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Simulating agricultural land-use adaptation under changing climate using Multi-Agent System model in the Upper East Region of Ghana

By

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In

Climate Change and Land Use

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Certification page

I hereby declare that this submission is my own work towards the PhD and that, to the best of my knowledge, it contains no material previously published by another person, nor material which has been accepted for the award of any other degree of the University, except where due acknowledgment has been made in the text.

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ABSTRACT

One of the operationalised tools of human-environment system (HES) modelling approach is Multi-Agent System (MAS) which has been used in a number of areas to study the dynamics and management of human and natural systems especially when facing unexpected disturbances. Therefore, increasing studies are interested in using Multi-Agent analyses for the understanding of agricultural adaptation to environmental changes. However, when it comes to the use of MAS for the operationalisation of adaptation decision making in agricultural land use based on farmers' perception of climate variability, only very few studies empirically operationalise the concept in their simulations. Also, another challenge is how to isolate planned adaptation within a large traditional number of autonomous adaptation practices. The current research therefore focused on the implementation of a MAS approach for investigating the traditional adaptive strategies in a small scale area in the Upper East Region of Ghana by considering farmers' perception of climate change and variability. In order to achieve the purpose of this, Land Use Dynamic Simulator (LUDAS) approach was adapted and modified by integrating the two step-decision making sub-models. This modified version of LUDAS called SKY-LUDAS (referring to the communities where it was implemented: *Sirigu-Sumbrungu-Kandiga-Yuwa*) was constructed to capture the empirical heterogeneity of farm household agents and landscape agents (biophysical environment), and also to explicitly simulate interactions between these two agent types.

From the results of the multivariate statistical methods, three farm household agent groups were identified. Also the factors explaining the decision of these three household agent groups on the choice of the six identified land-use types were analysed. Two sub-models were developed and calibrated for implementing the two-step decision making sub-models: *Perception-of-Climate-Change* and *Adaptation Choice* strategies. Simulation results of SKY-LUDAS suggested that the land-use behaviour in the study area reflects a tendency of subsistence farming. In terms of farm-households' livelihood strategy, especially the structure of the gross income, there was a growing contribution of rice and groundnut. Also the pattern of the gross income under the scenario of perception on climate change (PCC) showed explicitly the contribution of the adaptation options in the households' livelihood strategy. Accordingly, SKY-LUDAS has revealed a gradual shift among land-use types from traditional cereals farming to the cultivation of groundnuts, rice, maize and soybean.

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LIST OF ABBREVIATIONS

Acronym	Definition
ABM	Agent-Based Model
AGRHYMET	Centre for Agronomy Hydrology and Meteorology
CEC	Cation exchange capacity
CHES	Coupled human environment system
CV	Coefficient of Variation
DEM	Digital Elevation Model
ES	Environment System
FAO	Food Agriculture Organisation
GIS	Geographic Information System
HES	Human Environment System
HS	Human System
IFOAM	International Federation of Organic Agriculture Movements
IPCC	Inter-governmental Panel on Climate Change
KCA	K-means Cluster Analysis
KMO	Kaiser-Mayer-Olkin
LUCC	Land-use and cover change
LUDAS	Land-use Dynamics Simulator
MAS	Multi-Agent System
MNL	Multinomial logit
MOFA	Ministry of Food and Agriculture
NGO	Non-Governmental Organisation
NO-PCC	No perception of climate change
ODD	Overview, Design concepts and Details
PCA	Principal Component Analysis
PCC	Perception of climate change
PHC	Population and Housing Census
SES	Social-ecological system
UER	Upper East Region
WASCAL	West African Science Service Centre on Climate Change and Adapted Land-use
ZEF	Centre for Development Research

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1. INTRODUCTION

1.1 Background

Human alterations of land cover as a result of the use of land-based natural resources not only have local and regional impacts, but can also have important effects at the global level. For instance, man-made changes in land use over the last 150 years have contributed about as much carbon dioxide to the atmosphere as has come from fossil combustion (Turner *et al.*, 1995). As a result, immediate environmental consequences as feedback from land-cover impact the land-use and other biophysical and human driving forces (Veldkamp & Lambin, 2001) because land-use and land-cover changes (LUCC) are so pervasive that when aggregated globally they significantly affect key aspects of earth system functioning (Lambin *et al.*, 2001). The impacts of past, present and potential future LUCC on climate and carbon cycle have been addressed in a number of recent studies (Boysen *et al.*, 2014) and the consequences can be expressed in terms of its bio-geophysical and biogeochemical effects.

In the mid-1970s, it was recognised that land-cover change modifies surface albedo and thus surface-atmosphere energy exchanges, which have impact on regional climate. Then in the early 1980s, terrestrial ecosystems as sources and sinks of carbon were highlighted; This underscored the impact of LUCC of the global climate via the carbon cycle (Lambin *et al.*, 2003). Accordingly, climate-driven land-cover modifications interact with land-use changes. Land-use change is driven by synergistic factors of resource scarcity leading to an increase in the pressure of production on resources, changing opportunities created by markets, outside policy intervention, loss of adaptive capacity and changes in social organisation and attitudes (Lambin *et al.*, 2003). For the previous reasons, LUCC and global environmental change form a complex and interactive system linking human action to land use/cover change to environmental feedbacks to their impacts and human responses. Another factor complicating this system is the fact that the linkages occur at different spatial and temporal scales. The outflow of soil nutrients, for example, has immediate impacts on land productivity, vegetation changes and soil erosion, mid-term impacts on landscape fragmentation and land productivity, and possible long-term impacts on climate change (Turner *et al.*, 1995).

It is widely admitted that climate represents a powerful environmental constraint on many human activities. Among the most frequently cited, human systems likely to be affected by climate change are agricultural land uses (Smit *et al.*, 1996). Impacts of climate change on agricultural land use have been estimated in a variety of ways (Lambin *et al.*, 2003; Smit et *al.*, 1996). In this regards, agricultural land use is found as a global occurring activity which relates directly and powerfully to the present and future condition of the environment, economies and societies. While agriculture has provided for basic social and economic needs of people, it has also caused environmental degradation which has prompted a growing interest in its sustainability (Smit & Smithers, 1993). As a result, Turner et *al.* (1995) consider land as a dynamic canvas on which human and natural systems interact and where the understanding of factors influencing LUCC has been the focus of scientific study across multiple disciplines, locations and scales.

The recent legacy of human-environment interaction research began in the 1940s to the mid-20th century. During the 1950s, Steward (1955) developed the concept of "cultural ecology" wherein he was interested in determining how culture is affected, through land use, by the environment. Afterward, system approach to the study of human and environment interactions emerged in the 1960s and 1970s with an emphasis on trying to understand and quantify the flows of energy (usually food energy) that people worked to extract from the environments through agricultural and livestock production and the pathways to humans. By the 1980s, understanding of human-environment interactions included human behaviour and biology. The idea of including human as a natural component of ecosystems resulted in the need for better understanding of how human interacts with the natural environment. The increasing need of understanding the interactions between human and environment led to the formation and development of new approaches. Such approaches move beyond the previous research approaches as mentioned earlier for the following purpose: first, to focus on the patterns and processes that link human and natural systems; second, to conduct an integrated assessment of climate change and emphasise reciprocal interactions and feedbacks both on the effects of humans; and third, to understand within-scale and a cross-scale interactions between human and natural components (Scholz & Binder 2003; Parker *et al.,* 2003; Liu *et al.*, 2007). Accordingly, one of the high priorities for narrowing gaps between current knowledge and policymaking is to improve tools for integrated assessment, including risk assessment, to investigate interactions between components of natural and human systems and the consequences of different policy decisions (IPCC, 2001). A lot of progress has been made in this regard, and science has succeeded to hold many aspects of complexity of LUCC by implementing new interdisciplinary approach such as coupled human-environment system (CHES) approach (Winterhald, 1980; Reenberg et *al.,* 2008; Schreinemachers and Berger, 2011; Scholz and Binder, 2004a; Villamor et *al.,* 2012). One of the operationalised tools of this approach is Multi-Agent System (MAS) which has been used in a number of areas to study the dynamics and management of human and natural systems especially when facing unexpected disturbances (Bharwani, 2004, Schouten, 2013) due to climate change and variability. Weather and climate conditions have long been recognised as key determinants for success in agricultural land uses. For this reason, the capacity of agricultural land-use system to adapt to climate change and weather conditions is based on its natural resource endowment and associated economic, social, cultural and political conditions, without forgetting that the history of agriculture reflects a series of adaptations to a wide range of factors from both within and without agricultural systems.

Other factors such as technological developments, markets factors, public policies and programmes are all elements influencing the nature and dynamics of agricultural land use (Wall & Smit, 2005). However, studies on HES are often challenged by the complex nature of unexpected behaviour of not only the natural hazards but also human factors. In such circumstances, previous studies suggested that in order to improve estimates of climate impacts on agricultural land use and contribute efficiently to adaptation research, there is a need to know more about how farmers perceive climate and how they respond, in both the short-and long-term, to variable climate conditions, including the magnitude and frequency of extreme conditions (Smit *et al.*, 1996). In other words, the question here is how perception is considered in adaptation research in order to integrate it into modelling procedure because our view of the world, or our perception of any system, has a great deal of influence on how we go about dealing with that system. Likewise, our perception of how particular ecological systems operate determines the approaches that we advocate in attempting to modify or manipulate those ecosystems (Ellis & Swift, 1988).

1.2 Problem statement

Given the nature of this research, an essential approach based on the integrated assessment of agricultural driven land-use changes could be the modelling of consequences of farmers' decision-making on processes at smaller and wider scale. Also, because management decisions made at the household level have effects on the individual subcomponents of the household-level system, this can have aggregated effects at village, regional, watershed and landscape levels (Wijk *et al.*, 2012). However, simulating decision-making at farm and household levels could be a major challenge due to the very high variability of human reactions even when facing the same situations. This issue was taken into account in this research by using advanced statistical analysis to categorise the farm households in order to derive homogenous agent-groups. Apart from the problem of scale and the heterogeneous behaviour in decision making, there are two main research gaps in the knowledge on agricultural land-use adaptation that need to be filled: First, the consideration of adaptation in farming system and mitigation of climate change by the models developed along the line and second, the understanding of adaptation practices which are really stimulated by climate change and variability. For instance, Wijk *et al.* (2012) conducted a study in order to review the literature and evaluate how suitable existing farm and farm household models studied aspects of food security in relation to climate change adaptation, risk management and mitigation. To do so, they systematically scanned approximately 16,000 research articles covering more than 1000 models. About 126 models met the criteria for subsequent detailed analysis. The main criteria include models that consider explicitly the farm or farm-household level and whether they consider climate as direct or indirect variable. Although many models use climate as an input, few were used to study climate change adaptation or mitigation at farm level. In general, the techniques for integrated assessments of farm households in relation to climate change, adaptation and mitigation are there, but they are scattered and have not yet been combined in a meaningful manner (Wheaton & Maciver, 1999; Patt & Siebenhüner, 2005; Wijk *et al.*, 2012). The second challenge is related to the empirical issue faced in this area of adaptation research. Accordingly, farmers seem to be more concerned about socio-economic change rather than climate change, meaning that adaptation measures reported by farmers may be profit driven rather than climate change driven (Deressa *et al.*, 2008; Nhemachena & Hassan, 2007). This challenge is more developed in chapter 6. However, it is introduced in this section in order to clarify that adaptation can be classified either as planned adaptation or as autonomous adaptation (Malik *et al.*, 2010). In this approach, adaptation may be warranted when climate change stimuli have significant consequences on agricultural land-use system. Climate change stimuli are described in terms of changes in mean climate and climatic hazards (Downing *et al.*, 1997 cited in Smit & Pilifosova, 2003).

With regard to the aforesaid, the terms adaptation and vulnerability are well defined in literature but still need specific and wide-spread implementation in farm systems research. This research acknowledges that the aforementioned attributes (i.e. adaptation, vulnerability and mitigation) are not easy to model, as they require knowledge of the buffering capacity of many aspects of the farming system due to the complexity of the system as indicated earlier. However, it is recommended that progress is urgently needed in these areas of research, and this is where dynamic models can play an important role. The concerns raised by the aforementioned statement met exactly the purpose of this research, since it used MAS to investigate explanatory insights related to climate change in agricultural land-use system.

1.3 Objectives and research questions

The general objective of this research was to provide an understanding of the agro-ecological dynamics of rural societies by developing a multidisciplinary approach. Through the Multi-Agent System (MAS) model, this approach explores the relationships between local communities and natural savannah ecosystem under a changing climate.

Accordingly, the specific objectives were to

1. analyse and characterise the farming system of the study area;
2. examine farmers' perception of climate change and variability in the study area;
3. analyse the adaptation strategies used by farmers to increase the resilience of the farming system;
4. operationalise Land Use Dynamic Simulator (LUDAS) as MAS model in examining the implications of perception of climate change and adaptation strategies' decision-making in the farming systems of the rural social-ecological system.

Given the complex relationships of both human and environment systems involved in agricultural land-use system, the following research questions were clarified in this work:

1. What is the nature of farming systems in the study area?
2. What are farmers' perception of climate change and variability regarding the trend of climatological parameters?
3. What are the possible responses of farmers to the implications of climate change and variability in the farming systems?
4. Could multidisciplinary approach be integrated in the modelling procedure in order to investigate climate change implications in agricultural land use?

The concept of MAS is developed in Chapter 2; however, it is introduced briefly in this section to clarify why it was very useful for achieving the overall objective of this thesis. Generally speaking, MAS is the computational research of interacting autonomous entities, each with dynamic behaviour and heterogeneous characteristics. The "agents" interact with each other and their environment, resulting in emergent outcomes at the macroscale (Heckbert *et al.*, 2010). In other words, MAS also called Agent-based modelling (ABM) (Bousquet & Le Page, 2004) is defined as an approach for modelling actions and interactions of single entities called agents, with a view to testing their effects on the system as a whole. Since this modelling tool offers the ability to explore how macrophenomena emerge from microlevel behaviour among a heterogeneous set of interacting agents, with the structure of interaction of critical elements affecting the dynamics of the systems (Heckbert *et al.*, 2010), then, it was considered as a key element for achieving the overall objective of this research.

1.4 Outline of the thesis

This thesis has eight chapters. Chapter 1 analyses the main contextual problems related to agricultural land-use system based on previous studies and provided a basis for the formulation of the research objectives.

Chapter 2: This chapter introduced the coupled Human-Environment System (CHES) based on the theoretical background behind the approach with the aim of understanding its complexity. Then the following sections were developed with the aim of clarifying the technological concepts and methods of MAS: the complexity of agricultural land-use with focus on the West African case; the analysis of coupled HES based on the principle of this approach; introduction of the Multi-Agent System (MAS) and the description of the SKY Land-Use Dynamic Simulator (SKY-LUDAS) used as MAS in this thesis based on standard procedures.

Chapter 3: In this chapter, based on the heterogeneous farming systems of West African Savannah in general and the agricultural land use in the study area in particular, and also further socio-economic conditions, the farming system has categorised in the way it can be integrated in the modelling procedure. The human agents are also categorised into typical agent groups according to livelihood structure, using multivariate statistical techniques. Finally, land-use decision-making sub-models are developed, being partly dependent on the previously derived agent groups using regression analysis. The coefficients generated through the application of these statistical techniques are directly fed into SKY-LUDAS model.

Chapter 4: This chapter deals with the sources and data processing techniques of landscape attributes for developing the biophysical sub-models based on the land-use type and the specific productivity functions. Both spatial landscape attributes and biophysical sub-models are fed into SKY-LUDAS model.

Chapter 5: This chapter explores the farmers' perception with the purpose of developing a sub-model on farmers' perception of climate change and variability based on the selected socio-ecological indicators. The sub-model was calibrated, validated based on the climatological evidence then integrated into SKY-LUDAS model.

Chapter 6: In this chapter, adaptation measures in the study area were analysed. Then, some barriers as factors of disturbance to adaptation were also introduced. Finally, by using statistical methods and the selected socio-ecological indicators, key measures were selected to build a sub-model which explains the main determinants of adaptation choice. The sub-model was calibrated, validated during the participatory process then integrated into SKY-LUDAS model.

Chapter 7: This chapter presents the parameterisation of SKY-LUDAS through the implementation of the different sub-models developed and calibrated for this purpose and also further procedures required in LUDAS framework (see section 2.4 chapter 2). The results of the baseline simulations and the two step decision mechanism (scenarios) were presented.

Chapter 8: This chapter presents the synthesis of findings in terms of conclusion based on the four objectives of the thesis. The limitations of the work and recommendations are also provided.

2- COUPLED HUMAN-ENVIRONMENT SYSTEM (CHES)

2.1 Introduction

Between 1960 and 1999, the earth's population doubled from three billion to six billion people (Hunter, 2000). In many ways, this reflected good news for humanity because of the different characteristics that accompanied this significant life increase. However, the human society dynamics has important environmental implications. Therefore, during the same period, the changes involving the dynamics in the global environment began to accelerate. As human invention and social interactions grew more, it became increasingly clear that human society as a system has a powerful effect on the environment. Yet the exact relationship between human system dynamics and the environment system is complex and not well understood. As a result, the investigation of the complex relationship between the environmental system as affected by human action is considered a major scientific challenge (Scholz & Binder, 2004a). Human and environmental systems are conceived as two different systems that exist in essential dependencies and reciprocal endorsement. In their work "Principles of Human-Environment Systems Research", Scholz & Binder (2004a) brought some contributions in terms of the definition of the two systems. According to them, the term human systems, meaning social systems ranging from society to individuals (Apostle, 1952 cited by Scholz & Binder, 2004a) has been used since the time of the ancient Greeks. These systems are supposed to have a memory, language, foresight, consciousness, etc. In contrast to the concept of human systems, the term environmental system is not older than 200 years. The definition of environment as the "conditions under which any person or thing lives or is developed; the sum-total of influences which modify and determine the development of life or character" arose in the 19th century, when environmental impacts of the industrial age could already be readily observed (Simpson & Weiner, 1989 in Scholz & Binder, 2003 p. 2).

What is a system? In simple terms, a system could be defined as a set of components which interacts with each other to form some aggregated whole. A system could also be defined as “a set of related definitions, assumptions, and propositions that deal with cut-outs of reality as an integrated hierarchy of organisation of matter, energy, and or organisms (Miller, 1978 cited by Scholz & Binder, 2003). The conceptual thinking on human system and environmental system both within social and natural sciences is an old issue which has traditionally suffered from a long-term confinement because of the polarities the concepts have created between scientists. Malthusian theory for instance, formulated before the agricultural revolution, is built upon the assumption that environmental resources such as land are fixed (Hunter, 2000). Of course, at that time, Malthus did not foresee the technological changes that have accompanied modernization and allowed agricultural output to increase faster than population growth. In other words, Malthus tried to demonstrate that technology and environment are independent variables that work together to determine the dependant variable of population, which he saw mainly in terms of population growth and size. In contrast to the Malthusian theory, Boserup (1965) considered the population as an independent variable that influenced both agricultural development and natural resources (Marquette, 1997). Generally speaking, the two theories have conceptualised their models based on the relationships between the following three components: Population, environment through land resources and technology. The main controversy in terms of conceptualisation remains in the direction of arraying the relationships between the aforementioned three components of the models. Anyway, in this approach without taking any position on these ideological assumptions, I just first try to remind myself that the issue concerning the relationship between human and environment dated from a very long time and second to acknowledge that the boserupean approach has really stimulated one of the most important challenges of our century.

Nowadays, a number of thinking is focused on the issue discussing and writing on the relationship between human environment systems. In fact, the complexity of this area is may be based on its multidisciplinary aspects strengthened by the multidimensionality of the concepts involved in the definitions of the two systems as we have mentioned earlier. As a result, the social systems could be some time related to the size, distribution, density and or composition of an area's inhabitants of the human population. The environment too is no less complex to be defined as a system encompassing qualities of the air, water and land on which humans and all other species depend on (Hunter, 2000). In fact, as social systems are part of the environment, environmental literacy calls for looking at these systems over different scales, ranging from the individual to the world population (Scholz, 2011a). Hunter (2000) in her book "the Environmental implications of population dynamics" has adapted a framework for considering the relationship between population and the environment which has helped her to review the complex relationship in fairly simple terms.

The framework indicating the relationship between human system and the environment (Figure 2.1) seems to be more explicit than the one indicated previously in the sense that it has brought more insights into the conceptualisation of human-environment system by disaggregating some complicated relationships; while still considering the three main components. In this framework (Figure 2.1), human and environment systems are linked by what the so called "mediating factors" which includes the technological, political and cultural factors.

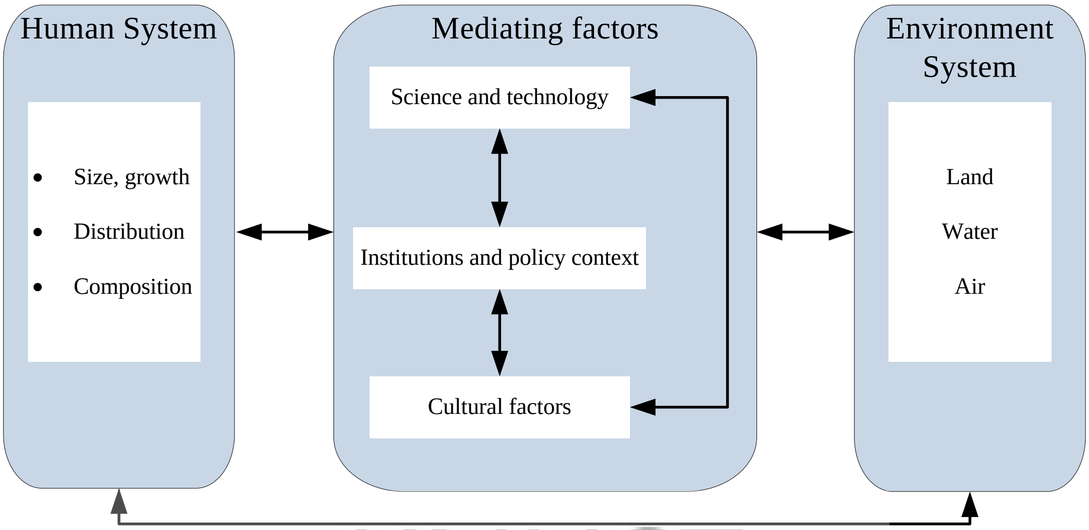


Figure 2.1: Relationship between human and environment system (adapted from Hunter, 2000)

In the Human-Environment System research, what makes the conceptualisation complex are also the relationships, inter and intra relationships that exist within the systems and become more complex over time with emergent phenomena resulting in the need to integrated knowledge for structuring the investigation of human-environment interactions which could cope with the complexity of the systems. In this regard, Scholz & Binder (2003) in "the paradigm of Human-Environment System", have stated that Human-Environment System (HES) are all environmental and technological systems that are relevant for or affected by humans. Based on the principles of this approach (HES), this chapter focuses on agricultural land use by analysing the interactions of the human environment systems in the research area.

2.2 Complexity of agricultural land-use system in West Africa

Human populations have been forced to adapt to biological, economic and social restrictions since the beginning of civilisation and have transformed ecosystems to ensure and enhance their survival. The 20th century witnessed two of the most profound social and demographic changes in recorded history. On one hand, population rose from around 1.6 billion in 1900 to over 7 billion in 2012. On the other hand, the transformation of a considerable portion of natural ecosystems in order to accommodate and supply this population grew accordingly in complexity and magnitude (Izazola & Jowett, 2009). Accordingly, the relationship between social system and natural resources is particularly important in developing countries where much of the population still depends on land-based subsistence production. Moreover, studies have focused on developing countries mainly due to the relatively higher population growth rates and the diversity of ecosystems found there, as well as the fact that the relationship between the two dimensions is clearer than in developed countries (Izazola & Jowett, 2009). However, it has been a challenge taken on by various disciplines due to its complexity as mentioned earlier and also because of the controversy and implications of the debate. In this regard, the alarming case of West Africa where the complexity of land tenure is as a result of the coexistence of several systems (whether customary, sometimes with religious influence, or state), none of which is completely dominant (Lavigne, 1998). Also, the disproportionality between agricultural production and growing population in West Africa is another situation justifying the appropriate focus of studies in this region as mentioned previously.

Accordingly, a shift from extensive to relative intensive systems of land use has been witnessed in almost every part of the world as a result of the pressure of population growth (Boserup, 1965). This explanation of land-use transitions emphasises the relationship between demand and land resources. In this regard, it is anticipated that both increased demand for land caused by population growth and land scarcity caused by declining agricultural land are likely to trigger land-use intensification (Jiang *et al.*, 2013) . In this context, because of the sustained and rapid increase of population growth rate, especially in West African rural areas, national policies must be strengthened for conditions of the rural agricultural land-use improvement as a pre-condition for transition to systems of shorter periods of fallow or no fallow at all. In the same point of view, Prabhu & Hans (1986) reported the following principal effects on farming systems generated from Boserup's analysis of population growth:

(1) It increases the intensity of land use, for instance causes the movement from shifting cultivation to permanent cultivation of land;

(2) It increases investments in land improvements especially by drainage, irrigation and terracing;

(3) It encourages the shift from hand hoe cultivation to animal traction;

(4) It reduces the average cost of infrastructure;

(5) It permits more specialisation in production activities;

(6) It induces a change from general to specific land rights; and

(7) It reduces the per capita availability of common property resources like forest, bush and or grass fallows, and communal pastures (Prabhu & Hans, 1986).

In particular, insights are sought in the parallels between natural and agricultural ecosystems, but, no easy answers are uncovered. Rather, a new long-term, multidisciplinary research programme is needed to develop agricultural methods that can feed a growing world and still preserve the vital services provided to humanity by the world's natural ecosystems (Tilman, 1999).

