of variable when considering the second factor axis. This contrast helped to assert that households whose heads ere well educated are those involved in charcoal production and consequently can gain more income. These households could probably be the youngest as well. As a matter of fact, it can therefore be asserted that the migrant's households contribute already to the forest cover destruction. On the other hand, the natives focus more their activities on agriculture. In addition, the migrant's people seem more involved in yam production than the native farmers. As already mentioned in the previous subsections, the yam crop demands at each cropping cycle some new clearings of parcel of lands. Based on these tendencies, the second axis can be named "*destruction axis*" of forest resources.

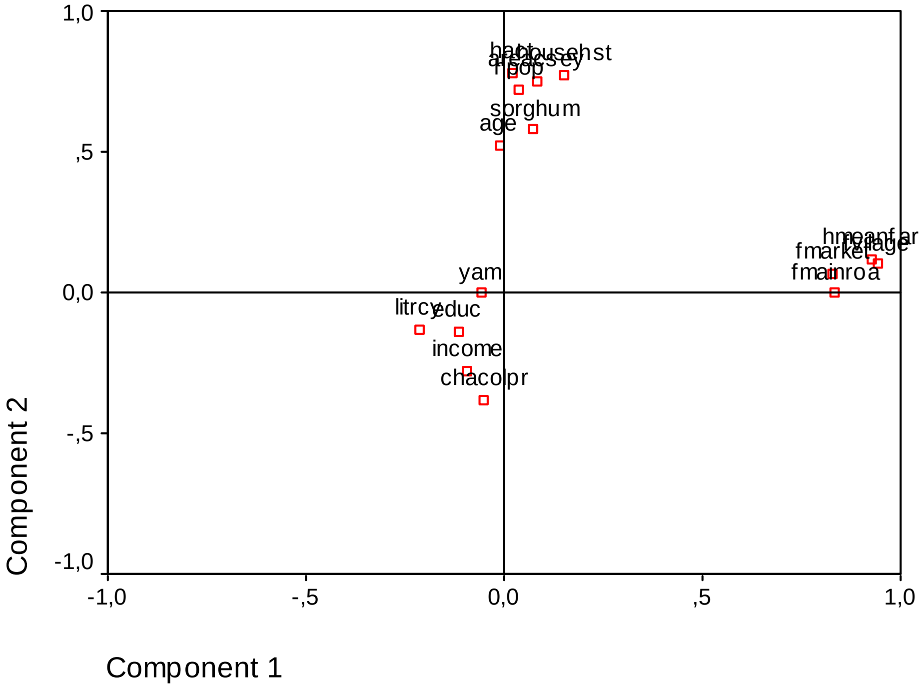

Figure 6.4.1: Component Plot in Rotated Space: Highlight of relationships among variables

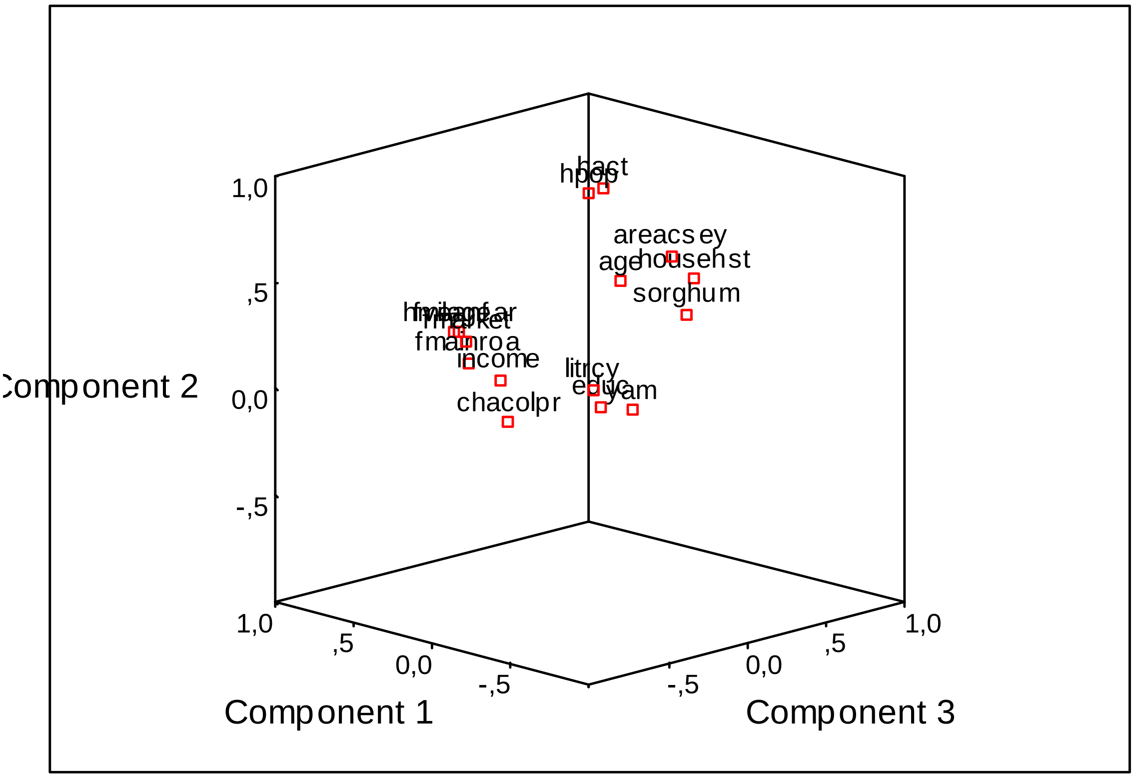

Figure 6.4.2: Factor loadings plot of variables: the three-dimensional plot that highlights the relations among variables

6.4.2 Relationship between socio-economic factors and annual income

From the previous subsection, it came out that income is one of the relevant socio-economic components or factors that could influence land-use in the study area. The present subsection tries to set up the relationship between the socio-economic factors and annual income of the farmers. For this purpose, a linear regression analysis was run based on a list of selected candidate variables that are supposed to influence the annual income of the farmers. These variables are relative to different parameters such as distance, demographic indicators, cropped area, etc. The *stepwise*[4] method was used for selecting the most significant variables. The results are presented in the following table (**Table 6.4.5**):

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[4] *Stepwise. At each step, the independent variable not in the equation which has the smallest probability of F is entered, if that probability is sufficiently small. Variables already in the regression equation are removed if their probability of F becomes sufficiently large. The method terminates when no more variables are eligible for inclusion or removal.*

Table 6.4.5: Results of stepwise linear regression showing significant predictors of farmer's income

Variables	B	Std. Error	t	Sig.
(Constant)	648000.14	52289.80	12.39	0.000
Are the crops produced well sold or not	-295925.79	70175.86	-4.22	0.000
Charcoal production or not	202936.67	122340.01	1.66	0.099

F = 13.29 P= 0.000 Adjusted R Square = 0.116

Dependent Variable: Farmers income

The results show that the model is globally significant with a probability level < 0.01. The adjusted R^2 is 0.116 which means that nearly 12% of variations in household's income are explained by a variation of two relevant variables included in the model: crops sale and charcoal production. The excluded variables from the model are listed in the following table (**Table 6.4.6**).

Table 6.4.6: Excluded variables from the regression model for farmers income

Variables	Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
					Tolerance
Since how many years	0.01	0.08	0.94	0.01	0.71
Average area (ha) of all crops for each year	0.13	1.40	0.16	0.10	0.56
Household age	0.06	0.87	0.38	0.06	0.95
Household-status	0.09	0.33	0.74	0.02	0.06
Dependence rate	-0.02	-0.36	0.72	-0.03	1.00
Education level of head household	-0.04	-0.57	0.57	-0.04	0.99
Number of fallow of the farmer	0.03	0.31	0.76	0.02	0.70
House to market distance	-0.06	-0.84	0.40	-0.06	0.97
House to water	0.00	-0.02	0.99	0.00	0.99
House to farm. mean	0.02	0.25	0.80	0.02	0.95
Farm to water	-0.07	-0.98	0.33	-0.07	0.99
Farm to main road	-0.06	-0.87	0.39	-0.06	0.97
Farm to market	-0.05	-0.70	0.48	-0.05	0.97
Farm to village	0.02	0.30	0.77	0.02	0.95
Need of energy	-0.02	-0.21	0.83	-0.02	0.69
Need of water	0.03	0.48	0.63	0.04	0.99
Need of health centre	0.05	0.68	0.50	0.05	0.97
Need of market	-0.08	-1.13	0.26	-0.08	1.00
Need of roads	0.01	0.14	0.89	0.01	0.89
Need of radio	0.01	0.18	0.86	0.01	0.95

6.4.3 Relationship between socio-economic factors and cropped area

Like the previous, this subsection aims to set up a correlation between the mean cropped areas by farmers each year and the other parameters that are supposed to influence the land-use through the area cropped. For this purpose a linear regression was run using a stepwise method. From the following table (**Table 6.4.7**), six (6) relevant variables (predictors of cropped area) were selected. These are: Household-status, Household active population, Need of water, Farm to water, House to market distance, Number of fallow of the farmer.

Table 6.4.7: Results of stepwise linear regression showing significant predictors of cropped area

Variables	Coefficients	Std. Error	t	Sig.
(Constant)	0.877	0.433	2.027	0.044
Household-status	3.526	0.377	9.350	0.000
Household active population	0.299	0.061	4.936	0.000
Need of water	-1.100	0.367	-2.995	0.003
Farm to water	0.318	0.140	2.274	0.024
House to market distance	-0.121	0.056	-2.141	0.034
Number of fallow of the farmer	-0.037	0.025	-1.493	0.137
F = 35.23	P = 0.000	R Square = 0.539	Adjusted R Square = 0.523	

Dependent Variable: Average area (ha) of all crops for each year

The results show that the model is globally significant with a probability level < 0.01. The results of the regression analysis can then be conclusively interpreted. The adjusted R^2 is 0.523 which means that nearly 54% of variations in cropped areas are explained by a variation of the six relevant socio-economic variables included in the model. In addition, it can be noticed that all the variables were significant with a probability level < 5% except the variable “Number of fallow of the farmer”. The other variables excluded from the model are listed in the following table (**Table 6.4.8**). The area cropped each year is positively correlated with the predictors “Household-status”, “Household active population”, and “Farm to water”. By contrast, the variables “Need of water” and “House to market distance” influence negatively the cropped areas. It can then be deduced from these results that native migrants clear more lands than migrants. This assertion confirms the results of the previous PCA. The remark is likely the same for the active population of the household.

Table 6.4.8: Excluded variables from the regression model for cropped area

Excluded Variables	Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
Household age	0,009	0,147	0,883	0,011	0,741
Household dependent population	0,060	1,026	0,306	0,076	0,752
Education level of head household	0,028	0,533	0,595	0,040	0,958
Literate or not	0,024	0,461	0,645	0,034	0,978
Charcoal production or not	-0,028	-0,507	0,613	-0,038	0,870
House to water	-0,068	-1,072	0,285	-0,080	0,631
House to closest farm	-0,037	-0,702	0,483	-0,052	0,919
House to farest farm	0,029	0,536	0,593	0,040	0,888
House to farm, mean	-0,002	-0,047	0,963	-0,003	0,900
House to main road	-0,067	-1,321	0,188	-0,098	0,993
Farm to main road	-0,070	-1,339	0,182	-0,099	0,925
Farm to market	0,029	0,468	0,641	0,035	0,656
Farm to village	0,008	0,145	0,885	0,011	0,893
Need of energy	-0,022	-0,344	0,732	-0,026	0,641
Need of health centre	-0,008	-0,157	0,876	-0,012	0,894
Need of market	-0,042	-0,814	0,417	-0,061	0,957
Need of roads	-0,022	-0,393	0,695	-0,029	0,802
Need of radio	-0,064	-1,208	0,229	-0,090	0,910

6.4.4 Influence of other human activities on LUCC

In addition to the previous relevant factors seen as contributors or explanatory variables that influence land-use, there are some anthropogenic activities which are necessary to sort out. This subsection focuses on some main human behaviour grouped into two broad categories: bush fires and wood extraction for diverse purposes (fields' installation, commercial wood extraction, fuelwood extraction, and charcoal production) and their relations with (or influences on) land-use and land-cover.

Bush fires and land-cover

The practices of bush fires which take place in the study area are organized either by native peasants or migrants. The interviewed migrants declared the practice of bush fires by migrants (17, 47.2%; n=36) and natives (15, 41.7%; n=36). The reasons often evoked by most of them are related particularly to:

- preparing of new fields installation and extension of existed ones;
- fertilizing the soils;
- grazing purpose (regeneration of new grasses leads to pasture production);
- establish fire breaks for protecting fields, crops, orchards and dwellings against possible uncontrolled fires damages.

In spite of precautions, bush-fires often happen. Oertel *et al.* (2004) quoted by Orthmann (2005) indicated that a high portion of land-cover in the Upper Ouémé Catchment is burned annually. Many consequences can result. These are often related:

- fields degradation, especially crops and/or orchards consumption;
- burning of certain dwellings;
- burning of some specific plant species. This can lead to a transformation species communities and even contributing to the reduction or extinction of certain varieties of plant species.

An example of active bush fire and results induced by fire effects are respectively shown by **Figure 6.4.3**a, b below.

Figure 6.4.3: a) Active bush fire closed to a cassava field (on left) and b) Young yam field covered by a series of dead and burn trees (on right)
Source: Film made by Orekan in 2002

Wood extraction

In the study area, It is obvious from field knowledge that vegetation is intensively subject to loggings for wood extraction and for diverse purposes. A detailed description about the logging system in the area of investigation is described by Orthmann (2005).

Before the installation of new fields, and due to slash-and-burn farming system, farmers used to clear new parcels of terrains within savanna or forest units. This assertion was confirmed by certain farmers, essentially migrants (6, 17%; n=36) who are involved in this activity. These statistics indicated very few migrants involved in logging activities. However, based on our knowledge of the field, this percentage of 17% may be discussed. The main reason relates that most of the migrants applied the shifting farming system. And as a proof, the results of this application are obvious on their fields. It can be effectively seen on the landscape many yam fields composed of dead and dry trees. These trees have been primarily burned starting from their trunk under the effect of fires. Then they are abandoned for a long period (sometimes many years). Finally they can be straightforwardly used as input for charcoal (33%) or firewood (64%) production. Some trees are completely let for facilitating yams' sheet rising as confirmed by Mulindabigwi (2005). Most of the interviewed peasants justify this practice by the need for an open and sunny air space, which therefore allows the fast development of yam crop. Off course, a yam production needs a temperature of 25 to 30°C as one of its main ecological exigencies for its stems (Bell *et al.*, 2000). Therefore, most tree leaves are removed by burning system in order to reduce shadow influence on the yam fields.

Charcoal production

Another anthropogenic activity that contributes to the land-cover degradation is the charcoal production. The investigations during the field check and household survey near the peasants show that both native and migrants contribute to forest degradation at different level. Whereas 36% (13 out of 36) of the migrants produce charcoal, only 17.7% (17 out of 96 natives among the 188 peasants of the second questionnaire of 2 pages) declared being involved in the same activity. From the Table 6.5 (Appendix 2), it appears that most of charcoal producers are located in Igbomacro. As a proof of this activity, some charcoal bags are often stored along the main road Wari-Maro to Kikélé, ready for transport. Some tracks are often in charge of the transportation of the sacks of charcoal to their destinations (nearby towns and generally to the main cities of Benin namely Parakou in the north (about 80 kilometres to the study area), Cotonou, and Porto-Novo in the south (between 400 and 450 kilometres to Wari-Maro). Species like *Pterocarpus erinaceus*, *Crossopteryx febrifuga* and *Detarium microcarpum* are more solicited for charcoal production (Tente, 2005; Orthmann, 2005; Natta, 2003; PAMF, 1996).

Commercial wood and fuelwood extraction

The wood and fuelwood commercialisation concern certain selective species which are more appreciated by people. More and more, the rare species are diminishing progressively because of their abuse logging. Some wood species are more utilized for timber production or household use especially for furniture than others. Among the useful species are: *Ceiba pentandra*, *Khaya grandifolia*, *Antiaris africana*, and *Chlorophora excelsa* (from deciduous forest islands and gallery or riparian forests) are appreciated as well as *Afzelia africana* and *Khaya senegalensi*s from woodlands and savanna (Orthmann, 2005). Fuelwood are extracted mainly for household use. It is necessary to point out here that fuelwood, either burned and transformed into charcoal, or dried, are the major source of energy for cooking in households in both rural and urban areas (Tente, 2005; Codjoe, 2004). These practices consequently cause more and more damages to the land-cover. There is the need for protecting the vegetation cover to avoid extinction of rare species. To reach this result, drastic measures are necessary since most logging activities that take place in the study area happen without any concession, or legal regulation.

The following pictures (**Figure 6.4.4**) show a tree-trunk cut for timber production (a) and some sacs of charcoal exposed for sale (b).

Figure 6.4.4: a) Wood cut at trunk level for timber production (on left) and some Sacks of charcoal exposed for sale in a nearby local market of Kpaawa village (on right)

Source: Film made by Orekan in 2002 and 2004

Over all, from the findings of this subsection, it comes out that agricultural land-use in the study area has multiple relationships with many socio-economic factors. Based on diverse factors, the LU/LC changes causes can be classified under two main causes: proximate and underlying causes.

6.5 Relevant causes of LUCC

In the previous section diverse relationships between land-use/land-cover changes and socioeconomic conditions in the study area are pointed out. This section attempts to summarize the main findings as causes for LUCC and will try to categorize the relative causes into two classes: proximate and underlying causes of LU/LC changes. The focus is on the relationships which can be derived from the correlation of remote sensed data with population growth on the one hand and between forest cover and population density on the other hand.

It is necessary to state here that proximate causes are human activities (land uses) which directly affect the environment and are seen to operate at the local level, e.g. logging, clearing for new fields, etc. (Geist and Lambin, 2001). The underlying causes are seen as a complex of social, political, economic, techno-logical and cultural variables (e.g. laws, land manure techniques,..) … They may also operate at the local level too (ibid.).

Relevant conclusions from the PCA

As a global finding from the general presentation of the area under study, it can be pointed out that the spatial pattern of land-use and land-cover depends essentially on the population i.e. through its main characteristics such as status, number of people living in area devoted to each settlement, and the growth rate. It also concerns the cropping system, especially the main crops produced by the farmers: yam, cassava and sorghum which are the main production recorded with the local farmers. It is noteworthy that yam crop plays an important role in area as stable food hence it needs new clearings of fertile soils annually.

The investigations conducted on the field resulted in a number of additional socio-economic factors that are supposed to influence the land-use changes in this area. Three groups of variables sum up the findings of the PCA. These are:

1) distance from house to farm (HMEANFAR), distance from house to main road (HMAINROA), distance from farm to market (FMARKET) and distance from farm to village (FVILLAGE);

2) farmers income (INCOME), literateracy or not (LITRCY), education level of household head (EDUC) and charcoal production (CHACOLPR); and

3) household status (HOUSEHST), sorghum as dominant crop per household (SORGHUM), household age (AGE), household population (HPOP), average area of all crops per year (AREACSEY) and household active population (HACT).

Gathering these variables assumes a correlation among them. Thus the first and third group quoted "*distance axis*" and "*destruction axis*" respectively are opposed to the second axis.

Relevant conclusions from the correlation analysis

This study intends to show the correlation between single variables. The results prove that there is a high correlation between income and three other variables namely cropped areas, household age, and household status. These findings confirm the results from the PCA analysis. In the same way, the cropped area variable is itself influenced by population (i.e. status, and active population), distances (farm to water and house to market), fallow practice, and specific need of water expressed by farmers.

Relevant conclusions from the anthropogenic influences

In addition to the previous interconnected relationships, some human activities which lead to LUCC are concerned. These are: bushfires, wood extraction, charcoal production, commercial wood and fuelwood extraction in the study area. These activities lead to strong changes of the land-use and land-cover.

Generally, as negative influences, bushfire destroys precious and rare plant trees, plantations (or orchards), and causes forest reserve depletion. Apart from destroying soils, nutrients making it infertile and causing erosion, desertification, fire also reduces plant population and pollutes the environment with dangerous carbon dioxide, which together with other gases makes the world hotter and hotter (All-africa.com, May 2006). Further more, fire may reduce the fuel wood availability, affect the rainfall pattern, and food production and lead to the drying of water bodies, forcing rural communities to travel long distances in search for water.

Finally, influences of wood extraction, charcoal production, commercial wood and fuelwood extraction can be summarized through the effects logging activities on the environment. Logging activities focus more and more focus on particular and individual tree species that are much appreciated. These last can led to deforestation, extinction of rare plant species, desertification, and soil erosion and further more drying of water bodies.

Finally, by summarizing the diverse causes resulting from above subsections, an attempt of classification of causes with regards to proximate and underlying causes can be depicted. Based on the characteristics of proximate and underlying causes' definition, the previous variables assumed to drive land-use and land-cover changes according to the surveyed farmers and derived remote sensed data. Thus, the following classification can be made:

1) distances (through roads or accessibility), income (economy growth), charcoal production, crops and cropped areas (through agriculture expansion) can be grouped in proximate causes;

2) household’s age, population and active (through demographics factors), literacy, education and household status (social) are put under underlying causes.

Having looked closely at the land-use patterns of the people in the study area, some relevant socio-economic factors that drive the land-use changes are indicated. In the next chapter, the CLUE-s modeling frame is used to model spatially these changes in this work.

7 IMPLEMENTATION OF THE LOCAL CLUE-s MODEL

The modeling technique applied in this research is based on the simulation of land-use changes with the CLUE-s model. Additional to the reasons mentioned in this chapter and in sections 1.2.1 and 2.5.1, the results of the analysis with the CLUE-s model can be used by land-use planners to decide about the desired land-use planning (Engelsman, 2002). This chapter firstly describes the motivation that guides the choice of the CLUE-s framework for modeling land-use/land-cover changes in the study area. The following sections give a general overview of the CLUE modeling framework and detail the CLUE-s model. The process of setting up the CLUE-s is described as well as the statistical and the sensitivity analysis that counted as important steps for the modeling approach. In the final section, the modeling outputs are described and discussed; the model was then validated with recent techniques and different scenarios were defined in regard to IMPETUS scenarios.

7.1 The CLUE Model framework

7.1.1 Why modeling with CLUE-s?

As stressed above in the second chapter, several models of LUCC have been described in the literature. Modeling approaches vary according to the goals and the discipline to which they are applied for. The present study aims to adapt the CLUE-s model to describe and understand the process of changes and estimate how land-cover will change in the future in the southern part of Upper Oueme Catchment. Several reasons motivated the choice of the CLUE-s model for modeling the land-use changes in the study area:

- CLUE-s is a hybrid model that combines estimation and simulation models (which use the parameters from the estimation model to predict the spatial pattern of land-use/-cover change that could occur under different boundary conditions (scenarios))
- CLUE-s is an empirical model that aims to quantify the relationships between variables using empirical data and statistical methods;
- it is a multi-scale land-use change model developed for understanding and predicting the impact of biophysical and socio-economic forces that drive land-use change;
- it projects and displays cartographically the future land-use patterns that results from the continuation of current land-use or actual land-cover map;

- the model may simulate and locate ‘hot-spots’ of land-use and land-cover changes at local scale (50 km x 30 km) with detailed input data (e.g. own socio-economic data) and spatial resolution of 30 m x 30 m;
- the model is friendly user and adaptable to tropical regions where it has been applied in many countries
- the modeling outcome may be used by land-use planners to decide about the desired land-use planning for the future.