A number of thinking in the area suggests agricultural intensification as a major alternative to the issues. In fact, in the case of Sub-Saharan Africa, three factors have discouraged rapid agricultural intensification (Boserup, 1965):

(1) First of all, there has been historically a lack of investment in rural infrastructure (roads, farm inputs, etc.). Accordingly, this lack of infrastructure and investment limits access and use of farming inputs (fertilizer, irrigation, etc.) that would allow rapid intensification;

(2) Secondly, the new systems of land use may entail land reform that could lead to disputes over land rights. With this point, governments and powerful members of society such as large landowners or tribal chiefs may resist changes in land use since it may upset structures of power;

(3) And then last but not the least, the reliance on food imports and aids to meet the gap between the growing populations' food needs and production has undercut the pressure for domestic intensification of agriculture.

In this regard, by offering food aid and subsidized and concessionary food imports, the developed world has made it more attractive for many Sub-Saharan African countries to import food rather than increase national production (Marquette, 1997). Yet what is needed is the ability of the social systems to manipulate the landscape at its disposal in order to be able to meet the needs of the rapid growing number of the population. Nevertheless, all alternatives in the purpose of supporting agricultural systems' development indicated previously by Boserup (1965) have been one of the stimuli of the developed nations to improve the agricultural economy and is still currently supported by the developing nations to promote agricultural development. For instance,

(1) expansion of food through forest clearing;
(2) intensification of production on already cultivated land and;
(3) development of infrastructure necessary to support the increasing population;

All these alternatives suppose reforms in terms of land-use changes. As a result of this point of view, land-use change is driven by a synergy of different factors. Accordingly, Lambin et *al.* (2003) brought more insights to the issues when they designed a typology of the driving forces of land-use change based on the following factors:

(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 organisation, in resource access, and in attitudes.

On the other hand, natural climate variability is also a strong driving force of land-cover modifications which interact with land-use change by making the whole system more complex. Therefore, long term projections in land-use land-cover research approach require, first a good understanding of the major human causes of land-use changes in different geographical and historical contexts. It also requires an understanding of how climate variability affects both land-use and land-cover. Such understanding is gained through a collection of local scale case studies on land-use dynamics, which highlight how people make land-use decisions in a specific situation (Stéphenne & Lambin, 2001). The previous issue is supported by the fact that local-level human-environment case studies can be used to create regional "generalities" of land-use and land-cover change that promise to improve understanding and modelling of critical themes in global change and sustainability studies. The implications of these pathways are significant for a number of broad themes that have captured the attention of researchers and policy-makers (Lambin *et al.*, 2001).

2.3 Analyses of the coupled human-environment system (CHES) of the rural communities in the study area

Studies in the rural communities when analysing and characterising multiple factors that affect social, institutional, economic and environmental dynamics in the rural areas as well as their mutual interrelations, deal with a set of wider disciplines including sociology, anthropology, ecology, agronomy, history, and so on (Ambrosio-Albala & Delgado, 2008). By doing so, this may have brought studies in the rural communities very closer to a multidisciplinary approach. In this research, I adapted the approach where the rural areas are defined as isolated areas away from more dynamic centres of activity, set aside from centres of decision-making, with economic and social structures closely dependent on agrarian activity, social and economic heterogeneity not always sufficiently evidenced, and highly sensitive to modernisation dynamics from urban areas (Schouten, 2013; Ambrosio-Albala & Delgado, 2008). In this regards, the rural area is considered as a Social Ecological System (SES) corresponding to the "Human-Environment System" (HES), comprising the social, economic (human) and the ecological (biophysical) characteristics (Ambrosio-Albala & Delgado, 2008; Darnhofer, 2010; Schouten, 2013). It is the consideration that a partial understanding of each one, of all the three characteristics must be taken together to obtain a full understanding of the system dynamics. Based on the previous conception of the rural areas, the agricultural land uses operated through the agrarian system of the area remain the central activities that determine the socio-economic structure of the rural communities. Given the existing bipolarity between ecological science and socio-economic theory, Liu et *al.,* (2007) and Berkes *et al.,* (2003) called for reconsideration and revision if necessary of these theories to recognise the increasing roles of natural systems in socioeconomic patterns and processes in order to better understand the social-ecological system as new discipline (Scholz, 2011a; Villamor, 2012) and for implementing government policies and management programmes that ensure socioeconomic and ecological well-being in the future. This is where research in this new discipline, calls for disciplinary inquiries for deeper investigations of the social-ecological system. Indeed, there is a growing number of scientific works where a lot have been done in the area especially on modelling environmental impact on farming, but few of these integrate social aspects (e.g. sustainability of rural communities, provision of landscape services) or allow for dynamic changes caused e.g. by farmers 'learning (Darnhofer, 2010). In this approach, based on the simplified representation of the coupled human and environment system (Figure 2.2) the relationship between the rural communities of the research area and their ecosystem regarding agricultural land use practices as related to adaptation to climate change of the coupled system was analysed. To conduct this analysis, the framework for investigating HES of Scholz *et al.,* (2004a) was considered more convincing. Its principles stated the following six assumptions to be respected:

(1) To conceive human and environmental systems as two different, complementary, interrelated systems with human action and "immediate environmental reaction" being part of both systems;
(2) To consider hierarchy of human systems with related environmental systems;
(3) To construct a "state of the art" model of the environmental system and its long-term dynamics;
(4) To provide a decision theoretic conceptualisation of the human system with the components of goal formation, strategy formation, strategy selection and action;
(5) To characterise and conceptualise different types of environmental awareness in each previous component, and;
(6) To distinguish and model primary and secondary feedback loops with respect to human action.

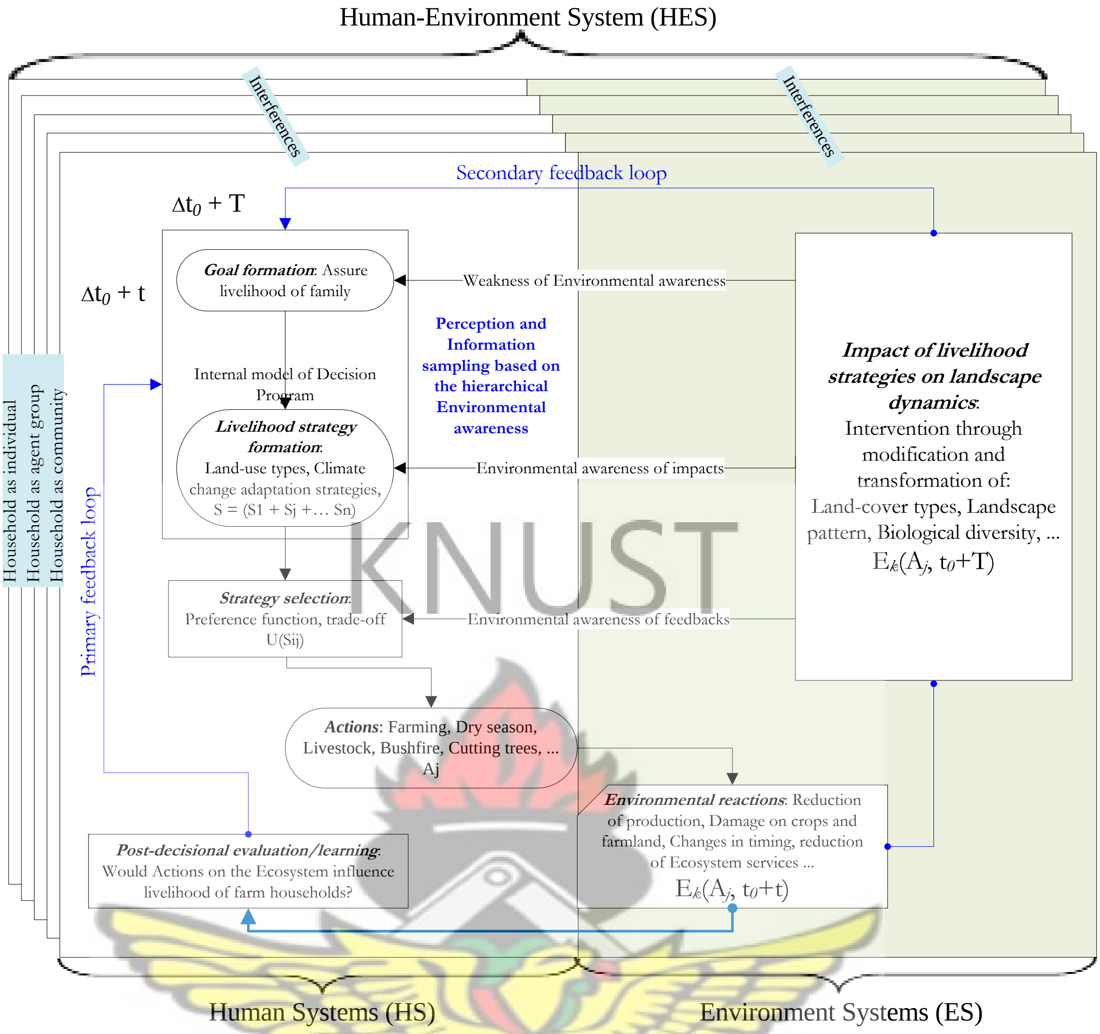


Figure 2.2: Simplified representation of the coupled human-environment system (CHES) as a case study of the rural communities where ith farmers pursued jth livelihood strategies (S) (modified from Scholz *et al.*, 2004a)

Complementarity of the HES: Figure 2.2 shows both Human system (HS) and Environment system (ES). The HS refers to scattered rural communities composed by the individual farm households and its internal organisation. The ES refers to the local environment (landscape) in the study area through its attributes among which land-cover types. The area is currently under pressure due to growing population, increased land degradation, declining agricultural productivity, changing land-use and livelihood strategies, and climate variability (Schindler, 2009). These two systems are inseparably interrelated in the sense that the rural communities intervene by conversion and modification of the natural ecosystem through agricultural land-use system (mainly farming, then livestock and dry season farming) and the ecosystem provides services to the socio-economic system. Dealing with modelling approach as an efficient scientific reasoning tool (Scholz, 2011b) requires a better understanding of the system elements, their relations, and interactions thus allowing for anticipating dynamics of complex HES.

Feedback-loop: based on the interrelationship described above, feedback-loops occur as reactions of the ecological system in which rural communities are affected. The loops can be positive or negative and can lead to acceleration or deceleration in rates of changes of both human and natural components as well as their interactions (Liu et *al.*, 2007). Two types of feedback loops within and among human and environment systems are considered: a primary feedback loop and a secondary feedback loop. They represent what the human system perceives, evaluates and learns about the intended *environmental reaction* and the *impacts of actions on environmental dynamics* (Scholz & Binder, 2003). For instance, in the study area, given the pressure of the increasing local communities on the ecosystem through many practices among which farming, supported by the climate variability, the land degradation and decreasing agricultural productivity have also taken over as reported by farmers themselves.

Hierarchy: For the purpose of taking right decisions, there is a need to know more about the hierarchical factors and mechanisms that control ecological functions across different spatial and temporal scales given the complex behaviour of ecosystems in space and time (Weston & Matthias, 1997; Viglizzo et *al.*, 2004; Gustafson, 2007). In general, beyond the decision-making, successful human problem-solving procedures are hierarchical and it has even been argued in this regard that a non-hierarchical complex system cannot be fully described, and even if it could, it would be incomprehensible (Simon, 1962; Wu & David, 2002). Accordingly, both HS and ES are composed of hierarchical structure. The HS hierarchy (Figure 2.2) refers to the individual farm households, the categorical household groups within the community and the whole population of the rural communities as aggregation of the first elements. The ES also comprises some levels of hierarchy including the individual family farms (Darnhofer, 2010), the sphere of influence (landscape vision) and the whole landscape.

Heterogeneity and time lags as stated by Liu et *al.* (2007) are varying intervals of time between human-nature interactions and their ecological and socio-economic effects. In some cases, the linkages between human and natural systems unfold slowly and the changes are usually not easily detectable. Also, the coupling HES vary across time, space and the organisational units as explained in the previous section. For instance, the socio-economic heterogeneity among farm households' agents in the study area leads to different choice and behaviour which in turn result in different ecological outcomes as land-uses. The heterogeneity of both HS and ES is described in detail in Chapter 3 and 4 respectively.

Interference: From a system-theoretic perspective, there are interactions among and within different hierarchy levels of human and environmental systems, from the micro (as referred to the individual farm households of HS) to the macro level (as referred to the rural population of HS) which cause trade-offs among these human systems (Scholz, 2011a). Accordingly, the behaviour at lower level of a system (microsystem) could explain a particular situation at a higher level (macro system). In the same point of view, local system dynamics may be greatly complicated by processes that occur at higher hierarchical levels (Cumming, 2011).

Decision making: the assumption of this approach is that human systems are intentional systems that act to satisfy goals and drivers in the sense that human behaviour is based on preference function (Scholz, 2011a). In other words, an individual farm household in making a single decision, may face trade-offs if he concomitantly follows different goals which sometimes cannot be simultaneously fulfilled. However, this is where the role of perception and information which is an internal process, based on hierarchical environmental information comes in, during the process of taking actions on the environment through goal formation, to the formation and selection of the livelihood strategies (Figure 2.2). For instance, as supported by Darnhofer (2010), farmers are well aware of the fact that change is on-going and that many changes are unpredictable and sudden. Hence, they have developed strategies to enhance diversity, as well as strategies to explore new opportunities. Whereas some farmers might implement only a few strategies, others implement a comprehensive approach to ensure the adaptiveness of their farm, thus strengthening the resilience of their farming systems. The reality is also, because of poverty, farmers also care about which strategy is less finance demanding, for instance, while having limited support from agricultural extension, with very low subsidy or not at all, and no information about weather forecast or environmental feedbacks, farmers take decisions, whether the choice was good or bad.

Environmental Awareness: As stated previously, HS are day to day dealing with decision making, therefore no matter how good is the perception, decisions must be made. In the approach of HES, accordingly to decision processes, which include goal formation, strategy formation and selection before actions will be taken, it is important to note that the environmental perception is also hierarchical.

(1) First, a human system can have no environmental awareness if, for example, the human system exclusively concentrates on its own interest without reflecting on the impacts and consequences of their actions on the environment. This case corresponds to what Russell & Norvig (1995) called “simple reflex agent”. For instance, these types of farmers have typical responses during the surveys on the adaptation to climate change:

they do not perceive any change in terms of long term temperature and rainfall and also they are not aware about any adaptation measures. In their farming perspective, they just respond to the logic of "condition-action rule" whenever it rains, they plant.

(2) Second, a human system can be aware of the *impacts* that may result from action, but does not conceive what it means for itself. This correspond to what Russell & Norvig (1995) called "A model-based reflex agent". In this case, farmers are aware about climate change, they even give good answers about most of parameters used to define a good perception of climate change, but they are not practicing any adaptation measures (No adaptation). Therefore, they also react in the same way as the reflex-agent when it comes to farming.

(3) Third, a human system can even be aware of the *feedbacks* that may result from the (unintended) change of the environment caused by an action. This correspond to what Russell & Norvig (1995) called A model-based, goal-based agent". This correspond to a situation where farmers perceive climate change and are adopting measures to mitigate the negative impacts, and can even give reasons of what they are practicing them as coping measures. This last case is considered as highest form of accessing environmental awareness (Scholz, 2011a; Scholz *et al.*, 2004a) where the actions are taken based on knowledge on the environment and the projective objectives. This leads to the concept of the rational agent: for each possible percept sequence, a rational agent should select an action that is expected to maximise its performance measure, given the evidence provided by the percept sequence and whatever built-in knowledge the agent has (Russell & Norvig, 1995).

2.4 Multi-Agent System (MAS)

Given the complexity underlined above, mathematical modelling can be considered as a "microscope" for investigating HES, allowing for the anticipation of possible dynamic patterns of complex systems (Scholz, 2011b). One promising approach for this perspective is MAS. MAS is a system composed of multiple interacting intelligent agents which can be used to solve problems which are difficult or impossible for an individual agent or monolithic system to solve (Fall, 2010). In this approach, the agent is considered to be anything that can be viewed as perceiving its environment through sensors (eyes, ears and other organs) and acting upon that environment through actuators (hands, legs, mouth and other parts of the body) (Russell & Norvig, 1995). More specifically, the intelligent agents are supposed to continuously perform three functions:

(1) perception of dynamic conditions in the environment;
(2) action to affect conditions in the environment and;
(3) reasoning to interpret perceptions, solve problems, draw inferences, and determine actions (Franklin & Graesser, 2001).

Many definitions on the concepts of MAS and even agents, exist in the literature, but in order to be more explicit in the definition of MAS, The following definition, which is widely accepted in the area of Human-Environment studies was considered. Therefore, a MAS is composed of:

(1) An environment E that is usually a space;
(2) A set of objects O. These objects are situated, that is to say, it is possible at a given moment to associate any object with a position in E;
(3) An assembly of agents A, which are specific objects (a subset of O) and represent the active entities in the system;
(4) An assembly of relations R, that link objects (and therefore agents) to one another;

(5) An assembly of operations Op, making it possible for the agents of A to perceive, provide, transform, and manipulate objects in O;

(6) Operators with the task of representing the application of these operations and the reactions of the world to this attempt at modification, which is called the laws of the universe (Ferber, 1999 cited in Bousquet & Le Page, 2004).

According to Fall (2010) the author, the idea of MAS model was developed as a relatively simple concept in the late 1940s; since, it requires computation-intensive procedures; it did not become widespread until the 1990s. Since then, international interest in the field has grown rapidly, especially in the area of LUCC where MAS models are suitable tools for representing complex spatial interactions under heterogeneous conditions and for modelling decentralised, autonomous decision making (Parker et *al.*, 2003; Bousquet & Le Page 2004). MAS models have been used by a number of studies, where in the area of natural resource management and agricultural system for instance, they have been applied to explore decision making processes and land use land cover pattern as related to socio-economic indicators, assumptions and scenarios (Federico & Morales, 2012; Schindler, 2009; Villamor, 2012; Le, 2005). MAS is also used to evaluate farm decision making in agricultural systems and understand how agricultural technology, market dynamics, environmental change, and policy intervention affect a heterogeneous population of farm households and their agro-ecological resources (Schreinemachers & Berger, 2011). Schouten (2013) also used MAS when exploring how the concept of resilience can be operationalised and implemented in decision-making for the management of rural social-ecological systems. In fact, the MAS approach has been used in a number of areas in simulation of land use land cover change (Parker *et al.*, 2001; 2003), understanding the driving forces of land use change and reconstructing the past changes (Stéphenne & Lambin, 2001), impact research of climate change on crop yields, crop rotation options (Troost *et al.*, 2012), and providing quantitative information for the development of the policies and interventions on rural producer organisations support (Latynskiy, 2014).

2.5 Description of the model based on standard procedure

Overview, design concepts, details (ODD) protocol is a standard used to document individual and Agent Based Model (ABM) with the aim of considering consistency in the text describing such models (Grimm *et al.*, 2006). The protocol has been updated (Grimm *et al.*, 2010) as it has been widely adapted in the socio-ecological research. In the same line, ODD protocol has also been updated as ODD+D in the way it emphasises on ABM that include human decision-making (Müller *et al.*, 2013). According to the authors, since the ODD protocol originates mainly from ecological perspectives, some adaptations are necessary to capture human decision-making. Modifications focus on the Design concepts and Details blocks of ODD protocol. Hence, this research followed the ODD+D protocol to describe the simulations of the current version of LUDAS called SKY-LUDAS (referring to the names of communities "*Sirigu-Sumbrungu-Kandiga-Yuwa*" where it was first implemented) as a MAS model used in this work. LUDAS (Land Use Dynamic Simulator) which is a Multi Agent System was created and implemented as VN-LUDAS by Le (2005) in Vietnam. Afterward, LUDAS found applications in several land use studies at the Centre for Development Research (ZEF) in Bonn. In this regards, LUDAS approach has been adapted and implemented as GH-LUDAS in the Upper East Region of Ghana (Schindler, 2009) and as LB-LUDAS in Sumatra, Indonesia (Villamor, 2012).

2.5.1 Overview

2.5.1.1 Purpose

The purpose of SKY-LUDAS was to explore the complex dynamics of agro-ecological systems in order to bring some insights into the understanding on how households' farming systems cope with climate change and variability in the study area. The model examines the relationship between population growth (household patterns), farming system (structure of household livelihood), ecosystem (through the land use patterns) and adaptation strategies to climate change and variability. Hopefully this exploration allows at the end of this work to capture the implications of climate change and variability in the farming system and responses of farm households. This research adapted the previous versions of Land Use Dynamic Simulator (Le, 2005; Schindler, 2009 and Villamor, 2012) which were designed first to support land-use decisions in the forest margins of Vietnam in considering different land-use policy interventions, then to explore the impact of policy interventions on future land-use/cover patterns and income indicators in the Upper East Region of Ghana and in addition to the above to explore the potential trade-offs and synergies of the policy interventions on the goods and services temporally and spatially in Sumatra (Indonesia). With regards to the general framework of LUDAS, SKY-LUDAS (Figure 2.3) also focused on land-use pattern and income generations through the rain fed agricultural land-use in the context of changing environment. Specifically, the study emphasises on farmers' perception of climate change and variability as condition of adopting any strategy innovated by farmers to support the resilience of the farming systems.

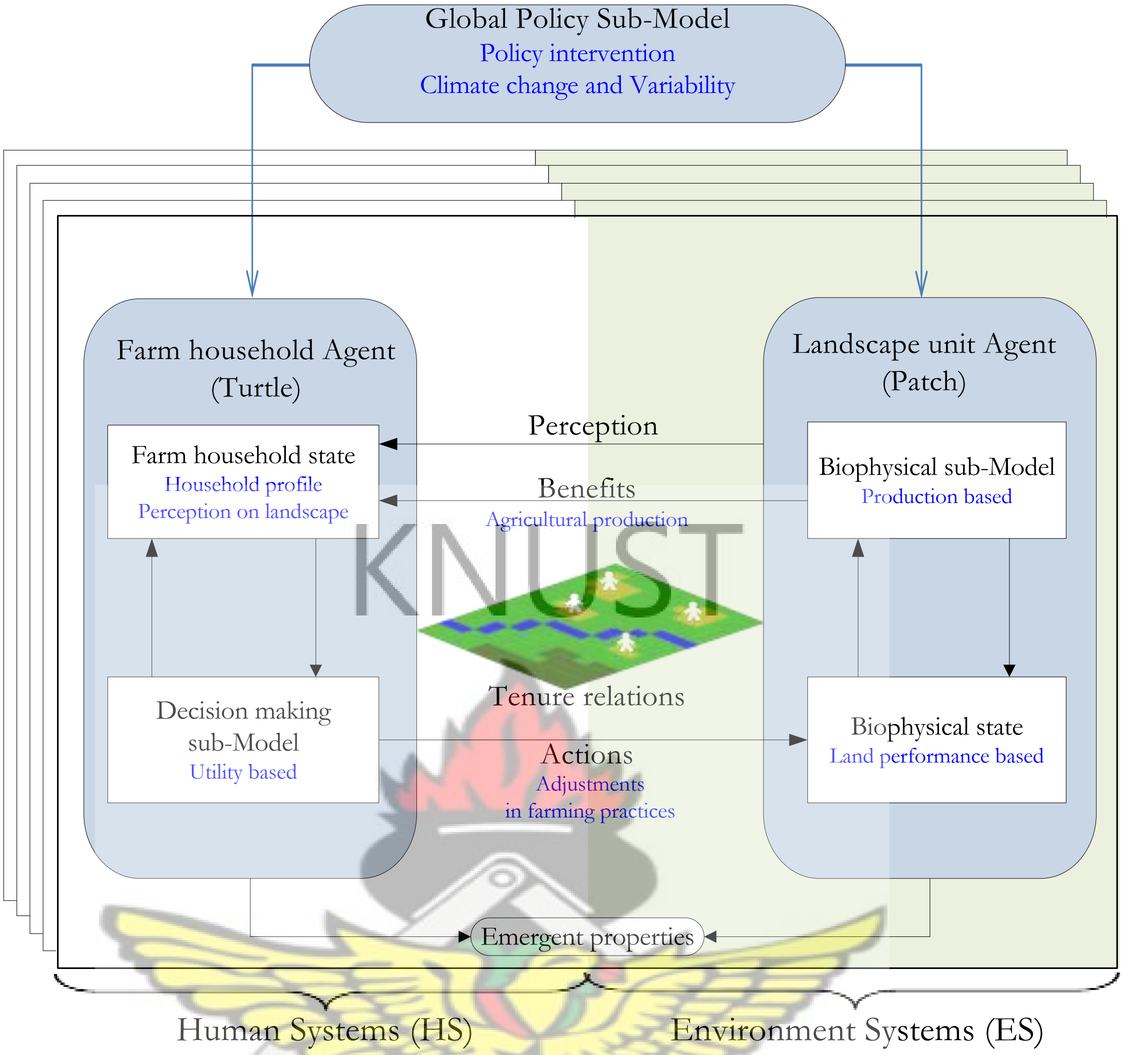


Figure 2.3: Conceptual framework of SKY-LUDAS (Adapted and modified from Le, 2005). Land Use Dynamic Simulator which is a Multi Agent System was created and implemented as VN-LUDAS by Le (2005) in Vietnam. Afterward, LUDAS found applications in several land-use studies at the Center for Development Research (ZEF) in Bonn. In this regard, LUDAS approach was adapted and implemented as GH-LUDAS in the Upper East Region of Ghana (Schindler, 2009) and as LB-LUDAS in Sumatra, Indonesia (Villamor, 2012).

2.5.1.2 Agents, state variables and scales

Two types of agents are considered in SKY-LUDAS:

(1) Farm households as human agents and;

(2) Landscape agents based on the land use/cover raster map.

Each type of agent is characterised by a number of attributes.

Human agents: human agents are represented by the individual farm households. The state variables of human agents are represented by several livelihood indicators which guide the livelihood strategies by considering the approach of the capital assets (see section 3.4) used to categorise the population. The variables include social identity (e.g. livestock); human resources (e.g. labour); land resources (e.g. landholding); financial resources (e.g. income); physical capital (e.g. proxy resources); and policy access (e.g. subsidy).