7.1.2 Overview of CLUE Model

The CLUE (Conversion of Land Use and its Effects) is an empirical multi-scale land-use change model developed for understanding and predicting the impact of biophysical and socio-economical forces that drive land-use change. This model simulates the recent and future changes in land-use patterns. Therefore, it is capable of identifying areas that have high probabilities for future changes in land-use, so called ‘hot-spots’ of land-use change (Engelsman, 2002). The CLUE modeling framework (Veldkamp and Fresco, 1996; Verburg *et al.*, 1999) was developed to simulate land-use change using empirically quantified relations between land-use and its driving factors in combination with dynamic modeling of competition between land-use types. The model was developed for datasets with coarse spatial resolution at national and continental level (> ~ 1x1 km pixel resolution) and applied for Central America (Kok, 2001; Kok and Winograd (in press)), Ecuador (De Koning, 1998a, 1998b, 1999a, 1999b), China and Java, Indonesia (Verburg *et al.*, 2000). In these applications, land-use is represented by designating the relative cover of each land-use type in each pixel, e.g. a pixel can contain 30% cultivated land, 40% grassland and 30% forest. In contrary to such large area, area of small spatial extent (< ~ 1x1 km pixel resolution) where land-use data are often based on land-use map or remote sensing images, homogeneous polygons or classified pixels as dominant land-use occupying one unit of analysis (grid cell) are considered. This is the main difference between CLUE and CLUE-s. This last is a special version of the CLUE specifically developed for the spatially explicit simulation of land-use change based on an empirical analysis of location suitability combined with the dynamic simulation of competition and interactions between the spatial and temporal dynamics of land-use systems (Verburg and Veldkamp, 2004). Some properties of the model are highlighted in the following table (**Table 7.1.1**).

Table 7.1.1: Summary of the CLUE model

Source: Extracted and adapted from Agarwal *et al.*, 2002

	Description criterion	**Characteristics**
Overview of the model	Model Type*	Discrete i.e. space represented as cells or blocks, finite state (as an objects in finite number of states or conditions) model
	Components/ Modules (Different modules, that work together)	- Regional biophysical module - Regional land-use objectives module - Local land-use allocation module
	What it explains / Dependent variables	Predicts land-cover in the future
	Other variables (Descriptive of other sets of variables in the model)	*Biophysical drivers* Land suitability for crops Temperature/Precipitation Effects of past land-use (may explain both biophysical degradation and improvement of land, mainly for crops) Impact of pests, weeds, diseases *Human Drivers* Population size and density, Technology level, level of affluence, Political Structures (through command and control, or fiscal mechanisms, Economic conditions, Attitudes and values
	Strengths	Covers a wide range of biophysical and human drivers at differing temporal and spatial scales
	Weaknesses	Limited consideration of institutional and economic variables
Spatial Characteristics	Spatial Complexity	
	Representation*	Yes
	Interaction*	Yes (attributes of one grid unit affect land-use outcomes in another unit)
	Spatial Scale	
	Resolution*	Raster In the generic CLUE model, size determined by extent divided by grid scale neutral matrix of 23 x 23 cells Can be scaled up or down
	Extent*	Multiple extents that correspond to different modules National: Costa Rica, 933 aggregate grid units Regional: 16 to 36 aggregate grids Local: 1 grid unit
Temporal and Human Decision-Making	Temporal Scale	
	Time Step*	One month to update model variables. Changes in land-use types however, are made on decisions for each year
	Duration of Model Run*	Set by user Example scenario is for several decades
	Human Decision Making	
	Complexity	Level: 4** It applies several human drivers
	Domain*	Incorporates collective decision-making levels, from local to national
	Temporal Range*	Considers the temporal range of decision making explicitly, in determining, for example the time period for updating changes in land-use types as well as minimum economic age and rotation length of the 10 different land-use types

* Meanings of words or expressions are given below
Model Type: Technical descriptive term
Representation: Static. Represents data on a map and may portray variation as well

Interaction: Dynamic. Includes effect of variation on processes as well as feedback between neighboring units and location of parcel within the larger scale
Resolution: Raster or vector. The area of the basic unit of analysis. A grid if raster.
Extent: Location and total area covered by model, e.g., grid area x # of grids
Time step: Time period for one iteration of the model. Modules may have different time steps -a function of the particular process
Duration of model run: Time step x number of runs
Domain: Jurisdictional domain
Temporal range: Short-run decision-making period and longer-run decision-making horizon

** Human decision making seen as a probability function depending on socioeconomic and/or biophysical variables beyond population variables with feedback from the environment to the choice function

The following subsection describes more in detail the specific version of CLUE-s. It focuses first on the structure of the model and tackles the process of setting up the model for its application to the Southern Upper Ouémé Catchment.

7.1.3 Structure of CLUE-s Model

In this subsection there is a focus on the general CLUE-s modeling structure and the specifications of the framework computed especially for Benin application case.

As developed by many authors (Verburg and Veldkamp, 2004; Verburg *et al.*, 2002; Soepboer, 2001; Engelsman, 2002; Willemen, 2002; Verburg *et al.*, 1999, and on CLUE Group web site (htpp://www.cluemodel.nl)), the CLUE-s (Conversion of Land Use and its Effects at Small regional extent) consists of two (2) modules: a non-spatial demand module and a spatial explicit allocation module, operating at respectively the regional (here the study area) and pixel level. The following figure (**Figure 7.1.1**) shows the structure of CLUE-s.

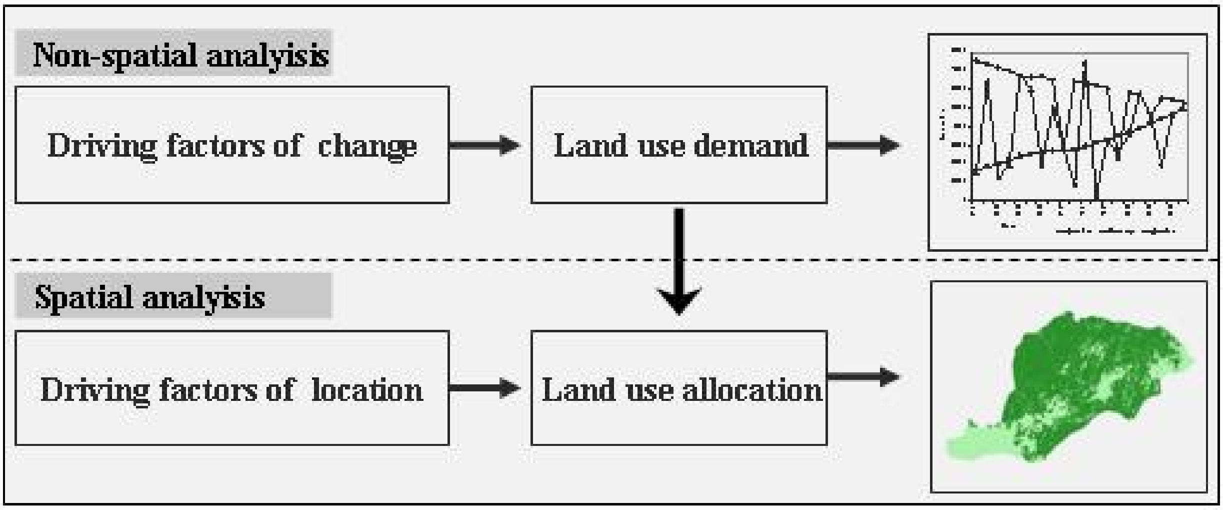

Figure 7.1.1: Overview of the CLUE-s modeling procedure

Source: Adapted from Verburg *et al.* (2002)

The demand module can be constructed based on specific model ranging from simple trend extrapolations (e.g. linear trend) to complex economic models (e.g. models of macro-economic changes). The demand module predicts the changes in demand for the total study area on a yearly basis, in area per land-use type (Soepboer, 2001). The spatial explicit allocation module translates the changes in demand by allocating changes in land-use pattern. For every year in the specified time frame, this module creates a land-use prediction map taking into account the required decisions rules and the results of statistical analysis of selected driving factors.

For matching the size of the model to the new application i.e. the very local study on village scale located in the Upper Oueme Catchment, a specific CLUE-s version had been configured. The main parameters that make this version different from the standard CLUE-s concern the size of the study area through the number of rows by number of columns of the input grids (with a cell size of 32m). In the former Clues2.2® the maximum extent is 800 rows by 800 columns of input grids (i.e. a maximum easting of 800 times and a maximum northing of 800 times the cell size) in the full version. The recent version of Clues2.4® (2005) specifies for the new application a size of 1122 rows by 2068 columns in grids in the main parameters.

7.1.4 Setting up the CLUE-s Model

The CLUE-s consists of two main parts: the non-spatial demand analysis and the spatial analysis. For both parts, the main information necessary to run the CLUE-s model is figured out. The following flowchart gives an overview of the detailed model description (**Figure 7.1.2**)

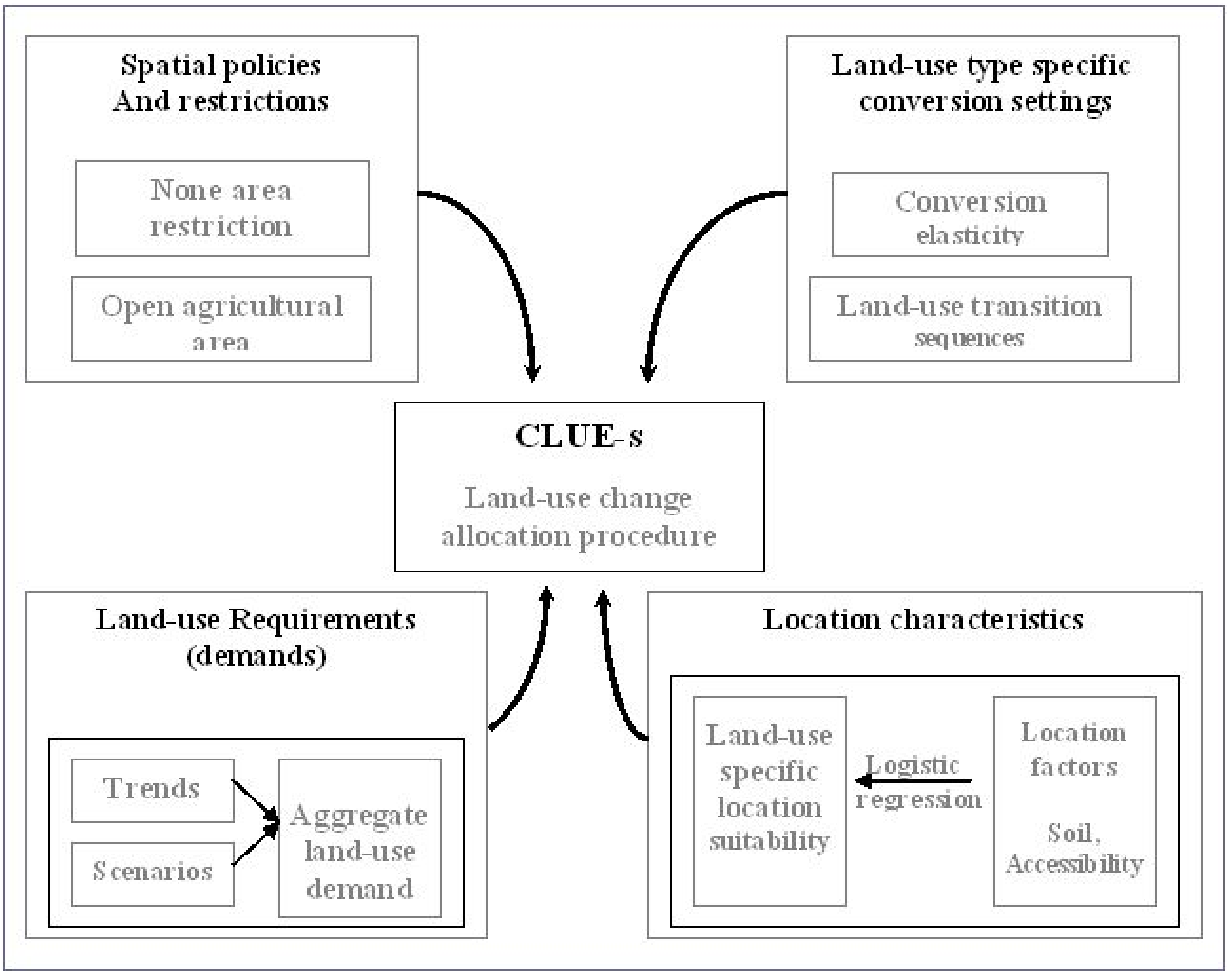

Figure 7.1.2: Overview of the information flow in the CLUE-s model
Source: Adapted from Verburg and Veldkamp (2004)

7.1.4.1 Non-spatial demand analysis

The non-spatial demand module is separated from the model framework. It defines for each land-use type the area needed for each year at the regional (aggregate) level, i.e. the southern part of Ouémé Catchment, without paying attention to the spatial configuration within the study area (Willemen, 2002). The results of demand (land-use requirements) are used as input in CLUE-s. The way to derive these results can be chosen in regard to the nature of the major conversions that are taking place and the aim of the study. Therefore, all kinds of economic methods can be used to derive the demand results.

In this study the demand in area is computed based on exponential trend scenario, between 1991 and 2000 and extrapolated to the year 2025.

Multiple images analysis could provide more data for the growth rate determination if there were some available. In the study area, most of the existed images are cloudy or covered by burned areas. Therefore, to avoid these types of images, only those from 13.12.1991 and 26.10.2000 free of cloud and burned area or less burned areas were the main used remote sensed data (Subsection 4.1.1) to derive this growth rate. Thus prior to the demand calculations, the growth rate of each aggregated land-cover unit was determined for the period 1991 to 2000 using the equation:

$$r_u = \left[\left(\frac{A_1}{A_o} \right)^{1/t} - 1 \right] \times 100$$

Where

r is the growth rate for land unit u;

A_1 is area of land-cover unit u in 2000;

A_0 the area of land-cover unit u in 1991;

t is the time period between 1991 and 2000

This equation was used based on observed population growth that increases exponentially in the study area during the last decade. Thus, the growth rate for each land-cover unit was estimated for the period 1992-1999. The results are: Forest: -1.814%; Agricultural area: 6.086% and Others: 2.40%.

Consequently, it is assumed that this increase induced in turn an exponential land-use development during the decade 1991-2000, especially after 1997 where the main road has been built. Therefore the growth rate was applied to compute demand in areas by using the following equation:

$$A_n = A_0 (1 + r)^t$$

Where

A_n is the area estimate for year n;

A_0 is the area of reference for year $_0$ i.e. 1991

r is the growth rate (%) during the time-period 1991-2000; and

t is the time-period which is the difference between year n and year $_0$.

These results a priori suggest that the study area is facing dramatic changes that could affect the environment in the future very rapidly. Regarding this aspect, additional assumptions were made:

(1) the “Others” class unit stays unchanged i.e. being constant over time-period because the components of this unit are constituted essentially of physical resources (water, inselbergs) which generally stay stable over the time (see subsection 4.3.1 for Land-use reclassification);

(2) it is expected that the exponential development of land-use already started just before 2000 will occur until 2025.

Based on all the previous assumptions, two main scenarios can be derived by using only one rate at time. In the first scenario, the forest rate (-1.814% per year) is applied to extrapolate the “Forest” area for the whole time-period. Then the “Agricultural” area is estimated as well for the whole time-period (i.e. 1992 to 2025) using the following equation:

$$Agric. = A - (For + Oth)$$

Where

$Agric.$ is “Agricultural” unit area;

A: the total land-cover area of the study area;

For : “Forest” unit area, and

Oth: “Others” unit (Constant)

The same procedure is used in the second scenario to estimate the “Forest” areas while the agricultural rate (6.086%) is applied to extrapolate the “Agricultural” areas.

7.1.4.2 Spatial analysis

The spatially explicit allocation analysis section focuses on the role of statistical analysis of probability maps calculation, the decision rules involved in land-use stability or conversion and finally the procedure allocations of change.

Statistical analysis

The statistical techniques are used by empirical models to derive the mathematical relationships between dependent variables and sets of independents (Soepboer, 2001). As stated in the previous section, CLUE is an advanced statistical land-use change model that uses such empirically quantified relations between biophysical and its driving factors (Lambin, 2004).

The statistical analysis with CLUE-s is carried out on the actual land-use and based on logistic regression analyses. These analyses provide the model with regression coefficients for each land-use type. In these functions of the model, drivers have also been given certain weight coefficients which are assumed to be constant. In this study, the drivers are time-dependent namely population density and distance to settlements (see 4.3.3 for more details). The regression coefficients are subsequently used to calculate the probability of a certain grid cell to be devoted to a certain land-use type given the value of driving factors in the year of the analysis. The response of these regression functions can then be visualized into raster probability maps of the study area, based on the location suitability (raster maps of driving factors), given the probability of the occurrence of a certain land-use type per cell. For every year of the simulation a new probability map is calculated with updated values of the driving factors that change in time (e.g. population density and distance to settlements). The relation between land-use and its driving factors are evaluated throughout stepwise logistic regression which is explained in more detail later in the next section of statistical analysis.

Decision rules

The decision rules in CLUE-s result in two main types: Spatial policies and restrictions, and conversion elasticities and land-use transition sequences. For each land-use type decision rules determine the conditions under which the land-use type is allowed to change in the next time step.

The first “spatial policies and restrictions” indicates the protected area, in which no changes are allowed. Areas in which land-use changes are restricted through policies or tenure status (Verburg and Veldkamp, 2004) are included in the list group as well. Conversions of land-use that are restricted by a spatial policy can be indicated in a land-use conversion matrix.

In this study no area is restricted. The research area is closed to two protected forests “*Forêt classée de Wari-Maro”* and *“Forêt classée de l’Ouémé Supérieur*” and no spatial policy is already set up in the study area by the local government.

The second decision rule type is constituted of two set of parameters that are conversion elasticities and land-use transition sequences which can characterize the individual land-use types.

The conversion elasticities are used to indicate the reversibility of land-use change and provide relative elasticities to change ranging from 0 (easy conversion) to 1 (irreversible change). The close the values are to 0 the more dynamic is the land-use conversion. Three cases of conversion situation can be specified:

- The value of 1 is given to stable land-use such as land-use with high capital investment (residential locations, fruit plantations, etc.) (Verburg *et al.*, 2002). After their first conversion, these types of land-use are not expected to be converted into other land-use types.

- Land-use types with opposite characteristics i.e. very dynamic, are given the value 0. A typical example of this situation is the shifting cultivation which can be converted easily to another land-use type after its initial conversion.

- There are a couple of land-use conversions that operate in between these two extreme situations. For this case, the stability settings are based on expert knowledge or observed behaviours in the recent past in the study are; the relative elasticity should therefore vary between 0 and 1.

The following table (**Table 7.1.2**) indicates the stability settings for the case study in the Ouémé Catchment based on expert knowledge and set during the calibration of the model.

Table 7.1.2: Different stability settings for the southern Upper Ouémé Catchment which have been calculated with CLUE-s

Land-cover type	**Elasticity**				
	Default	Unstable	Stable	Forest unstable	Agriculture Unstable
Forest	1	0	1	0	1
Agricultural area	0.8	0	1	0.8	0
Others	1	1	1	1	1

Due to increase in cropland each year, subsequent to population growth, especially migrant farmers, it is assumed that the demands in agricultural area will likely increase and forest area may decrease year by year. In addition to the default setting, elasticity is set to very dynamic (value 0) respectively for forest and agriculture in forest unstable and agriculture unstable settings. For the case of forest unstable, both forest and agriculture are set to dynamic since it is assumed that savanna dynamic could influence forest too because activities could be extended to forest cover type. On the other hand, forest is set to 1 for agriculture unstable when forest is supposed to be protected against logging. The stable and unstable cases are supposed to be facing different situations in land-use change.

The second set of parameters which must be specified is the allowed land-use transition sequences. Not all land-use changes are often possible and many land-use conversions follow a certain sequence. As examples for the first case, it is unlikely that residential areas can be converted to forest. Example of transition sequence includes fallow land and forest regrowth following shifting cultivation (Verburg and Veldkamp, 2004). These sequences can be specified in a land-use conversion matrix in which it is indicated in what other land-use types each land-use type can change during the next time step. In the present study, it is assumed that all conversions are allowed in the land-use conversion matrix.

Once established, the conversion elasticities and land-use transition sequences are taken into account in the allocation of change calculation procedure.

Allocation of change procedure

Once all input (regression results, decision rules in combination with actual land-use map, and the demand) are provided the CLUE-s model calculates the most likely changes in land-use through the allocation procedure summarized in **Figure 7.1.3**.

This allocation procedure follows five (5) steps as described by many authors (Verburg and Veldkamp, 2004; Verburg *et al.*, 2002, Verburg *et al.*, 2001)

1) In the first step, all grid cells that are allowed to change are determined. In addition, grid cells that are either part of a protected area or not allowed to change are excluded from further calculation. Also some restricted locations indicated by the conversion matrix are identified.

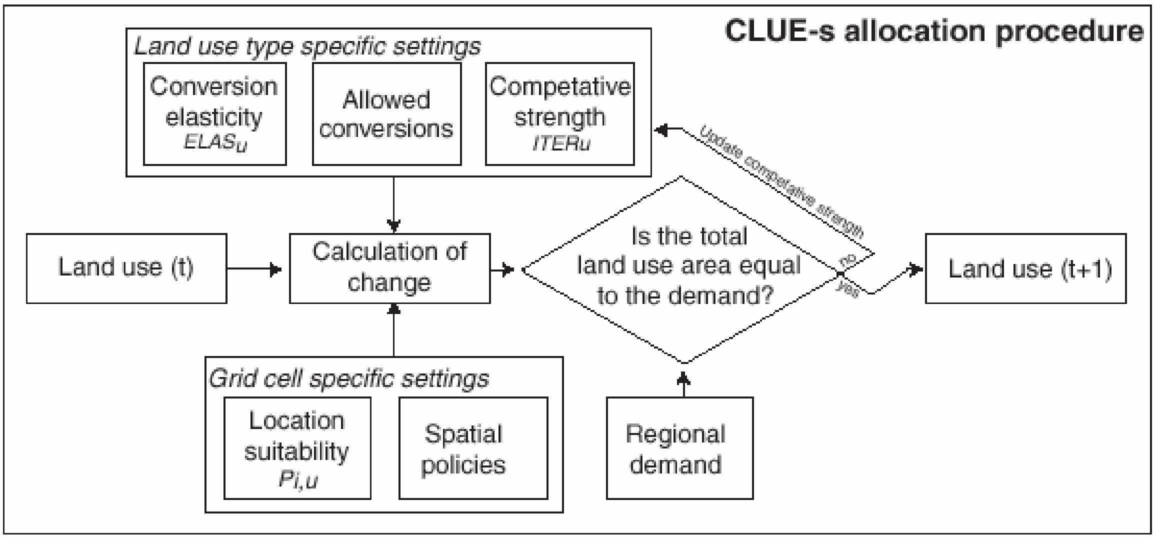

Figure 7.1.3: Flow chart of the allocation module of the CLUE-s model

Source: Verburg and Veldkamp, 2004

2) For each grid cell i the total probability ($TPROP_{i,u}$) is calculated for each of the land-use types u according to equation:

$$TPROP_{i,u} = P_{i,u} + ELAS_u + ITER_u,$$

Where

$P_{i,u}$ is the suitability of location i for land-use type u (based on the logit model),

$ELAS_u$ is the conversion elasticity for land-use u and,

$ITER_u$ is an iteration variable that is specific to the land-use type. $ELAS_u$ is the relative elasticity for change specified in the decision rules and is only given a value if a grid cell i is already under land-use type u in the year considered.

3) A preliminary allocation is made with an equal value of the iteration variable ($ITER_u$ for each land-use type. The land-use type with the highest total probability is allocated in the considered grid cell without the conversions that are not allowed according to the conversion matrix.

4) The total allocated area of each land-use is now compared to the land requirements (demand). If the allocated area is smaller than the demanded area the value of the iteration variable is increased. For land-use types for which too much area is

allocated the value is decreased

5) Steps 2 to 4 are repeated as long as the demands are not correctly allocated. When allocation equals the demand the final map is saved and the calculations can continue for the next yearly time step.

The following flow chart (**Figure 7.1.4**) displays the development of the iteration parameter for different land-use types during a simulation.

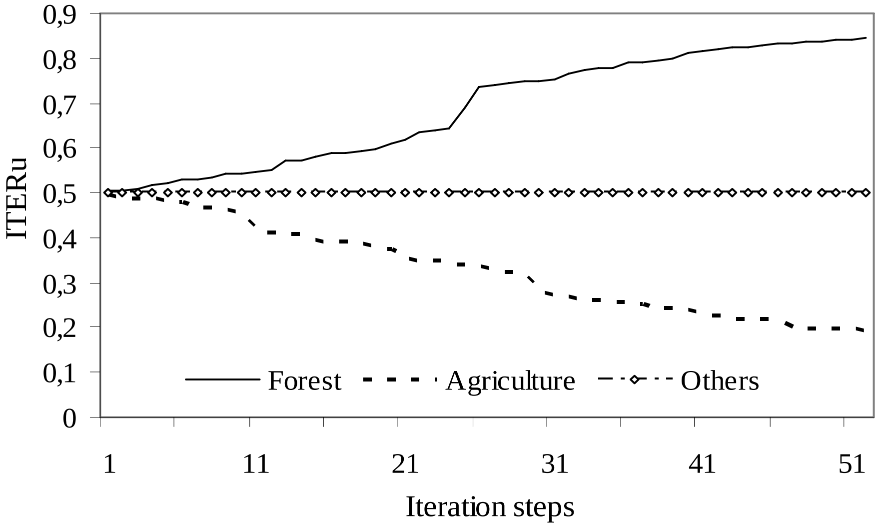

Figure 7.1.4: Change in the iteration parameter (ITERu) for different land-use types during the simulation within one time-step

7.1.4.3 Statistical analysis

As stated before, the CLUE-s model uses binomial logistics regression to define the relationships between the land-use types and its driving factors. The present section describes in detail the logistic regression method used in determining the regression coefficients as input for the model.

CLUE-s is based on homogeneous cells. The grid size is supposed to be so small that the land-use in a grid cell is represented by one (1) dominant land-use type. The statistical method for deriving the relation between driving factors and land-use will therefore base on binomial logistic regression. Binomial Logistic Regression (BLR) is a form of regression that is used when the dependent variable is dichotomous (0 or 1) and the independent variables are continuous or categorical. The land-cover types in the actual land-use map of the

CLUE-s model, i.e. the dependent variables, have a value of 0 or 1 to indicate the absence or presence of a land-cover type in each grid cell. The BLR applies a maximum likelihood estimation to maximize the odds before transforming the dependent variable into a logit variable. A logit variable is the natural log of the odds that the dependent occurs or not. The "odds" of an event is defined as the probability of the event occurring divided by the probability of the event not occurring (Garson, 2005). As such, a logistic regression gives the probability of the occurrence of certain land-use using the independent variables (also called the driving factors of land-use) as predictor values (Garson, 2005). The probability is a function of the logit coefficients which are also called Maximum Likelihood Estimates (MLE), belong to the independent variables. These logit coefficients can only be estimated by an iterative process of estimation, which is provided by statistical software packages (Soepboer, 2001). The SPSS package is used for this purpose.

Logistic regression equation with several independent variables could be represented in this form:

$$Log\left(\frac{P_i}{1-P_i}\right)=\beta_0+\beta_1 X_{1,i}+\beta_2 X_{2,i}\ldots+\beta_n X_{n,i}$$

where P_i is the probability of a grid cell for the occurrence of the considered land-use type and the X's are the driving factors. The coefficients (ß) are estimated through logistic regression using the actual land-use pattern as dependent variable.

In this study (as often used in land-use change research methodology (Overmars and Verburg, 2005; Geoghegan *et al.*, 2001; Serneels and Lambin, 2001)) the stepwise procedure of logistic regression is used (forward stepwise regression with probability levels of 0.01 for entry in the model and 0.02 for removal from the model) to select the relevant driving factors from a larger set of factors that are assumed to influence or explaining the land-use pattern. Variables that have no significant contribution to the explanation of the land-use pattern are excluded from the final regression equation (Verburg *et al.*, 1999). Calculations are made based on sample of five percent (5%) drawn from the total cells dataset available in the grid (n = 898644). This approximates that every category occurs only once in the dataset and can help to reduce spatial autocorrelation[1].

In addition to the selection of relevant factors, the regression model fit i.e. its performance needs to be evaluated. The 'Relative Operating Characteristics' (ROC)-method

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[1] In a unit of observation each category can be represented in the spatial data as several grid cells; therefore this can cause spatial autocorrelation because cells from the same category, which are neighboring cells have the same properties.

is therefore used for this purpose (Pontius and Schneider, 2001).

A more detail on this method and its utility in this study is given in validation approach section.

7.1.4.4 Sensitivity analysis

The sensitivity analysis refers to parameters variation across model runs and resultant changes in the model performance (Klepper, 1997 quoted by Manson, 2001). The sensitivity analysis in this study is focused essentially on variation of decision-rules and stability settings, conversion matrix, demand and neighborhood setting. Changes in the decision-rules and stability settings are based on conversion elasticities while demands are concerned by variation in land-use type rate application in calculation. Finally, the knowledge of the study area is used to set the neighborhood and the conversions matrix. The resultant simulations show how sensitive the CLUE-s modeling framework is to input parameters variation. The retained most relevant parameters according to the best simulation results are used in the final model simulation for validation.

7.1.5 Model validation

Model validation requires use of multiple, complementary methods to identify shortfalls in data, theory and methodology (Manson, 2001). This triangulation method which is the mainstay of quantitative research is applied in this study. For this purpose, the following methods are considered to validate the simulation of LUCC with CLUE-s model:

1) Regression models goodness-of-fit based on ROC for selecting relevant LUCC drivers

2) Indicators of Goodness-of-Fit based on recent validation method (Pontius *et al.*, 2004)

3) Multiple Resolution Procedure of Goodness-of-Fit

7.1.5.1 Relative Operating Characteristic (ROC)

The ROC technique is a method of validation that uses a quantitative measurement which applies to any model that predicts a homogenous category in each grid cell (Pontius and Schneider, 2001). This method is based on the ‘true-positive’ and the ‘false-positive’ proportions (**Table 7.1.3**). By overlaying the simulation map on the map of reality of a landscape, a contingency table can summarize the results. In this table, the rows show categories of the map of the model's output and the columns show the categories of the map of reality. The entries are the number (or proportion) of cells that fall into each category combination. The occurrence or non-occurrence (event) of a certain land-use type is respectively considered positive or negative.

Table 7.1.3: Two-by-two contingency table showing the proportion (or number) of grid cell in a map of reality versus a map of simulation
Source: Engelsman, 2002; Schneider & Pontius, 2001)

Model	Reality		
	Positive	Negative	Total
Positive	True-positive$^{\mathbf{A}}$	False-positive$^{\mathbf{B}}$	A+B
Negative	False-negative$^{\mathbf{C}}$	True-negative$^{\mathbf{D}}$	C+D
Total	A+C	B+D	A+B+C+D

The true-positive (A) and the true-negative (D) are two ways that an event can agree with the prediction while the false-positive (B) and the false-negative (C) are the ways an event can disagree. To plot the ROC-curve the true-positive rate (A/A+C) and the false-positive rate (B/B+D) are used respectively on the vertical and the horizontal axis. It is recourse in the following equation to an integral calculus’ trapezoidal rule to calculate the area under the curve that connects the plotted points.

$$\mathit{Area\ under\ curve} = \sum_{i=1}^{n} \left[x_{i+1} - x_i\right]\left[y_i + y_{i+1} - y_i / 2\right]$$

where x_i and y_i represent respectively the rate of false-positives and true-positives for scenario i, and n the number of suitability groups. The accuracy of the model is measured in surface beneath the ROC-curve. The values differ from 0.5 to 1, with 0.5 (true-and false positive proportions are equal) if the model does not predict the changes any better than a random approach i.e. a completely random model. If the value is 1 (the true-positive rate is 1, false-positive rate is 0) the discrimination is perfect i.e. a perfect fit.

The resulting ROC-value helps to evaluate the logistic regression and thus the predicted probabilities by comparing them with the observed values over the whole domain of predicted probabilities. This method is appropriate for the CLUE-s model, because a wide range of probabilities is used within the model calculations.

In this study, a logistic regression is run and a ROC-value is calculated for each of the three land-use types. The spatial distribution of the land-use types within the study area can be explained by the selected driving factors in the regression model as indicated by the high ROC-value: the closer is the ROC value to 1, the better is the fit of the logistic regression model. In addition Exp(Betta)[2] is calculated to evaluate the change in odds upon one unit change in the independent variable.

7.1.5.2 Visual examination and indicators of agreement

After run the model, it is important to analyze the model performance. To achieve this objective, a visual examination (Visser, 2004) between the output map that the model produced (simulation map) and a reference map that is reserved for validation (reality map) is the first approach used. The visual examination is based on images from 1991 and 2000.

In addition to the visual examination, which shows similarities between images but not very helpful for precision in prediction of correct changes location (Pontius *et al.*, 2004), a statistical comparison is necessary. Completion of this validation technique is achieved with an application of three maps that are: Reference maps from 2000 and 2003, and the simulated map of 2003. This is based on the three-villages-image subset mentioned above (see **4..1** for more details). Therefore indicators of agreement between images that budget the sources of agreement and disagreement are computed (Pontius *et al.*, 2004). Processing was made with the help of Erdas Imagine®, ArcView® 3.3 and ArcGIS® 9 packages. Agreement statistics were produced specifically with Idrisi Andes 15.0.

The mathematical expressions used to budget these indicators i.e. components of agreement and disagreement during two maps (reference and simulated) comparison are given in the following figure (**Figure 7.1.5**).

In this figure the notation means: j—index for categories, j—number of categories, n—index for pixels, Ng—number of pixels in the map at resolution g, g—resolution as a multiple of the length of the side of a pixel of the raw data, Wgn—weight of pixel n at resolution g, Rgnj—proportion of category j in pixel n at resolution g of the reference map, Sgnj—proportion of category j in pixel n at resolution g of the simulation map.

The logic that underlies this approach is developed by Pontius *et al.* (2004) and is

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[2] When Exponential Beta, Exp (B)>1 the probability increases upon an increase in the value of the independent variable and when Exp (B)<1 the probability decreases (Verburg *et al.*, 2002).

briefly explained in the following lines. More details can be found in the aforementioned literature and others (Pontius, 2000; 2002; Pontius and Suedmeyer, 2004, IDRISI 15.00, the Andes Edition). Expressions are categorized in two classes: Information of quantity and Information of Location represented respectively on row and column. Each expression is in a particular column according to its level of information of quantity or location.

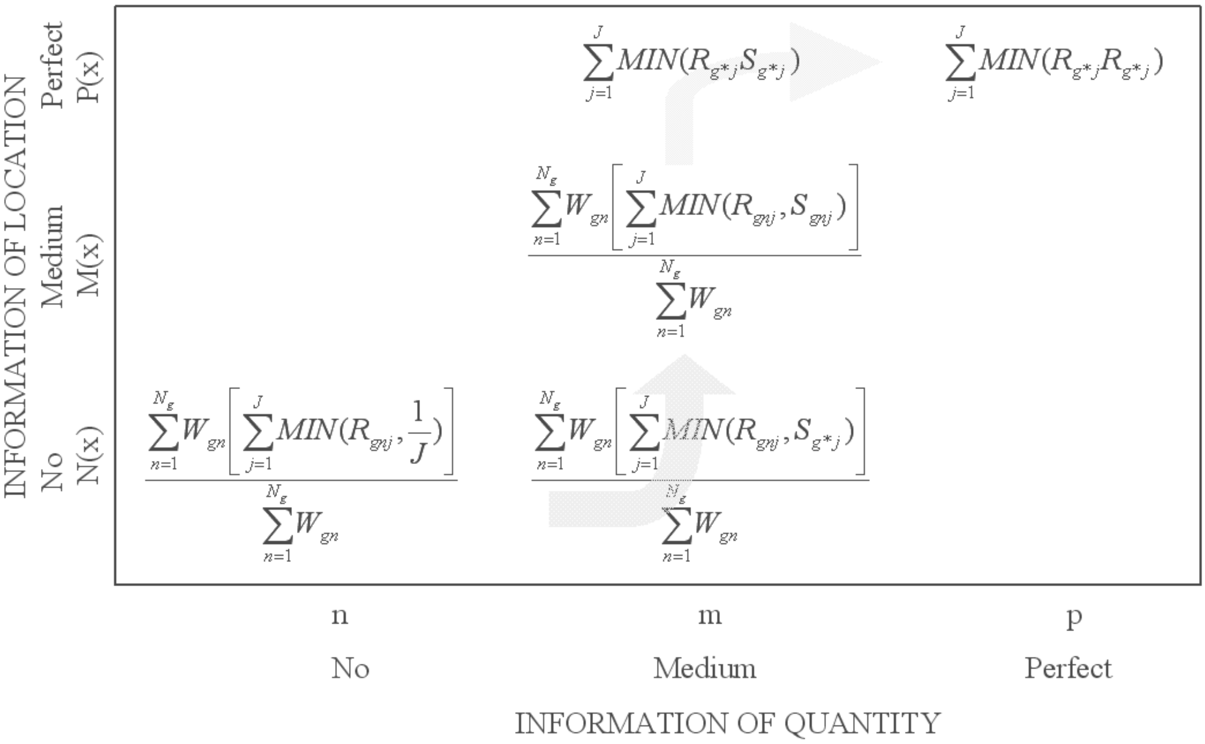

Figure 7.1.5: Mathematical expressions for five measurements defined by a combination of information of quantity and location (Pontius *et al.*, 2004)

Letters on row represent information of quantity where: **n** means no information, **m**, medium information, and **p**, perfect information. In the same way, the capital letters represent information of location: N(x) means no information, M(x), medium information, and P(x), perfect information. As shown on the figure, the series of expressions start in the lower left corner, climbing up the central column, and end in the upper right corner. N(**n**) is the agreement between the reference map and a map in which every pixel is identical and has partial membership of 1/J for each of the J categories. N(**m**) is the agreement between the reference map and a map where every pixel is identical and has membership equal to the predicted proportion for each of the J categories. M(**m**) is the agreement between the reference map and the unadjusted predicted map. P(**m**) is the agreement between the reference map and an adjusted map in which the location of pixels of the predicted map are rearranged in space to match as closely as possible the pixels in the reference map. P(**p**) is the agreement between the reference map and a map that has been adjusted perfectly in terms of both location and quantity of pixels, therefore P(**p**) always equals 1. Each subsequent expression in the sequence shows the agreement between the reference map and an adjusted map that usually has increasingly accurate information, therefore usually $0 < N(\mathbf{n}) < N(\mathbf{m}) < M(\mathbf{m}) < P(\mathbf{m}) < P(\mathbf{p}) = 1$. The difference between each subsequent expression in the sequence is a component of agreement or disagreement. N(**n**) is the agreement due to chance. N(**m**) - N(**n**) is the agreement due to the predicted quantity. M(**m**) - N(**m**) is the agreement due to the predicted location. P(**m**) - M(**m**) is the disagreement due to the predicted location, which derives from error in a suitability map. P(**p**) - P(**m**) is the disagreement due to the predicted quantity, which derives from error in extrapolation. These components form a budget of sources of agreement and disagreement.

The disagreement due to location and disagreement due to quantity are the two most important components dedicated to scientists who are interested in improving the model. This is the usefulness of this approach in this study in the case of CLUE-s model.

7.1.5.3 Multiple Resolution Procedure

By contrast to pixel-by-pixel comparison at a single resolution, the Multiple Resolution Procedure (MRP) of goodness-of-fit (Costanza, 1989, Pontius *et al.*, 2004, Visser, 2004) aims to evaluate a model performance over a range of resolutions. It consists of a pixel aggregation procedure whereby a number of neighbouring pixels are averaged at each coarser resolution. For instance, for resolution 2, four neighbouring grid-cells become a single coarse cell. Therefore a 12 x 12 map of original cells yields a 6 x 6 map. At a resolution 3, it is obtained a 4 x 4 map of coarse cells in which the length of the side of each coarse cell is three times length of the side of each original fine-resolution cell (Pontius and Suedmeyer, 2004). This technique quantifies the degree of matching or similarity between complex spatial patterns. For this purpose, an expanding "window" is used to gradually degrade the resolution of the comparison (Verburg *et al.*, 2002). At each step of degradation <the correspondence between the simulated and observed land-use pattern is calculated>.

Following this process, the components of agreement and disagreement of quantity and location of the categories at various resolutions are assessed.

7.1.6 Scenarios settings and development

This section focuses on scenarios settings for simulating land-use change with CLUE-s modelling framework. In combination to the integrated scenarios relative to some CLUE-s parameters (decision-rules and stability), two types of scenarios were used in this study. More information about development of the integrated parameters of the CLUE-s framework can be found in the model description and its application to this specific study area. The following subsection focuses on the two additional scenarios that are supplied for the model running.

7.1.6.1 "Business as usual" scenario

In the frame of IMPETUS project, three scenarios were developed based on problem clusters that occurred in the Ouémé Catchment which follow different storylines (Speth *et al.*, 2005; Speth *et al.*, 2004). The scenario B3 "Business as usual" extrapolates the recent trends. It is characterized by a local political stability and low rate of innovations that induces strong informal and weak integration and low competitiveness on the world markets. This scenario assumes a general continued decline in population growth but still remains high in local level as it is the case in this study area (population growth rates range from 4 to 13% in the different villages of the two Districts studied: see section 3.3 in Chapter 3). This leads to an expansion of agricultural area and livestock farming.

As described earlier, this scenario is a so-called baseline scenario where the land-use requirements follow a linear extension of the recent developments between 1991 and 2000. In this period, there was a lot of development in southern part of the Upper Ouémé Catchment especially concerning the increase in croplands and settlements. This leads to a high rate of change in land-use and land-cover. For this baseline scenario, it is assumed in the next 10 to 20 years developments are expected to occur at the same speed as they were observed between 1991 and 2000. This expectation is based on our own population projection[3] and that produced within IMPETUS-project (Bollig *et al.*, 2004), all referring to official census data from 1992 and 2002. As at the time of this research, there is no available statistics for the very local settlements under the villages and no projection data for the villages, our projection approach took into account the population statistic from the household interviews conducted in 2003. Therefore this population scenario expects

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[3] No change at the parameters, the population projection was calculated based on intercensal population growth rate of the period 1991 to 2002 and extrapolated to the year 2025.

an annual population growth that ranges from 4% to 13% (the villages Wari-Maro, Dogue, Igbomakro, and Kikele record respectively 13.08%, 5.93%, 4.31%, and 7.66%) in the next 20 years (2025). That is the same rate as in the period between 1991 and 2000. The same growth of the population makes it likely that the development of new settlements will proceed. The developments in agricultural area are assumed to be the same as in the previous years before the simulation time period (up to 2000) since no concrete spatial policy is known up to now and none is set by local authorities. As a consequence the application of only forest growth rate (-1.814% i.e. an annual decrease rate) to demand projection will result in a forest area decrease and a progressive increase in agricultural area with an extension of savanna cover type. Another assumption sets the area of water, rock and bare lands in “Other” class of Land-use classification remains unchanged over simulated years.

7.1.6.2 “Environmental damage” scenario

The second scenario so-called “environmental damage” assumes to apply the annual growth rate of 6.09% of agricultural area for the demand calculation. Following the same logic as in the first scenario, sole the forest area is estimated (see section 4.4.1 for more methodological approach). In this scenario, all things being equal and the demographic characteristics remain similar like it is with a special mention to migrant settlers; the land-use/land-cover change (demand requirements) will follow the same pattern. Due to lack of quantitative indicators on migration phenomenon in the local area, even in regional case, the demand calculation projection is limited only to agricultural growth rate. Then the cropland will still increase drastically while the forest area will decrease rapidly so that it will remain very few surfaces left to satisfy the demand requirements. Therefore, there is not enough forest area left in 2020 to clear. Increasing of cropland will probably affect the surrounding protected forest since farmers will need more and more available fertile land for cropping.

7.2 Modeling Output

This section assesses the modeling results regarding the main settings as inputs for the model running. It focuses as well on what types of land-use/land-cover changes are taking place and explores the relevant factors that drive land-use changes. Furthermore, two last sub sections focus on CLUE-s model performance and its fitting through several techniques. Investigations of the accuracy of the model output are made as well.

7.2.1 Model Settings

This section focuses on the main settings results that are related to regression models, demand scenarios and decision rules.

7.2.1.1 Regression functions

The following table (**Table 7.2.1**) shows the beta and exponents beta values for the three (3) land-use classes according to the relevant drivers that are used as input for CLUE-s. In the last row, the ROC values for the three land-uses classes (Forest, Agriculture and Others) are shown. All the variables (drivers) that are cited in these models are significant at p<0.001. All the other variables are excluded from the models through the stepwise process of the logistic regression.

Table 7.2.1: Regression models for the different land-use classes

	Forest		Agriculture		Others	
Driver	Beta	Exp(Beta)	Beta	Exp(Beta)	Beta	Exp(Beta)
Constant	1.09699		-1.1262897		-5.0582884	
Distance to road	0.00012	1.00012	-0.00012	0.99988		
Distance to stream	0.00017	1.00017	-0.00016	0.99984	-0.0007259	0.99927
Distance to "*forêts sacrées*"	-0.00012	0.99988	0.00012	1.00012		
Population density (1991 to 2000)	-0.00295	0.99706	0.00292	1.00293		
Distance to settlements (1991 to 2000)	0.00018	1.00018	-0.00018	0.99982	-0.00009	0.99991
ROC Value	0.74804		0.75030		0.62869	

* All variables significant at p<0.001

As explained in the model validation section, Exp(Beta) values indicate the change in odds upon one unit change in the independent variable. When Exp(Beta)>l the probability increases upon an increase in the value of the independent variable while when exp(Beta)<l the probability decreases.