Landscape agents: landscape agents are represented by individual congruent land patches with resolution of 30 m as corresponding to the GIS-raster layers (e.g. raster pixels of Landsat imagery and other landscape attributes such as Digital Elevation Model) of biophysical spatial variables (e.g. land cover). The following variables are also related to landscape agents: spatial proximity (e.g. distance from house to the main river); landscape vision which is a sphere of influence (local environment) for household agent. Space is implicitly included in the model through the landscape where the coverage area is 192 km^2 and the size of a cell pixel is 30 m x 30 m. The model runs with annual time steps over a period of 20 years. The policy factors (subsidy on farm inputs, agricultural extension services to farm households, information on weather and climate change) are considered externally with regard to the boundary of the modelled system in order to define different scenarios and policy management. Other factors such as population growth and land cover transformation and modification as consequences of land use decision are internal of the system.

2.5.1.3 Process overview and schedule

Basically, the main steps specified by SKY-LUDAS are reported in Figure 2.4 including farmers' perception and adaptation choice routines located in the simulation programme. These last two sub-models as two algorithms added to the simulation programme, represented the focus of this research. The time loop so called annual production cycle, included sequential steps, which are agent-based and integrated with patch-based processes. In most cases, all household agents and landscape agents (patches) are called and perform task in parallel (i.e. synchronising actions).

2.5.2 Design concepts

2.5.2.1 Theoretical and empirical background

In addition to the main purpose of GH-LUDAS (Schindler, 2009) implemented in the research area, which consisted of exploring the land-use land-cover pattern and the socio-economic dynamics through interaction among farm households and the agro-ecological landscape in the study area (see chapter 3) under the influence of certain policies, the current version focused on the complexity of coupled Human-Environment System through exploring innovated adaptation practices in farming systems in the context of changing environment. The approach was designed in the way that only those farm households who perceived climate change will adapt by selecting innovated method for adjusting their land-use systems based on their livelihood indicators. The agent decision making is utility based using probabilistic function of choice. Other sub-modules (i.e. agricultural productivity, etc.) are ecological sub-models built into the model of landscape agent through statistical regression methods (based on empirical data collected to parameterise the model (Surveys in 2013). The empirical data come from the following sources: surveys on farming system data, perception of climate change, adaptation of cropping system to climate change; participative workshops with stakeholders; spatial (landscape) data (land-use/cover raster, DEM, soil map, etc.); field measurements (plots and households' locations and plot areas).

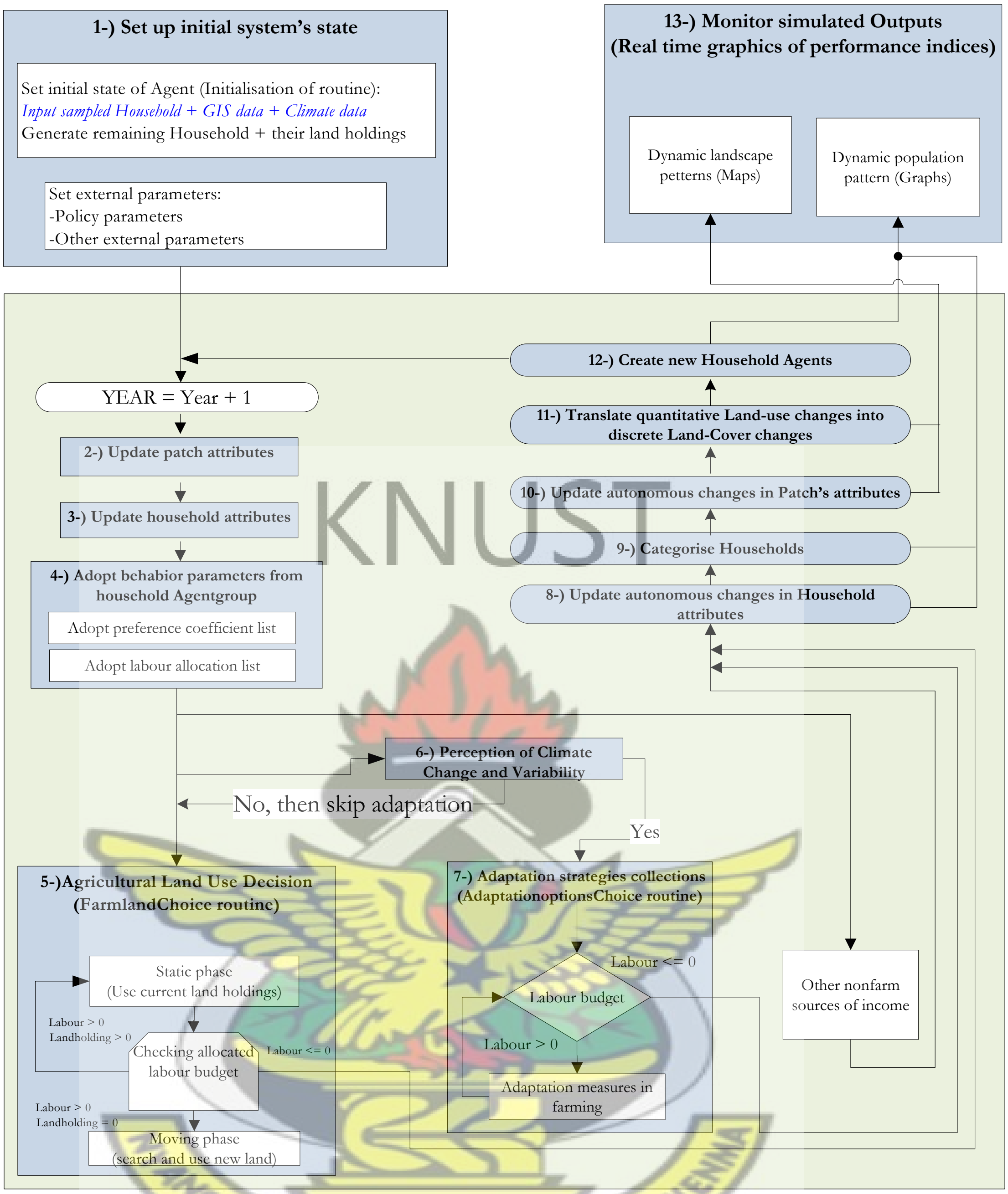


Figure 2.4: Time loop procedure in 13 Steps of Multi-Agent Simulation process (modified from Le *et al.*, 2008)

2.5.2.2 Individual decision making

Decision making is modelled at the individual household level as a routine integrated into Human Decision making sub-model simulating household-specific land use behaviour. After every time step, each agent is assigned to the group with similar values (updated household attributes). Hence within the household agent group where the socio-economic features are assumed to be similar, all households exhibit also similar decision making. In the SKY-LUDAS framework, like many other MASs the dynamic processes are scale dependent. In other words, especially in the area of land use land cover change research, the process of LULC at the higher level of the whole population is the result of the interaction at the lower levels. Hence, in the model the Human System is hierarchically designed. Also since at the end of each time step, a household is allocated to the group that has the highest similarity, if this is a case, then he will also adapt the new behaviour parameters of this new group which will affect the decision structures. The household decision making is utility-based modelled by the decision making mechanism which represents choices among a discrete set of options (land use types, adaptation options) using utility function to estimate the profit coming from each option. Utilities for each choice are calculated by multinomial logistic analyses. And the mechanism works based on the inputs from the household profile, policy-related variables and the state variables of the perceived landscape patches.

2.5.2.3 Learning

The implementation of learning in the model enables simulations of adaptive behaviour, since an agent would base its decisions on constantly updated information (Latynskiy, 2014). In SKY-LUDAS model, adaptive traits of each individual agent are explicitly processed mainly by land-use decisions and the change in behaviour strategies. At first, agents adapt to current socio-ecological conditions by choosing the best land use in the best location in terms of utility. Then, a household's behaviour model may change by imitating the strategy of that household group most similar to it (Le et al., 2010). This way, individual agents' decision model may change over time and context. Also, a household agent generates its landscape knowledge by updating landscape visions to provide the basic landscape space (Villamor, 2012).

2.5.2.4 Individual sensing

For evaluating land-use choice, household's agents are assumed to know perfectly the landscape characteristics through the landscape vision, which are different depending on the household agent category. Then the evaluation of adaptation strategies is guided by the perception of climate change sub-model.

2.5.2.5 Individual prediction

The model has a landscape vision module which stores spatial information perceived by each household agent from the landscape, and a programme of instructions for generating agent behaviour under different circumstances. Accordingly, household agents recognise spatial information for optimising the spatial land-use choices only within their own plots (Villamor *et al.*, 2014a).

2.5.2.6 Interaction

In this modelling procedure, household agents and their local environment are characterised by complex systems of interactions. In this regard, agents may not only interact with each other, but also with the environment, thus redefining its state. For instance, household agents transfer information (i.e., state variables) to young agents for their best land-use alternative in the same location. Interactions between household and landscape agents occur mainly through tenure relations and a perception-response loop. Tenure relations are institutional rules that regulate the household's access to land resources. The perception-response loop involves information flows between households and patches. The information flowing from household to patch reflects the decision made by the household on land use on the patch. The information flowing from patch to household corresponds to the perceived bio-physical state and benefits that the household can derive from the use in arriving at decisions. Policy and other macro-drivers influence the system behaviour through modifying the functional relationships between the human and environmental system (Le, 2005).

2.5.2.7 Collectives

Both human system and landscape system are self-organised in a hierarchy of three organisation levels.

- The human system follows the three levels of organisation:

(1) Household agents, representing the individual farm households of the study area;

(2) Groups of household agents which refer to the collection of household agents with similar livelihood typology therefore assumed to have similar land use behaviour, and;

(3) The whole population representing the collection of all agents which pattern is a result of emerging processes at the lower levels of the hierarchy system.

- The Landscape system is also represented in the form of a hierarchy of spatial scales referring to three levels of organisation as indicated earlier:

(1) Landscape agent;

(2) Landscape vision and;

(3) Entire landscape.

2.5.2.8 Heterogeneity

Farm household agents are heterogeneous in varied ways: variable states, spatial locations, agent categorisation. They are also heterogeneous in their decision making in terms of land use. Another factor of heterogeneity is also the adaptation decision mechanism which in addition to the household profile, is guided by the probabilistic sub-model of farmers' perception regarding climate variability.

2.5.2.9 Stochasticity

At the implementation level, empirical data are used for initialising the household state and landscape attributes. Then for every time loop of the simulation programme, the values of household attributes are proximated stochastically within the uncertainty ranges of the values of the previous time step. Such stochasticity is presented in the following sub-modules:

(1) Update household attributes;

(2) Adopt behaviour parameters from household Agent group;

(3) Update autonomous changes in household attributes and;

(4) Categorise households and Create new household Agents.

2.5.2.10 Observation

The strength of the MAS-LUCC in general and SKY-LUDAS in particular is that it gives a very informative set of outputs. When running a simulation, at any point in time and space, the model will give three main types of outputs: simulated world, predefined indicators and graphics (Le, 2005). This way, all simulation outputs including a spatially explicit map of land use/cover, graphs indicating the temporal performance of land use and the living standards at the local community level can be exported to other data processing software in order to analyse and compare the results of selected scenarios.

2.5.3 Details

2.5.3.1 Implementation Details

The theoretical framework was programmed in the Netlogo package 5.0.3 (Wilensky, 1999). Netlogo is a multi-agent modelling environment, which offers both a convenient language to programme agents (and interactions) and tools to visualise and export results. As MAS, the platform allows programming intelligent agents, their interactions and monitoring the connections between micro-level behaviour of agents and macro-level patterns of the whole system (Le, 2005). Netlogo consists of two main pages between which the user can switch, one reserved for the programme code, and a second, the model interface which allows the setting of model parameters and the visualisation of results.

2.5.3.2 Initialisation

During the initial state (at t = 0 of the simulation run) the model followed the procedure steps of the LB-LUDAS (Villamor, 2012):

Step 1: The data of the household sample (Ns) are imported, and the user can select the size of the total population (Nt). The source of variation depends on the size of Nt that is set by the user. The initial landscape of the model is imported as GIS-raster files of landscape variables that are either from empirical data (conversion of land-use GPS based to raster) or from secondary data (DEM, satellite images, etc.) produced separately by spatial analyses (slope, wetness index, etc.). At this level, the variables of both households and landscape are deterministically set.

Step 2: In this step, still at the implementation level, the land parcels of newly generated households are created using the bounded-random rules.

2.5.3.3 Input Data

Data and parameters are defined, calibrated externally and organised in text format by the modeller. Such data, include GIS-raster, household data and specific parameters. The household and the GIS datasets were needed for the initialisation of the coupled human-landscape, while parameters were needed to specify various internal routines of the model. For the annual increment of the population, the model used the annual population growth rate of 2.5% according to the 2010 population and housing census in Ghana.

2.5.3.4 Sub models

Basically the general framework of LUDAS model comprised more than 10 key sub-models and calculation routines which are integrated. SKY-LUDAS adapted the basic procedures of LUDAS as reported in Table 2.1 and because of the specific objectives assigned to this research, two following additional procedures were added in the decision programme routine specifically in the *FarmlandChoice*: Farmers' perception and Adaptation choice, the two nested as two step decision making. All the procedures are described in Table 2.1.

Table 2.1: Main sub-models and calculation routines integrated in LUDAS (modified from Le, 2005). Under certain sub-models, some procedures have been modified and others contain two or more procedures such as farmers' perception and adaptation choice procedures integrated under FarmlandChoice procedure.

Sub-models/Calculation routines	Functions	Entities involved
Initialisation	(1) Import GIS data, (2) Import sampled household data, (3) generate the remaining population, (4) generate the holding plots, (5) generate the household coefficients	Household-agent Plot-agents (pixel)
Labour-allocation	Set the labour list of the household annually	Household
FarmlandChoice	Perform land-use choices based on the bounded-rational choice and nested with rule-based algorithm	Household-agent Plot-agents (pixel)
Perception	Under *FarmlandChoice*, this procedure performs the household perception of climate variability	Household-agent Plot-agents (pixel)
AdaptationChoice	Under *FarmlandChoice* routine, this procedure performs the adaptation choices based on the bounded-rational choice	Household-agent Plot-agents (pixel)
AgronomicYieldDynamics/ Income	Using the productivity function, calculate yield production of farmlands in response to production inputs and site conditions	Household-agent Plot-agents (pixel)
Update-household-state	Update the changes in household profiles annually	Household-agent
AgentCategoriser	Based on the updated household profiles, categorise households into similar groups	Household-agent
Generate-household-coefficients	Generate behaviour coefficients of household, allow variants within the group but stabilise behaviour structure of the group	Household-agent
Update patch variable/natural transition	Update land-use type for patches that had undergone land-cover change during the simulation of the previous procedures	Plot-agents (pixel)
Create-New-Households	Create a young new household agents controlled by an empirical function of population growth	Household-agent
Plot-Graphs	Draw different graphs of system performance indicators	Household-agent Plot-agents (pixel)

3. CAPTURING HETEROGENEITY IN AGRICULTURAL LAND-USE SYSTEM

Land-use change can be described by the complex interaction of behavioural and structural factors associated with the demand, technological capacity, social relations affecting demand and capacity, and the nature of the environment in question (Verburg *et al.*, 2004a). As a result, land-use change patterns are the result of the complex interaction between the human and physical environment. Another factor of complexity of land use change is its heterogeneity especially in African land-use systems where the diversity is considered as a norm (Berhan *et al.*, 2011). Such heterogeneity from farming systems to the land-use decisions through cropping systems reflects the livelihood strategy. For theoretical understanding, an approach representing this heterogeneity in modelling procedure is highly required.

From the same point of view, important issues in the use of MASs are how to appropriately represent the heterogeneity of agents and their environment as software objects in the ways that accurately reflect the heterogeneity of "real-world" objects, and what effects heterogeneity has on the outcomes of the models (Brown & Robinson, 2006). In this regard, heterogeneity characterises livelihood strategy of agents as well as specific behaviour with respect to land-use decisions for human agent groups (Le, 2005). Accordingly, it is admitted that advanced statistical analyses can use process empirical data and derive such heterogeneity. Therefore, this chapter pursued the following objectives:

(1) To briefly identify and describe the farming systems in West African Savannah with focus on the study area and characterise the cropping system as land-use system or livelihood strategy of farm-households;

(2) To develop the farm household agent groups based on the identified livelihood typology, and then;

(3) To determine and calibrate land-use choice models, where land-use behaviour should be determined by the specific livelihood groups of the households.

3.1 Overview of Farming Systems in the West African Savannah

In 2001, the FAO carried out a global assessment of 15 distinct farming systems in Sub-Saharan Africa (Figure 3.1). These farming systems have been categorised based on the following criteria (Dixon *et al.*, 2001):

(1) Natural resource base;

(2) Principal crops and domestic animals;

(3) Level of crop-livestock interaction and;

(4) Scale of operations.

A farming system is defined as a population of individual farm systems that have braoadly similar resource bases, enterprise patterns, household livelihoods and constraints, and for which similar development strategies and interventions would be appropriate (Dixon *et al.*, 2001). The household, its resources, and the resource flows and interactions at this individual farm level are together referred to as a farm system. Accordingly, among the classified farming systems, the "cereal-root crop mixed farming" system is considered with high interest because it targets the West African Sudanian savannah. Some overall characteristics of the area are described below:

West African Sudanian savannah accounts for 312 million ha of the land area of the region and supports an agriculture population of 59 million (15% of the region). Livestock is the second important activity with a high proportion of cattle. Cereals such as maize, guinea corn and millet are as important as root crops such as yam and cassava. Intercropping is very common and a wide range of crops are grown and marketed. The temperatures are high in the area characterised by mono-modal rainfall regime with a length of growing period of 120 to 180 days. Some of constraints which explained the vulnerability of population are drought, low animal traction, poor transport and communication infrastructure (Dixon *et al.*, 2001).

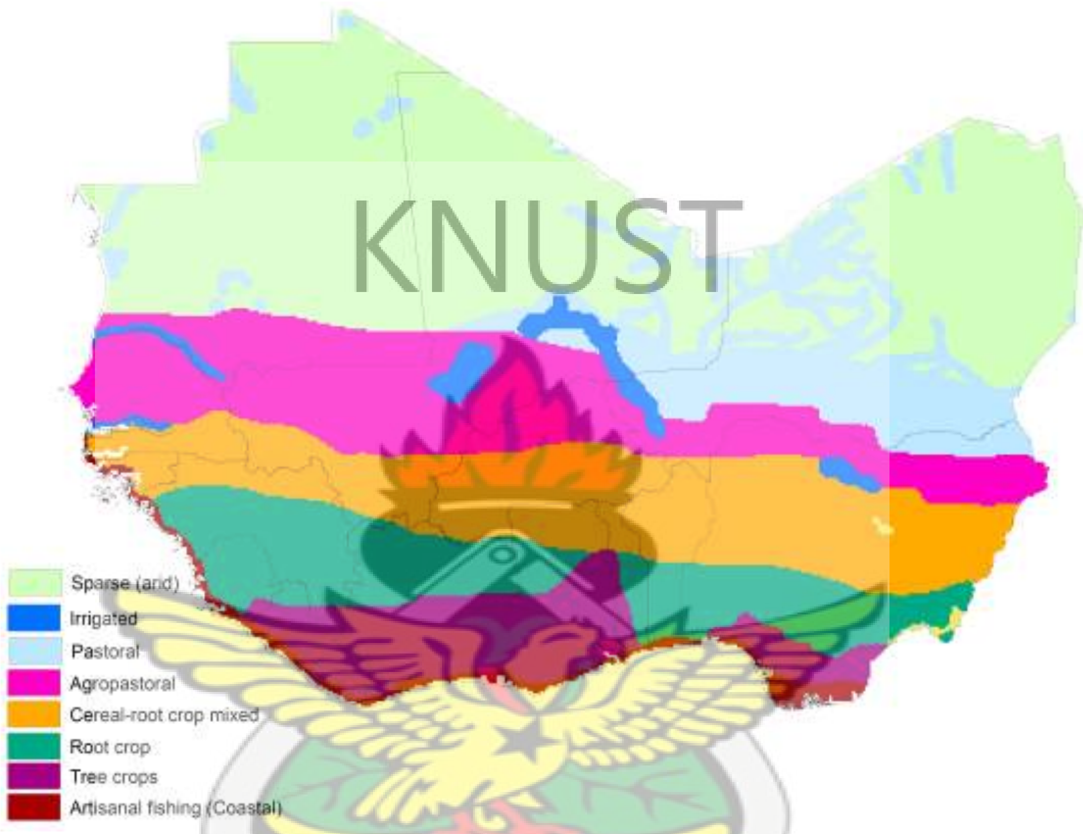


Figure 3.1: West African farming systems (Dixon et al., 2001)

Historically, West African farming systems were under relatively low population density until the beginning of the century where shifting cultivation was based mainly on fallow migratory system. Nowadays, these migratory systems are modified into the more sedentary bush fallow and compound farming systems in response to the growing pressure on the land (Gyasi, 1995). The bush fallow system is characterised by clearing and burning of vegetative cover. This farming system typically involves intercropping among natural economic trees in the form of agroforestry in out-fields operated on a rotational basis 1-6 km from the compound house. The system comprises lowland bush fallow farms, upland bush fallow and *faddama* which is floodland and irrigated farming (Gyasi, 1995). The compound farming system, on the other hand is an in-field relatively permanent mixed cropping system centred on the compound house. The land at the immediate vicinity of the house is the most intensively cropped and because of the high soil fertility often maintained through waste and animal manure (Gyasi, 1995; Schindler, 2009). However, nowadays the area especially the Sudanian savannah is facing a shift of the ecological zones characterised by the desertification of the Sahel region or "Sahelisation" of the savannah and even "Savannisation" of the forest with the corresponding changes in the existing cropping systems (Callo-concha *et al.*, 2012). In considering these agro-ecological changes, a study conducted by the International Federation of Organic Agriculture Movements (IFOAM) in 2004 found that there was a strong coincidence in the distribution of Africa's floristic regions and the farming systems identified and mapped by Dixon et *al,* (2001) as shown by Ching *et al.* (2011).

3.2 Geographic location and characteristics of the study area

The study area is located within Atankwidi catchment which is a tributary of the White Volta in the Upper East Region of Ghana between Navrongo and Bolgatanga. the catchment has its upper reach in Burkina Faso (Martin, 2006). The study area of this research lies at 10°50'41" - 11°00'35" N latitude, and 1°03'47" - 0°53'02" W longitude along the border between Ghana and Burkina Faso. Within the catchment, the study focused on the area (192 km^2) populated by four villages: *Yuwa* in the Navrongo district, *Sirigu* and *Kandiga* in the Paga district and *Sumbrungu* which is in the Bolgatanga Municipal District (Figure 3.2). This area is in the Sudano-savannah agro-ecological zone where the loss of land productivity is negatively affecting communities who are relying on natural resources for their subsistence lifestyle (Higgins, 2007). The vegetation is dominated by scattered trees such as the baobab (*Adansonia digitata*), locust bean (*Parkia biglobosa*), acacias (*Acacia spp.*) and sheanut (*Butyrospermum* *parkii*) (Salifu & Agyare, 2012). The study area is also characterized by a mono-modal rainfall distribution with a distinct rainy season lasting approximately from May to September (see chapter 4). The long-term mean annual rainfall is 990 mm at the Navrongo weather station which is closer to the study area. The temperature is high throughout the year with an average daily maximum temperature of 35 °C and average daily minimum temperature of 23 °C. Relative humidity is highest (65 %) during the rainy season. It drops quickly after the end of the rainy season in October, reaching a low value of less than 10 % during the Harmattan period in December and January (Martin, 2006). In addition to the aforementioned characteristics, the area was chosen because it is located in one of the poorest regions of Ghana, where research on the impact of policy interventions on local socio-economic and agro-ecological conditions could be of high importance especially when it comes to a sustainable improvement of local living conditions.

3.3 Farming systems of the study area

In the West African Savannah belt, the sustainability of farming systems relies on the way peasants cycle organic matter produced on-site (Manlay *et al.*, 2004a). When focusing on the study area, it has been stated that the small farming system follows a "concentric ring" pattern where three types of agricultural lands are defined: Compound land, Family land and Bushland (Figure 3.3) (Laube, 2005; Callo-concha et *al.*, 2012). This structure of farming systems is very common in West African Savannah. The previous three fragmented rings described by Laube (2005) are summarised by Manlay, et *al.* (2004b) in the following three rings: (1) compound ring; (2) bush ring and (3) savannah or forest ring.