Thus, the table 7.2.1 shows the relative importance of drivers to the land-use in the study area. The regression model for Forest is constituted of five (5) coefficients. It shows that Forest probability is mainly influenced by three of them: distance to road, distance to stream and distance to settlements, since the exponents of these coefficients (Exp(Beta)) are superior to one (1) while distance to “*forêts sacrées*” and Population density are less than one. Therefore the last two variables do not influence forest probability.

The regression model for Agriculture is constituted of five (5) coefficients as well. But the regression model in contrast shows that Agriculture probability is influenced by the two coefficients which are excluded from the Forest regression model i.e. distance to “*forêts sacrées*” and population density.

Finally, only two coefficients constitute the “Others” regression model. But none of them influences the probability.

By comparing all the three regression models, the Agriculture model has the highest accuracy assessment (0.750) quite closer to Forest (0.748).

The result of the regression analysis can also be shown in a probability map of each land-use type (**Figure 7.2.1**)

7.2.1.2 Demand scenarios

In this section, two demand scenarios are compared: the base-line scenario so-called “business as usual” and “environmental damage” scenario based on fast agricultural growth rate.

Demand for scenario 1

The first is the reference to which all simulations are compared to. In this case, demands are calculated based on linear extensions of the development between 1991 and 2000. And the assumption is that due to low population increase in this period, a linear development has occurred until 1997, year from which more migrant settlers were recorded continuously until 2000. This record leads to an extension of this demographic phenomenon to the whole period 1991-2000. The thus found development can be observed with limited images like the one from LANDSAT ETM satellite 2000 image from which statistics were derived and compared to 1991 satellite image’s statistics. This development is shown in **Figure 7.2.2**. With the assumption that the “Others” land-use class won't expand its area anymore, a scenario is made for the 25-year period of 2000 to 2025. Increase in demands is made based on forest change rate from 1991 to 2000 (**Table 7.2.2)**.

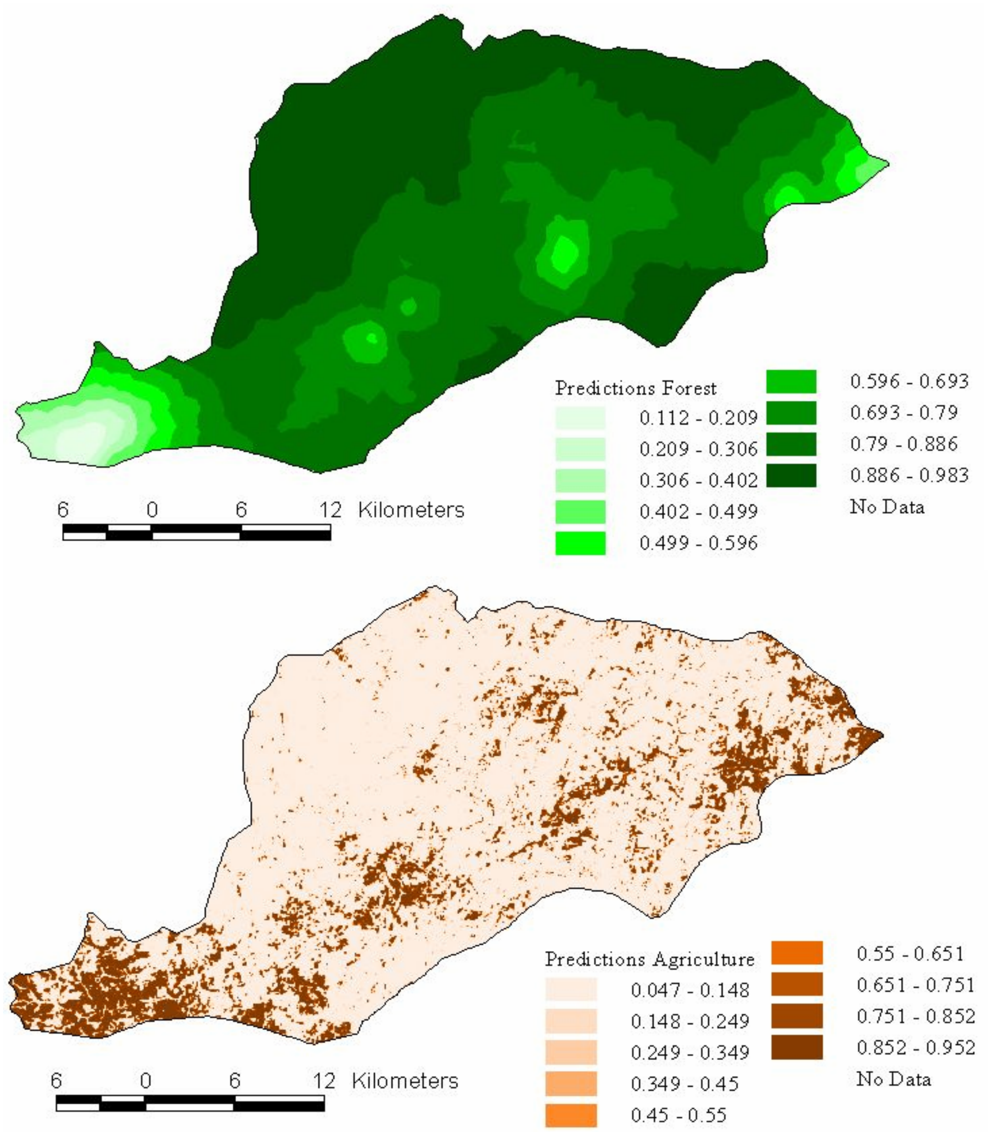

Figure 7.2.1: Prediction maps of the Forest (on top) and Agriculture (bottom) land-use classes in the study area

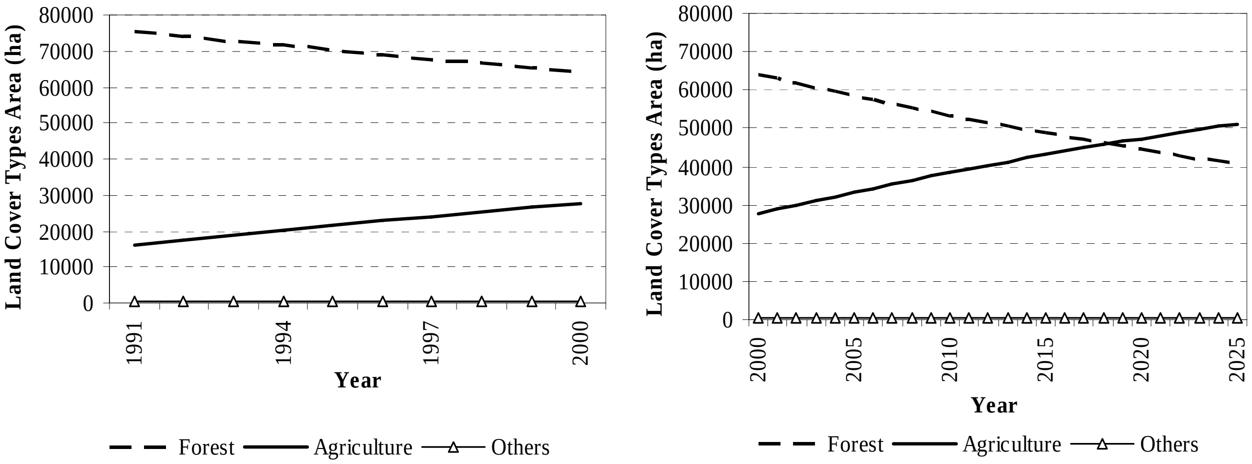

Figure 7.2.2: Development of different land-cover types from 1991 to 2000 (left) and demands for the base-line scenario from 2000 to 2025 (right)

Table 7.2.2: Development of areas and changes rate for land-use types in the study area from 1991 to 2000

Land-use type	Area (ha) in 1991	Area (ha) in 2000	Total change area (ha)	Increase per year (ha)	Change rate 1991-2000 (%)
Forest	75577.24	64099.74	-11478	-1275	-1.81
Agriculture	16197.84	27566.9	11369	1263	6.09
Others	304.13	376.63	72	8	2.40

Demand for scenario 2

In the second scenario, assumption is made that an exponential increase in agricultural area followed the population growth rate that occurred; that is seen concrete through the application of its growth rate (6.09%). The remaining forest area is determined afterwards. The developments that occur in this case show a fast decline in forest due to rapid increase of agricultural are. This is a consequence of high population growth rate. Finally, the scenario stops in 2020 because of complete extinction of forest cover (**Figure 7.2.3**).

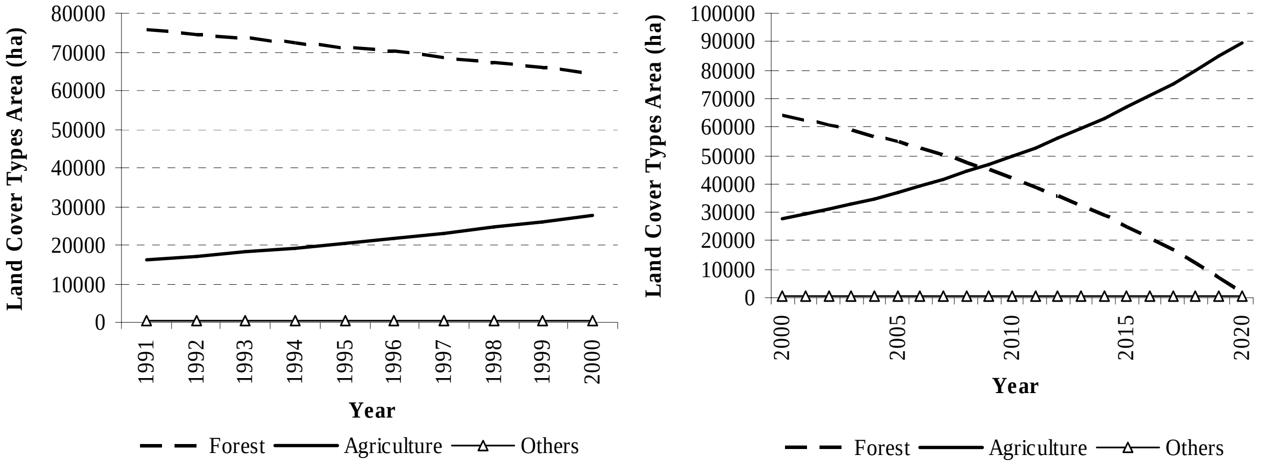

Figure 7.2.3: Development of different land-covert types from 1991 to 2000. Right: Demands for the environmental damage scenario from 2000 to 2025

In the case all activities related to land-use changes will continue likely, no better situation of land-use and land-cover can not be expected for the future. Consequently, a damaged environment will occur. Therefore, this scenario was excluded from the input parameters for land-use change simulations.

7.2.1.3 Decision rules

Stability settings

In addition to the default elasticities, four situations of the land-cover type elasticities have been distinguished (see **Table 4.4.1** in chapter on Data and Methods for more information): unstable, stable, forest unstable and agriculture unstable. Agriculture land-use type which is a mixture of fields and savanna classes is experiencing a very high development, especially conversion of savanna area to fields and later in urban area at some spots. As a consequence, agriculture is designed to being more unstable (0) in most situations (four out of five) than forest which is less unstable (two out of five cases). The land-use type forest appears to be relatively stable (1). As an explanation to this, agricultural areas are often derived from savanna land-use type after the trees (notably tree savanna, savanna woodland and woodland) are cleared for the need of shifting cultivation, the use of timber or to create an area for future settlement development. Therefore, the dense forests covers remain stable (compared to agriculture).

In addition to elasticity settings, the dynamic of land-use changes shows different sequences that can be specified in a land-use conversion matrix which indicates how the conversion of one land-use type to another during the next time step can take part. It is assumed in this study that all land-use conversions are allowed in the land-use conversion matrix. This is done because conversions are possible between the two main land-use types (forest and agriculture). For additional land-use types, and sound land-use history, it is possible to indicate special areas for conversion. This can be done by specifying a number and a map that indicates where the changes are allowed (Verburg *et al.*, 2002).

Convergence criterion

In the allocation procedure of CLUE-s modeling approach, iteration variables are necessary to produce probability maps. Among the three numbers that should be specified for the iteration variables[1], two convergence criteria and an iteration mode are expressed. In this study, the first convergence criterion indicates the maximum allowed deviation between demand changes and actually allocated changes as a percentage of demand. The calibration process of the model helped to set this value to 0.33 %.

Area restriction

Apart from very few local patches of forest so-called “*forêts sacrées*”, not much dense forests are found in the study area. However, some protected forests surround the southern part of the Ouémé Catchment. These are *Forêt de l’Ouémé Supérieur*, *Forêt de Wari-Maro* and *Forêt des Monts Kouffé*. Due to increase in population in agglomerated villages and therefore an increase in demand for food (which require more cropland), it seems too restrictive to reduce the available agricultural cropland for park purpose in the remaining area of this southern part of the catchment. At present, this reason can be emphasized by a lack of policy from the local government and decision makers. Consequently, none area restriction was proposed.

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[1] Three iteration variables are defined as follow: 1: iteration mode 0 means that convergence criteria are expressed as a percentage of the demand; 2: first convergence criterium i.e. average deviation between demanded changes and actually allocated changes (defined here by minimal value of 0.33: 1 grid cell divided by the number of land-use types (3)); and 3: second convergence criterium i.e. the maximum deviation between demanded changes and actually allocated changes (minimum value set to the percentage of one cell change of the land-use type with the smallest demand, e.g. for the smallest land-use type with a demand of 304 ha and a cell area of 0.1024 ha, the value is 0.1024/(304/100) = 0.336). A value of 1 situated between the default value of 3 and the minimum of 0.336 was chosen. Finally the three values are: 0, 0.33, and 1.

Above all, from the previous settings, the following synthesis can be made with regards to:

1) Regression functions

There is a high probability that Forest land-use type is mostly influenced by distances variables (distance to road, distance to stream and distance to settlements) while agriculture land-use type is supposed to be influenced by distance to "*forêts sacrées*" and Population density. Both land-use types have very high accuracy assessment through their ROC value.

2) Demands scenarios

Demands in land-cover referred to two scenarios: the base-line scenario so-called "business as usual" and "environmental damage" scenario. The first demand scenario for prediction took into account forest change rate in the study area during the observation years. By contrast, the second was based on fast agricultural growth rate which shows a fast decline in forest due to rapid increase of agricultural area. As a consequence the model can only run the scenario to 2020 because of complete extinction of forest cover.

3) Decision rules

To allow the model running, three decision rules were set up: elasticity, convergence criteria and area restriction. The proposed elasticities repose mainly on land-use changes dynamic with regards to stability and instability. The convergence criteria and the iteration mode were set to defined values (0, 0.33, 1). The land-use conversion matrix allowed all conversions in an area where no restriction is made.

In combination with other variables, all the parameters were input for the model running. The outputs of the simulations are indicated below.

7.2.2 Simulation Output

This section focuses on simulations results according to different above settings, their comparison, and a final discussion on these results.

7.2.2.1 Default result

The simulations of land-use and land-cover changes in the study area have been achieved for a timeframe of 25 years, from 2000 to 2025. The output of the model using the default settings is shown if the following figure (**Figure 7.2.4**).

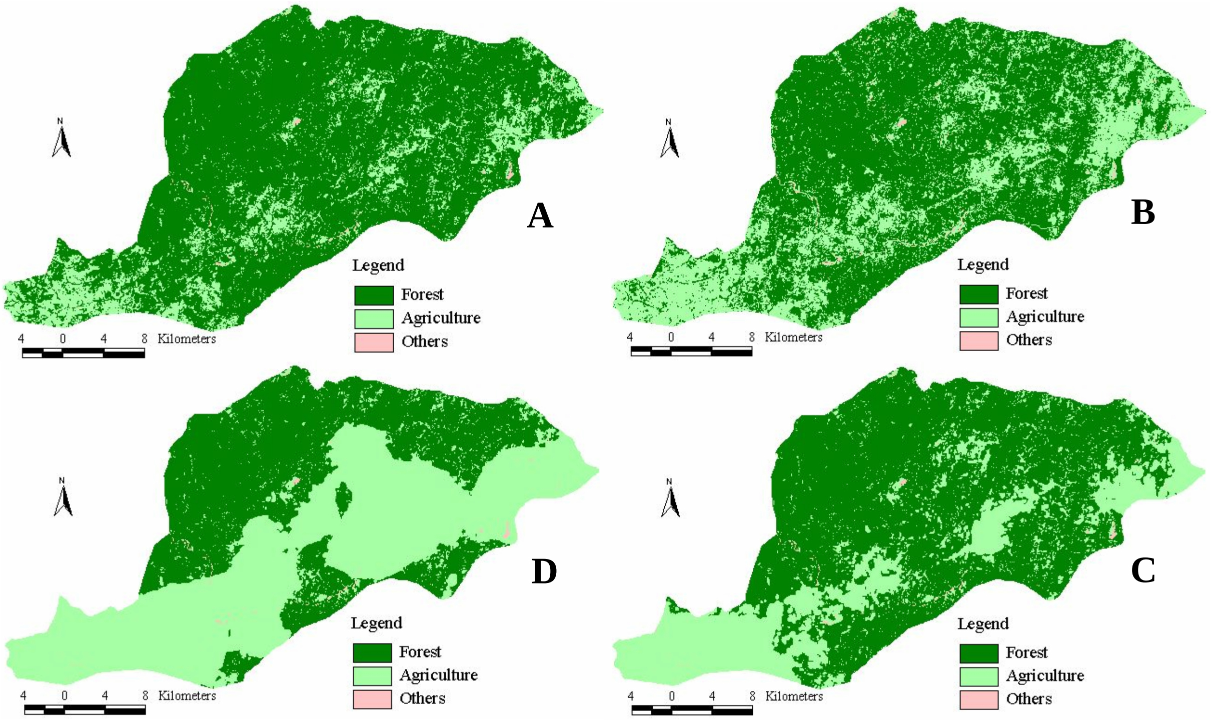


Figure 7.2.4: Land-use real, 1991, 2000 and simulated, 2000 and 2025 using default model settings (scenario 1) in the study area

A: Land-use real in 1991(left on top) B: Land-use real in 2000 (right on top)

C: Simulated land-use in 2000 (bottom right) D: Simulated land-use in 2025 (bottom left)

The above figure shows in A and B the real land-use in 1991 and 2000 on the one hand and in C and D the simulated land-use of the study area in 2000 and 2025 based on default model settings on the other hand. Simulations are based on the base-line scenario) .

From the real situation, derived from the satellite images, the followings observations can be made:

- the land-use maps show the distribution of the three aggregated land-use units in distinctive percentage cover: Forest, agriculture and others. In both maps of reality, it can be pointed out a decrease in percentage of these land-use units: a high percentage of forest is followed by agriculture and finally the “Others” class unit remains the little part of the total area of the study area;

- agricultural areas are dominant in the agglomerations along the main road crossing the sector from north east to south west;

- the extreme west part of the study area that mostly encompasses Kikélé village shows very small reserve in forest in benefit of agriculture from 1991 to 2000;

- the opposite extreme east part of the study area which encompasses Wari-Maro village and surrounding hamlets, shows dominant agricultural area as well.

The default simulation results are the reference point to which the other settings results are compared to. This will be the focus subject of the simulations comparison section below.

7.2.2.2 Simulation 1 (Trend-scenario or Business as usual)

The CLUE-s model was run for the two developed scenarios based on the two demands. **Figure 7.2.5** shows the resulting predicted land-use pattern of the model run for 2025 with demand 1 (demand for the base-line scenario) without area restrictions. On this figure can be seen the areas with change range in 2025. Simulated land-use maps in 2025 are displayed accordingly to two categories of settings ranging from A to B. The first category regroups the default, stable, forest stable and agriculture unstable settings while the second category constitutes only on unstable setting. This classification was made since the simulation based on the first category settings show similar results steadily different to the result based on the second category. The simulated results were thus summarized to the two following maps which show simulated land-use change in 2025 for the first category of settings on the left, and the second setting on right (**Figure 7.2.5**). These results indicate the most land-use changes occurring in the central part of the study area and especially along the main road axis. The whole Kikele village territory located in the west part of the study area will be totally converted in 2025 into agriculture without any forest remaining. Only the “Other” class remains always unchanged. The predicted land-use change maps A in this area shows some patches of forest surrounded by agriculture area. The patches observed in 1991 remain unchanged as well in the north area where forest area is dominant in the other three village’s territories (Igbomacro, Dogué, and Wari-Maro). By contrast, the figure B shows a smooth and regular landscape either in the converted area to agriculture or forest area unit with less forest patches inside the agriculture area.

As an observation for these outputs of modeling, the previous show that the defined settings do not affect the final results. However different results are output when the two main land-cover types undertake some land-use changes.

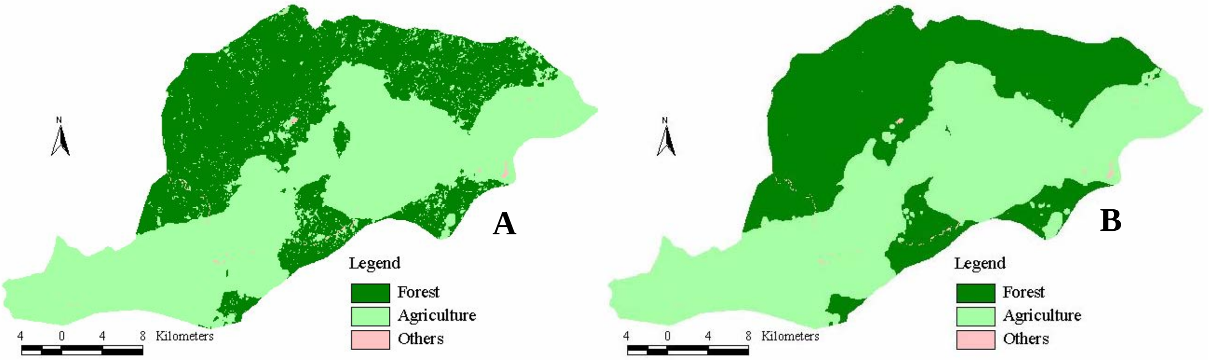


Figure 7.2.5: Simulated land-use in 2025 using Default model, Stable, Forest unstable, and Agriculture Unstable settings (A); and Unstable setting (B), based on "*business as usual*" scenario in the study area

7.2.2.3 Simulation 2 (Environmental damage scenario)

Figure 7.2.6 shows the simulation outcomes of the CLUE-s run with demand 2 (environmental damage scenario) without area restrictions as well. Demand 2 aims in increasing in agricultural area followed by population growth rate that occurred. This demand has quite an impact on the land-cover changes since the rapid population growth is mostly influenced by farmers' population, which increases year by year due to the migration phenomenon. Consequently, the more the population increases, the more the agriculture area increases (with a high growth rate of more than 6%); and this can lead to forest cover reduction. According to the simulation 2 results, very little forest area will remain in 2025. In the whole study area, a large part of forest area is already converted into agriculture in 2020.

The most interesting outcome of this simulation with the main settings within the scenario 2 is that after 20 years, there is no forest left in the area. After 20 years of simulation the number of forest cells in the 21st year is less than the number of agriculture cells so that there is not enough forest left to convert into another land-use type.