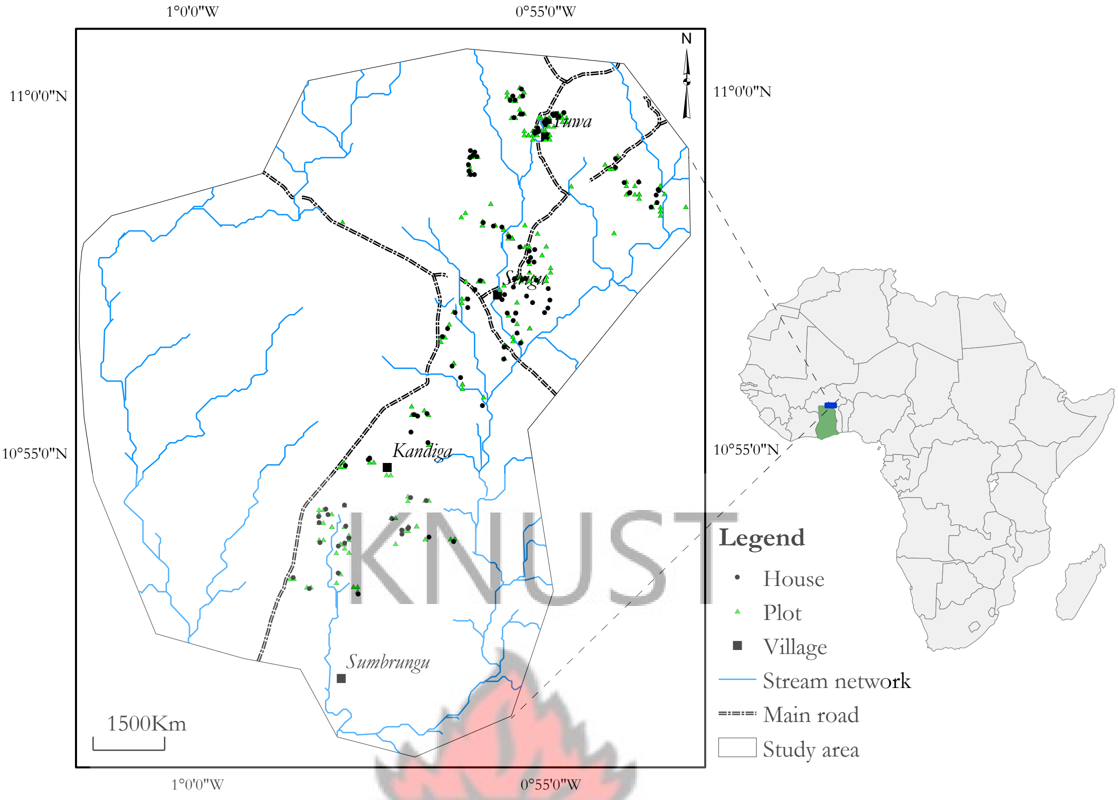


Figure 3.2: Location and boundary of the study research area

(1) Compound ring: In this type of farming system, intensified continuous farming takes place due to the continuous manure application and household waste. Early and late maturing crops are growing where the early maturing cereals like early millet in this ring play a very strategic role since it matures in less than three months during a period when farmers are very busy and cereal prices in the market are the highest. Also, some crops like vegetable leaves and okra (*Hibiscus esculentus*) are found in this system;

(2) Bush ring: This ring is described by Manlay *et al.* (2004b) as a ring which consists of a mosaic of bush fields mainly cash crops and young to old fallows. Accordingly, fertility is mainly sustained by fallow practice. This ring is considered as family lands (Laube, 2005). In this ring, shifting cultivation is practiced, intercropping predominates and the application of manure is poor;

(3) Savannah ring: The main characteristic of the savannah ring is the long distance from the house. The so called savannah or forest ring (Manlay *et al.*, 2004b) is also called bush land (Laube, 2005). This land is mainly used for grazing and pastures, whereas the integration of livestock and farming system remains low, which all the authors mentioned were in agreement.

This simplified organisation of village of the mixed farming system by ring is very common in West African savannah belt. However, there are small variations due to the fact that in certain communities a village is compact (all households in the same area) and in others a village is composed by the spread households organised in compounds like the case of the Upper East Region of Ghana. The land tenure system is shifting cultivation as elsewhere in West African Savannah where villages moved within a demarcated zone, clearing the woodland, farming for some years and moving on. Allocation of lands in bush farms was through the earth priests or *tendaana*, but the abundance of land was such that competition for land was almost absent. Trees in the bush and preserved on farms were the property of the chief or earth-priest and could only be harvested or cut with their permission (Blench & Dendo, 2006). The inheritance of land in the study area is patrilineal, with only few women being in charge of the land in cases where the husband died or is disabled and the male children are still of young age (Schindler, 2009). These land tenure systems have generally been maintained up to the present. Although land is bought and sold around larger urban settlement, such as Bolgatanga, intense pressure on land in rural areas has not led to monetarisation and individualisation of land rights as has been reported elsewhere in West Africa (Blench & Dendo, 2006).

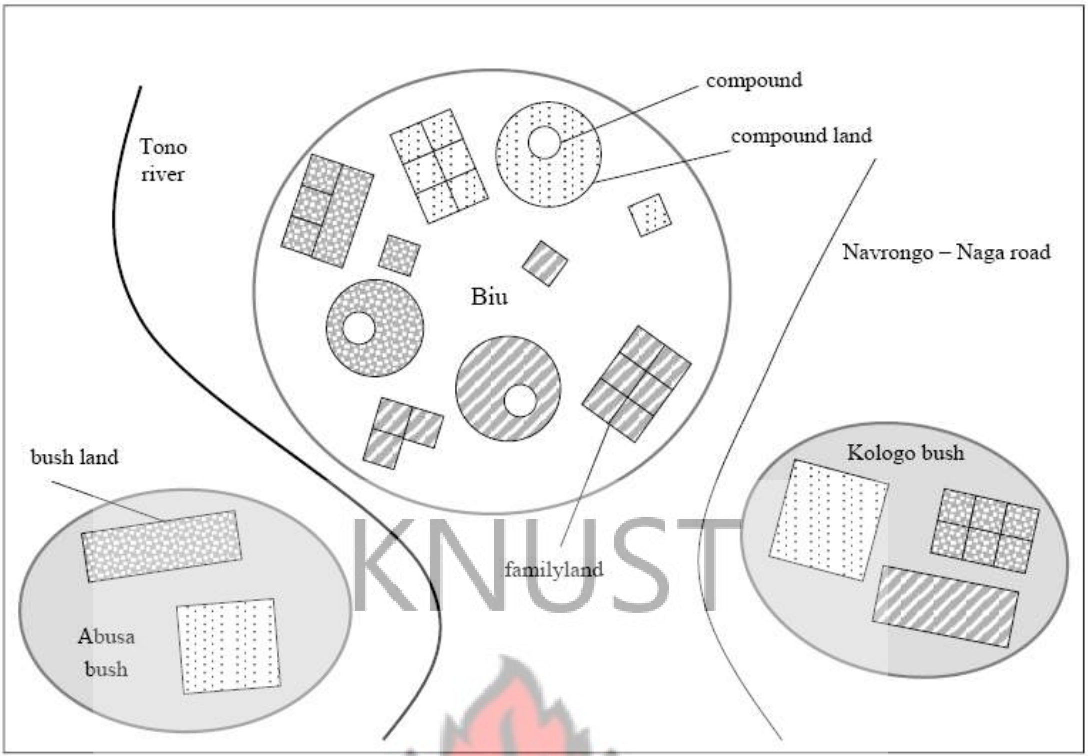


Figure 3.3: Traditional land tenure during the rainy season in Biu, Upper East Region (UER) of Ghana (Laube, 2005)

3.4 Characterisation of the main cropping systems as land-use types in the study area

As indicated in the previous section from the West African (Figure 3.1) to the local view (Figure 3.3), the high heterogeneity of the agricultural land uses characterised by a combination of a number of cropping systems leads to a very high diversity of land use types if all the combinations are under consideration. Therefore, based on the purpose of this research which focused on the analyses of agricultural land uses and its distribution and dynamics through a modelling approach, there is a need to obtain a valid characterisation of the agricultural land use types of the study area. In this regard, the following are the different sources of information that were considered for the characterisation of the cropping systems in the study area: the literature review, general observation, field visits, the land use/cover maps of the study area, the socio-economic surveys conducted on the farming systems during the dry season and the farming practices monitored during the rainy season. According to all the previous sources and the way data were collected by considering the crop practices at a plot level and the combinations of crops grown within each plot of land, the following land uses were identified to represent livelihood background of the farm households and their endogenous strategies:

(1) Compound multiple cropping;

(2) Groundnut based multiple cropping;

(3) Groundnut mono-cropping;

(4) Cereals based mono-cropping;

(5) Rice mono-cropping and;

(6) Soybean farming.

(1) ***Compound multiple cropping***: It is a continuous "traditional" way of growing more than one crop in a combination at the same time and on the same plot of land surrounding the compound house (Figure 3.4). This type of cropping includes row intercropping and mixed intercropping. This cropping system represents a case of land-use intensification in time and space dimensions. Some key important factors are considered in this type of cropping system as land-use intensification: types of crops in the mixture, the spatial arrangement of crops, the plant density, the maturity dates of crops being grown and the plant architecture (Sullivan, 2003). A wide range of crops are grown: early millet or *Naara*, (*Pennisetum typhoides*), late millet (*Pennisetum spicatum*), guinea corn or sorghum or *Kamolega* (*Sorghum bicolor, Sorghum vulgare*), beans or *Teae (Vigna unguculata)*, *neere* or *Sama* (cucurbitaceous family), the list is not exhaustive since there are still some vegetable leaves, okra and even tobacco which are not considered in this research. One of the complexities of compound multiple cropping is due to its diversity. There is small variation depending on the community in the way farmers implement this cropping system. But,

generally it is an intercropping between either early and late millet or early millet and guinea corn because of the higher fertility of soils and care in the purpose of taking advantage as much as possible from the length of the mono-modal rainy season. But most of the time, there is a mixture of grains of one or two other crops sown in the same hole with either early millet or late millet or guinea corn which have a vegetation cycle of 6 months. For instance, the grains of early millet are mixed with grains of nere and sown in the same hole and the grains of either late millet or guinea corn are mixed with beans and okro sown in the same hole (Figure 3.5).

Figure 3.4: Compound multiple cropping system where the early millet is ready for harvest and the guinea corn is still in the growing period

Figure 3.5: Grains of guinea corn, cowpea and nere mixed during the sowing time in compound cropping system

(2) ***Groundnut based multiple cropping:*** In this cropping system, two or three crops are grown annually on the same plot of land and the main crop in the system is groundnut (*Arachis hypogaea*). It is also a form of land use intensification which includes intercropping by rows of cereal (millet or guinea corn) (Figure 3.7) and mixed cropping of Bambara beans or cowpea. The system is also a widespread cropping system in the study area.

(3) ***Groundnut mono-cropping***: This system refers to growing only groundnut on a plot of land annually. This cropping system is often undertaken on poor gravelly

soils (Figure 3.6). Hence, this system is less labour intensive than other systems (Laube *et al.*, 2012). The system is undertaken especially by women and farmers specialised in the commercialisation of cash crops (Schindler, 2009).

Figure 3.6: Soil for groundnut mono-cropping is usually characterized by light topsoils with substantial amounts of gravel

Figure 3.7: Case of multiple cropping with groundnut intercropped with guinea corn

(4) ***Cereal based mono-cropping***: The system refers to growing cereal crops on a plot of land. The crop can be maize (*Zea mays*) as shown in Figure 3.8 or a combination of crops like early millet and guinea corn only. usually, this system is undertaken at distant places from the compound around 1 km (Schindler, 2009). However, some plots of maize are located close to the house because of stealing during the harvest time. Growing maize is relatively widespread in the area, but it is still considered as cash crop. The crop is fertilizer demanding but very profitable to market. Based on the findings of the group discussions and individual interviews during the surveys, maize is considered as a new farm household strategy to climate variability introduced in the area, therefore, it will be considered in adaptation strategy as a new crop introduced in the study area (see Chapter 6).

(5) ***Rice mono-cropping***: Rice (*Oryza glaberrima*) is mostly grown in mono-cropping system (Figure 3.9), but it can also be intercropped with crops like

okra. Even though this system can be a case for cereals based, we separated it from the previous cropping system because of its importance in farm household strategy in the study area. The system is also widespread, but more developed for farmers with extra labour and especially for farmers engaged in more developed rice farming which needs more finance to support the farm inputs. In fact, fertilizers and labour for land preparation and care have to be taken into consideration in this cropping system.

Figure 3.8: Maize grown in cereal based mono-cropping

Figure 3.9: Mono-cropping of rice during the harvest time

(6) ***Soybean farming***: the system is not widespread in the study area, but still exists in some areas because it concerns minor crops like soybean (*Glycine max*) and sweet potatoes (*Ipomoea batatas*). In most cases, farmers allocate very small plot of lands for these crops.

3.5 Methodology

3.5.1 Categorisation of farm household agents

The agricultural system of the study area is heterogeneous making the land-use analyses complex (see section 3.3). In this regard, the livelihood strategies of the farm households when looking for welfare can create the diversity of land-use decisions which could only be understood by categorising these households into groups with individual livelihood strategies (Schindler, 2009). In this chapter, based on the empirical data collected during the field work (2012), statistical approaches were used to derive such agent typologies as well as specific behaviour with respect to land use for each agent category.

3.5.1.1 Identification of farm household agent groups

Selection of livelihood indicators

For the selection of the indicators that represent the livelihood structure and strategy of the farm households and its performance, the capital assets approach was adapted. In this approach, five core asset categories were considered comprising physical, financial, social, natural and human capitals (Campbell *et al.*, 2001). Accordingly, when focusing on the dynamic nature of natural resource management, the livelihood indicators are interacted and integrated, therefore for an appropriate selection of these indicators, the approach should represent the full spectrum of the capital assets. In the next section, statistical analyses were used for the selection of indicators.

3.5.1.2 Statistical analyses

Two statistical methods were used for the identification of the farm household agent groups: Principal Component Analysis (PCA) and K-means Cluster analysis (K-CA). Principal Component Analysis is used as pre-processing step for the clustering in order to denoise the data, transform categorical data to continuous ones or balanced groups of variables with the purpose of deriving clusters of cases which are agent groups of farm households. PCA is probably the oldest and best known of the techniques of multivariate analysis. According to Jolliffe (2002) it was first introduced by Pearson in 1901 and developed independently by Hotelling in 1933. Basically, a principal component method is used to describe a dataset (X with I individuals and K variables) using a small number ($S < K$) of uncorrelated variables while retaining as much information as possible. The reduction is achieved by transforming the data into a new set of continuous variables called the principal components (Husson *et al.*, 2010). The principal components are ordered in the way that the first few retain most of the variation present in all of the original variables.

Since we are dealing with many livelihood indicators, given the possibility of the PCA to condense variables that highly correlate with each other to one principal component, we then use this method to reduce the dimension of these variables. The principal components are derived as linear combinations of the standardised original variables as follows:

$$PC_j = \sum_j b_{ij} X_i$$

where, X_i are the standardised original variables, and b_{ij} are the loading coefficients. PCA was run with Varimax rotation and the Kaiser normalisation when only components with Eigenvalues greater than 1.0 were interpreted and used for subsequent analyses. Then finally, the weights of the loadings b_{ij} helped to name the extracted rotated Principal Components. The standardised scores of these components were then used to run K-means Cluster Analysis in order to derive the household agent groups. The combination of these two statistical analysis, Principal Components Analyses and K-means Cluster is considered with importance in this approach. Indeed, as mentioned earlier, PCA can be viewed as a denoising method (Husson *et al.*, 2010) which separates signal and noise. In this regard, the first principal components extracted the essential of the information while the last ones are restricted to noise. Then without noise in the data, the clustering of the agent groups is more stable and more homogenous than the one obtained from the original variables. Hence, based on the extracted standardised scores of the principal components, it is desirable in this purpose to organise the agent groups into relatively homogenous groups, as farm households within the same group may be sufficiently similar to be treated identically for the purpose of land-use choice modelling, whereas this would be impossible for the whole heterogeneous dataset (Jolliffe, 2002).

This is where the role of the K-means Cluster comes in. The K-means clustering approach works in the way that each cluster is associated with a centre of the points and each point is assigned to the cluster with the closest centroid which is typically the mean of the points in the cluster. The number of k must be specified as representing the initial centroids and then the initial centroids are often chosen randomly. In other words, the algorithm (K-means Cluster) works in the ways it maximises the inter-groups variance and minimise the intra-groups variance in the purpose of minimising the heterogeneity of groups based on the following formula:

$$V = \sum_{i=1}^{k} \sum_{x_j \in S_i} (x_j - \mu_i)^2$$

Where S_i, i = 1,….k are the k clusters agent groups, the $x_j \in S_i$ the elements of each agent groups, and the μ_i are the centroids or means of each cluster.

Each of the x_i and μ_i has as many dimensions as the data set. Thus, $(x_j - \mu_i)^2$ can be regarded as the distance of the agent x_j from the group centroid μ_i. We run the algorithm with 500 as maximum number of iterations (recomputing the centroid of each cluster until the centroids do not change) and used random as option on which farm households are assigned to agent groups in the first iteration of clustering.

Based on the statistical analyses, the following livelihood indicators for categorising the farm households were identified:

(1) Three variables indicating the household's human resources (households size, labour and dependency ratio);

(2) Two variables as financial capital of the households (percentage of gross income and gross income per capita);

(3) Two variables as natural capital of the households (total landholding and landholding per capita) and;

(4) Two variables representing the physical and social capital of the households (livestock index and number of cattle).

In addition to the above, three indicators were added in the selection, the percentages of income from the compound farming (which is commonly cereals based), the groundnut farming and the rice farming (Table 3.1). These last three indicators reflect the most commonly used farming systems in the area with sometimes different variants. For instance, compound farming as said earlier is very common and the system is mostly mixed and intercropped cereals based, the groundnut farming is either in monoculture or intercropped with cereals but still groundnut based or mixed cropped with bambara beans or beans and the rice farming is in monoculture. It is important to include the indicators that represent these farming systems since they directly indicate the livelihood strategy regarding land use in the area.

Table 3.1: Original variables used as livelihood indicators for farm households' categorisation

Variable	Description
h_size	Number of household members
h_labor	Available annual number of days of work (Man day)
h_dep_ratio	Dependency ratio (Number of dependents/Number of workers)
h_%gross_income	Gross annual household income (percentage)
h_gross_income/capita	Gross annual household income/capita (Cedis)
h_total_cultivated_lands	Total land holding by the household (ha)
h_land_area/capita	Total land holding by the household/capita (ha)
h_livestock_index	Livestock Unit (LSU)/total lands (ha)
h_cattle_number	Number of cattle owned by the household
h_%inc_groundnut	Percentage of income from groundnut farming
h_%inc_mixed_cereals	Percentage of income from the compound farming
h_%inc_rice	Percentage of income from rice farming

3.5.2 Modelling land-use choices

3.5.2.1 Multinomial logistic regression for modelling land-use choices

The multinomial logit (MNL) framework has been widely applied in the area of modelling production and development policies in the agricultural sector. Based on the literature exploration, the framework has been used to determine the socio-economic factors affecting the households' food consumption (Kohansal & Firoozzare, 2013), it has also been used to analyse the choice of the households in their practices of soil management (Ayuya *et al.*, 2012). In the same line, it has been used to explore the determinants affecting the choice of crops (Kurukulasuriya & Mendelsohn, 2007), livestock (Seo & Mendelsohn, 2006), then used to identify determinants of land use choices by household agent groups (Le, 2005; Schindler, 2009; Villamor, 2012). In this study, the multinomial logit is also used to parameterise the decision making sub-models regarding the determinants and the choices among land-use types in the study area. The model is based on the random utility model for each choice of land use type based on the following formula:

$$\Pr\left(Yi = {}^{j}/_{Xi}\right) = \frac{e^{\beta'_j X_i}}{1+\sum_{k=1}^{J} e^{\beta'_k X_i}} \ , j = 0, 1, 2, \ldots, J \ , \ \beta_0 = 0$$

Where, P_r is the predicted probability of land use to choose option Y_i, j represents the categories of the dependent variable Y as observed outcome for the *i-th* observation, X_i is a vector of the *i-th* observations of the explanatory variables, β_k is a vector of all regression coefficients (preference coefficients) in the *j-th* regression.

The maximum likelihood algorithm is used to estimate the preference coefficients based on the dataset of each household agent group.

3.5.2.2 Specification of the variables for the multinomial logit model

Dependent variable

The dependent variable of the m-logit model is the land-use choice by the farm households. This variable represents a set of categories of six following land-use alternatives as choice (Table 3.2):

The land-use types were already described in the previous section 3.3. Therefore, based on the conclusions of the group discussions with stakeholders and the findings of the surveys, the following two land-uses are considered as new alternatives introduced by farmers to escape from poverty: soybeans and monoculture of cereals (which is mostly based on maize). These are the two alternatives which farmers have introduced as new crops in the study area because of the high profit they generate for farmers and as adaptation strategies to climate change and variability. Therefore, the two land-uses were considered in the *AdaptationChoice* as new sub-model created for the purpose of this study (see Chapter 6).

Table 3.2: Dependent variable and the hypothesised explanatory variables used in modelling land-use choices

Variable	Definition	Data source	Direct linked module
Dependent variable			
P_landuse	Coded rainy season land-use type according to the household type: (1) Compound multiple cropping; (2) Groundnut based multiple cropping; (3) Groundnut mono-cropping; (4) Rice mono-cropping	Field surveys (2013) and observation of cropping systems during the rainy season in 2013	Patch landscape
Characteristics of household head (Plot user)			
h_age	Age of the household head	Field surveys (2013)	Household-population
h_gender	Sex of the household head		
h_depend	Dependency ratio (number of dependents/number of workers)		
h_size	Total number of household members		
h_labor-farm	Available annual labour for farming (Man day)		
h_cattle	Number of cattle owned by the household		
h_holding	Total cultivated land (ha)		
h_nplot	Number of plots owned by the household		
h_%income	Annual gross income (%)		
Policy related variables			
h_subsidy	Accessibility to farm inputs subsidy	Field surveys (2013)	Household-population
h_extension	Accessibility to agricultural extension service		
p_distance-road	Distance from house to the road (km)	GIS_based calculation	Patch landscape
P_distance-market	Distance from house to the market (km)	GIS_based calculation	Patch landscape
Natural attributes of the land plots			
p_upslope	Upslope contributing area (m^2/m)	GIS_based calculation	Patch landscape
p_soilfertility	Soil fertility (ranking scale from 4 to 1)		
P_slope	Slope at the plot location (degree)		
p_distance-plot	Distance from plot to the house (km)		

Hypothesised explanatory variables

The agricultural land-use system is very complex in the study area due to its heterogeneity (see section 3.4). However, within the same community the farming systems seem to be homogenous. But in reality, the choice of which cropping system to implement depend on a number of indicators which could be related to farmers themselves, to the plots of land, to the neighbouring environment and also to the policy implemented in the local territory. The hypothesised variables of household characteristics, which determine the choice of cropping systems to implement as land use in the rainy season includes (Table 3.2): age of the household head, gender, size, dependency ratio, total land holding, fertilizer, cattle number and the percentage of the cultivated area of the main land use as main cropping systems which determine the land use tendency of the area.

Age: In the study area, new crops are mostly implemented by the young generation of farmers. During the last decades, a gradual shift among land use types from traditional cereal farming to the cultivation of rice and groundnut was observed (Schindler, 2009). For these reasons, the age of farmer is assumed to influence their land-use preference.

Gender: Like elsewhere in West Africa, female farmers tend to focus on the cultivation of groundnut and bambara beans because these crops are less labour intensive. Also, multi-method approach was used to explore how males and females differ in their perspectives in terms of land-use (Villamor *et al.*, 2013).

Labour availability: Based on the cropping systems' monitoring conducted during the rainy season, it was observed that household size play an important role in the land-use choice. In this regards, a farmer may depend on a number of factors such as availability of household labour. This is true for labour demanding crop like rice. In addition to labour, cultivation of rice needs more farm inputs (e.g. fertilizer application), and ploughing the plot at the beginning of the season. Therefore, it is assumed the variables income and cattle number will play an important role in the type of crops to grow.

Dependency ratio: This is an indicator of the number of mouths each worker needs to feed; Households with high dependency ratio could be forced to grow a larger variety of crops (Schindler, 2009). Therefore, this variable is also assumed to be an indicator of subsistence farming.

The total land holding: This is also another important variable which is much correlated to the number of plots. In the study area, it is observed that the availability of enough land like other factors (e.g. climate, labour, etc.) gives the possibility of diversifying the land uses.

Subsidy and extension: The accessibility of household to agricultural extension services is assumed to be an important factor influencing land-use choice because it is acceptable that farmers with better access to these services will likely adopt the land-use promoted by the extension programme (Le, 2005). The second important factor related to policy and can also influence the land-use choice, is the subsidy on farm inputs (Villamor, 2012). Since the application of agrochemicals increases the productivity of land, the provision of agrochemicals allows farmers to reduce costs for farming input, and thus the agricultural profit of subsidised farmers is increased.

Distance to the market and distance to the road: Infrastructure like market and road are also important factors assumed to play key roles in land-use choice. As a result of access to markets and having a road closer to the house allows farmers to acquire farm inputs they need because, apart from the availability, accessibility of inputs even if a farmer has a mean of transportation was also another concern for farmers. Moreover, for farmers, farming is not only good production, selling the products at the right time is also a key issue especially for those involved in cash crop production.

Spatial attributes: Landscape variables are also assumed to play an important role in land use decisions. Because water availability critically affects agricultural production (Le, 2005), the two topographic factors **slope gradient and upslope contributing area** by determining respectively soil erosion and the relative position of plot of land as indicated earlier, influence the moisture content. Therefore, they are assumed to influence significantly and negatively the land-use choice even in flat areas. The soil fertility also has its importance in land-use choice in the area where the abundance and type of grass on a piece of land, some physical properties of soil (colour, texture), soil moisture are considered as indicators for the decision among the various land-use types (Schindler, 2009).

Factors of spatial accessibility including distance from the plot to the compound house and distance from the main river to the compound house were also hypothesised to influence land-use choice. The **distance from the plot** to the compound is minimal for land-use of multiple compound farming as shown in Figure 3.2 (Laube, 2005). In contrast, the distance from plot to the house is relatively important for other land-uses like groundnut and cereals mono-cropping. These two land-uses need less attention in terms of labour and management as reported by farmers.

3.5.3 Data sources

The socio-economic data used in this research were collected using semi-structured household questionnaires, which have been pre-tested with 10 farm households in the Bolgatanga district in November 2012 while the main survey was carried out between January and April 2013. Qualitative and quantitative data were collected on the topics of (1) farming systems, (2) farmers' perception of climate change and variability and (3) adaptation strategies used by the communities to improve the resilience of their farming systems. A total of 186 farm households were interviewed. These households are distributed within four villages (*Sirigu*, *Sumbrungu*, *Kandiga Yuwa*) which are under three administrative districts (Paga, Bolgatanga, Navrongo) in the Upper East Region of Ghana were. The sample was composed of 15 % female-headed households of which 66 % of them were widows, while 85 % were male headed households. Based on the official list of farmers provided by the MOFA (Ministry of Food and Agriculture) of each district, the following farm households were randomly selected: 51 households in *Sirigu*, 62 households in *Sumbrungu*, 32 households in *Kandiga* and 41 households in *Yuwa*. As key decision markers within the house, the household heads were interviewed. The surveys were conducted by the Agricultural Extension Agents (AEA) used as enumerators. The AEA were trained on the approach of the data collection used in this research (participatory workshop, questionnaire administration and plot measurements supported by Global Positioning System (GPS) technology). The plot measurements consisted of taking coordinates of each household location and also the areas and coordinates of its landholding plots. Two participatory workshops were organised during the period of the field work (19th January and 06th November 2012). This participatory process has been an opportunity first to adapt the framework of the adaptation research approach (see chapter 6 Figure 6.1) to the study area and second to design the boundary of the study area (see Figure 3.2) based on the enhanced participatory mapping, using a high resolution satellite imagery with a resolution of 2.4 m (Quick bird).

3.6 Results

3.6.1 Typological household agent groups

3.6.1.1 Identification of the typological agent groups

All original variables used as livelihood indicators for farm households' categorisation under PCA were subjected to the Kaiser-Mayer-Olkin (KMO) test in order to check the sampling adequacy. Only the values of the following three variables, gross income per capita (G_i/capita), total cultivated lands (total lands) and total cultivated lands per capita (lands/capita) were under 0.5 with respectively 0.469; 0.499 and 0.424. The overall value of KMO was greater than 0.5, which is acceptable in performing the PCA.

Table 3.3 summarises the total variance explained by the principal components after running the PCA. Based on the values of the Eigenvalues greater than 1, the principal components were extracted. Accordingly, five principal components with total Eigenvalues of 1.059 were extracted. These components explain 78.56 % of the total variance meaning that the loss of information amounted to 21 % when replacing the initial variables through principal component. The extracted principal components are described and named, based on the weight parameters b_{ij} among the principal component and the initial variables which will at the end of the day help to design the livelihood typologies.

3.6.1.2 Definition of the principal components

The loadings (b_{ij}) between the initial variables and the rotated principal components supported by the percentage of the total variance were used to describe and name these components (Table 3.4). The first principal component is highly correlated with the variable dependency ratio (b_{ij} = 0.786), therefore, such component is named *dependency factor*. Also, this component has a negative significant correlation (bij = -0.572) with the variable gross income per capita which reflect the empirical evidence regarding the existence of the inverse relationship between dependency ratio (proportion of non-active people) and income per capita. This is in line with the assumption indicating that the lower the dependency ratio, the higher the income per capita. The *dependency factor* accounts for 20.05 % of the total variance of the initial dataset.

Table 3.3: Total variance explained by the principal components (PC)

PC	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.600	30.002	30.002	3.600	30.002	30.002	2.406	20.047	20.047
2	1.869	15.571	45.574	1.869	15.571	45.574	2.142	17.851	37.898
3	1.704	14.199	59.773	1.704	14.199	59.773	2.080	17.333	55.231
4	1.196	9.969	69.742	1.196	9.969	69.742	1.449	12.072	67.303
5	1.059	8.823	78.565	1.059	8.823	78.565	1.351	11.262	78.565
6	.869	7.241	85.805						
7	.676	5.630	91.435						
8	.543	4.526	95.962						
9	.351	2.921	98.883						
10	.100	.833	99.716						
11	.034	.284	100.000						
12	4.87E-7	4.06E-6	100.000						

The second principal component has good correlations with the variables size (b_{ij} = 0.70), labour (b_{ij} = 0.72) and percentage of gross income (b_{ij} = 0.71). Then because of these variables, the component is named *labour and income factor.* This factor is also positively correlated with the variable percentage of income coming from rice farming (b_{ij} = 0.65) suggesting that only households with extra labour and financially stable are efficiently involved in rice farming. The higher the labour and income, the more the farmer is able to involve in rice farming which is more labour and farm inputs demanding. This factor accounts for 17.85 % of the total variance of the initial dataset. The third principal component is highly correlated with the variables percentage of income coming from groundnut (b_{ij} = 0.96) and cereals (b_{ij} = -0.89), and named the component as *Cereals and Groundnut factor.* This factor opposes these two variables meaning that the more the household is involved in compound farming the less it is involved in groundnut farming especially grown groundnut in monoculture as shown by the income structure (Figure 3.10: a1, b1 and c1). This factor accounts for 17.33 % of the total variance. The fourth principal component is highly correlated with livestock (b_{ij} = 0.75) and cattle number (b_{ij} = 0.85 %), therefore the factor is named *livestock factor*. This factor accounts for 12.07 % of the total variance. The fifth principal component is highly correlated with the variables total landholdings (b_{ij} = 0.81) and land per capita (b_{ij} = 0.95). Such factor is named *land factor*, accounting for 11.26 % of the total variance.

Table 3.4: Rotated component matrix using varimax rotation and Kaiser normalisation of the five extracted principal components

	Principal component				
	PC1	PC2	PC3	PC4	PC5
	Dependency factor	Labour and income factor	Cereals and Groundnut factor	Livestock factor	Land factor
Variable	(20.047 %)	(17.851 %)	(17.333 %)	(12.072 %)	(11.262 %)
Size	0.451	**0.702**	0.004	0.241	-0.235
dep_ratio	**0.786**	-0.066	0.145	-0.081	0.022
labor	-0.001	**0.718**	0.091	0.107	0.175
%_G_income	-0.274	**0.713**	0.366	0.023	0.257
G_i /capita	**-0.572**	0.259	0.425	-0.122	0.486
total lands	0.130	0.461	0.047	0.082	**0.809**
lands/capita	-0.172	-0.029	0.069	-0.092	**0.952**
livest_index	-0.134	-0.217	-0.020	**0.749**	-0.358
cattle_numb	0.067	0.238	-0.080	**0.849**	0.207
%inc_groundnut	0.123	-0.090	**0.964**	0.015	0.023
%inc_rice	-0.213	**0.645**	-0.047	-0.219	0.112
%inc_cereals	0.003	-0.277	**-0.889**	0.109	-0.085

Based on the factor score of the five rotated principal components, the k-mean cluster analyses was applied resulting in three clusters which represent the specific livelihood agent groups I, II and III with respective group size of 78, 55 and 53 farm households. Table 3.5 summarises the descriptive statistics of all variables used for the agent categorisation.

3.6.1.3 Livelihood typology of the household agent groups

The three livelihood agent groups identified using the k-mean cluster analysis, are characterised in this section based on:

(1) The descriptive statistics of the key categorising variables of each agent group (Table 3.5);

(2) The income structures of the three household types (Figure 3.10. a1, a2, a3);

(3) The percentage of the cultivated lands (Figure 3.10. b1, b2, b3) and;

(4) Some five livelihood indicators of the household type (Figure 3.11).

Table 3.5: Descriptive statistics for the categorising variables for each agent group

Variable	Agent group	N	Confidence Level (95%)	Max	Mean	Min	Std	St error
size	I	78	0.47	12	5.86	2	2.07	0.23
	II	55	0.66	15	5.05	2	2.44	0.33
	III	53	1.02	21	8.66	3	3.71	0.51
dep_ratio	I	78	0.24	5.00	1.10	0	1.05	0.12
	II	55	0.09	1.25	0.36	0	0.31	0.04
	III	53	0.13	2.00	0.55	0	0.49	0.07
labor	I	78	14.98	273.55	141.74	19	66.43	7.52
	II	55	17.57	262.75	106.95	19	65.00	8.76
	III	53	32.99	669.60	279.73	63.5	119.67	16.44
%_G_income	I	78	0.06	1.39	0.47	0.08	0.26	0.03
	II	55	0.05	0.77	0.28	0.07	0.19	0.03
	III	53	0.11	2.67	0.91	0.25	0.40	0.06
G_i /capita	I	78	71.83	2100	418.39	71.67	318.60	36.07
	II	55	53.33	1040.65	278.93	24.46	197.28	26.60
	III	53	85.53	1531.00	554.50	102.45	310.31	42.62
total lands	I	78	0.27	5.90	1.96	0.28	1.20	0.14
	II	55	0.29	4.43	1.44	0.21	1.09	0.15
	III	53	0.42	9.30	3.27	0.90	1.52	0.21
lands/capita	I	78	0.07	1.97	0.39	0.05	0.31	0.04
	II	55	0.08	1.30	0.33	0.02	0.28	0.04
	III	53	0.07	1.23	0.44	0.11	0.25	0.03
livest_index	I	78	1.63	55.39	4.28	0	7.24	0.82
	II	55	3.18	57.61	7.56	0	11.75	1.58
	III	53	1.19	23.83	4.26	0	4.34	0.60
cattle_numb	I	78	0.37	6.00	0.97	0	1.65	0.19
	II	55	0.48	5	1.49	0	1.76	0.24
	III	53	0.89	12	3.30	0	3.23	0.44
%inc_gdnt	I	78	4.39	100	53.26	0	19.47	2.20
	II	55	3.60	39.08	9.65	0	13.33	1.80
	III	53	4.30	71.73	30.45	0	15.62	2.14
%inc_rice	I	78	2.23	45.87	3.86	0	9.90	1.12
	II	55	2.19	34.33	2.96	0	8.11	1.09
	III	53	5.01	78.10	21.09	0	18.16	2.50
%inc_cereals	I	78	4.18	100	42.88	0	18.52	2.10
	II	55	4.43	100	87.39	48.63	16.40	2.21
	III	53	4.72	100	48.46	13.55	17.13	2.35

Farm household Type I

The farm household Type I is composed of households with averagely six family members per household and a maximum of twelve members. The annual labour used for the rain fed farming amounted to 142 man-days. This group constitutes the middle class in the study area with relatively enough land availability (mean of 2 hectares) and an average income per capita of 418 Cedis. The main factor of difference of this agent group is the high production of groundnut which amounted to 55 % as percentage in terms of contribution of groundnut to the gross income. Looking at the income composition (Figure 3.10 a1), the high production of groundnut of this agent group is explained by the production of groundnut in monoculture (35 %) and in multiple cropping (21 %) which occupied respectively 24 % and 16 % (Figure 3.10 b1) as percentage of total cultivated lands. The livelihood strategies developed by farm household groups are explained by the diversification of land use. As a result, in addition to groundnut, the group is specialised in the commercialisation of cash crops like maize in monoculture of cereals and soybean. In this group, livestock is not very important as shown by the radar diagram (Figure 3.11). In fact, the group is also distinguished by the high size in terms of family members explaining the low score of gross income per capita (Figure: 3.11) and the high values of dependency ratio (Table: 3.5). This agent group 1 constitutes 42% of the whole population in the study area.

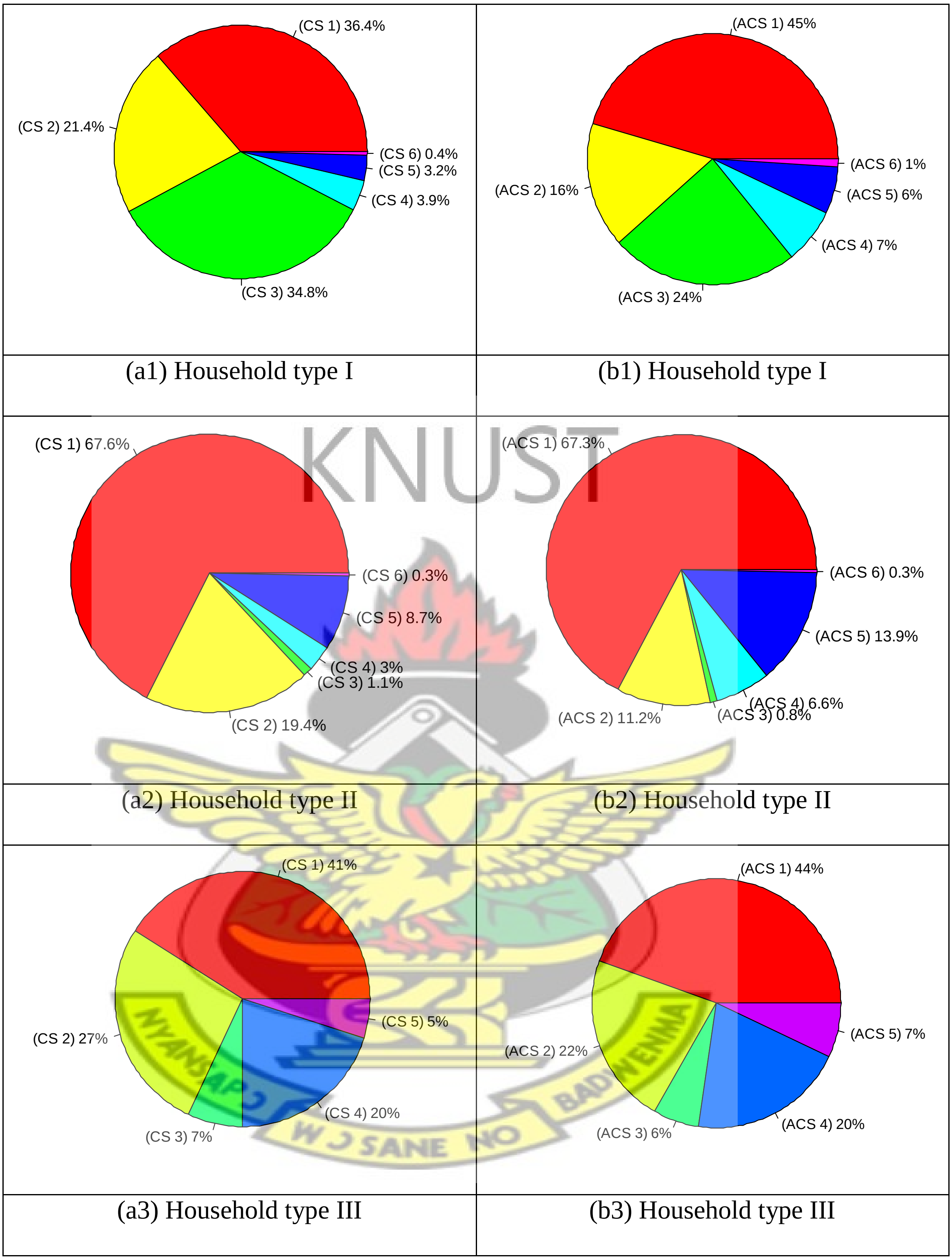


Figure 3.10: (a1), (a2), (a3) Income composition reflecting different livelihood strategies of the three household types. (b1), (b2), (b3) Land-use composition of the three household types. Note: CS refers respectively to the cropping system (land-use type) and ACS refers to the area allocated for each cropping system: compound multiple cropping (CS1), groundnut based multiple cropping (CS2), groundnut mono-cropping (CS3), cereal based mono-cropping (CS4), rice mono-cropping (CS5) and soybean (CS6). There is no soybean in the case of household type III where CS 4 represents rice and CS5 represents cereal based mono-cropping.

Farm household Type II

The household Type II is composed of an average of five family members per household. The annual labour for rainfed farming activities amounted to 107 man-days. This agent group is characterised by the low land availability (1.4 hectares) and an average income per capita of 279 Cedis. Based on the previous characteristics, this agent groups can be considered as a group of vulnerable farm households. Also another factor that discriminates this agent group from the two others is its very high production of cereals justifying the 87.4 % as broad contribution of compound farming in the gross income when compared to the two other main land uses (Table 3.5). Therefore, the livelihood strategy of this group consists of specialisation in subsistence farming by intensifying the diversification of mixed cropping system rather than cash crops (Figure: 3.10 a2). In fact, the cultivated land occupied by mixed cropping system reaches 67.3 % (Figure 3.10 b2). The group is also involved in livestock (Figure 3.11), even though the score of livestock index is justified by the fact that this farm household type often keeps relatively more chickens, goats and pigs. The contribution of rice in the gross income is low (3 %) because the crop is demanding in terms of labour and farm inputs (Table 3.5). This type of agent group constitutes 30 % of the whole population within the study area.

Farm household Type III

The farm household Type III is characterised by high size and enough labour which accounted for an average of 279 man-days as annual labour for the rainy season. The group has also enough lands with an average of 3.3 hectares by household. So far, the group is more stable economically than the two others with 554 Cedis as an average income per capita. Because of its availability in terms of labour and lands, and also the importance of high income per capita, the group is well involved in rice farming supported by 20 % (Figure 3.10 a3) as contribution of this crop in the income composition. For this agent group, the livestock is more explained by the number of big animals as shown by the cattle number in Table 3.5, which makes the use of bullock easy for working on large size of lands. Based on the radar diagram (Figure 3.11) and the income composition (Figure 3.10 a3), this group seems to have better livelihood strategy. It would be self-sufficient in food with poor main road access (Figure 3.11). The group constitutes 28 % of the whole population.

As shown by the radar diagram (Figure 3.11), all the three agent groups seem to have an integrated mixed farming at least for the compound farming because of the existence of livestock for each household type. Obviously, farmers understand the integration of livestock and crop production in farming practices. Livestock provides many services to farmers in the area, in addition to meat and milk, livestock is essential for recycling of nutrients from crop residues and natural vegetation back into the farms (Ching *et al.*, 2011). This is particularly important for all areas which are marked by the dry and moist seasons where farmers are dependent on rainfall for their crop production. Most farm households are trying their best in integrating crop-livestock with the aim of recycling soil nutrients. That is the reason why it is often easy to find compost hole in front of most of the houses investigated. The function of domestic animals is very well understood by farmers in the study area.

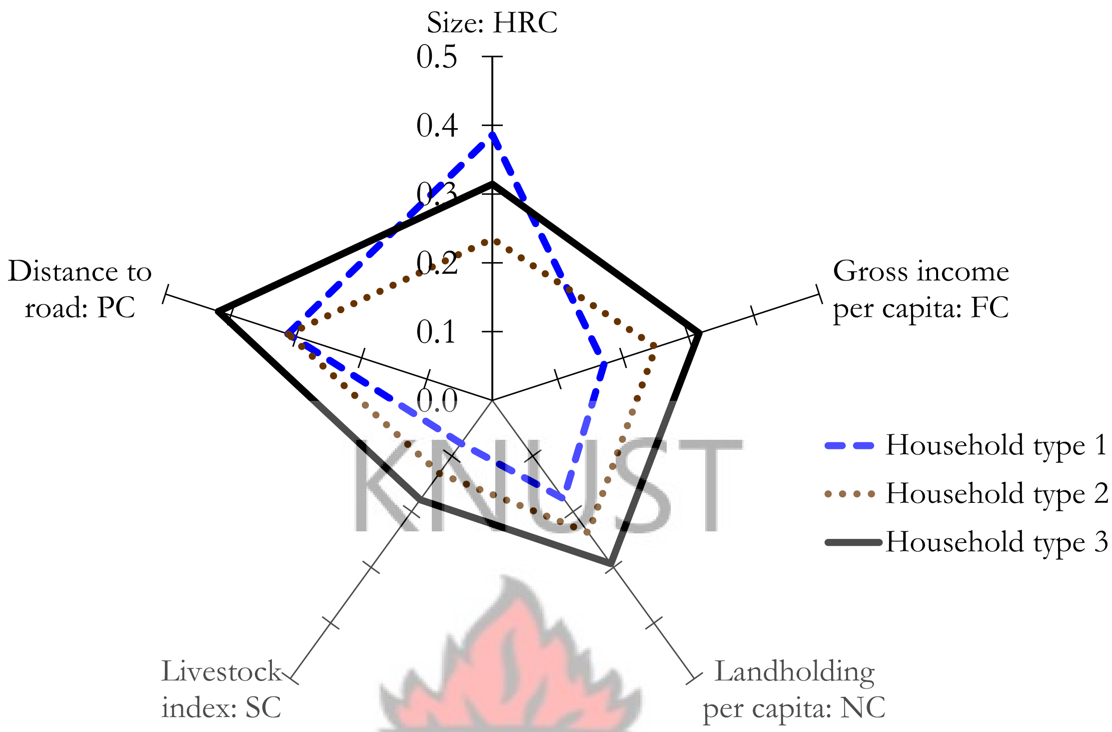


Figure 3.11: Keys indicators normalised between 0 to 1 indicating the variation between the three household types. PC: Physical capital, SC: Social capital, NC: Natural capital, FC: Financial capital and HRC: Human resources capital

3.6.2 Modelling land-use choices for the three household agent groups

For all the three household types, the land use "multiple cropping of groundnut" was used as base category for the computation of the reference coefficients. This land use type is one of the livelihood strategies undertaken by each household. The choice of the base category did not have any influence on the calculated preference coefficients, since the m-logit estimates probabilities of shift from base to other categories. In short, it estimates relative probability of outcomes to base outcome.

3.6.2.1 Factors affecting land-use choices for household Type I

The results of the empirical m-logit analysis of land-use choice for the household agent group 1 are summarised in Table 3.6 and Table 3.7. The Chi-square test shows that this empirical model is highly significant (p = 0.0001) in exploring land-use choice by farmers of this agent group. The Nagelkerke pseudo R^2 equals 0.532 revealing that 53.2

% of the total variation in the probability of land-use choice is explained by the selected explanatory variables. In this agent group, the variables that significantly affect decisions to implement the multiple cropping of cereals comprise labour (h_labour-farm), income (h_%income) and distance from house to the market (p_distance-market). Accordingly, in this category of farmers the land-use decision is mainly based on the family labour. Also, the financial stability allows farmers of this group to diversify their livelihood strategies as indicated by the variable percentage of income. The variable distance from house to the local market (p_distance-market) was significant, suggesting that the location of the house to the local market was revealed as a constraint, which is understandable since this household agent group is specialised in the commercialisation of cash crops (Figure 3.10 a1). The variables age (h_age), labour (h_labour-farm) and income (h_%income) were also significant in the decision of implementing mono-cropping of groundnut. These variables confirm also the importance of family labour in this agent group. Again, as this household agent group is specialised in cash crop production including groundnut, then the distance from house to the market (p_dist-market) plays an important role in the commercialisation while the variable age indicates that this land-use type is more implemented by young generation of farmers. Then the decision of cultivating rice is more explained by the variable number of plot (h_nplot) which reveals the importance of the diversity of plots in different locations when it comes to implement this land-use type. In the study area, even though rice can be cultivated on uplands, it is in general cultivated on heavy and fertile soils which are found mostly along the river side usually not close to the road as indicated by the variable distance from house to road (p_dist-road). This empirical land-use sub-model model has a good predictive power where the choice of multiple cropping of cereals, multiple cropping of groundnut, mono-cropping of groundnut and mono-cropping of rice is correctly predicted for 58 %, 48 %, 53 % and 43 % of the sample respectively. And the overall percentage of correct prediction is 53 % (Table 3.7).

Table 3.6: M-logit preference coefficients of land-use choices by household Type I using multiple cropping of groundnut as base category. (number of households = 78; number of plots = 158)

	Multiple cropping of cereals		Mono-cropping of groundnut		Mono-cropping of rice	
	Coefficient	Error	Coefficient	Error	Coefficient	Error
Constant	3.010	2.769	5.488*	3.107	-4.659	4.710
h_age	-0.045	0.028	-0.080**	0.031	-0.021	0.041
h_gender	-0.612	0.879	-0.847	1.090	0.260	1.455
h_depend	0.425	0.302	0.293	0.373	0.090	0.511
h_size	-0.103	0.159	-0.073	0.177	-0.094	0.282
h_labor-farm	0.027**	0.012	0.033**	0.013	-0.007	0.025
h_holding	0.000	0.000	0.000	0.000	0.000	0.000
h_nplot	1.028	0.758	1.045	0.807	3.798***	1.351
h_%income	-3.254**	1.620	-3.498*	1.810	-2.204	2.548
h_cattle	0.007	0.203	0.060	0.231	0.204	0.281
h_extension	0.824	0.718	1.032	0.856	1.707	1.350
h_subsidy	8.909	42.303	8.992	42.304	1.421	74.750
p_soilfertility	-0.284	0.317	-0.263	0.349	-0.860	0.626
p_upslope	0.027	0.019	0.027	0.019	0.001	0.039
p_slope	-0.309	0.206	-0.266	0.236	-0.086	0.353
p_dist-road	0.844	1.039	0.829	1.151	3.481**	1.714
p_dist-river	0.367	0.381	0.197	0.444	0.009	0.753
p_dist-market	-1.039**	0.417	-1.695***	0.493	-1.680**	0.732
p_dist-plot	0.122	0.187	-0.003	0.326	0.035	0.259

Prediction *Fitness and accuracy of the model*:
Likelihood test (chi-square statistics): 106.248 *df* = 54 p = 0.0001
Pseudo R^2 (Nagelkerke) = 0.532
***, ** and * indicate the significance level at 1, 5 and 10 % respectively.

Table 3.7: Percentage of correct prediction

from \ to	Multiple cropping of cereals	Multiple cropping of groundnut	Mono-cropping of groundnut	Mono-cropping of rice	Total	% correct
Multiple cropping of cereals	38	6	18	4	66	58 %
Multiple cropping of groundnut	12	15	1	3	31	48 %
Mono-cropping of groundnut	19	2	25	1	47	53 %
Mono-cropping of rice	4	3	1	6	14	43 %
Total	73	26	45	14	158	53%

3.6.2.2 Factors affecting land-use choices for household Type II

The empirical m-logit analysis of land-use choice for the household agent group 2 are summarised in Table 3.8 and Table 3.9 based on the same rang of variables as previously. The likelihood ratio test showed this empirical model is also highly significant (p = 0.003) in exploring land-use choice by farmers of this agent group. The Nagelkerke pseudo R^2 equals 0.779 revealing that 78 % of the total variation in the probability of land-use choice is explained by the selected explanatory variables. Among them, the following variables influence significantly the decision of cereals' multiple cropping: dependency ratio (h_depend), total land holding (h_holding), slope of the plot (p_slope) and distance from house to road. This group of farmers is the smallest in terms of size; therefore, having an important number of young people in the house is an opportunity for the household to diversify its livelihood strategies in addition to multiple cropping of cereals as indicated by the variable dependency ratio. The significant variable of total land holding confirms the extensive behaviour of this land-use type. This land-use type is implemented on flat areas with gentle slope surrounding the compound house and not necessarily related to the local road as reflected by the two variables: p_slope and p_dist-road. None of the selected explanatory variables is significant in implementing mono-cropping of groundnut due to the very small percentage (1 %) of this land-use type in this agent group (Figure 3.10 b2). In this group, rice is likely chosen by younger generation of farmers. It is considered as cash crop and its choice is necessarily determined by high labour and landholdings. The choice of rice in this vulnerable group is rather more sensitive to the variables income, number of cattle, and access to extension and soil fertility. Subsidy to farm inputs is relatively very low. The plots under this land-use type are also located along the river side far from the house and road. In general, because rice farming is a very demanding cropping system in terms of farm inputs, labour and soil fertility, also the fact that this category of farmers is more vulnerable compared to the two others, make the probability of chosen this land-use type very sensitive to most of the selected variables. This empirical land-use sub-model of agent group 2 has a very good predictive power where the choice of multiple cropping of cereals, multiple cropping of groundnut, mono-cropping of groundnut and mono-cropping of rice is correctly predicted for 90 %, 53 %, 50 % and 88 % of the sample respectively. The overall percentage of correct prediction is 80 % (Table 3.9).