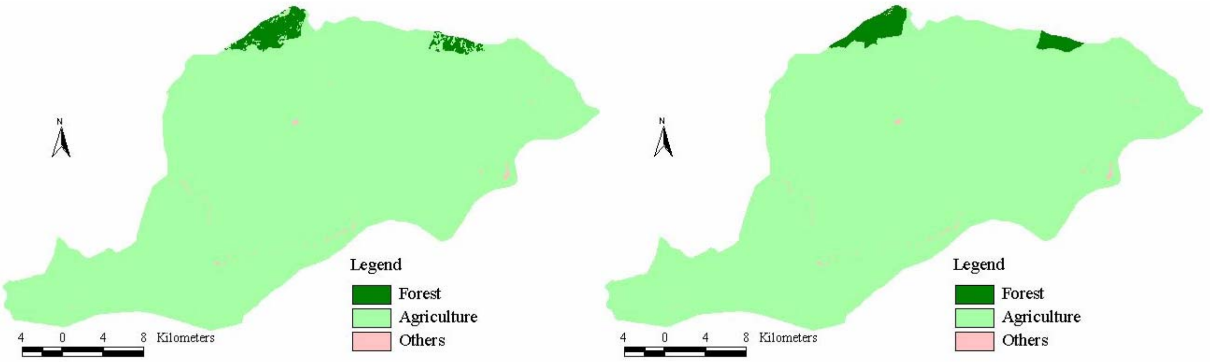


Figure 7.2.6: Simulated land-use in 2025 using Default model, Stable, Forest unstable and Agriculture Unstable settings (A) and Unstable setting (B) based on “*environmental damaged*” scenario in the study area

By comparing these two simulations maps, based on the two previous categories of settings, the same remark can be pointed out: the settings of the first category do not affect the final result while the unstable setting results in a smooth map. In both situations, the predicted land-use change shows more dominant agricultural area with very little forest area remaining. The forest area left is located in the extreme north of the study area.

To better appreciate the predicted maps, it is necessary to assess these results by applying additional means. The following section will focus deeply on this topic.

7.2.3 Model Fitting

This section focuses on a triangulation method (Manson, 2001) to demonstrate how the CLUE-s performs and by which means it can be validated. Three techniques are being applied: ROC method, visual comparison and multiple resolution technique.

7.2.3.1 ROC (**R**elative **O**perating **C**haracteristic)

The ROC method (Pontius and Schneider, 2001) is a quantitative method used as quantitative mean to validate a land-cover change model in order to appreciate the model’s prediction accuracy. The section 7.2.1.1 portrayed the ROC statistics for all the different selected driving variables that explain well the spatial distribution of all land-use types in the study area, specifically for forest and agriculture. ROC is used by CLUE-s model to evaluate the predicted probabilities by comparing them with the observed values over the whole domain of predicted probabilities (Verburg *et al.*, 2002). **Figure 7.2.1** depicted the probability maps of Forest and Agriculture in 1991. Probability or suitability maps are used at each run of the model to generate maps of simulated future change and an ROC for each land type. By overlaying the suitability information with the one of reality contained respectively in the map of suitability and the map of reality, contingency tables can be produced (for different scenarios) for calculating the ROC. Thus these statistics could be produced for assessing quantitatively the fitting of the model. But this result will not account for the spatial arrangement of the model's successes and errors. Moreover no location information is contained in a contingency table. Therefore it is advised to supplement this method with visual comparison and additional measures of association that account for spatial pattern (Pontius and Schneider, 2001; Costanza, 1989; Turner *et al.*, 1989). Preference is thus given to this advice which accounts for the most dominant part of the next section.

7.2.3.2 Visual comparison and agreements components

The visual approach is important because a visual examination is the quickest way to reveal spatial patterns (Pontius & Chen, 2006). The visual comparison is between the reality maps (from 1991 and 2000) on the one hand and between the reality map of 1991 and the simulation maps (from 2000 and 2025) on the other hand for the two scenarios. Thus changes in land-use have been set out through the following combinations: real images from 1991 and from 2000 are compared between them, real map 1991 and simulated image from 2000 and finally among real image 1991 and simulated maps in 2025 according to the default model settings for the baseline scenario and the environmental damaged scenario. The difference between pairs of images (e.g. difference between real image of 1991 and real image of 2000) was used for this purpose. It consists mainly in subtracting one image from another one. In all cases the same run was repeated without area restriction i.e. no forest is protected. **Figure 7.2.7** shows the hot-spots of changes according to each case study. Changes are marked in black while non-black areas represent static behavior of the landscape through space and time.

The previous **Figure 7.2.4** shows some similarities between the real image of 2000 and simulated map of 2000 even some differences appear. For the purpose of more helpful visual comparison, the **Figure 7.2.7**, through A and B, is suitable. This figure shows the distribution of true and predicted changes respectively in both images (A and B). Thus, widespread changes can be observed in the whole study area during the reference period from 1991 to 2000 (A). The simulated map of 2000 compared to reality map of 1991 shows most concentrated changes in the west area and in densely populated settlements located in the east and centre of Wari-Maro village (B). More changes occur from there to 2025 along the main road axis (C). By focusing on the second scenario, only small area of forest will remain in 2020 where very little forest area could not satisfy demand in agriculture. Therefore, no prediction could be done with the model over the period of 2020.

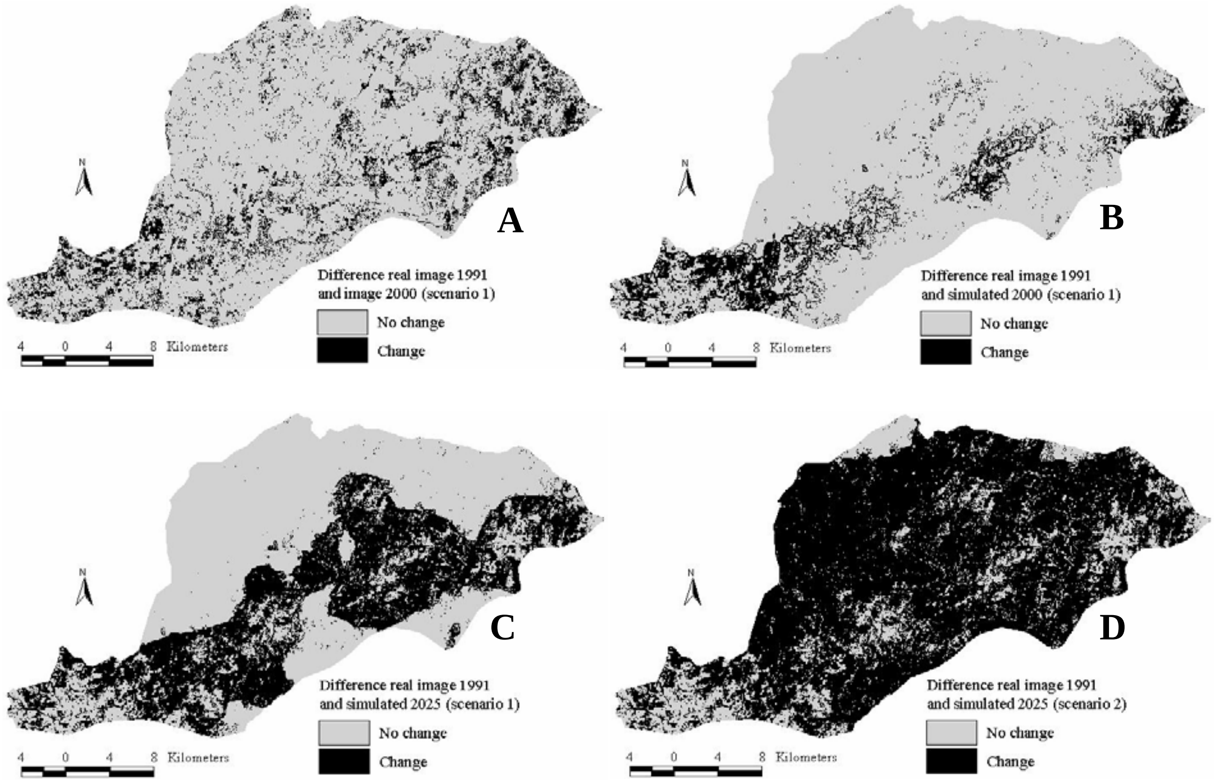


Figure 7.2.7: Land-use changes comparison using the difference in real and simulated images.
Land-use simulations are based on default model settings for the *baseline scenario* (A) from land-use real 1991 and real 2000; (B) from land-use real 1991 and simulated in 2000; (C) from land-use real 1991 and simulated in 2025; and for the *environmental damage scenario* (D) from land-use real 1991 and simulated in 2025 (scenario 2)

The previous findings indicate that the model is able to approximate the land-use / land-cover changes in the study area. Just by visual interpretation it is difficult to assess precisely the correct locations of the important and complex patterns of changes. The assessment of this result is subjective to the viewer's appreciation and it can be misleading as well (Pontius *et al.,* 2004; Pontius and Chen, 2006). Therefore, a statistical comparison technique is necessary to compute the errors i.e. some losses "human eyes can not detect" to complement the analysis.

The statistical technique developed by Pontius *et al.* (2004) is used for this purpose. To separate the calibration process from the validation process, another image from 2003 (part of the study area) has been used to apply the technique (see chapter “Data and Methods” for more information). The technique considers the agreement between two pairs of maps. The first comparison is between the reference map of time t_1 (here image of 2000) and the reference map of time t_2 (here image of 2003). The second comparison is between the predicted map of time t_2 (i.e. the simulated map of 2003) and the reference map of time t_2. Lastly, the procedure evaluates the two comparisons: the first comparison vis-à-vis the second comparison. The following figure (**Figure 7.2.8**) shows the three images used for comparison. **Figure 7.2.9** plots the components of agreement and disagreement at the fine resolution of 32 m. The first stacked bars show the components of agreements between the 2000 image and the reference image of 2003 while the second bars gives the components between the simulated map of 2003 and the reference image of 2003. The figure shows for both comparisons of the two pairs of maps, five components developed by the statistical technique mentioned lastly: Disagreement due to quantity, disagreement due to location, agreement due to location, agreement due to quantity and finally agreement due to chance. According to Pontius and Suedmeyer (2004), while the agreement computes in the simplest way the proportion of cells that agree between the two maps, the first two disagreements (computed at a more sophisticated level) are the most important for every scientist who needs to improve a model.

The disagreement due to quantity is defined as “a disagreement between the maps in terms of the quantity of a category”. The disagreement due to location is defined as “a disagreement such that a swap of the location of a pair of cells within the comparison map increases overall agreement with the reference map”. In other words, the disagreement of location is determined by the amount of spatial rearrangement possible in the comparison map, so that its agreement with the reference map is maximized.

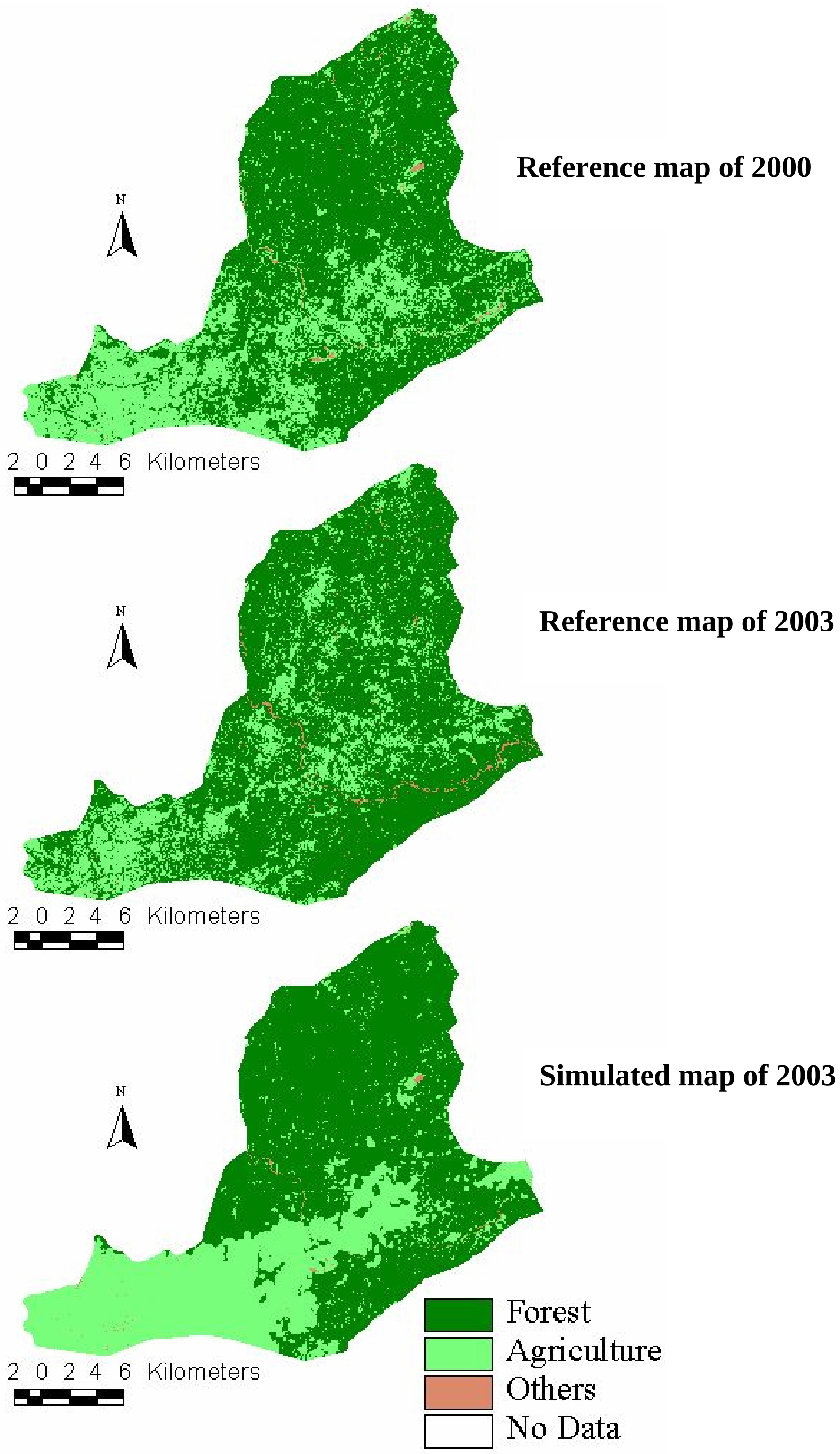


Figure 7.2.8: Land-cover maps of 2000 (upper), 2003 (middle) and simulated map 2003 (base-line scenario) in a partial outlook of the study area

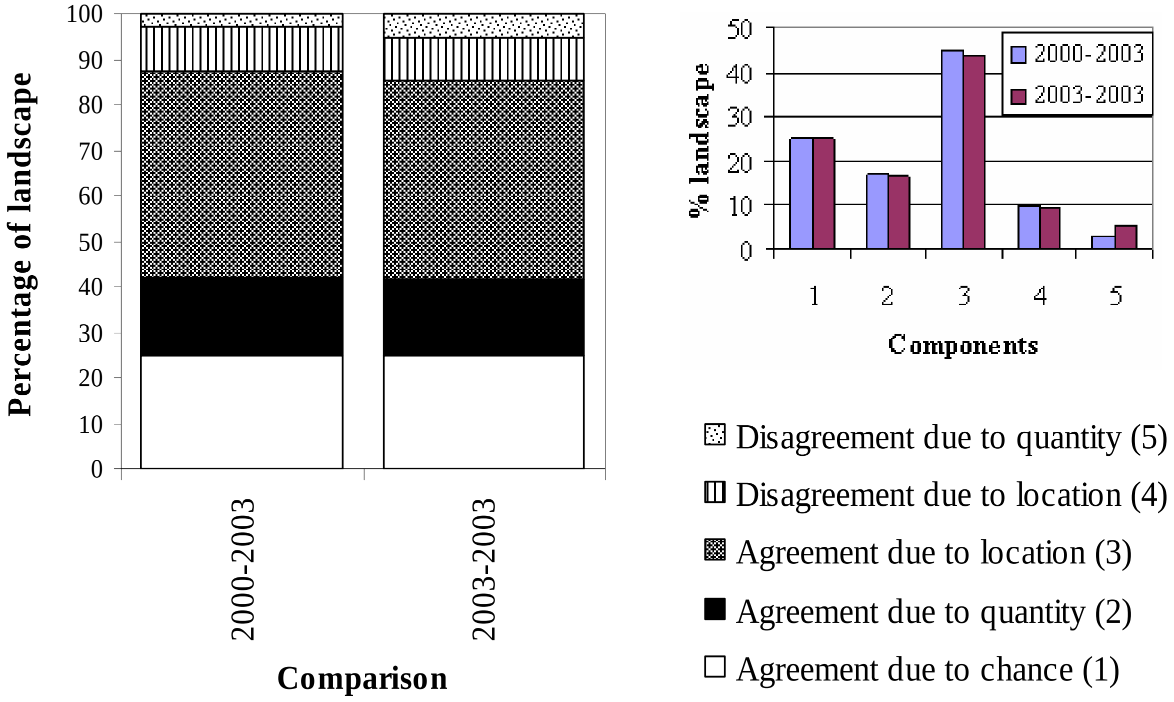


Figure 7.2.9: Stacked bars showing the components of agreement and disagreement between the reference map of 2000 vs. map of 2003 and simulated map of 2003 at a resolution of 32 m cell size

The histogram in the upper right corner shows the same components numbered 1 to 5 defined in brackets in the legend of the stacked bars as well.

From the stacked bars, it can be seen that apart from agreements due to chance and to quantity which are equal for both pairs of maps, the agreement due to location and all the disagreements vary. The agreement due to chance illustrates that the model has 25% chance to correctly predict the land-use changes in both pairs of images (2000 vs. 2003 and 2003 vs. 2003) regardless location or quantity information. The agreement due to quantity indicates that the comparison map shows 17.5 and 16.6% accuracy in terms of specifying the quantity of each land category respectively in 2000 vs. 2003 images on the one hand and 2003 vs. 2003 map on the other hand. The agreement due to location shows the ability of the comparison map at the grid cell level to specify the location of each category in the study area. The figure (**Figure 7.2.9**) indicates an accuracy of 45 and 43.5 for 2000 vs. 2003 images, and 2003 vs. 2003 images respectively (see additional information from the histogram in the right corner o the same figure). Based on this result and the previous **Figure 7.2.8**, it can be stressed that visually, the similarity that appears between the reference maps of 2000 and 2003 is not necessarily obvious between the predicted map 2003 and the reference of 2003. By comparing images from 1991 vs. 2000 and simulated 2000 vs. 2000 real (as indicated for the visual approach), an accuracy of 51% was obtained for the two comparisons. This result shows a tidy difference in the two techniques.

Concerning the disagreements, they specify the amount of error associated with the fact that the comparison map fails to specify perfectly the correct quantity of each category according to the reference map or the correct locations of categories at grid cells within the study area. The results indicated an increase in error due to quantity from 3 to 5% respectively for the two pairs of images while the disagreement due to location has decreased slightly from 9.7 to 9.3% respectively for the two pairs of images. By comparing pairs of images from 1991 and 2000, the results are opposite to the previous ones.

These outputs confirm the assertion of the authors since the most important variations occurred with the two disagreements: the first due to location (negatively) and the second due to quantity (positively). This illustrates that the ability of the model to correctly predict the location of land-use changes increases on the one hand and its ability to correctly predict the quantity of pixels that change decreases.

These findings gave the components that budget the sources of agreement and disagreement for the two pairs of maps at the finest resolution of 32 m. In other words, they compare the two pairs of maps through a pixel-by-pixel comparison at a single resolution. The most striking observation that could help to better understanding these components at a variable resolution of pixel size is the multiple resolution technique.

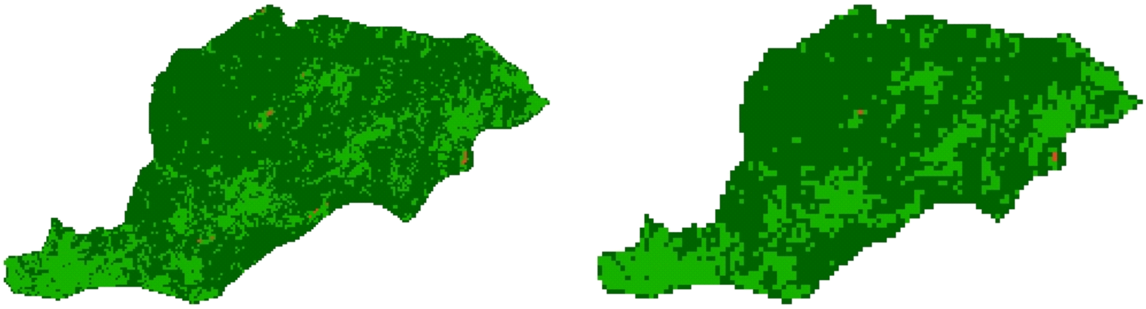
7.2.3.3 Multiple resolution technique

The multiple resolution technique requires at each new resolution a new set of maps (Pontius and Suedmeyer, 2004). Some examples of the map of 1991 at different resolutions of cell-size are shown in the following figure (**Figure 7.2.10**) below. Theses maps are the results of the aggregation technique applied to the source classification of 1991.

The figure shows the “pixel aggregation procedure whereby four neighbouring pixels are averaged at each coarser resolution. Therefore, the length of the side of the pixel grows at each subsequent level of aggregation in a geometric progression, i.e. as multiples of 2.” (Pontius and Suedmeyer, 2004; Pontius, 2002) The procedure can be done through an arithmetic or geometric progression. In the case of arithmetic progression, “the length of the pixel side grows by an equal increment at each step in the aggregation process”. Finally, both “geometric and arithmetic progressions produce coarse pixels with partial memberships in more than one category” (Pontius and Suedmeyer, 2004; Pontius, 2002). The geometric progression procedure is used in this study to calculate the degraded maps, either for 1991, 2000 reference maps or the simulated map of 2000. The previous figure shows the steps of resolution 2, 4, 8, 16, 32, and 64 which correspond respectively to pixel sizes of 64 (i.e. 32 m x 2), 128 (32 m x 4), 256 (32 m x 8), 512 (32 m x 16), and 1024 (32 m x 32). It can be seen on these maps that while the resolution increases, the number of pixels decreases. Therefore the number of land-cover types reduces. For instance, at resolution 32, none “Other” land-cover unit is observed in the map. At resolution up to 1024, the entire map is in one cell (an exact number of 1833 at which none progression is possible is obtained automatically).

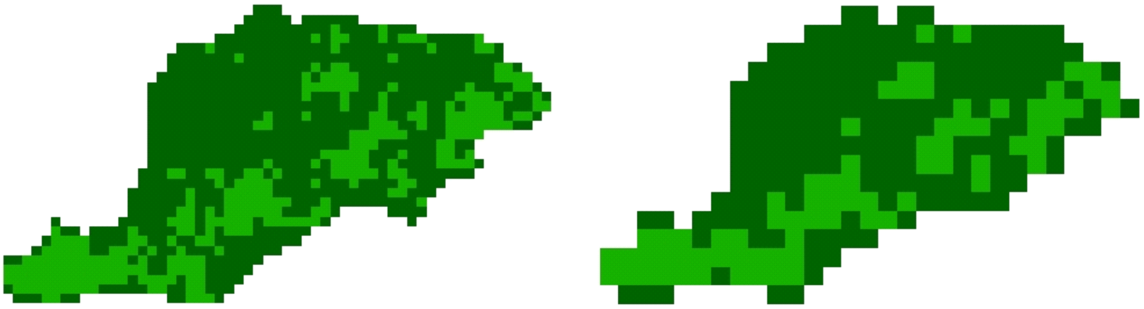
Resolution 2

Resolution 4



Resolution 8

Resolution 16



Resolution 32

Resolution 64

Figure 7.2.10: Map of 1991 at six different resolutions (m)

On the map, the dark green color represents “Forest”, the light green “Agriculture” and the red “Others”

With this aggregation technique in mind, the aggregated maps were produced for each map. Following the same principle like in the previous section (separate calibration process from validation process), the subset image from 2003 was used as a reference image. Then the components that budget the sources of agreement at each resolution were computed for the two pairs of maps (i.e. 2000 vs. 2003; and 2003 vs. 2003). The following figures plot the components (agreement and disagreement) between the reference map of 2000 and the reference map of 2003 (**Figure 7.2.11**) on the one hand and between the reference map of 2003 and the simulated map of 2003 (**Figure 7.2.12**) on the other hand at multiple resolutions. The **Figure 7.2.13** indicates the curves of components at diverse resolutions.

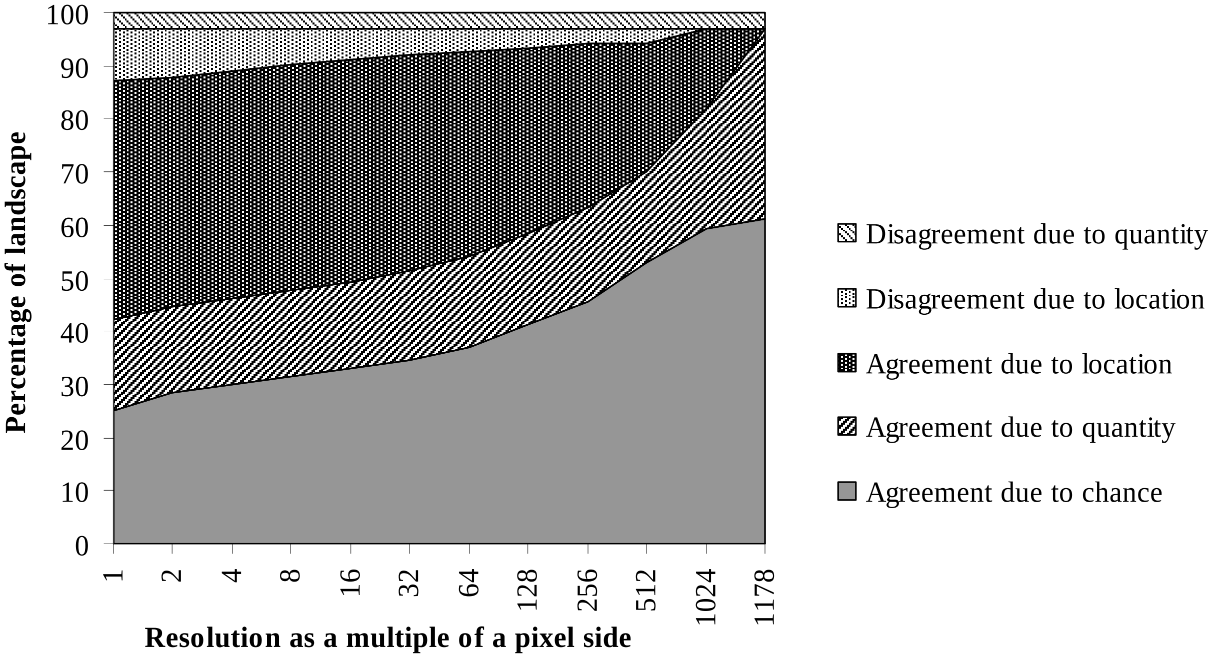


Figure 7.2.11: Components of agreement and disagreement between the reference map of 2000 and the reference map of 2003

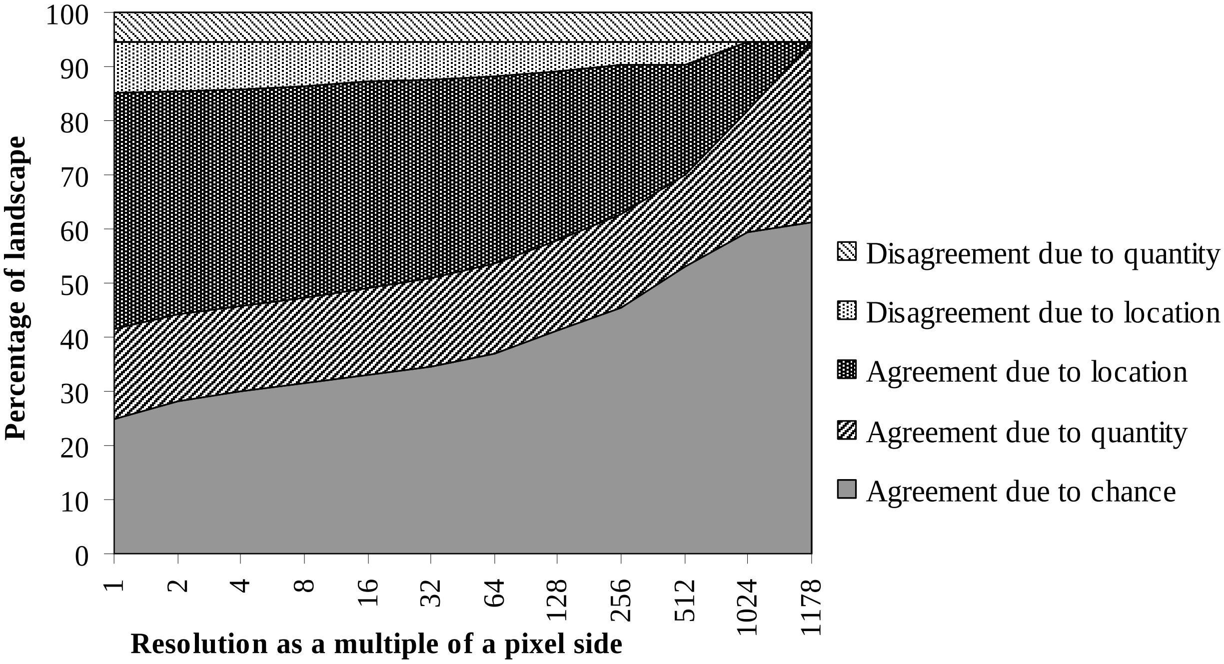


Figure 7.2.12: Components of agreement and disagreement between the reference map of 2003 and the predicted map of 2003

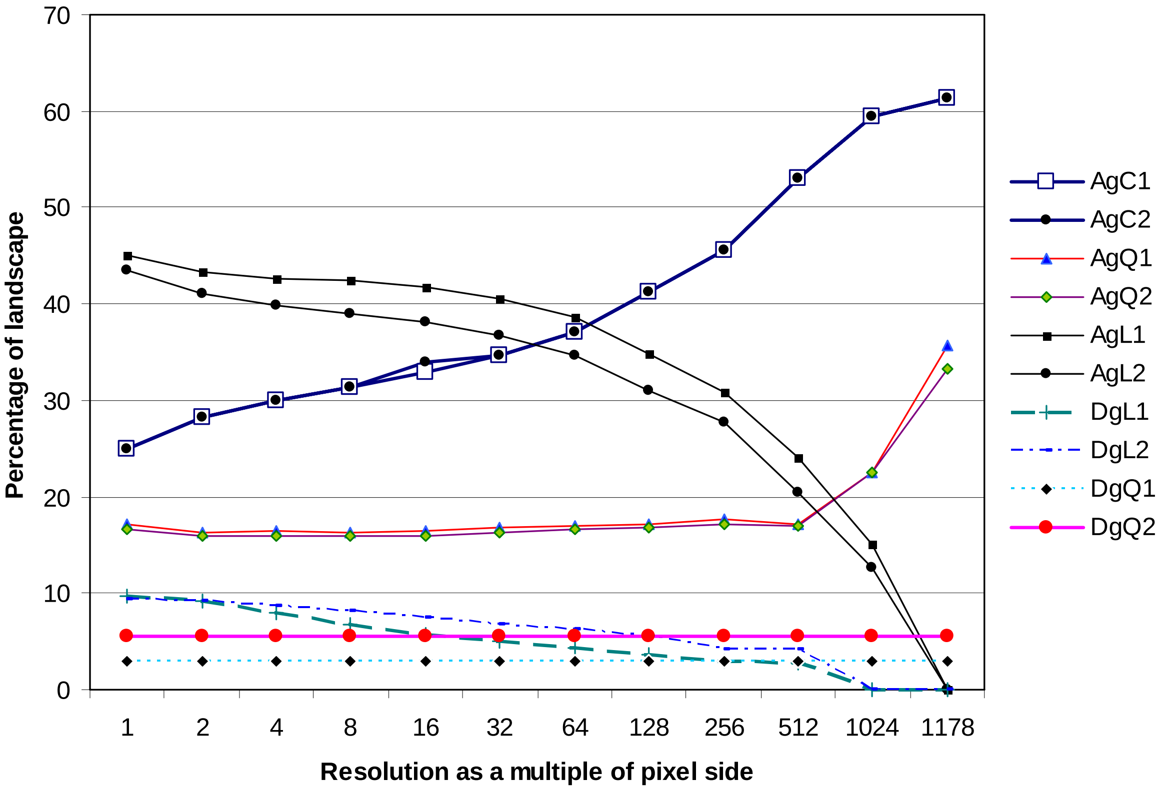


Figure 7.2.13: Components of agreement and disagreement for two pairs of maps comparison (2000 real vs. real 2003 quoted 1 and real 2003 vs. simulated 2003 quoted 2)

AgC1: Agreement due to chance for 2000-2003; AgC2: Agreement due to chance for 2003-2003
AgQ1: Agreement due to quantity for 2000-2003; AgQ2: Agreement due to quantity for 2003-2003
AgL1: Agreement due to location for 2000-2003; AgL2: Agreement due to location for 2003-2003
DgL1: Disagreement due to location for 2000-2003; DgL2: Disagreement due to location for 2003-2003
DgQ1: Disagreement due to quantity for 2000-2003; DgQ2: Disagreement due to quantity for 2003-2003

By analysing the previous figures (**Figure 7.2.11** to **Figure 7.2.13**), it can be pointed out that agreement due to chance and agreement due to quantity increase quite similarly as resolution becomes coarser while disagreement due to quantity remain constant regardless the pair of maps. By contrast, both agreement due to location and disagreement due to location decrease as resolution becomes coarser. This observation is similar for both comparisons of pair images as well. At a resolution of 1178 where the entire study area is in one grid, all these components (i.e. agreement and disagreement due to location) are null (zero). These results can be interpreted by the fact that the grid cell level location becomes less important as the cells become coarser and ultimately looses meaning at the final resolution (Pontius and Chen, 2006). These observations indicate that both pairs of maps compared show the same evolution: disagreement and agreement due to location decrease as resolution becomes coarser while agreement due to chance and to quantity increase. However, the disagreement due to quantity is independent of resolution, since it always remains constant whatever the resolution of the pixel.

In order to know the resolution at which the agreement between the simulated map and the ending time map is larger than the agreement between the beginning time map and the ending time map, two additional components of agreement (P(m) and M(m))[2] were recorded (for more information on these indicators of agreement, see section 7.1.5.2). P(m) and M(m) were computed for the two comparisons of pair images named Null model and CLUE-s model respectively for 2000 vs. 2003 real images and 2003 real and 2003 simulated maps (Pontius & Chen, 2006; Pontius *et al.*, 2004). The Null model uses the 2000 reference map as the prediction for 2003 while the simulated map results from CLUE-s is used as comparison map to the reference map of 2003. To compare both models, the criterion of Null resolution is used. The later is a resolution at which the accuracy of the predictive model (CLUE-s M(m)) matches the accuracy of the Null model (Null M(m)). This resolution is approximately between 512 and 1024 (i.e. 512 or 1024 times the raw grid cell size of 32 m) on **Figure 7.2.14** which corresponds to grid cells of approximately 33,000 square kilometer (32768 m² ≈ 330 hectares). The null resolution represents the distance at which the simulation model begins to perform better than a null model that predicts persistence only (Pontius & Chen, 2006). This can be seen on the figure where the simulation model's curve (CLUE-s M(m)) starts to rise on the lower horizontal line of the Null model's P(m).

Finally, the results obtained are similar to Pontius *et al.* (2004) who conclude that the predictive model is less accurate than the Null model at resolution finer than the Null resolution. By contrast it is different to the same author on the second side where he stressed that the predictive model is more accurate than the Null model at resolution coarser than the Null resolution. The CLUE-s predictive result shows very different situation where it is quite performing less than the null model.

These results can be misinterpreted if no more indicative explanations are made. It

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[2] M(**m**) is the agreement between the reference map and the unadjusted predicted map. P(**m**) is the agreement between the reference map and an adjusted map in which the location of pixels of the predicted map are rearranged in space to match as closely as possible the pixels in the reference map

is worth noting that these results are only based on a subset of three villages of the whole study area. This subset misses the main village (excluded due to cloud cover on the satellite image) as explained in the chapter 4) that hosts a high number of migrants and new settlements that contribute mostly to the increase in agricultural area in the study area. By comparing the land-use/-cover statistics derived from the area subset of the three images (1991, 2000 and 2003), it can be concluded that Wari-Maro contributes for a great part. The figure below (**Figure 7.2.15**) shows less agricultural area (a decrease) and more forest (an increase) than observed in 2002 while all the previous results showed the opposite. The reason is just that the Wari-Maro village that contributes mostly to the decrease in forest area is not included in these statistics. The agricultural fileds were also well developed in the migrants' densely populated hamlets (like Kpaawa and Adjimon) closed to Wari-Maro. As a proof, an example of this increase in agricultural area and decrease in forest is depicted by the **Figure 7.2.16** (in the next section) which shows the land-use changes simulated for 2004.

However, the results are promising since the CLUE-s prediction accuracy arises to more than 80% (**Figure 7.2.14**) to allocate correctly the land-use changes with less disagreement.

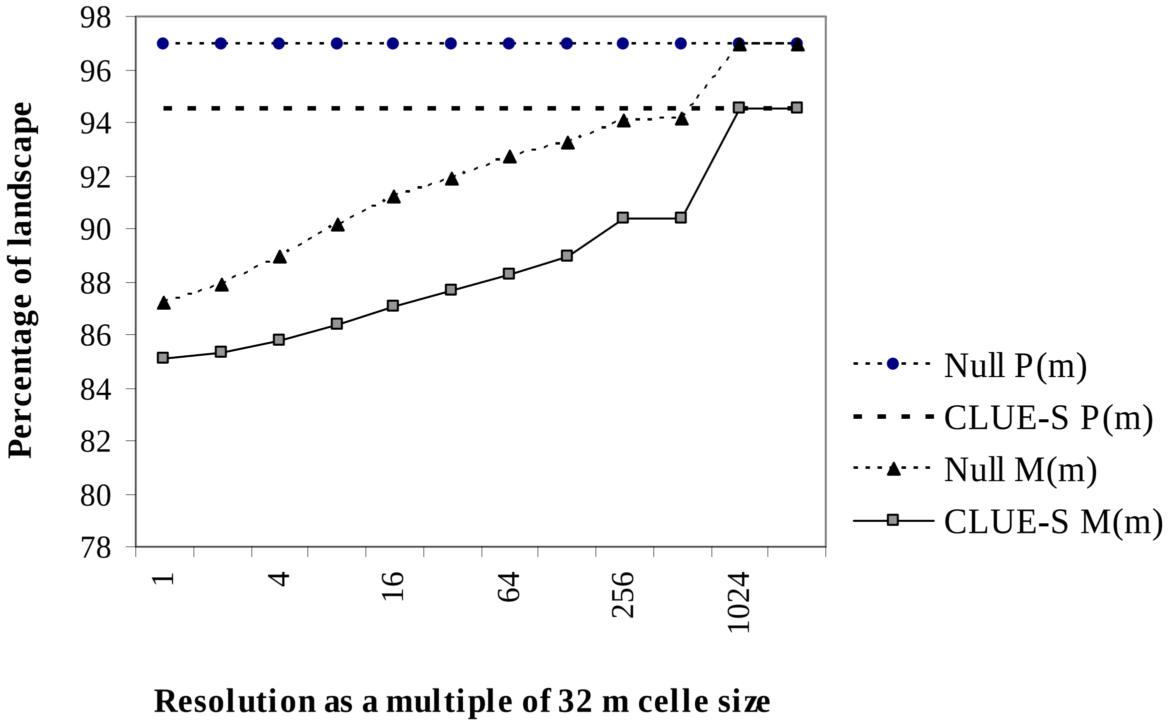

Figure 7.2.14: Components of agreement P(m) and M(m) for the Null and CLUE-s models The Null model for M(m), defined for the real images is compared to the predictive CLUE-s model for M(m) based on the criterion of Null resolution (point at which both models match).

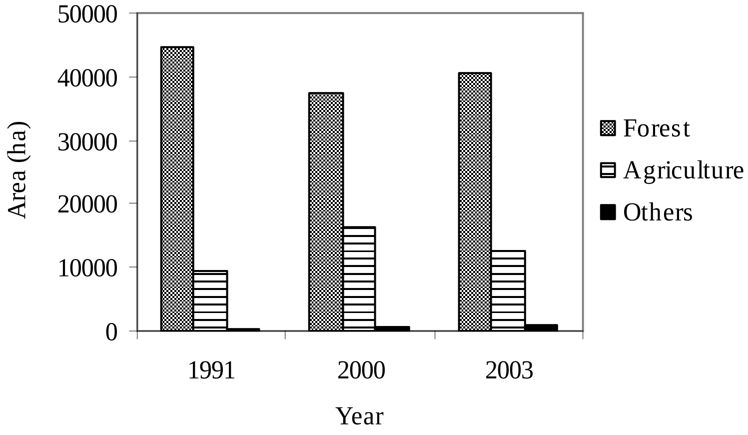

Figure 7.2.15: Land-use/-cover statistics for three subset images from 1991, 2000, and 2003 Forest area is growing in 2003 because the area of Wari-Maro is not included

Once the validation statements are made for spatial and quantitative assessment of the model, it would be interesting to appreciate how and at what rate the land-use changes are taking place in the study area in the next section.

7.2.4 How and at what rate does land-use change in the study area?

Like most of the land-use change models, this modeling research aims at predicting the spatial pattern and the rates of changes by addressing two questions: where are land-use changes taking place and at what rate are land-cover changes likely to progress? (Serneels and Lambin, 2001). These two questions refer to location and quantity issues according to Pontius and Schneider (2001) quoted by Serneels and Lambin (2001). In addition to these issues, a new focus can be put on how i.e. the way or the processes by which the land-use changes.

The previous findings from the simulation and the quantification of changes help to better answer the location and the quantity issues respectively.

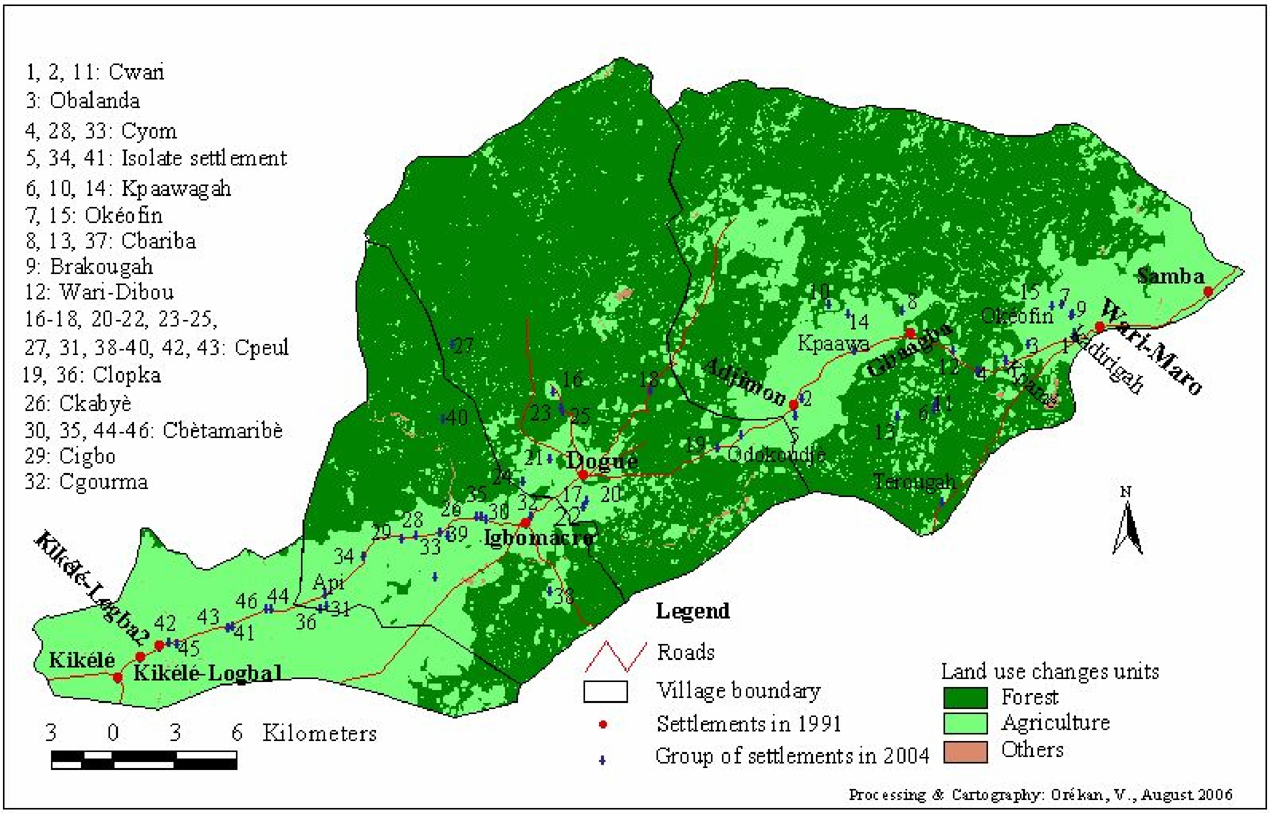

Figure 7.2.16: Land-use changes simulated in 2004 (scenario 1, decision rule 1-0-1) and settlements distribution in 2004 in the villages of the study area

The settlements names symbolized by numbers in the map are indicated in the upper left of the map. Camps populated by the same sociocultural group are indicated by the name of dominant group e.g.: 6-18…Cpeul (Cpeu = Camp of Peul) indicates the settlements numbered 6 to 18 are Peul camps. The groups are: Yom, Bariba, Peul, Lokpa, Kabyè, Bètamaribè, and Gourma). Other camps are indicated by the name of founder e.g. Brakougah and Kadirigah (on the map) or the name of the hamlet of village to which they are close to e.g. Cwari, Kpaawagah, Cigbo (igbomacro), or finaly by the name of the quarter e.g. Obalanda, Okéofin, Wari-Dibou.