Table 3. 8: M-logit preference coefficients of land-use choices by household Type II using multiple cropping of groundnut as base category. (number of households = 55; number of plots = 80)

	Multiple cropping of cereals		Mono-cropping of groundnut		Mono-cropping of rice	
	Coefficient	Error	Coefficient	Error	Coefficient	Error
Constant	5.468	3.943	-21.205	127.734	-343.781**	153.294
h_age	0.036	0.065	0.391	0.983	-5.539**	2.514
h_gender	-1.709	1.536	10.245	50.651	73.943**	33.000
h_depend	-4.629**	2.301	-66.853	76.967	120.165**	54.471
h_size	0.442	0.366	2.049	5.169	3.911	2.484
h_labor-farm	0.025	0.021	-0.262	0.720	-0.155**	0.074
h_holding	0.000**	0.000	0.001	0.002	-0.010**	0.005
h_nplot	-0.744	0.660	-14.495	27.871	60.568**	26.943
h_%income	-4.256	3.627	94.572	154.435	82.319**	41.623
h_cattle	-0.121	0.355	-6.751	11.938	35.033**	15.832
h_extension	-2.857	1.796	-43.676	57.286	105.327**	46.562
h_subsidy	-1.229	1.408	43.713	101.180	-63.451**	29.024
p_soilfertility	-0.045	0.477	-2.226	23.065	18.804**	9.083
p_upslope	0.041	0.097	0.111	0.131	0.191	0.159
p_slope	-1.082**	0.501	-0.202	6.499	1.599	1.261
p_dist-road	-3.142*	1.767	-9.475	34.619	105.814**	47.568
p_dist-river	-0.178	0.691	3.366	37.469	7.957	7.404
p_dist-market	0.310	0.821	-0.268	24.638	12.814	8.918
p_dist-plot	0.363	0.623	14.195	16.498	18.632**	8.825

Fitness and accuracy of the model:
Likelihood test (chi-square statistics): 87.01 *df* = 54 p = 0.003
Pseudo R^2 (Nagelkerke) = 0.779
***, ** and * indicate the significance level at 1, 5 and 10 % respectively.

Table 3.9: Percentage of correct prediction

from \ to	Multiple cropping of cereals	Multiple cropping of groundnut	Mono-cropping of groundnut	Mono-cropping of rice	Total	% correct
Multiple cropping of cereals	46	3	0	2	51	90 %
Multiple cropping of groundnut	9	10	0	0	19	53 %
Mono-cropping of groundnut	0	0	1	1	2	50 %
Mono-cropping of rice	1	0	0	7	8	88 %
Total	56	13	1	10	80	80 %

3.6.2.3 Factors affecting land-use choices for household Type III

For the same range of variables, a similar m-logit analysis was conducted for the household agent group 3. The results of this empirical model are summarised in Table 3.10 and Table 3.11. The likelihood ratio test showed this empirical model is not significant (p = 0.750) in exploring land-use choice by farmers of this agent group. This may be explained by the smallest size of this agent group and principally by the relative high proportion in terms of livelihood strategy based on the main land-use types (mixed cereals, groundnuts and rice) (Figure 3.10 a3, b3). Hence this agent group has a diversified strategy especially when compared to the agent group II where the main strategy focuses on mixed cereals (68 %). As a result, the Nagelkerke pseudo R^2 equals 0.31 meaning that only 31 % of the total variation in the probability of land-use choice is explained by the selected explanatory variables. Only two variables (soil fertility and distance to market) were significant in the choice of groundnut mono-cropping. The variable p_soilfertility supports that this cropping system is undertaken on poor soil while p_dist-market indicates the importance of local market in this cash crop production. Consequently, this empirical land-use sub-model of agent group 3 has a poor predictive power where the choice of multiple cropping of cereals, multiple cropping of groundnut, mono-cropping of groundnut and mono-cropping of rice is correctly predicted for 66 %, 37 %, 60 % and 26 % of the sample respectively. And the overall percentage of correct prediction is 47 % (Table 3.11).

Table 3.10: M-logit preference coefficients of land-use choices by household Type III using multiple cropping of groundnut as base category. (Number of households = 53; Number of plots = 139)

	Multiple cropping of cereals		Mono-cropping of groundnut		Mono-cropping of rice	
	Coefficient	Error	Coefficient	Error	Coefficient	Error
Constant	0.197	3.590	8.195	8.855	-1.563	3.802
h_age	0.000	0.026	-0.064	0.062	-0.003	0.028
h_gender	-0.581	0.856	0.417	1.654	0.051	0.881
h_depend	0.079	0.619	1.926	1.449	-0.086	0.658
h_size	0.032	0.076	0.078	0.207	-0.014	0.079
h_labor-farm	0.009	0.008	-0.023	0.019	0.008	0.008
h_holding	0.000	0.000	0.000	0.000	0.000	0.000
h_nplot	0.035	0.596	-0.356	1.406	0.632	0.633
h_%income	-0.138	0.666	1.009	2.066	-0.456	0.719
h_cattle	-0.038	0.087	-0.008	0.177	-0.100	0.099
h_extension	0.253	0.599	2.572	1.594	0.276	0.647
h_subsidy	0.422	1.153	-2.587	2.710	0.867	1.212
p_soilfertility	-0.372	0.318	-1.506**	0.636	-0.511	0.335
p_upslope	0.008	0.010	-0.063	0.125	0.007	0.010
p_slope	-0.178	0.223	0.499	0.447	0.147	0.238
p_dist-road	0.759	1.194	3.070	2.278	0.339	1.273
p_dist-river	0.307	0.653	-0.793	1.053	-0.073	0.680
p_dist-market	-0.058	0.428	-2.574*	1.351	0.115	0.461
p_dist-plot	0.510	0.444	0.628	0.549	0.438	0.449

Fitness and accuracy of the model:
Likelihood test (chi-square statistics): 46.675 *df* = 54 p = 0.750
Pseudo R^2 (Nagelkerke) = 0.31
***, ** and * indicate the significance level at 1, 5 and 10 % respectively.

Table 3.11: Percentage of correct prediction

from \ to	Multiple cropping of cereals	Multiple cropping of groundnut	Mono-cropping of groundnut	Mono-cropping of rice	Total	% correct
Multiple cropping of cereals	35	11	0	7	53	66 %
Multiple cropping of groundnut	15	14	2	7	38	37 %
Mono-cropping of groundnut	3	1	6	0	10	60 %
Mono-cropping of rice	18	9	1	10	38	26 %
Total	71	35	9	24	139	47 %

3.7 Conclusion

The existing heterogeneity of land-use choice behaviour is reflected in the agricultural land-use system through the mutual considerations of each farm households on a range of personal characteristics, natural conditions of the landscape and particular policy factors. Accordingly, even though the study area is small (192 km^2) six land-use types have been identified including compound multiple cropping; groundnut based multiple cropping; groundnut mono-cropping; cereals based mono-cropping; rice mono-cropping and soybeans. Key variables differentiating household livelihood categories within the communities have been selected based on the approach of capital asset (Campbell *et al.*, 2001), followed by the application of PCA and K-mean cluster. Based on the primary selected variables, PCA revealed five principal factors that discriminate the livelihood typologies of farm households in the study area. These are dependency factor; labour and income factor; cereals and groundnut factor; livestock factor and land factor. These five factors were then extracted and used in the K-mean cluster analysis and resulted in three livelihood typologies of households. Then, m-logit model was applied for each household type with the purpose of differentiating the patterns of land-use decisions. The preference coefficients for the calibrated land-use decision sub-models were determined for each group separately since the household categorisation was relevant. With respect to the aforesaid, the findings of these sub-models reflect the heterogeneity and the livelihood strategy regarding the local agricultural land-use decision of the study area.

Finally, the results and structure of these land-use choice sub-models were then integrated into SKY-LUDAS within the decision programme where the preference coefficients were used to compute the land-use choice probabilities whereby each land-use option during the model run is selected by an individual household agent with respect to its probability, thus allowing bounded rational decision-making behaviour.

4. ECOLOGICAL DYNAMICS OF HETEROGENEOUS LANDSCAPE AGENTS

4.1 Introduction

Ecological systems are generally considered among the most complex due to the fact that they are characterised by a larger number of diverse components, nonlinear interactions, scale multiplicity and spatial heterogeneity (Wu & David, 2002). Ecological processes and systems have several implications on land-cover change through both conversion and modifications. Also, land-cover change is driven largely by land uses (Turner *et al.*, 1995). Land-use decisions are influenced by environmental drivers (e.g. topography, soil conditions, etc.) which often vary over space and time. These environmental conditions can be changed by human interventions or by natural processes that are beyond human control (e.g. climate variability, land degradation). A better understanding is needed on the past and future impacts of changes in LUCC. In any attempt to model environmental dynamics, it is therefore important to consider the initial spatial heterogeneity of the landscape as well as natural processes and ecological impacts driven by human agents, leading to changes in this heterogeneous pattern of the landscape (Schindler, 2009). These dynamics as well as the initial biophysical conditions should be captured and calibrated in a spatially explicit way in order to match real-world processes. Accordingly, the following tasks were addressed in this chapter:

(1) Identification and analyse of relevant biophysical characteristics for the initialisation of landscape agents;

(2) Identification of the variables that are ecologically and economically relevant to productivity and;

(3) Development and calibration of ecological sub-models representing the temporal dynamics of the landscape agents.

4.2 Biophysical characteristics

Climate

The study area is characterised by clear seasonal changes between the dry and rainy season (Laube, 2005). As reported in Figure 4.1, rainfall is marginal from November (Julian day 306) to April (Julian day 92) with slightly increased likelihood of rain in April, then almost all precipitation is received between May (Julian day 122) and October (Julian day 275). The long-term annual mean of rainfall in Navrongo, the closest weather station to the study area, is 989.57 mm as calculated from daily data for the period (1970-2010). Temperatures are considerably higher than in the rest of the country, with mean monthly temperatures ranging between 18 °C and 38 °C (Martin, 2006). Temperatures are high throughout the year, with an average daily maximum temperature ranging from 29.5 °C to 40.1 °C and average minimum temperature ranging from 18.7 °C to 27.1 °C (Figure 4.1). the lowest daytime temperatures coincide with the peak of the rainy season, while the lowest night-time temperatures occur in December and January, caused by the northerly Harmattan winds (Martin, 2006).

Regarding agriculture, the single rainfall regime received in this area limits full utilisation of the physical capacity of the people, as most of them are employed only during the short wet season and unemployed for the rest of the year (Yaro, 2000 cited in Schindler, 2009).

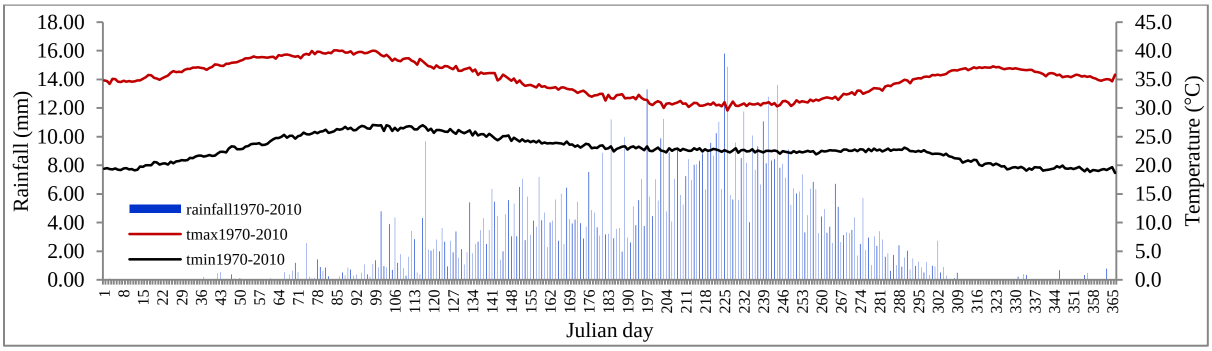


Figure 4.1: Daily average of rainfall, minimum and maximum temperature during the period 1970-2010 at the Navrongo weather station (Source: Meteorological Services Agency of Ghana)

Soils

No detailed soil map is available for the study area. Some soil associations comprising *Bianya, Kolingo, Kupela and Siare-Dagare Complex* are prevalent in the study area (Schindler, 2009). These associations correspond to the following broad groups from the FAO soil classification: Lixisols (*Bianya, Kolingo*), Leptosols (*Kupela*) and Luvisols (*Siare-Dagare Complex*) which are developed over granites, sandstones and Precambrian basement rocks, respectively (Martin, 2006). The soils over granites and sandstones have mainly light topsoils varying in texture from coarse sands to loams, and heavier subsoils varying from coarse sandy loams to clays with a variable amount of gravel. Soils developed over basic rocks and most of those in the valley bottoms have heavier topsoils and subsoils (Schindler, 2009).

Vegetation

The natural vegetation is characterised as an open tree-savannah with Baobab, Shea nut, Neem and Acacia trees at a large spacing in the natural surrounded by grass and shrubs. Mango trees are often planted in the vicinity of compounds. The study area is largely used for small-scale agriculture. This is predominantly rainy season farming of millet, sorghum and peanuts. Approximately 70 % of the area is covered by small plots of rain-fed agriculture during the rainy season (Martin, 2006). The area is typical savannah parkland, which is a savannah landscape highly modified by agricultural use and settlements, thus being an extreme anthropogenic landscape. Within the basin, the natural vegetation is characterised as an open tree-savannah with *Vitellaria paradoxa* (55.5%), *Diospyros mespiliformis* (15.5%), *Acacia albida* (9.5%), *Bombax costatum* (2.5%), *Parkia biglobosa* (2.0%) and *Mangifera indica* (2.0%) which are natural tree species not eliminated from farming areas because of their economic and social values (Schindler, 2009).

4.3 Methodology

4.3.1 Biophysical landscape variables

The spatial variation of soil/water status is essential for ecological modelling on landscape scale since it is considered as major determinants of the ecosystem's primary productivity (Le, 2005). In the case of MAS modelling, if the phenomenon intended to be modelled is complex, it still needs to be modelled with respect to its constituent drivers. Therefore, the soil and water dynamics should be represented in terms of their primary drivers, variables that play decisive roles in soil-forming processes and in regulating soil/water-landscape patterns (Le, 2005). The following landscape parameters were chosen to represent soil/water conditions: soil fertility, slope, upslope contributing area and wetness index.

Soil attributes

In the study area where fallow practice is infrequent, soils on croplands are poor in organic matter and in addition to low organic inputs during the cropping period, the annual burning of vegetation and exportation of crop residues lead to a continuous decline of soil fertility through the depletion of soil organic matter content complicated by low reserves of N and P and low cation-exchange capacity or CEC (Callo-concha *et al.*, 2012). With respect to crop productivity, where soil fertility can represent the three major interacting components (chemical, physical and biological), from a methodological point of view, this parameter was used as explanatory factor for crop productivity based on the general classes as a rank from 1 to 4 (Schindler, 2009) (Figure 4.2).

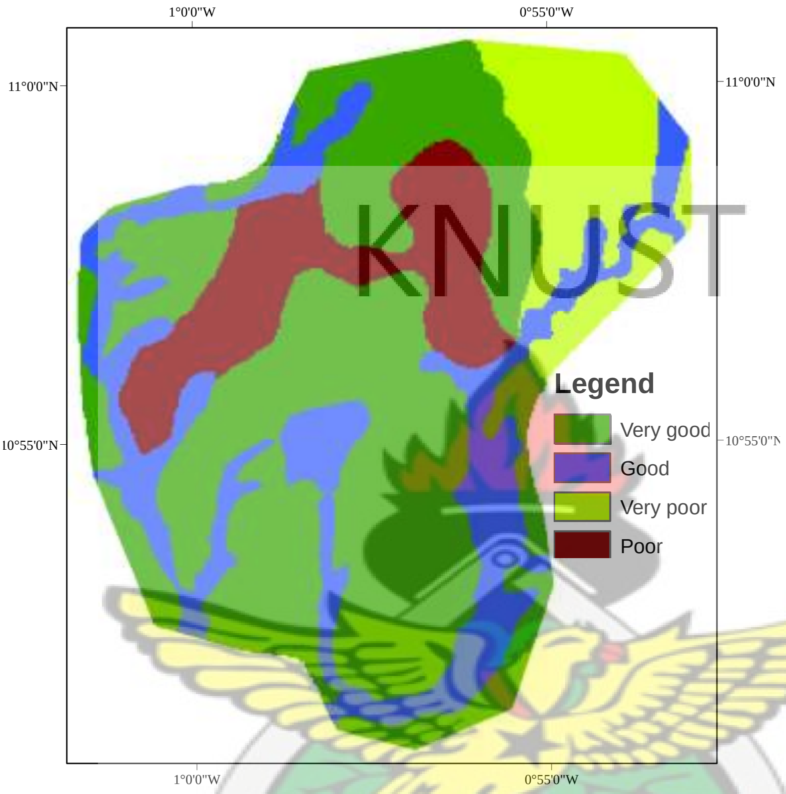


Figure 4.2: Soil fertility in the study area

Topographic attributes:

Digital Elevation Models (DEMs) are important source of information in GIS applications. They have been widely used for soil-erosion and landscape-evolution modelling or automatic drainage network extraction (Zhang *et al.*, 1999). In this work, all basic terrain attributes (elevation, slope, upslope, wetness index) were derived from DEM. In the case of agricultural land use analyses it is known that actual productivity of a site is more or less a balance between the accumulation potential represented by upslope and the degradation risk approximated by slope. As a result, coupling these attributes, can approximate soil/water landscape variability in modelling ecological dynamics of landscape agents, such as the dynamics of crop yields (Le, 2005).

The flow accumulation or Upslope contributing area ($P_{upslope}$) defines the amount of upstream area (in number of cells) draining into each cell. In other words, it is defined as the total area above a point on the landscape (Le, 2005). Flow accumulation is especially important to understand topographic controls on water, carbon, nutrient and sediment flows within and over full watersheds (Do *et al.,* 2011). Basically, the flow accumulation tool counts the number of cells that are flowing into it. Therefore, since it is supported that this parameter indicates the accumulation potential of soil and water, thereby it is assumed positively to affect soil productivity of a site.

The slope gradient represent the main factor determining the overall physical force of soil erosion in the sense that this parameter is key in creating the kinetic energy of the water flow (Le, 2005). In agricultural land use, the role of slope in limiting the overall productivity of a site is impressive, as the parameter has been used for zoning the landscape capabilities of land uses. Thus, slope gradient is also used in this work for indicating soil degradation potential of a site.

The wetness index so called topographic wetness index, which combines local upslope contributing area (flow accumulation raster) and slope, is commonly used to quantify the topographic control on hydrological processes. The index has been used to describe spatial soil moisture patterns; to study scale effects on hydrological processes, to identify hydrological flow paths for geochemical modelling as well as to characterise biological processes such as annual net primary production, vegetation patterns and forest site quality. Because topography affects soil moisture and also indirectly soil pH, the topographical wetness index has also been used for predicting the spatial distribution of plant species richness (Sørensen *et al.*, 2005). From Figure 4.4.c, the wetness index values of the study area vary by landscape and DEM and in this case, they range from 2.9 (from the dry cells) to 21.8 (for the wet cells). The higher the values of wetness index (along the river network) the higher the degree of water saturation in that place. Slope and upslope are used in the following formula to assess wetness index:

$$P_{wetness} = \ln\left(\frac{P_{upslope} \times r}{\tan P_{slope}}\right),$$

where, $P_{wetness}$ is the wetness index, $P_{upslope}$ the upslope contributing area, P_{slope} the slope gradient and r is the resolution of the DEM raster. The above formula was used in the Raster Calculator of Map Algebra in Spatial Analyst tool (ArcGIS) package to calculate the index where the resolution of the DEM is 30 m x 30 m.

Spatial accessibility

Variables determining spatial accessibility are often key variables when modelling land-use choice, as they define the spatial variations in required patch attributes when making land-use decisions (Schindler, 2009). It is admitted that spatial accessibility has social, economic and environmental dimensions, which all can be seen to be important in the development processes including land use and management (Le, 2005). In this work, proxy variables that were hypothesised to play a significant role include distance to the road and distance to the main river. The calculated values of distance from house to the farm and distance from house to the market were also used in land-use analyses as indicated in Chapter 3.

4.3.2 Land cover classification

As one of the key variables in modelling land-use land-cover change, an accurate mapping of land use land cover is required. In this regard, Remote Sensing Unit of the University of Wurzburg through the work package on remote sensing-based analysis worked out a crop mapping of WASCAL sites in West Africa (Gerald *et al.*, 2014). This research derived the main land-cover types by developing a multi-levels analysis of satellite images covering the study area via automatic classification method. Hence the approach adopted reduced the confusion between crop and non-crop areas with an overall accuracy of 94% and a Kappa of 0.88 (Gerald *et al.*, 2014). The classified cover types as described in Table 4.2 are mixed cereals, rice areas, groundnut and grass areas, mixed vegetation, forest and trees, bare areas, urban areas and water bodies. In the context of LUDAS approach, classification of current land cover plays an important role as initial categorisation of landscape agents into ecologically functional types in terms of land-cover. This classification creates a basis for further development of yield response functions for each cover type, as well as spatial extrapolation of variables measured on limited sampling units (Le, 2005). The land-cover percentages reported in Table 4.2 were calculated from the 30 m resolution land-use raster using ArcGIS package. The raster with such resolution (i.e., 30 m) corresponds to the patch size in SKY-LUDAS. And it is also required to make the calibration of the agricultural yields as part of ecological dynamics of landscape agents and other landscape parameters (e.g. raster of slope gradient, raster of soil map, etc.) easy.

4.3.3 Modelling agricultural yield response

The cropping systems in the study area made the analyses of agricultural yield dynamics more complicated (especially in the case of mixed and inter-cropping systems where many crops are grown on the same plot of land at the same time). The data on crop production were collected together with data on adaptation and farmers' perception of climate change during the 2012 surveys. During the interview, the amount harvested was estimated in terms of local means of measure (bags, crates, etc.) then converted to kg, and the plot areas were calculated in acres using GPS measurements and converted to hectares. Considerable errors and distortions may be associated with either GPS measurements especially for small plots or farmers' estimation of the amount harvested from the fields. Some crops like bambara beans, okra, nere, roselle are not considered in the yield analysis. This is because of the small size of the plots of lands used to grow such crops and also the difficulty of determining the amounts harvested. A simple power function is used for modelling agricultural land-use dynamics. The number of selected variables in the function depends on the type of cropping system. For instance, pesticides and fertilizers represented by the variable *I-chem* are not applied in compound farming where early millet, late millet and guinea corn are cultivated as mixed cereals; and organic matter inputs (*I-org*) are not used in rice plots. The selected variables are summarised in Table 4.1 and the power function used for computing agricultural yield is formulated as follows:

$$P_{a-yield} = a.I_{labor}^{\beta_1}.I_{chem}^{\beta_2}.I_{org}^{\beta_3}.I_{livest}^{\beta_4}.P_{soil}^{\beta_5}.P_{area}^{\beta_6}.P_{slope}^{\beta_7}.P_{upslope}^{\beta_8}$$

where, $P_{a-yield}$ is the agriculture yield of a plot, *a* is a constant, I_{labor} is a labour input, I_{chem} is the agrochemical input like fertilizers and pesticides, I_{org} is organic matter input, I_{livest} is a livestock index, P_{soil} is patch soil fertility, P_{area} is a patch area, P_{slope} is a patch slope, $P_{upslope}$ is a patch upslope and β_1 to β_8 are the yield elasticity for the corresponding parameters. All the parameters are listed in Table 4.1. This function is an extended production function (Cobb & Douglas, 1928) and the advantage of its use is to investigate the effect of any explanatory variable while holding all other variables constant. It has its relevance in representing the spatial bio-complexity of the agro-ecosystems, since it is a non-linear combination among variables of the natural landscape and human interventions (Le, 2005). And since the elasticity is considered as a percent change in the dependent variable as a result of a 1 % change in the explanatory variable, then the output elasticity measures the responsiveness of output to a change in levels of an explanatory variable when all other things are being held equal (Villamor, 2012).