From this figure, the villages that already existed in 1991 (Kikélé, Kikélé Logba 1 and 2, Igbomacro, Dogué, Adjimon, Gbaagba, and Wari-Maro) are separated by an irregular black line which constitutes their boundary. Inside the map can be distinguished the main central road along which most settlements (in blue color) are established. Some additional tracks join that main road. Very few settlements are located outside the agricultural area. Most of the isolated settlements located deeply within the savanna belong in general to non-agricultural household (Peul socio-cultural group which focuses their activity on animal husbandry).

By overlaying the spatial configuration of groups of settlements in 2004 or the simulation outputs of 2004 (**Figure 7.2.16**), conclusion can be made that changes occur along the main road from West to East area. Of course, the changes along the road, as mentioned ahead (in previous sections), has been accelerated with the renovation of the road in 1997. Up to now, the population of in-migrants in this area has more than doubled (See settlements groups and corresponding population from 1991 to 2004 Table 7.1 in Appendix 2) especially in some migrants hamlets (like Kpaawa) and isolated hamlets (like Adjimon) and thus contribute to drive changes through many pathways. At the first phase of their installation, the “pioneer” migrants settled close to a village in order to get easy access to the socio-economic infrastructures that already existed (local market, water, schools, health centre, church, mosque, etc.). Sometimes, far from the agglomerated village, the roads created by logging activities (pathways drawn by tracks for collecting timber, polewood, or charcoal) guide migrants to settle in isolated settlements. Thus, from this point start the land-use changes processes which contribute substantially to the modification or conversion of the landscape. This situation is confirmed by Mertens and Lambin (2000) and Chomitz and Gray (1996) who stressed the role played by roads in deforestation by increasing accessibility of the forest by migrants. From year to year, the single settlements start to grow up by increasing their settlers and huts. The area under farming activities grows up too, expanding according to the rate of increase of new agricultural colonists inside the savanna. The very new fields installed close to the riparian forest (yam) start to be transformed to into other land-cover i.e. other stages of forest depletion as often observed in Africa (Marcoux, 2000). The author assets the transition sequence that most prevails is that from closest forest to short fallow, typically of small-scale subsistence farming (closed forest > open forest > fragmented forest > other land-cover i.e. savanna, field and finally fallow).

By contrast to the general observation, an agricultural “hot-spot” is drawn in the northern part of Wari-Maro without any presence of settlement. This could result in logging activity essentially where most natural vegetation suitable for commercial wood extraction is under continuous fraudulent exploitation.

Finally, as a general observation made on the field during fieldworks, it can be concluded that changes in land-use follow the population density and settlements growth. Therefore, the spatial configuration of the landscape follows the structure of increase in population and settlements on the one hand and a typical forest depletion sequence from close forest to fallow on the other hand.

7.2.5 Driving factors of LUCC

Land-use changes can be remote by a variety of driving forces. From the previous analysis, table 5.2.1 shows two categories of relevant driving factors: distances and population density. The distances drivers include distance from road, distance from stream, distance from “*forêts sacrées*” and finally distance from settlements while population density has its own component from which can be derived many others like need of cultivable land i.e. fertile soil, fuelwood collection, grazing in forests (settlements), subsistence agriculture, logging, population growth, and migration.

Distances driver rely mainly on accessibility purpose. Proximity to road or tracks, to water spots and to the dwellings often guides the settlers in their installation for cropping, goods transportation and for water supply. “Forêts sacrées” are some islets forest, which constitute the remaining forest from the initial old natural forest, and protected by traditional religion practices from logging. In general, they are found in every village (when they are not destroyed) where specific religion like “*Oro*”, “*Abiku*”, etc. is practiced. By conserving the natural resources, theses land-covers also play the role of archives of ancient practices that are conserved by a small group of initiated people around which a community of persons is agglomerated. Therefore, these isolated forests are considered relevant driver of land-use changes. In addition, the forest itself can be considered as a cultural factor which has a sociological characteristic, which sometimes influences in maintaining social security inside the locality.

According to population density, it relies on initial population density of 1991 and change in population density (1991 to 2004). This factor is linked to a group of factors such as need of cultivable land i.e. fertile soil which is the main reason of immigration in this low-population density area (Lambin and Geist, 2002) where subsistence agriculture is the main practice. The soil fertility factor which seems important for colonist migration is rejected by the model regression. This could be due to the low quality or less detailed information of the soil suitability data used to parameterize the model. Unoccupied areas (like forest or wooded savanna) are often the frequent destination chosen by settlers seeking new agricultural land. Thus immigration increases the changes in landscape. As a main source of energy, fuelwood collection contributes to land-use changes too, since a vast majority of people either in rural or urban areas is dependent on the traditional fuels of wood (World Energy Council & FAO, 1999 quoted by Marcoux, 2000). Increase of population in a system of shifting cultivation is always accompanied by more land clearance (Lambin *et al.*, 2001; Marcoux, 2000). In addition, the increase in consumption of energy *per capita* and changes habits in cities (dwellers prefer charcoal to wood) increases the impact of a high population growth on wood resources and therefore on the whole landscape. Finally, grazing in forests (Peul settlements) and logging are also done at the expense of forests of wooded cover. Concerning grazing, excessive pressure on the vegetal cover by animals can be a crucial problem in certain areas when the density of the livestock increases. In this study area, forest clearing due to pastures is a minor factor among the linked factors to demographic parameters. It is more driven by demand in animal products than population growth. According to the field knowledge, logging is rarely affected by demographic parameter in the local area. In effect, this activity is always done by “external people” who invest in commercial investment in order to increase their income. Therefore, logging is not a major factor of deforestation as stressed by Marcoux (2000): “logging concerns smaller areas than forest clearing for agriculture, does not destroy the whole vegetation, and does not involve the destruction of organic matter (including seeds) that forest burning does”.

On the whole, many studies recognized demographic parameters through population growth and population density a major determinant of land clearing in shifting cultivation through the growth in requirements for food and other agricultural products. But it is important to notice that the role of population factors in land-use changes can also vary from one setting to another one depending on the local pattern and human occupancy.

The modeling outputs bring out clearly the land-use and land-cover changes patterns in the study area. The next chapters will conclude the work and print out the perspectives.

8 CONCLUSIONS AND OUTLOOK

To modeling land-use and land-cover changes at a local scale in central Benin, the statistic, dynamic and spatial CLUE-s model was applied using socio-economic and remote sensing data. Due to the fact that the available official database for the test area is poor, there is a necessity for collecting and processing required preliminary data. Collecting the socio-economic input data needed for the modelling consumed a large part of the study time-period. The identification of the relevant drivers of land-use changes and the calibration of the model regarding the complex pattern of land-use and land-cover was not an easy task. Finally, the limitation in accessing valuable remote sensing data without noise (cloud-free images and/or not or less burned areas) remains a scientific challenge. Nevertheless, fruitful output has been achieved.

8.1 The main changes in land-use and land-cover

The study area faces a high deforestation rate of about 6% during the period 1991-2000. This is confirmed by Orékan *et al.*(2006), Menz *et al.*(2006); Thamm & Judex(2006), and Thamm *et al.*(2005b). The most important land-use/-cover changes are related to conversion from different land cover types to other types. A transition of more than 20% from woodland savannah to shrub savannah occurred during this decade. Among natural vegetation, the most transition occurs from woodland to woodland savannah (8%). Timber, charcoal production and firewood collection for domestic and commercial purposes could be associated to these changes. The transition of natural vegetation to cropland is related to an increase in demand for fields (more clearings) and in logging activities. Up to now, it has not been possible to quantify objectively the changes induced by these activities in the study area due to the lack of high resolution remote sensing images.

On the whole, the LUCC can be resumed in a decline in woodland and savannah, an increase either in savanna areas or agricultural areas.

8.2 Simulating LUCC with CLUE-s model on local level

The CLUE-s model was successfully implemented to the local study area. The determination of the main driving factors and the decision rules is guided by the socio-economic survey, the demographic growth, and the expert knowledge of the study area. The statistical significant drivers are mainly related to two dynamic factors: distance to settlements and population density. At this household level (defined at a spatial scale of 30m-1050m according to Braimoh, 2004), the land-use change processes are heterogeneous and a large amount of data is required to characterize these changes. With the available dataset, at a resolution of 32 times the finest resolution (i.e. about 1.024 km), the accuracy of prediction is about 93 % agreement between the predicted map and the reference map. The accuracy of predicting increases as resolution becomes coarser (Pontius *et al.*, 2004). As well the accuracy of prediction could have been increased with the precision of the input data.

Finally, two scenarios for future development of the boundary conditions were defined according to the findings of the IMPETUS project: the baseline scenario "*business as usual*" assumes a high local population growth which leads to a linear expansion of agricultural area; and the "*environmental damage*" scenario which assumes an increase of 6 % a year of agricultural area. The stability parameters were set based on conversion elasticities to indicate the reversibility of land-use change whose values vary from 0 (easy conversion) to 1 (irreversible change). In addition to the default elasticities, four situations were distinguished: unstable, stable, forest unstable and agriculture unstable.

The outcome of the baseline scenario predicts that there will be some forests left in 2025 while the second scenario results in nearly complete deforestation of the area in 2020. In general, the resulting spatial pattern of the predicted changes shows strong changes along the main road Ouberou-Kikélé where most of the immigrant farmers settle. This tendency will be maintained as long as the population increases.

Based on the abovementioned prediction outcome, it can be concluded to a successful run of the CLUE-s model to simulate LUCC at local scale.

8.3 The main drivers of LUCC in the study area

There is a variety of socio-economic factors that drive land-use and land-cover changes in the area described either by statistical or modeling approach.

The statistical analysis revealed that the "cropped area" is influenced by a set of variables declared by farmers (population, distances, fallow practice, and water need). The "household income" is correlated with crop, and charcoal sale instead.

By linking remote sensed with socio-economic data, a high correlation is achieved between agricultural areas, and forest cover derived from remote sensing on the one hand, and population density derived from socio-economic data on the other hand.

Finally, these correlations showed that the increase in agricultural or cropped area and forest decline have kept pace respectively with population growth, and population density associated with distances and cropping system. Socio-economic data are therefore able to explain land-use and land-cover changes in the study area. Further modeling research could implement the model with relevant and improved drivers either biophysical or socio-economic.

On the whole, by combining results from socio-economic survey and modeling approach, the main variables which drive LUCC in the study area can be grouped under two categories of causes: proximate and underlying causes.

Proximate causes regroup variables such as distances (accessibility), income (economic growth), charcoal production, crops and cropped areas (agricultural expansion) while underlying causes assemble household’s age, population (through demographics factors), literacy, education and household status (social).

8.4 Outlook and implications of modeling for Decision Support System setting

The previous outcome revealed that the study area faces some drastic land-use changes which seem to be maintained in the future due to permanent anthropogenic activities. Finding a means for better management of natural resources is relevant. Therefore, the following suggestions and measures are of importance:

- local authorities should supply the area with a valuable policy for a better monitoring of the population and their activities concerning LUCC to build up sound socio-economic database;
- delineating the village boundaries is a crucial issue to improve future “inter-district” partnership and development in order to avoid conflicts among neighborhood villages;
- to preserve the natural resources and warrant their sustainable use, a proper land-use/land management planning needs to be set up. For example, some forest reserves for park purpose, agricultural zone reserved only for agriculture, diverse infrastructures zone, tourism, etc.;
- implementing sustainable measures to avoid illegal logging that lead to deforestation;
- co-managing natural resources through a permanent dialogue among different actors;
- better control of bush fires practices by the Agriculture Department, Non Governmental Organizations (NGO), and farmers themselves. Diverse means can be used to increase the public awareness on those practices;
- land degradation can be reduced by associating land-use intensification with agricultural, agro-forestry or grazing systems;
- avoid as possible shifting cultivation by adopting selected planning fast growing trees combined with intensive agriculture;
- encourage farmers to practice fallow, crops rotation and trees plantation mainly cashew for sustainable land-use and preserving land-cover for future generations.

Beside the previous suggested measures, the development of adapted and sustainable management options for the actors of the land-use changes, the stakeholders and the decision makers, based on the output of this research is a key issue of the IMPETUS project. Modeling land-use and land-cover changes is essential to indicate the hot-spots of deforestation. By integrating socio-economic and remote sensed data, this research has provided relevant information which can be used for setting up a Decision Support System that will make land resources planning and management effective in the study area. Finally, this Decision Support System will be transferred to local authorities, and stakeholders for decision-making for sustainable local resources management.

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APPENDICES

Appendix 1: Data and Methods

Table 4.1: Land Cover/Use key interpretation of IMPETUS

Vegetation types / Types de végétation

Code	*English*	*French*	*Observations*
Nr.	Vegetation types	Types de végétation	Observations
1000	Natural vegetation	Végétation naturelle	
1100	Savanna	Savane	
1110	**Grass Savanna**	**Savane herbeuse**	**weniger als 2% strauch-/Baumanteil**
1111	**Grass Savanna (bas-fond)**	**Savane herbeuse (bas-fond)**	
1112	**Dry Grass Savanna**	**Savane herbeuse sèche**	
1115	**Saxicol Savanna**	**Savane saxicole**	
1120	**Shrub Savanna**	**Savane arbustive**	**mehr als 2% weniger als 5% strauch-/Baumanteil**
1130	**Tree Savanna**	**Savane arborée**	**5 - 25% Baumanteil**
1140	**Savanna woodland**	**Savane boisée**	**20 - 50% Baumanteil**
1200	Forest	Forêt	
1210	**Woodland**	**Forêt claire**	
1211	**Woodland (Isoberlinia)**	**Forêt claire à Isoberlinia**	
1212	**Woodland (Anogeissus)**	**Forêt claire à Anogeissus**	
1213	**Woodland (Uapaca)**	**Forêt claire à Uapaca**	
1220	**Closed forest**	**Forêt dense**	**dicht nicht laubwefend**
1230	**Gallery or Riparian forest**	**Galerie forestière**	
1235	**Degraded Gallery forest**	**Galerie forestière dégradée**	
1240	**Forest islet**	**Ilôt de forêt**	
1300	Special terrain	Terrain spécial	
1310	**Inselberg**	**Inselberg/Colline**	
1320	**Clearing**	**Clairière**	

Land use : Utilisation des terres

Nr.	Types	Types d’utilisation	Observations
2000	**Field in general**	**Champ en général**	
2100	**Cereals**	Céréales	
2110	**Sorghum**	**Sorgho**	
2120	**Maize**	**Maïs**	
2130	**Rice**	**Riz**	
2140	**Millet**	**Mil**	
2150	**Wheat**	**Blé**	
2160	**Barley**	**Orge**	
2170	**Rye**	**Seigle**	
2200	Tuber	Tubercules	
2210	**Yam**	**Igname**	
2220	**Manioc**	**Manioc**	
2230	**Spud**	**Patate douce**	
2240	**Potato**	**Pomme de terre**	

2300	Farm	Fermes	
2310	**Peanut**	**Arachide**	
2320	**Cotton**	**Coton**	
2330	**Bean**	**Haricot**	
2340	**Tomato**	**Tomate**	
2350	**Chili**	**Chili**	
2400	Fruiterer	Fruitiers	
2410	**Banana**	**Bananeraie**	
2420	**Sugar cane**	**Champ de canne à sucre**	
2430	**Mango tree**	**Manguier**	
2440	**Avocado tree**	**Avocatier**	
2450	**Pineapple**	**Ananaseraie**	
2460	**Palm tree**	**Palmeraie**	
2470	**Cashew**	**Anacarderaie**	
2480	**Coconut tree**	**Cocoteraie**	
2490	**Lemon**	**Champ de citron**	
2500	**Teak**	**Teckeraie**	
2510	**Eucalyptus**	**Eucalyptus**	
2600	Pasture	Pâturages	
2700	Fallow	Jachères	
2800	Burned area	Surface brûlée	

Terrain without vegetation / Terrain nu

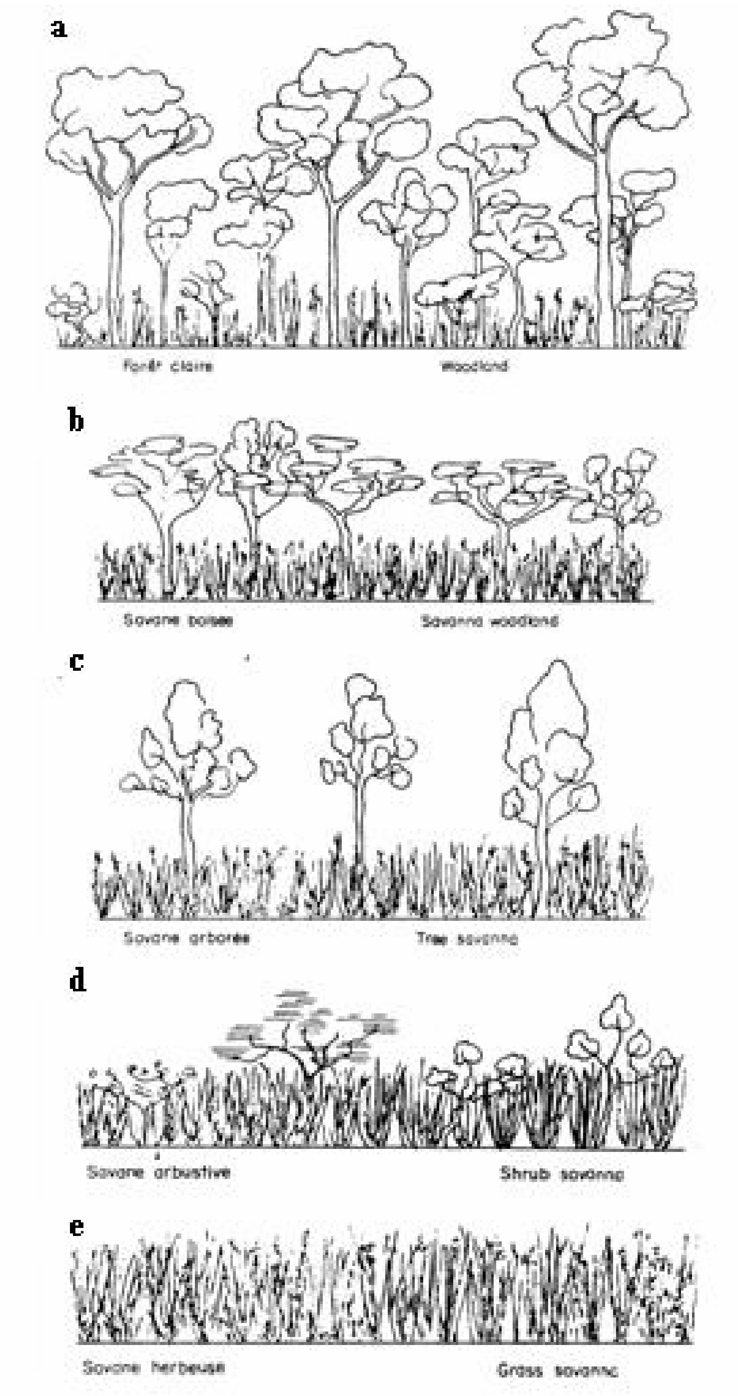
Nr.	Types	Types de terrain	Observations
3000	Free vegetation	Vegetation	
3100	**Natural vegetation**	**Vegetation naturelle**	
3110	**Swamp**	**Marais/bas-fond**	
3120	**Rock**	**Rocher**	
3130	**Clay**	**Argile**	
3200	**Anthropogenic**	**Anthropique**	
3210	**Agglomeration**	**Agglomération**	
3215	**Settlement**	**Campement ou habitation isolée**	
3220	**Roads**	**Voies**	
3230	**Bridge**	**Pont**	
3240	**Rail way**	**Chemin de fer**	
3260			

Water / Plan d'eau

Nr.	Types	Types de plan	Observations
4000	**Water**	**Eau**	
4100	**Water channel**	**Chenal cours d'eau**	

Figure 4.1: Scheme of sample vegetation types

Source: Adapted from YANGAMBI, 1956



Legend:

a: Woodland (Forêt Claire)

b: Savanna woodland (Savane boisée)

c: Tree savanna (Savane arborée)

d: Shrub savanna (Savane arbustive)

e: Grass savanna (Savane herbeuse)

Doc. 4.1: Chayanov's theory of demographic differentiation and land use

(Excerpt from Perez & Walker, 2002)

"The theoretical foundation of the importance of household life cycles for land use was laid by A.V. Chayanov, who studied farming practices among peasants following the 1917 Revolution in Russia (Thorner, Kerblay, & Smith, 1986). Chayanov observed that peasant households contained families with different age structures, and that those households also farmed different quantities of land. He reasoned that age structures are older in households with larger numbers of economically active adults and/or smaller numbers of dependent children, both of which allow for greater allocation of labor to agriculture, which in turn enables cultivation of larger land areas. Chayanov extended this insight about labor availability and child dependency by noting that the age structure changes through the course of a household's life cycle. He distinguished among life cycle stages, where early on the household age structure is young (due to the presence of infants and young children), and relatively little land is farmed due to limited labor available for agriculture. As time passes, the average age among the children increases and children become more economically active, allowing expansion of the land area cultivated. By distinguishing households in terms of their age structure, Chayanov provided a domestic life cycle explanation for differences in land area cultivated among Russian farms."

Doc. 4.2 : Survey questionnaire N°1

Fiche d'entretien N°1

Fiche n°…… **Date**…./…/2003 **Enquêteur** : ………………..……………………….

Commune………………...… **Village/Hameau** ………….………**Campement**…..………..

Identification de l'enquêté(e)					
Nom de l'enquêté (e)					
Age		Ethnie			
Etat matrimonial	Marié (e) ☐		Célibataire ☐		Veuf (ve) ☐
Type de Ménage	Autochtone ☐			Allochtone ☐	
Si ménage allochtone	Année installation : …………… Provenance : …………………… Raison d'installation : ………….…………………………………….……….		Année de retour : …………………… Lieu de naissance : …………………….…		
Composition du Ménage (effectif)	Catégorie	Actifs (14 – 55 ans)		Dépendants (0–13 & > 55 ans)	
	Homme				
	Femme				
	Enfants	0 – 5 ans	6 – 10 ans	11 – 15 ans	16 ans +
Niveau d'instruction	Illettré (e) ☐ Secondaire ☐			Primaire ☐ Supérieur ☐	
Alphabétisation	Alphabétisé (e) ☐			Non Alphabétisé (e) ☐	

1.1 Quelles sont les cultures que vous pratiquez en saison pluvieuse?

Ordre	**Cultures**	**Période (mois extrêmes)**		
		De …	**A …**	**Nb. mois**
1ère				
2e				
3e				
4e				
5e				

1.2 Combien de champs avez-vous en jachère ? ………………………………..………………

1.3 Depuis combien d'années ? ……………………...………………………………………

1.4 Quand pensez-vous l'exploiter ?…………………………………………………………

1.5 Après combien d'années beaucoup le font dans cette localité ?……………………………

1.6 Quelle est la superficie de champ que vous (ou allez) défrichez(r) par culture ? (en ¼ ha) :

Cultures	**An 2002**	**An 2003**	**An 2004**	**Chaque année**
1^ère^				
2^ème^				
3^ème^				
Toutes cultures				

1.7 Estimez la distance qui sépare des lieux ci-après (en km):

Lieux	**Distance**	**Lieux**	**Distance**
Maison au Marché plus proche		Champ au Point d'eau plus proche	
Maison au Point d'eau plus proche		Champ à la Route principale	
Maison au Champ plus proche		Champ au Marché plus proche	
Maison au Champ plus éloigné		Champ au Village	
Maison à la Route principale			

1.8 Produisez-vous du charbon ? Oui ☐ Non ☐

1.9 Vos productions agricoles sont-elles souvent vite écoulées ? Oui ☐ Non ☐

1.10 A combien estimez-vous vos revenus agricole par an ? …..…………………….(F CFA)

1.11 Quelle(s) infrastructures sociales souhaiteriez-vous voir installée(s) dans votre localité ? (cocher les cases correspondantes)

Electricité à partir de générateur		Marché	
Point Eau (moderne - traditionnel)		Routes	
Centre de santé		Station radio	
Autres (préciser)			

1.12 Quels sont vos projets agricoles pour le futur ?
…………………………………………
……………………………………………………………………………………..…………
……………………………………………………………………………………………..

1.13 Que comptez-vous faire à l'avenir pour améliorer votre production agricole ?
……….………………………………………………………………………………………
……………………………………………………………………………………………

1.14 Quelles mesures préconisez-vous pour gérer durablement vos terres ?…..………………
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

Doc. 4.3 : Survey questionnaire N°2

Fiche d’entretien N°2

Fiche n°…… **Date**…./…/2003 **Enquêteur** : …………………..…………………

Commune………………...… **Village/Hameau** ………….……….**Campement**…..………

Identification de l’enquêté(e)					
Nom de l’enquêté (e)					
Age		Ethnie			
Etat matrimonial	Marié (e) ☐		Célibataire ☐		Veuf (ve) ☐
Motifs et but de l’installation du ménage	Année installation : …………………Année de retour : ……..………………… Provenance : ……………………Lieu de naissance : …………………… Raison d’installation : ……………………………………………………………... …………………………………………………………………..…………………..				
Composition du Ménage (effectif)	Catégorie	Actifs (14 – 55 ans)		Dépendants (0–13 & > 55 ans)	
	Homme				
	Femme				
	Enfants	0 – 5 ans	6 – 10 ans	11 – 15 ans	16 ans +
Niveau d’instruction	Illettré (e) ☐		Primaire ☐		
	Secondaire ☐		Supérieur ☐		
Alphabétisation	Alphabétisé (e) ☐		Non Alphabétisé (e) ☐		

I – UTILISATION DES TERRES

1.1 Quelles sont les cultures que vous pratiquez en saison pluvieuse?

Ordre	**Cultures**	**Superficie**	**Période (mois extrêmes)**		
			De …	**A …**	**Nb. mois**
1ère					
2e					
3e					
4e					
5e					

1.2 Combien de champs avez-vous en jachère ? ……………………………..………………

1.3 Depuis combien d’années ? ……………………...……………………………………

1.4 Quand pensez-vous l'exploiter ?………………………………………………………………

1.5 Après combien d'années beaucoup le font dans cette localité ?……………………………

1.6 Quelle est la superficie de champ que vous (ou allez) défrichez(r) par culture ? (en ¼ ha)

Cultures	**An 2002**	**An 2003**	**An 2004**	**Chaque année**
1ère				
2ème				
3ème				
Toutes cultures				

1.7 Abattez-vous tous les arbres qui se trouvent dans votre champ avant d'installer de nouvelles cultures ? ☐Oui ☐Non

- Si oui, pourquoi le faites-vous ?……………………………………..………………………

- Et quelles sont les espèces d'arbres que vous abattez souvent ?…………………….………
…………………………………………………………………………………………..…………

- Si non pourquoi ………………………………………………………………………..………

- Et quelles sont les espèces d'arbres que vous conservez ? …...……………………….………
………………………………………………………………………………………………..…
……………………………………………………………………………………………..………

1.8 Que faites-vous des arbres abattus ?

Bois de feu ☐ Charbon ☐

Bois d'œuvre ☐ Autres (à préciser)………………………………

1.9 Produisez-vous du charbon ? Oui ☐ Non ☐

II - FONCIER

2.1 Combien de champs avez-vous ?…………………………………………………………

2.2 Quel est le mode d'accès à la terre (faire valoir) dans votre localité ?

Mode	**Nb.**	**Sup.**	**Mode**	**Nb.**	**Sup.**
Location			Achat		
Héritage			Libre installation		
Autres (préciser)					

2.3 Qui vous a attribué vos terres ? Chef du village ☐ Parent ☐

Propriétaire ☐ Autres (à préciser)…………………………………………………

2.4 Quelle redevance versez-vous à votre fournisseur de terre par an ou à la fin de la période de culture ?………………...…………………………………...…………………………

2.5 Etes-vous autorisé à planter des arbres sur votre parcelle ? Oui ☐ Non ☐

2.6 Qui exploite (nt) les arbres fruitiers qui se trouvent sur votre terrain ?
……………………………………………………………………………………………

2.7 Qui a donné le nom de votre localité ?

Fournisseur ☐ Autres (à préciser)……………………..………………………

III – FEUX DE BROUSSE

3.1 Quelle est la période des feux de brousse ? ………………………………………………

3.2 Quels sont les auteurs des feux ?

Communauté ☐ Autochtones ☐ Ecoliers ☐

Allochtones (étrangers) ☐ Autres (à préciser)…………………………..…………

3.3 Quelles sont les causes de ces feux de brousse ?
……………………………………………………………….……………………

3.4 Quels sont les dégâts souvent enregistrés par rapport :

- aux cultures ?..…………………….………………...…………………………………

- aux habitations ?……………………………………………………..………………

- aux récoltes ? ……………………………….…...………………………………

- autres (à préciser) ? ………………………………..……………………………

3.5 Avez-vous été victime une fois de ces dégâts ? Oui ☐ Non ☐
- Si oui, comment le litige a-t-il été réglé ?……………………………………………

3.6 Quels sont d'après vous les avantages des feux de brousse ? ……….……………………..
……………………………………………………………………………………………

3.7 Comment s'organisaient les feux de brousse ? ……………………………………………
……………………………………………………………………………………………

3.8 Existe-il une politique traditionnelle de mise à feu ? Oui ☐ Non ☐

3.9 Si oui, comment peut-on améliorer cette politique ? ……………………………..………
……………………………………………………………………………………..

3.10 Si non, que suggérez-vous ?……………………………………………………………
……………………………………………………………………………………………

3.11 Connaissez-vous les autorités politico-administratives du village ? Oui ☐ Non ☐
- Si oui, qui sont-ils ? ……………………………………………………………………………
……………………………………………………………………………………………………

IV - TRANSHUMANCE

4.1 Quelle est l'origine des transhumants Peulhs ?
……………………………………………………………………..…………………………

4.2 Quels rapports existent-ils entre vous et les transhumants ? (Conflictuel, complémentarité, travail, etc.)
……………………………………………………………………………………………………

4.3 Quels sont les dégâts qu'occasionnent les transhumants ?
……………………………………………………………………………………………………
……………………………………………………………………………………………………

V - GESTION DES RESSOURCES

5.1 Avez vous des plantations ? Arbres forestiers Oui ☐ Non ☐

Arbres fruitiers Oui ☐ Non ☐
- Préciser les espèces plantées…………………………..………………….…………….……
……………………………………………………………..……………..…………………

5.2 Depuis combien d'années les avez-vous réalisées ?………………………………………

5.3 Quelle superficie de plantation réalisez-vous chaque année ?……………………………

5.4 Quelle superficie de plantation disposez-vous au total ?…………………………………..

5.5 Les revenus que vous rapportent ces plantations sont-ils plus intéressants que

ceux provenant des cultures annuelles Oui ☐ Non ☐
- Si oui, combien ? ……………………(en franc CFA/an)

VI - MARCHÉS ET ORGANISATION DE LA PRODUCTION

6.1 Vos productions agricoles sont-elles souvent vite vendues ? Oui ☐ Non ☐

6.2 Quels marchés fréquentez-vous souvent ?……………………………..……………..…
…………………………………………………………………………………………….….

6.3 A quelle distance se trouve le plus proche marché ? (en km) ………………….…………

6.4 Quels sont les produits que vous y échangez ?……………………………………………
…………………………………………………………..…………………………………

6.5 Vos produits sont aussi vendus à des commerçants ambulants ?

Tout le temps ☐ Souvent ☐ Rarement ☐

6.6 Les prix de vente des produits vous sont-ils satisfaisants ? Oui ☐ Non ☐

6.7 Si non, pourquoi ?………………………………………………………………………..…
……………………………………………………………………………………..………

6.8 Quel est le prix de vente des produits ligneux :

Saison	**Bois de feu (F cfa)**	**Charbon (F cfa)**	**Bois de service (F cfa)**
En saison sèche ?			
En saison pluvieuse ?			

VII - PERSPECTIVES

7.1 Quelle(s) infrastructures sociales souhaiteriez-vous voir installée(s) dans votre localité ? (cocher les cases correspondantes)

Electricité à partir de générateurs ou autre		Marché	
Point Eau (moderne - traditionnel)		Routes	
Centre de santé		Station radio	
Autres (préciser)			

7.2 Quels sont vos projets agricoles pour le futur ? …………………………………………
……………………………………………………………………………………..…………
…………………………………………………………………………………………………

7.3 Que comptez-vous faire à l’avenir pour améliorer votre production agricole ?
………..……………………………………………………………………………………
…………………………………………………………………………………………………

7.4 Quelles mesures préconisez-vous pour gérer durablement vos terres ?….……………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

Appendix 2: Results

Table 5.1: Land-use and land-cover change matrix in the study area for 1991 and 2000

	Land-use and Land-cover Classes for 2000												
1991	**FD**	**FC**	**SB**	**SA**	**Sa**	**Ss**	**Sh**	**W**	**BF**	**Set**	**Agr**	**Inselb**	**Total 1991**
FD	1381	21581	1087	741	3746	0	26	169	20	0	237	22	**29010**
FC	1374	182114	39366	19019	20892	61	687	389	634	21	4014	48	**268619**
SB	1304	74812	284742	58535	95537	264	8520	555	2260	81	16192	179	**542981**
SA	88	1899	13947	41638	19965	47	1050	10	124	22	3221	11	**82022**
Sa	483	2535	13237	5003	139372	237	2232	61	149	89	23512	601	**187511**
Ss	2	3	13	7	260	632	1	2	0	1	50	13	**984**
Sh	0	1	4	3	100	6	5300	2	1	0	68	18	**5503**
W	0	118	48	16	272	0	17	1202	2	0	20	3	**1698**
BF	0	0	0	0	0	0	0	0	1227	0	0	0	**1227**
Set	2	7	9	6	142	0	1	0	2	228	74	0	**471**
Agr	77	161	218	126	7146	107	71	19	17	139	3400	129	**11610**
Inselb	11	93	22	4	394	7	11	5	19	1	301	1195	**2063**
Total 2000	**4722**	**283324**	**352693**	**125098**	**287826**	**1361**	**17916**	**2414**	**4455**	**582**	**51089**	**2219**	**1133699**

Legend: Dense Forest (FD)
Woodland (FC)
Woodland savannah (SB)
Tree savannah (SA)
Shrub savannah (Sa)
Saxicol savannah (Ss)
Grassland savannah (Sh)
Water (W)
Wetland (BF)
Settlement (Set)
Agricultural fields (Agr)
Inselberg (Inselb)

Table 6.1: Household status per village

Source: Field Survey, 2003

Census village		Household Status		Total
		Migrant	Native	
Kikélé	Count	25	35	60
	%	41.7	58.3	100.0
Igbomakro	Count	20	20	40
	%	50.0	50.0	100.0
Dogue	Count	20	20	40
	%	50,0	50.0	100.0
Wari-Maro	Count	27	21	48
	%	56.3	43.8	100.0
Echantillon	Count	92	96	188
	%	48.9	51.1	100.0

Table 6.2: Allcohtonmous localities origin
Source: Field Survey, 2003

Origin	**Frequency**			**Frequency**	
	Count	**%**	**Origin**	**Count**	**%**
Afékoukou	3	3.3	Koukoulounda	2	2.2
Bajoudè	5	5.4	Kpaou	1	1.1
Bétérou	1	1.1	Matéri	1	1.1
Boukoumbé	1	1.1	Natitingou	7	7.6
Chabi-Kouma	1	1.1	Ouaké	5	5.4
Djougou	40	43.5	Paparapanga	1	1.1
Kaki-Koka	1	1.1	Partago	1	1.1
Kawado	1	1.1	Pkéka	1	1.1
Kikélé	1	1.1	Séro	1	1.1
Kopargo	6	6.5	Sirou	1	1.1
Korokondé	1	1.1	Soubouré	2	2.2
Kouandé	3	3.3	Togo	5	5.4
Total	**64**	**70.0**	**Total**	**28**	**30.0**

Table 6.3: Average household age per village

Source: Field Survey, 2003

Census village	Household Age	
	Average	Std Deviation
Kikélé	43,17	12,07
Igbomakro	48,28	17,29
Dogué	44,23	17,97
Wari-Maro	40,67	10,95
Total (sample)	43,84	14,59

Table 6.4: Cropped area per village
Source: Field Survey, 2003

Census village	Household-status	Area (ha) of all crops for year1		Area (ha) of all crops for year2		Area (ha) of all crops for year3		Average area (ha) of all crops for each year	
		Mean	Std Deviation	Mean	Std Deviation	Mean	Std Deviation	Mean	Std Deviation
Kikélé	Migrant	,00	,00	,00	,00	,00	,00	,00	,00
	Native	4,87	2,54	5,96	3,50	6,16	3,68	5,37	3,22
	Total	2,84	3,10	3,48	3,98	3,60	4,15	3,13	3,62
Igbomakro	Migrant	1,80	2,14	2,09	2,46	2,09	2,46	2,09	2,46
	Native	5,53	2,47	6,20	2,48	6,23	2,61	5,48	2,61
	Total	3,66	2,96	4,14	3,21	4,16	3,26	3,78	3,04
Dogue	Migrant	2,08	2,22	3,09	2,73	3,05	2,64	1,71	1,29
	Native	5,18	2,72	5,80	3,04	5,95	2,93	5,00	2,49
	Total	3,63	2,91	4,44	3,17	4,50	3,12	3,36	2,57
Wari-Maro	Migrant	,81	1,52	1,12	2,39	1,32	2,86	,73	1,37
	Native	3,90	2,00	4,62	2,38	4,62	2,38	4,24	2,17
	Total	2,16	2,32	2,65	2,94	2,77	3,11	2,27	2,48
Sample	Migrant	1,08	1,82	1,45	2,39	1,51	2,51	1,04	1,68
	Native	4,86	2,49	5,68	3,00	5,79	3,08	5,07	2,74
	Total	3,01	2,89	3,61	3,44	3,70	3,54	3,10	3,04

Table 6.5: Distribution of migrant according to charcoal production per village

Census village	Household-status	Charcoal production or not					
		No		Yes		Total	
		Count	%	Count	%	Count	%
Kikélé	Native	23	92	2	8	25	100
	Migrant	35	100			35	100
	Total	58	96.7	2	3.3	60	100
Igbomakro	Native	12	60	8	40	20	100
	Migrant	20	100			20	100
	Total	32	80	8	20	40	100
Dogue	Native	16	80	4	20	20	100
	Migrant	20	100			20	100
	Total	36	90	4	10	40	100
Wari-Maro	Native	24	88.9	3	11.1	27	100
	Migrant	21	100			21	100
	Total	45	93.8	3	6.3	48	100
Sample	Migrant	75	81.5	17	18.5	92	100
	Native	96	100			96	100
	Total	171	91	17	9	188	100

Source: Source: Field Survey, 2003

Table 7.1: Population per village, settlement and group of settlements: 1979, 1991-2004

N°	Settlement	Group	Year	1979	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
1	WariMaro		15è s	257	843	887	1003	1134	1283	1451	1640	1855	2098	2372	2683	3034	3431	3880
2	Samba		1987	14	26	27	30	34	39	44	50	56	64	72	82	92	104	118
3	Etou		1988	16	30	31	35	40	45	51	57	65	73	83	94	107	121	137
4	Adjimon		1970	171	315	331	375	424	479	541	612	692	783	885	1001	1134	1282	1450
5	Terougah		1993				5	6	7	8	9	10	11	13	15	16	19	21
6	Kadirgah	Peul Bari	1993				14	15	18	20	22	25	29	32	37	41	47	53
7	cwari1		1995						3	3	4	4	5	6	6	7	8	9
8	cwari2		1995						5	6	6	7	8	9	10	12	13	15
9	Kpawa		1997								571	645	730	825	933	1056	1194	1350
10	Gbagba	Berba	1997								42	48	54	61	69	78	88	100
11	Oke ofin	Peul Bari	1998									63	71	81	91	103	117	132
12	Obalanda	Peul	1998									19	22	24	28	31	35	40
13	c Yom	Yom	1998									6	6	7	8	9	11	12
14	Hi1		1998									15	17	20	22	25	28	32
15	Kpawagah	Peul	1999										72	81	92	104	118	133
16	okeofin2	Peul Bari	2000											70	79	89	101	114
17	Kpame	Peul	2000											48	54	61	69	78
18	bariba1	Peul Bari	2000											24	27	30	34	39
19	Brakou Ga	Peul Bari	2001												92	104	118	133
20	Kpaawa Ga	Peul	2001												71	80	90	102
21	warisud	Peul Bari	2002													45	50	57
22	Wari Dibo	Pila Pila	2003														72	81
23	Bariba	Peul Bari	2003														50	56
24	Kpaawa Ga	Peul	2003														38	43
25	Oke ofin	Peul Bari	2004															146
26	Dogue		16è s	235	909	1017	1077	1141	1209	1281	1356	1437	1522	1612	1708	1809	1917	2030
27	cpeul	Peul	1995						23	24	25	27	28	30	32	34	36	38
28	cpeul1	Peul	1995						17	18	19	21	22	23	24	26	27	29
29	cpeul2	Peul	1995						10	11	11	12	13	14	14	15	16	17
30	c Lokpa	Lokpa	1998									11	11	12	13	13	14	15
31	c Peul1	Peul	1998									35	37	40	42	45	47	50
32	c Peul2	Peul	1998									69	73	78	82	87	93	98

Table 7.1: Population per village, settlement and group of settlements: 1979, 1991-2004 (continued)

N°	Settlement	Group	Year	1979	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
33	Peul2	Peul	1999										23	25	26	28	29	31
34	Odokoudje	Peul	2000											122	130	137	145	154
35	Peul1	Peul	2000											15	16	17	18	19
36	Peul3	Peul	2000											22	24	25	26	28
37	Peul	Peul	2001												17	18	19	20
38	Kabye	Kabye	2002													7	8	8
39	Peul	Peul	2004															20
40	Igbomacro		16è s	326	790	851	888	926	966	1007	1051	1096	1143	1193	1244	1298	1354	1412
41	cyom	Yom	1994				18	18	19	20	21	22	23	24	25	26	27	28
42	cigbo	Yom	1995						4	4	4	5	5	5	5	6	6	6
43	c Betamar	Betamarib	1998								35	36	38	40	41	43	45	47
44	c Peul3	Peul	1998								12	12	13	14	14	15	15	16
45	Gourma	Gourma	1999										28	30	31	32	34	35
46	Yom	Yom	1999										18	19	19	20	21	22
47	Nagot	Nagot	2000										11	11	11	12	12	13
48	Api		2000										142	148	154	161	168	175
49	Betamari	Gourma	2001												22	23	24	25
50	Lokpa	Peul	2001												11	11	12	12
51	Bari	Peul Bari	2002													18	19	20
52	Peul1	Peul	2004															46
53	Peul2	Peul	2004															25
54	Peul3	Peul	2004															30
55	Kikele		15è s	447	1634	1701	1831	1972	2123	2285	2460	2649	2852	3070	3305	3559	3831	4124
56	KikeleLo1		1980	204	338	351	397	449	437	471	507	546	588	633	681	733	790	850
57	KikeleLo2		1980	334	554	577	653	738	683	735	792	852	917	988	1063	1146	1233	1327
58	c Nagot	Nagot	1998									11	12	13	14	15	16	17
59	c Peul4	Peul	1998									11	12	13	14	15	16	17
60	Peul	Peul	1999										17	18	19	21	22	24
61	Betamarib	Betamarib	2000											23	25	27	29	31
62	Betamarib	Betamarib	2000											13	14	16	17	18
63	Betamarib	Betamarib	2001												17	18	20	21

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PERSONNAL DATA

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EDUCATION

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Institution:	Benin National University
Date :	September 2000
Degree :	M Sc. (*D.E.A.*) Environment Management

Institution:	Benin National University
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Institution:	Benin National University
Date :	August 1988
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LANGUAGES

Language	Speech	Write
French	5	5
English	3	4
Yoruba (native)	5	5
Fon (local)	4	4
Goun (local)		

RESPONSIBILITY, SKILLS, AND POSITION

Responsibility within instance and organization	Since 2002	Ph.D. Studies in ***Modeling Land-use/Land-cover changes in Upper Ouémé Catchment in Benin*** Grant for research by DAAD and IMPETUS
	Since 1996	Research Assistant in Laboratory of Biogeography. Geography Department /FLASH/Benin National University
Computer skills	Currently use of Microsoft Word and statistic packages (SPSS, Microsoft ACCESS, EXCELL) Operating system: Windows; CLUE-s Model Programming language: FORTRAN - PASCAL	
	Good knowledge in Erdas Imagine, ArcView, Microsoft PowerPoint, Internet	
	Fair knowledge in ArcGIS, ATLAS GIS, MINITAB	
Actual position	Ph.D. student as Research Assistant within IMPETUS Benin	

PROFESSIONAL EXPERIENCES

Date	Since 2002
Country	Benin/Germany
Organism	"Integrated approach to the efficient management of scarce water resources in West Africa" - IMPETUS
Occupation	Research Assistant
Work	Data collection; images processing and ground truths assessing, Survey and collaboration for diverse fieldworks under WP3

Date	1998 to 2002
Country	Benin
Organism	National Coordination Unity of Inland Valley Consortium
Occupation	Coordinator Assistant
Work	Administrative management, research on key site of IVC, reports, workshops preparation and proceedings writing

Date	Since 1996
Country	Benin
Organism	Laboratory of biogeography / Geography Department in Benin National University
Occupation	Research Assistant
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PUBLICATIONS, THESIS, AND PROCEEDINGS

2006 Orékan, V., 2006 (ongoing). Implementation of local land-use and land-cover changes model for central Benin using socio-economic and satellite data. Ph.D. thesis under Promotors Menz, G.; Thamm, H-P; and Sinsin, B.University of Bonn, Bonn

2006 Orékan, V.; Sinsin, B.; Thamm, H-P & Menz, G., 2006. Spatial Effects of migration on land cover in the Upper Ouémé Catchment in Béni*n*. GECOREV Symposium on "Co-management of natural resources and the environment: For a dialogue between researchers, civil society and decision makers", University of Versailles-Saint-Quentin-En-Yvelines, 26-28 June 2006, France.

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1998 Orékan, V.O.A., 1998. Contribution à la géographie de la santé dans la sous-préfecture de Savè. Bachelor of Science (Maîtrise), Dissertation in Geography. FLASH/UNB, Abomey-Calavi, January 1998.

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Cotonou, February the 05th 2007

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