Table 4.1: Variables used for modelling agricultural yield dynamics

Variable	Definition	Data source	Direct linked module
Dependent variables: Yield responses			
P_yield_rice	yield of rice plot (kg/ha/y)	Interview of the plot owner during surveys 2013	Patch-landscape
P_yield-early-millet	yield of intercropped early millet plot (kg/ha/y)		
P_yield-late-millet	yield of intercropped plot (kg/ha/y)		
P_yield-sorghum	yield of intercropped sorghum plot (kg/ha/y)		
P_yield-groundnut	yield of groundnut plot (kg/ha/y)		
Independent variables			
Labour-farm availability (I-labour)	Available labour to farm a plot (man day/ha/y)	Interview of the plot owner during surveys 2013	Household-population
Agrochemical inputs (I-chem)	Monetary values of fertilizers and pesticide, only for rice plots and maize plots (local currency: Cedis)	Interview of the plot owner during surveys 2013	
Manure and compost application (I-organic)	Monetary values of organic matter application, only for compound farms and maize plots		
Livestock index (I-livest)	Livestock index (Livestock Unit/ha/y)		
Soil fertility (p-soilfertility)	Soil fertility with ranked values from 4 (very good) to 1 (very poor)	GIS analyses based on soil map	Patch-landscape
P_area-crop	Plot area occupied by each crop (m^2)	Field measurement using GPS area calculation	
Slope (p-slope)	Slope angle of the plot (degree)	GIS analyses based on DEM	
Flow accumulation (p-upslope)	Unit upslope contributing area of the plot (m^2/m)	GIS analyses based on DEM	

4.4 Results

4.4.1 Landscape characterisation

Land-cover classification

From the 2012 land-cover map, eight land-use types were classified (Figure 4.3). These land-types are reported in Table 4.2 as follow: Mixed cereals (39.4 %), Rice (4.5 %), Groundnut and grass (14.6), Mixed vegetation (8 %), Forest and trees (14.9 %), Bare lands (9.7%), Urban areas (8.4 %) and Water bodies (0.4 %). These values are in accordance with previous studies conducted in the study area where the croplands appeared as dominant cover type (Schindler, 2009; Martin, 2006).

Topographical characterisation

The raster of Digital Elevation Model of the study area is shown in Figure 4.4.d. The elevation values vary from 162 m in the south to 240 m in the north within an area of 190 km^2.

The slope gradient raster is shown in Figure 4.4.b where the values in degree vary from 0 to 13°. In the study area, generally the slope is gentle as indicated by the weak difference of the two extreme slope values which reflect the flat characteristic of the terrain.

Table 4.2: Land cover surface in the study area (2012)

Land-use/cover	Description	Surface (ha)	Percentage (%)
Mixed Cereals	Cropland where millet, sorghum and maize are the main crops in the cropping system	7569.45	39.4
Rice	Cropland referring to rice in mono-cropping	857.07	4.5
Groundnut and grass	Cropland of groundnut and Grassland	2813.67	14.6
Mixed vegetation	Combinations of shrub, trees and grass	1538.64	8.0
Forest/trees	Areas with a tree cover greater than 70% and single trees on farm plots	2873.79	14.9
Bare lands	Bare areas and laterite roads	1859.31	9.7
Urban	Houses, settlements, rock outcrops, tarred roads and other artificial surfaces	1608.21	8.4
Water	Small reservoirs and rivers	79.74	0.4
No Data	Areas covered by clouds	23.4	0.1

The calculated upslope contributing area (p_upslope) and the topographical wetness index (p_wetness) grids are shown in Figure 4.4.a and Figure 4.4.c. the upslope contributing area indicates the water flow accumulation while wetness index reflects the degree of water saturation of the site. The higher the values of upslope contributing area, the higher the potential of water flow accumulation and also the higher the values of wetness index, the higher the degree of water saturation. Accordingly, the higher values of both upslope and wetness index are located in lowland and along the stream network.

Spatial accessibility

The grids of the proximate distance from house to the road and to the river are reported in Figure 4.4.e and Figure 4.4.f respectively. Both proximate variables are keys for the farm household crop production. The distance to road is found significant by affecting the land-use choice model especially in cash crops' cropping system (see chapter 3). The distance to the main stream is also significant by affecting the decision for irrigation farming as farm livelihood strategy to climate change and variability (see chapter 6).

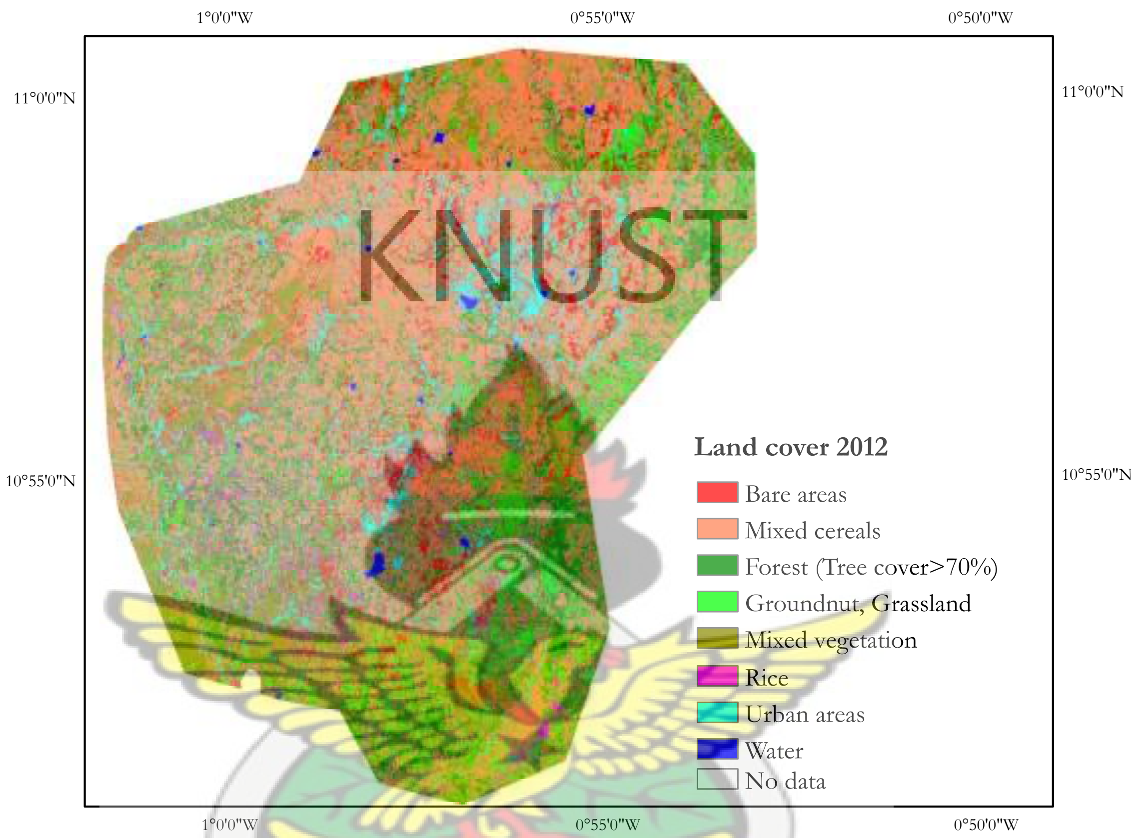
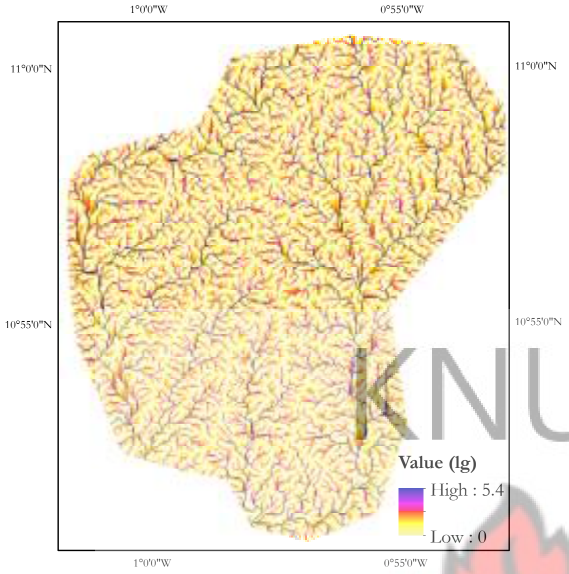


Figure 4.3: Land-use land-cover types of the study area in 2012 (Gerald *et al.*, 2014)

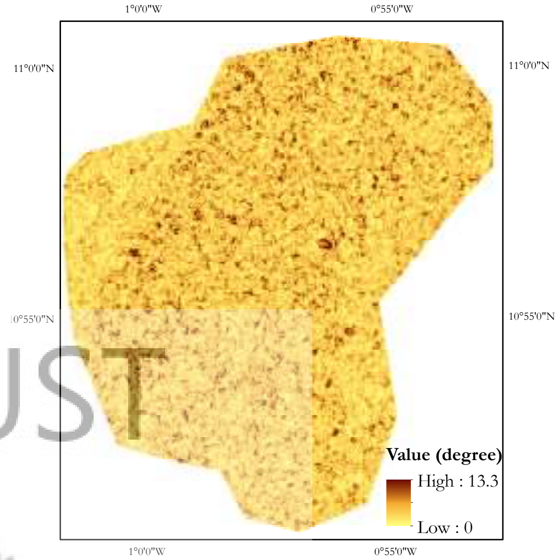
4.4.2 Modelling agricultural yield dynamics

4.4.2.1 Descriptive statistics of variables used for agricultural yield sub-models

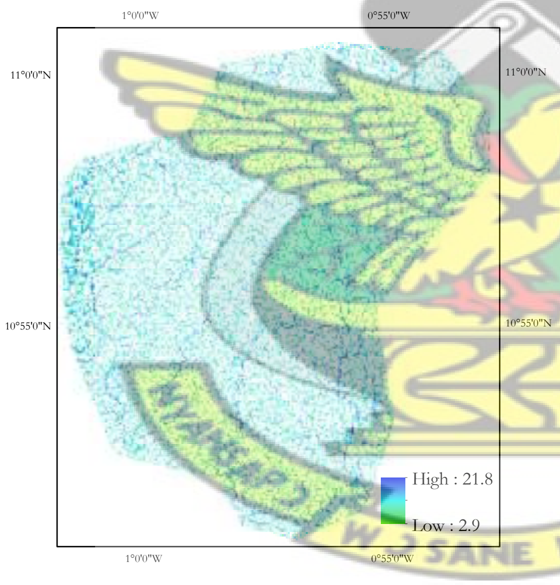
The descriptive statistics of variables used to calculate the agricultural yield are reported in Table 4.3. In terms of crop production, this study focused on the rain fed cropping system where only one harvest is possible during the year. The crop yields are estimated annually. The annual average rice yield amounted to 1257 ± 270 kg ha^{-1} y^{-1} which is very low compared to the official average yield (3800 kg/ha) collected by the Ministry of Food and Agriculture (MOFA) during the period 1992-2009. In the study area, the production of rice is based mainly on labour and land availability.



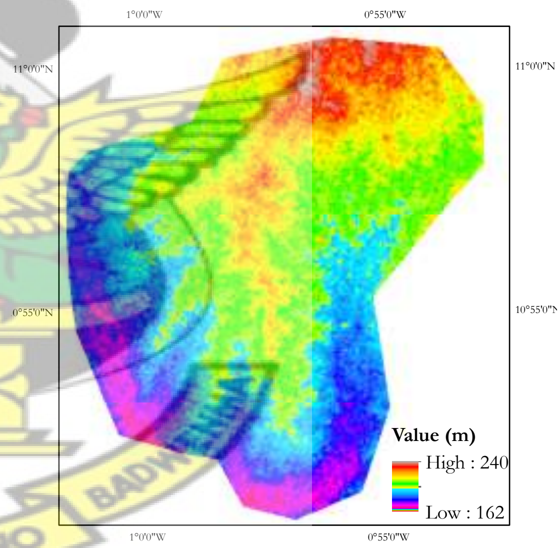
(a) Upslope contributing area



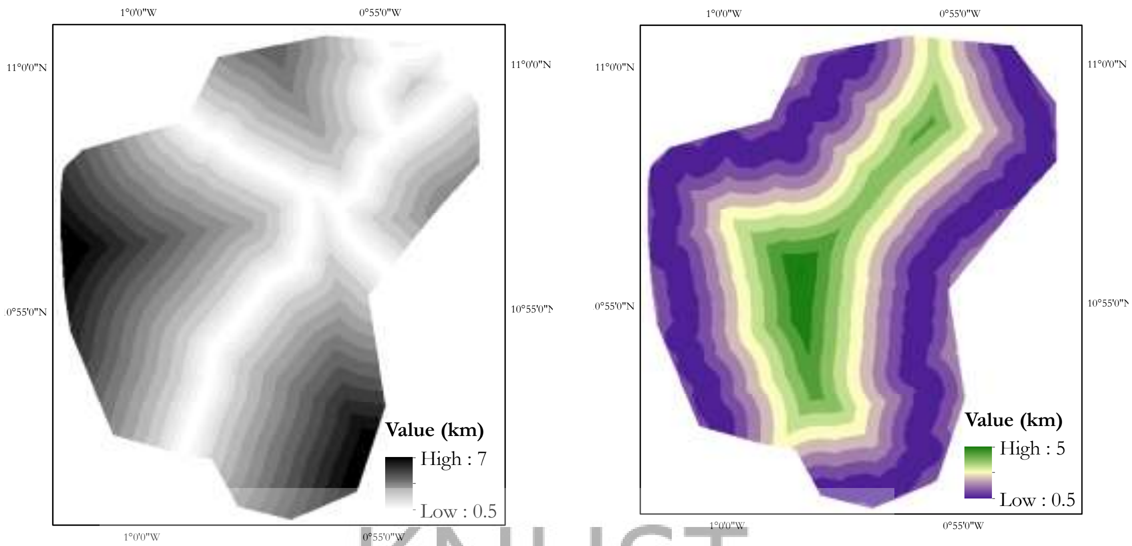
(b) Slope



(c) Wetness index



(d) Elevation



(e) Distance to road (f) Distance to river

Figure 4.4: Landscape attributes of the study area: (a) Upslope contributing area (m^2/m), (b) Slope gradient (degree), (c) Wetness index, (d) Elevation (m), (e) Distance to the road (km), (f) Distance to river (km)

The use of fertilizer is very low (60 ± 14 Cedis). Apart from rice, the three main cereals are early millet, late millet and guinea corn, which are usually grown together through an intercropping system. No fertilizer is used in this cropping system. Instead, the use of organic matter is key in the sustenance of this cropping system. Also, the system is usually undertaken on compound lands, where the distance from house to the farm is not a constraint even for poor households for the transportation of manure, compost and other house waste. The average yield calculated for these three cereals were 1160 ± 107 kg ha^{-1} y^{-1}for early millet; 1490 ± 159 kg ha^{-1} y^{-1} for late millet and 1514 ± 112 kg ha^{-1} y^{-1} for guinea corn. The cereal yields are also lower than the official yields collected by the extension agent during 1992-2009: 1700 kg/ha for millet and 1900 kg/ha for guinea corn respectively. The yield of groundnut was about 1085 kg ha^{-1} y^{-1} which is also low when compared to the official yield collected by MOFA (1400 kg/ha). One of the reasons for low groundnut yields is because it is mostly grown on marginal lands with gravels and poor soils.

Table 4.3: Descriptive statistics of variables for the agricultural yield sub models (Data source: Surveys, 2012)

	Number of plots (n)	Mean	Standard Deviation	Standard Error	Confidence Level (95 %)
P_yield-rice (kg/ha)	61	1257	1050	134	269.92
I-livest (LU/ha)	61	3	4	0	0.97
I-chem (Cedis)	61	60	105	14	27
P-slope (degree)	61	2	1	0	0.30
P-upslope (m^2/m)	61	35	153	20	39.31
I-labor (manday)	61	75	47	6	11.96
P-soilfertility	61	3	1	0	0.35
P-area-rice (m^2)	61	3434	2655	340	680.94
p_yield_E_millet (kg/ha)	185	1160.08	54.03	734.87	106.60
I-livest (LU/ha)	185	4.99	0.56	7.62	1.11
p-slope (degree)	185	1.73	0.09	1.21	0.18
p-upslope (m^2/m)	185	274.97	247.33	3364.02	487.96
I-labor (manday)	185	73.60	2.83	38.42	5.57
p-soilfertility (rank)	185	3.19	0.09	1.21	0.18
I-organic (cedis)	185	38.95	7.62	103.69	15.04
p_area-early-millet (m^2)	185	3996.06	221.32	3010.23	436.64
p_yield-late-millet (kg/ha)	143	1490	80.32	960.47	158.77
I-livest	143	5.06	0.66	7.91	1.31
p-slope	143	1.70	0.10	1.16	0.19
p-upslope	143	340.24	319.72	3823.27	632.02
I-labor	143	76.26	3.36	40.13	6.63
p-soilfertility	143	2.97	0.11	1.33	0.22
I-organic	143	50.17	10.05	120.21	19.87
p_area-late-millet	143	4391.38	250.93	3000.63	496.03
p_yield-guineacorn (kg/ha)	156	1513.72	56.88	710.43	112.36
I-livest	156	4.92	0.56	6.95	1.10
p-slope	156	1.78	0.10	1.28	0.20
p-upslope	156	27.18	13.62	170.08	26.90
I-labor	156	75.10	2.99	37.34	5.91
p-soilfertility	156	3.17	0.10	1.25	0.20
I-organic	156	40.83	8.82	110.21	17.43
p_area-guineacorn	156	4244.14	235.07	2936.04	464.36
p_yield-groundnut (kg/ha)	148	1085.83	35.43	431	70.01
I-livest	148	4.13	0.50	6.14	1.00
p-slope	148	1.96	0.10	1.21	0.20
p-upslope	148	18.87	13.57	165.05	26.81
I-labor	148	69.12	2.78	33.88	5.50

p-soilfertility	148	3.24	0.10	1.21	0.20
p_area-groundnut	148	3214.58	197.28	2399.97	389.86

4.4.2.2 Log-linear regression for yield of rice, early millet, late millet, guinea corn and groundnut

The results of the log-linear regression analyses for the agricultural yields model of rice, early millet, late millet, guinea corn and groundnut are reported in Table 4.4. The F-statistic of all the log-linear models shows significant values ($p < 0.01$) indicating that these agricultural yield models are relevant in explaining the variation in the yield of these crops. Also, given the heterogeneity of the cropping systems in the study area, an R^2 value of 0.4 to 0.5 would be considered as good fit, because the data of most variables were obtained through interviewing plot owners (except plot areas) rather than field measurements (Le, 2005). With respect to the results, the log-linear regression indicates that some of the basic variables are significant in explaining crop response (Table 4.4). For instance, livestock index (*I-livest*), agro-chemical input (*I-chem*) and area of plot (*p-area-rice*) are all positively related to the rice yield indicating that the higher the livestock index, agro-chemical input and plot area, the higher the response of rice yield. In contrast, soil fertility (*p-soilfertility*) has a negative relation with rice yield indicating the over-fertilisation of rice plots especially for plots located in lowlands along the river side with important amount of nutrients through seasonal flooding. This variable (*p_soilfertility*) is also negatively related to the yields of early millet and groundnut. In the same line, the variable organic fertilisation (*I-organic*) affects negatively the yield of late millet. The reason for this negative relation may be also an over-fertilisation of the land-use types located in the compound lands where the organic matter is frequently transported. In this regard, only crops with higher demand in terms of soil fertility can be affected positively by this variable (soil fertility), like the case of guinea corn. The variable plot area, affects positively and significantly the yields of all the crops. As a result, this variable reveals the extensive behaviour of the farming system in the area. The explanatory labour input (*I-labour*) is significantly related to the yields of early millet and late millet indicating that the higher the labour input, the higher the yields of millet. The positive and significant relationship between the yield of cereals and the explanatory variables labour (*I-labour*) and plot area (*p-area-crop*) reveals the subsistence behaviour and the extensiveness of the farming system in the area.

Table 4.4: Results of log-linear regression for agricultural crop yields

	Coefficient (yield elasticity)	Standard error	Pr > Chi²
Mean ln(p_yield-rice (kg/ha)) = 6.737; sdt error = 0.122; CV = 0.245; R^2 = 0.470; p = < 0.0001			
Constant	7.336	0.414	< 0.0001
ln(I-livest)	0.042	0.025	0.098
ln(I-chem)	0.002	0.001	0.003
ln(p-slope)	-0.027	0.082	0.739
ln(p-upslope)	0.000	0.001	0.975
ln(I-labor)	0.003	0.003	0.295
ln(p-soilfertility)	-0.122	0.073	0.096
ln(p-area-rice)	0.000	0.000	< 0.0001
Mean (p_yield-early-millet (kg/ha)) = 6.80; sdt error = 0.06; CV = 0.1; R^2 = 0.50; p = < 0.0001			
Constant	7.656	0.175	< 0.0001
ln(I-livest)	-0.005	0.005	0.338
ln(p-slope)	0.001	0.036	0.982
ln(p-upslope)	0.000	0.000	0.531
ln(I-labor)	0.003	0.001	0.001
ln(p-soilfertility)	-0.059	0.033	0.071
ln(I-organic)	0.000	0.000	0.273

ln(p_area-early-millet)		0.000	0.000	< 0.0001
Mean (p_yield-late-millet (kg/ha)) = 7.06; sdt error = 0.06; CV = 0.13; R^2 = 0.46; p = < 0.0001	Constant	7.725	0.196	< 0.0001
ln(I-livest)		0.002	0.006	0.750
ln(p-slope)		-0.056	0.043	0.184
ln(p-upslope)		0.000	0.000	0.800
ln(I-labor)		0.003	0.001	0.014
ln(p-soilfertility)		0.044	0.034	0.199
ln(I-organic)		-0.001	0.000	0.019
Ln(P_area-late-millet)		0.000	0.000	< 0.0001
Mean (p_yield-guineacorn(kg/ha)) = 7.33; sdt error = 0.06; CV = 0.12; R^2 = 0.42; p = < 0.0001				
Constant		7.880	0.226	< 0.0001
ln(p-livest)		0.003	0.007	0.650
ln(p-slope)		-0.025	0.041	0.545
ln(p-upslope)		0.000	0.000	0.695
ln(I-labor)		-0.001	0.001	0.664
ln(p-soilfertility)		0.085	0.039	0.029
ln(I-organic)		0.001	0.001	0.340
ln(p_area-guineacorn)		0.000	0.000	< 0.0001
Mean ln(p_yield-groundnut (kg/ha)) = 6.88; sdt error = 0.04; CV = 0.09; R^2 = 0.27; p = < 0.0001				
Constant		7.396	0.161	< 0.0001
ln(p-livest)		0.011	0.006	0.056
ln(p-slope)		-0.064	0.030	0.035
ln(p-upslope)		0.000	0.000	0.568
ln(I-labor)		0.001	0.001	0.176
ln(p-soilfertility)		-0.052	0.029	0.067
Ln(p_area-groundnut)		0.000	0.000	< 0.0001

4.5 Discussion and Conclusions

The ecological entities of landscape agents were described in this chapter with the purpose of addressing its diversity, variability and heterogeneity. Because these landscape characteristics are assumed to play a role in land-use decision making. The landscape characterisation of this study area reveals spatial patterns of landscape attributes that are relevant to human-environment interaction including the description of soil-water distribution, spatial accessibility to the river and land-cover. In this approach, the hypothesised spatial heterogeneity which was found significant in the land-use decision is considered and is integrated in the land-use modelling subsequently. As a result, the integration of these various ecological processes contribute to reduce the existing strong parallels between pattern-process interactions in social and ecological systems (Cumming, 2011, Cumming *et al.*, 2012). Also, since spatial heterogeneities, in concert with the diversity of human agent and categories result in the complexity of LUCC (Le, 2005), then this approach contributes to the understanding of the complexity of land-use/cover change research.

Biophysical sub-models were developed for the specific crops undertaken in different land-use types. The role of these sub-models was to define the productivity of the various land-use types and also to determine the conversion among land-use types. In this regard, all biophysical factors are important in the local crop productivity. For that reason, both social-related and environmental variables were considered in the sub-models for yield response. However, the variables are specific to every human agent in the sense that they explain the heterogeneity of agricultural yield response in terms of non-linearity. In general, all selected explanatory variables as hypothesised, do influence the agricultural yields in different directions.

5. FARMERS' PERCEPTION OF CLIMATE CHANGE AND VARIABILITY

5.1 Introduction

The countries in Africa are among the most vulnerable continents to the effects of climate change. Much of the population depends on agriculture particularly rain-fed agriculture but at the same time widespread poverty renders them unable to withstand climate stresses. As an example, the recurrent droughts in many African countries has demonstrated the effects of climate variability on food resources (Stanturf *et al.*, 2011). As a result, many people face food insecurity, adding to already existing poverty. In West Africa for instance, particularly the belt of Sudan Savannah of Sub-Saharan Africa is one of the regions where farming system is the main activity in semi-arid rural areas. However, the region is particularly vulnerable by its ecological fragility, institutional weaknesses and political instabilities now aggravated by climate change. In Africa, little is known about how climate interacts with other drivers of change in agricultural systems and broader development trends. The likely impacts of climate change on the vulnerability of agricultural systems need to be better understood, so that the resilience to current climate variability as well as the risk associated with longer-term climate change can be gauged, and appropriate actions taken to increase or restore resilience where it is threatened (Thornton *et al.*, 2008).

As are other parts of West Savannah Africa, the Upper East Region (UER) of Ghana has been, since colonial times (1904–1957), the poorest part of the country. The area suffers from difficult climatic conditions, relatively high population density and patterns of underdevelopment, which are the result of discriminatory colonial and post-colonial policies (Laube et *al.*, 2012). Accordingly, apart from climate change, large population growth has occurred over the last century, which has led to increasing pressure on natural resources such as soils, pastures and forests. Degrading resources have led to decreases in the output of the traditional agro-pastoral production system consisting of rain-fed agriculture and livestock husbandry (Laube *et al.*, 2012). Given the dynamics and complexity of the agricultural systems and other livelihood strategies, there is a greater need to better understand the impacts of climate change on the vulnerability of the systems. In this situation, the complexity of the situation means that for many in Africa, adaptation is not an option but a necessity (Boko *et al.*, 2007). Accordingly, it is admitted that adaptation can greatly reduce vulnerability to climate change by making rural communities better able to adjust to climate change and variability, moderate potential damages, and cope with adverse consequences (IPCC, 2001).

However, in the context of West African savannah, agricultural adaptation is about decisions and changing conditions at farm and local levels (Bryant *et al.*, 2000). In fact, farmers have diversified their livelihoods to adapt to uncertain environmental conditions in various ways including many possible responses, such as changes in crop management practices, livestock management practices, land use and land management and livelihood strategies (Boko *et al.*, 2007; Bryan *et al.*, 2013; Laube *et al.*, 2012). Previous studies suggested that, in order to improve estimates of climate impacts on agricultural system and contribute efficiently to adaptation research, there is a need to know more about how farmers perceive climate and how they respond, in both the short- and long-term, to variable climate conditions, including the magnitude and frequency of extreme conditions (Smit *et al.*, 1996). Moreover, literature on adaptations also makes it clear that perception is a necessary prerequisite for adaptation (Maddison, 2006). Nevertheless, there is little knowledge whether farmers perceive climate change in adopting adaptation measures (Fosu-Mensah *et al.*, 2010) in the West African region where much research is taking place. In fact, one of the findings of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) is the need to continue generating and sharing new knowledge from different fields and sectors because climate change is not static (Vermeulen, 2014).

Why farmers' perception?

A number of studies have shown that the success of any adaptation measures would mean farmers having the right perceptions about climate change and variability. Studies conducted by Salick and Byg (2009) indicate that local knowledge and experience have helped to advance understanding of climate change and its impacts on agriculture. For example, a study among coffee producers in Central America and Mexico (Tucker *et al.*, 2010) supports the importance of local knowledge and perceptions of climate as critical ingredient in guiding policy responses on adaptation. In South Africa and Ethiopia, research studies highlighted the role of individual perceptions in understanding the importance of education and awareness building and in identifying available options to enable farmers to adapt (Bryan et *al.*, 2009). Legesse *et al.,* (2012) stated that understanding perceptions and adaptation strategies of individual households or communities in certain area does not only provide better location specific insights but also helps generate additional information relevant to policy and interventions to address the challenges of sustainable development in the light of variable and uncertain environments. Mahmood *et al.,* (2010) reiterates the importance of measuring perception level about climate change and formulation of coping strategies. With these studies, a better understanding of farmers' perception of climate change, ongoing adaptation measures, and the decision-making process is important to inform policies aimed at promoting successful adaptation of the agricultural sector. Adaptation will require the involvement of multiple stakeholders, including first and foremost, farmers, but also policymakers, extension agents, NGOs, researchers, communities and the private sector (Bryan *et al.*, 2013). The aim of this chapter was to determine the farmers' perception of climate change and to compare those perceptions with historical climatological evidence. With this, we can address the research questions of "*Do farmers' perception of climate change agree with empirical climatological evidence? Which of the climate change parameters have mis-conception?"* Also, factors that influence farmers in their perception of climate variability in the study area were investigated.

5.2 Methods

5.2.1 Climatological evidence

The historical climatic data from Navrongo weather station (GMA, 2013) was used to examine farmers' perception of climate change and variability in the study area. The choice of this weather station is based on the availability of long climatic records and its closest location to the research area. The data cover a period of 50 years (1961-2010). These data were used to compute the annual average of temperature (minimum and maximum) and rainfall. Other parameters related to the rainy season such as onset and cessation dates of the rainy season and number of days without rains (i.e. drought) were computed over a period of 40 years because only the period 1970-2010 of the data has been recorded on a daily basis.

When computing the average of annual rainfall values, only the seasonal period of seven months (i.e. from April to October) for each year has been considered in order to ensure that only the effective crop growing period was used.

The agro-climatologic approach was then applied to compute the dates of onset and end of the rainy season and the intra-seasonal number of days without rains (dry spells).

- ***Onset of the rainy season***: In the literature, several models have been proposed for determining the dates of onset of the rainy season, depending on the area of interest (Ati *et al.*, 2002). The definition used in this approach is based on the daily rainfall data in considering the length of the dry spells as supported by several authors (Sivakumar, 1988; Sivakumar, 1990; Morel, 1992; Diallo, 2001; Punyawardena, 2002; Stern *et al.,* 2005). In this regards, the date of the onset of the rainy season is defined as the date after first April when the amount of rainfall accumulated over three consecutive days is at least 20 mm and when no dry spell within the next 30 days exceeds 20 days.

- ***End of the rainy season***: The definition of end of the rainy season is based on the water balance approach which refers to the soil drying process in order to determine the end of the growing season (Yaakov *et al.,* 2004). Therefore, the date of the end of the rainy season is defined as the date after first October, when a soil with 60 mm of field capacity is totally depleted by a daily evapotranspiration loss of 5 mm (Stern *et al.*, 2005; Morel, 1992). Then, it is assumed that the soil is at field capacity of 60 mm on the last day of rain.
- ***Intra-seasonal dry spell***: The dry spell is defined as consecutive days without rains (Stern *et al.*, 2005). Since a long dry spell after the start of the growing season (onset) causes a 'false start' or crop failure, so it is very important to consider the parameter in this analysis especially in this case where farmers themselves were indicating during the surveys that 'the drought after the sowing dates causes death of crops' as referring to crop failure. Based on the importance accorded to this concern of farmers in the study area, the dry spell was computed during the next thirty days after the date of the onset. And the average date of the onset of the rainy season in this area is stated at 122 Julian days which corresponds to first May (Table 5.1).
- ***Duration of the rainy season***: The duration or length of the rainy season which refers to the length of the growing season in this analysis is calculated by subtracting the date of the beginning (onset) from the date of the ending of the

rainy season. This parameter, in addition to those defined previously are assumed to be the main concern of agriculturist in the West African savannah (Edoga, 2007).

Table 5.1: Descriptive statistics of climatic parameters used to analyse farmers' perception of climate change and variability (1970-2010). The change corresponds to the difference of the extreme values (first year and last year) of the trend line (Data source: Meteorological Services Agency of Ghana)

Parameter	Mean	Max	Min	Standard deviation	Coefficient of variation	Change
Temperature max (°)	35	36	34	0.48	0.20	1
Temperature min (°)	23	24	22	0.46	0.28	1
Rainfall (mm)	974	1360	632	154	2.24	-5
Start season (Julian day)	122	162	95	17	2.21	9
End season (Julian day)	282	299	275	7	0.38	4
Duration (day)	160	193	122	16	1.61	-5
Dry spell, May (day)	10	17	5	3	5.01	3
Rain days (day)	70	85	58	7	1.60	-1

All these parameters were standardised in order to determine the trend during the series and explore the inter-annual variability. To do so, the standardised anomalies have been computed using the difference between an annual mean as observation and average of the data series divided by the standard deviation (Equation 1). The average of the data used is in line with the requirements of the World Meteorological Organisation (WMO) which suggested the following periods as normal climatology (30 years) for any climatological studies: 1961-1990 and 1971-2000. The following formula is used to calculate the standardised anomalies:

$$\text{Standardised anomaly} = \frac{X_i - \bar{X}}{\delta} 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation (1)}$$

Where, X_i represents the annual value or observation of year i, $\bar{X}$ is the climatological average and δ is the standard deviation of the normal climatology.

5.2.2 Data analysis

The perception of climate change is defined on the right awareness of a farmer about the following five climatic parameters: rainfall, temperature, onset, drought and the end of the rainy season, which were based on the historical climate records. During the surveys, farmers were asked whether they have observed any long term changes in temperature and rainfall over the last 20 years. In other words, farmers were simply asked whether the number of hot and rainy days have increased, decreased, or stayed the same over the last 20 years. The same approach was used for the onset, the end of the rainy season and the dry spell. Farmers gave their points of view on these last three parameters which characterised the rainy season through the following answers: (1) earlier; (2) late; (3) no change; (4) increased; (5) decreased; or (6) do not know.

To consider that a respondent has perceived climate change and variability correctly, all of the five following parameters must be in agreement with the respondent's responses: 1) decreased in rainfall, 2) increased in temperature, 3) late for the onset date, 4) early for the ending season date, and 5) increased drought frequency. Any disagreement in one of the five parameters leads to a deviated perception of respondent on climate change. This conception of changes is based on the projection of the IPCC, when it is predicted that changes in climate variability and extremes are likely to be increased (IPCC, 2001) and especially when agriculture, food and water are the key vulnerable sectors identified particularly in the case of Sub-Saharan Africa (Boko *et al.*, 2007).

Further, the binary logistic regression model was used to determine the factors that influence farmers' perceptions of climate using the formula in Equation 2:

$$\log\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_{ik} \quad \ldots\ldots\ldots\ldots \quad \text{Equation (2)}$$

Where, i denotes the i-th observation in the sample, P_i is the predicted probability of farmers' perceptions which is coded as a dummy variable with the value of 1 when a farmer has a good perception of the climate change and 0 otherwise ($1 - P_i$). β_0 is the intercept term, and β_1, β_2, and β_k are the coefficients associated with each explanatory variable X_1, X_2 and X_k. The term (P_i /1-P_i) is the odds. The coefficients in the logistic regression were estimated using the maximum likelihood estimation method.

5.2.3 Variable specifications for Binary logistic regression in modelling farmers' perception

Dependent variable

Farmers' perception was considered as a dependent variable. It was used as a dummy variable represented by the value 1 when a respondent has given all right answers on the long term changes in rainfall, temperature, onset, drought frequency and end of the rainy season and 0 when one of the five answers is wrong (see section 5.2.2). Since the farmers' perception of climate change is a categorical variable with binary outcomes, the binomial logistic regression was considered appropriate for analysing these data (Train, 2009; Greene, 2002; Greene, 2012). In the area of adaptation studies, farmers' perception of climate change is most of the time based on the perception of average change of temperature and rainfall which are the main climatic parameters used in previous studies. The questions are always referred to the long-term change into several categories such as perceived increase, perceived decrease, and no change. In the data analyses, whether farmers have perceived climate change or not, binary model has been used (Bryan *et al.*, 2013), but probit model has also been used as well (Deressa *et al.*, 2008, Gbetibouo, 2009). In addition to the two common climatic parameters used by the previous studies, this research considered the onset of the rainy season, the end of the rainy season and the drought or the number of days without rains in the analyses of farmers' perception.

Explanatory variables

In the area of adaptation studies, the characteristic of the households, the institutional factors and the environmental attributes are usually used to understand the factors that determine farmers' perception of climate change and variability (Maddison, 2006). In this research, the following variables were hypothesised to influence farmers' perception of climate change and variability (Table 5.2):

(1) Age, gender and farming experience of the household heads as characteristics of the households;

(2) The information about weather or climate received from extension officer or any media as institutional factor and;

(3) The values of slope and elevation of the location of the households as agro-ecological factors.

All these variables have also been used in previous studies (e.g. Deressa, 2008; Gbetibouo, 2009; Bryan *et al.*, 2013) for the purpose of exploring farmers perception of climate change and variability. The hypothesised influence expected by these explanatory variables is also indicated in Table 5.2. Since the climatic data of only one weather station was used and also because of the small size of the study area (192 km^2), temperature and rainfall were assumed to be quite uniform and only the slope and elevation were considered as two factors which could have sensitive influence on the ecological conditions of the landscape in the area.

Table 5.2: Variables hypothesised to influence farmers' perception of climate change and variability

Variable	Description	Expected effect	Data source
Dependent variable			
Perception of climate change	Dichotomous responses based on the answer of farmer on the changes in temperature and rainfall		Field surveys (2012)
Independent variable			
Characteristics of household head			
Age	Age of the head of the farm household	(+/-)	Field surveys (2012)
Gender	The gender of the farm household head	(-)	Field surveys (2012)
Farming experience	Number of years of farming experience of the household head	(+)	Field surveys (2012)
Institutional or policy related factors			
Clim-info	Dummy variable on whether the household is getting information about weather or climate from extension officer or any media	(+)	Field surveys (2012)
Agro-ecological setting of the households location			
Elevation	Value of the elevation (m) of location of the household	(+)	GIS based calculations
Slope	Value of slope (degree) of the location of the household	(-)	GIS based calculations

5.3. Results

5.3.1 Farmers' perception on long term changes of rainfall and temperature versus climatological evidence

Among the farmers interviewed in the study area, 82 % perceived the long-term changes in temperature over the last 20 years (Figure 5.1a). About 71 % of them perceived temperature as increasing in contrast to the 11 % which perceived that temperature is decreasing. In comparing this perception with the actual trends of the maximum and the minimum temperature recorded during the last 50 years (Figure 5.1b and 5.1c), there was a clear increase, suggesting that the farmers' perceptions in terms of long term changes in temperature are supported by the climatological evidence.

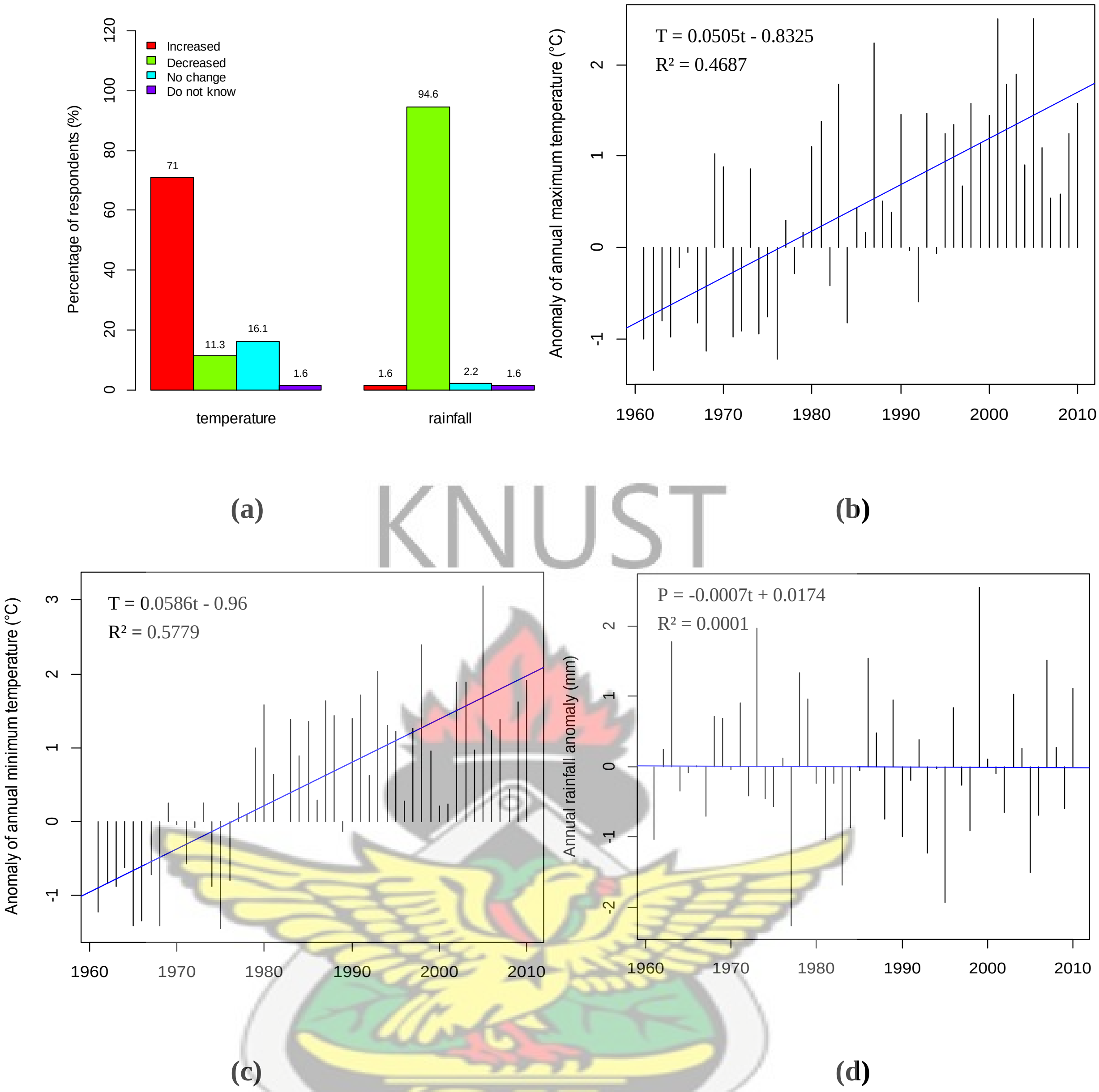


Figure 5.1: (a) Farmers' perception of long term changes in temperature and rainfall, the trends of (b) maximum temperature, (c) minimum temperature and (d) rainfall.

The majority of the respondents (96 %) interviewed within the basin also perceived the long-term changes in rainfall pattern over the last 20 years. About 95 % of them claimed that they have observed a decrease in the amount of rainfall and the rainy season is becoming shorter (Figure 5.1a). In contrast, 2 % of respondents reported rainfall has increased during the last 20 years. Unlike temperature, rainfall seems to be better observed by farmers since 16 % of them did not observe any change while 11 % observed a decrease in temperature which is assumed to be a consequence of lack of information. Nevertheless, comparing the farmers' perception with the recorded climate data shows that there is no real evidence that rainfall in terms of amount has reduced as claimed by 95 % of farmers (Figure 5.1a). Even though the trend of the rainfall pattern during the last 50 years is decreasing, the decrease is not significant (R^2= 0.0001) at all due to the high inter-annual variability of the rainfall (Figure 5.1d). This observation raises the questions on whether perception of farmers about climatic parameters has certain limits over time or whether farmers are more interested in climatic parameters in different ways which are more relevant for them, because it is more related to their farming activities.

5.3.2 Farmers' perception on long term changes of onset and end of the rainy season versus climatological evidence

Farmers of the study site paid much attention to the characteristics of the rainy season over time. About 99 % and 98 % of interviewed farmers have reported that there is a long-term change in the start and end of the rainy season, respectively (Figure 5.2a). In terms of the date of the onset of rainy season, 97 % of the respondents have reported the late onset which is shifting from April to June during the last 20 years while only 2 % of the respondents have reported that the dates of the onset are early (Figure 5.2a). On the other hand, the dates of end of the rainy season are nowadays early shifting from November to October over the last 20 years according to 96 % of farmers interviewed, and only 3 % of farmers thought that the rainy season is ending late. In comparison with the climatological data, the trend of the annual onset dates of the rainy season during the last 40 years (1961-2010) shows a clear increase, suggesting that the rainy season is starting late (Figure 5.2b). Thus, there is an agreement between the climatology and the farmers' perception about the late dates of onset.

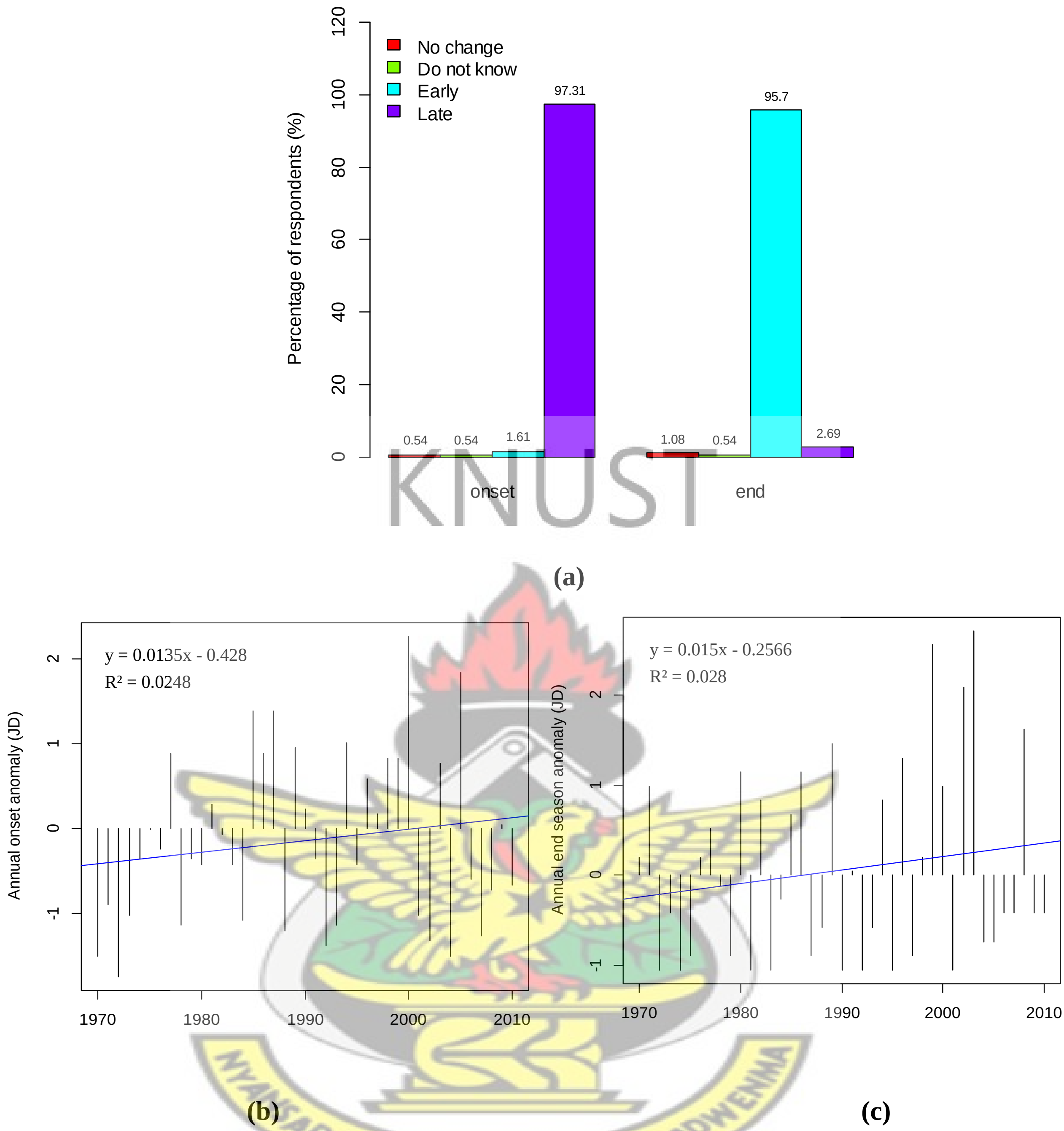
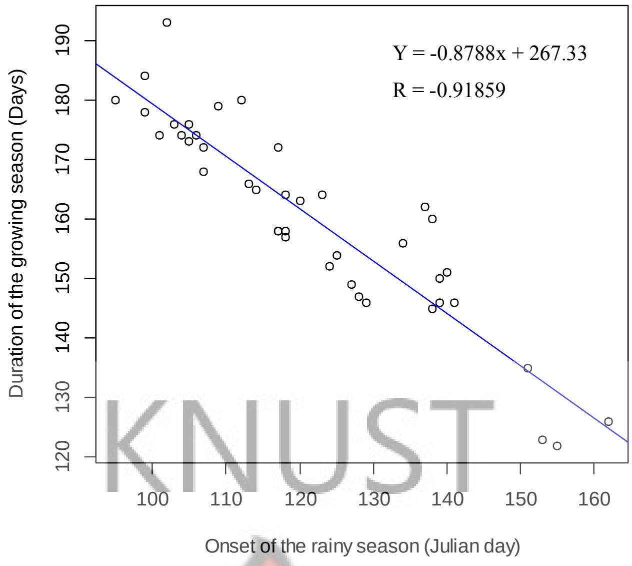
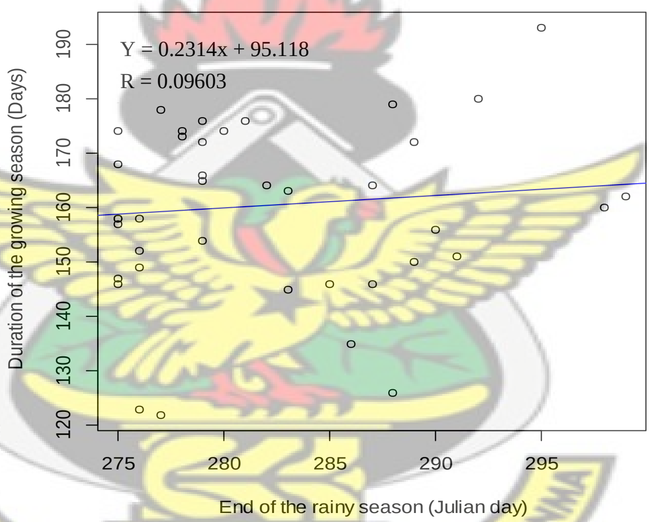


Figure 5.2: (a) Farmers' perception of long term changes of onset and end of the rainy season, standardised anomalies of (b) the onset dates and (c) the cessation dates of the rainy season computed respectively based on the dates of the onset and end of rains in Julian days.

However, there is a contradiction between the climatological data and the perception of farmers concerning the cessation dates of the rainy season (Figure 5.2a). About 96 % of respondents reported that the rainy season is ending early while the trend of the end season anomaly shows a slight increase suggesting that the rainy season is ending late. In fact, the trends of the onset and the end of the rainy season are not statistically significant because strong inter-annual variability existed in the recorded data. However, to understand where the confusion of the respondents is coming from in terms of their perception about the end of the rainy season, we further explored the relationships between the duration of the rainy season and the dates of the onset and the dates of the end of the rainy season over the last 40 years (1970-2010). In this analysis, it is important to note that the duration of the rainy season corresponds to the effective growing period. The results of this analysis show a strong negative correlation (R = -0.918) between the duration of growing season and the dates of the onset of the rainy season (Figure 5.3a). This suggests that the earlier the onset date is the longer the growing period. On the other hand, a very weak correlation exists (R = 0.09603) between the duration of the growing season and the dates of the end of the rainy season (Figure 5.3b), which suggests that during the 40 years period in the study area, the duration of the growing period was not related to end of the rainy season at all. This statement is in line with the views of the respondents stating that "*when you miss the onset of the rainy season (during the sowing period at the beginning of the rainy season), it is very likely to lead to a poor yield especially for some cereal crops like early millet*". Obviously, based on the recorded data, the late start of rainy season strongly influences the period of the growing season, and farmers are presuming this reduction of the growing period to both parameters (onset and end) of the rainy season. For farmers, even though the rainy season starts late, they still expect to get the same length of the growing period they are used to.



(a)



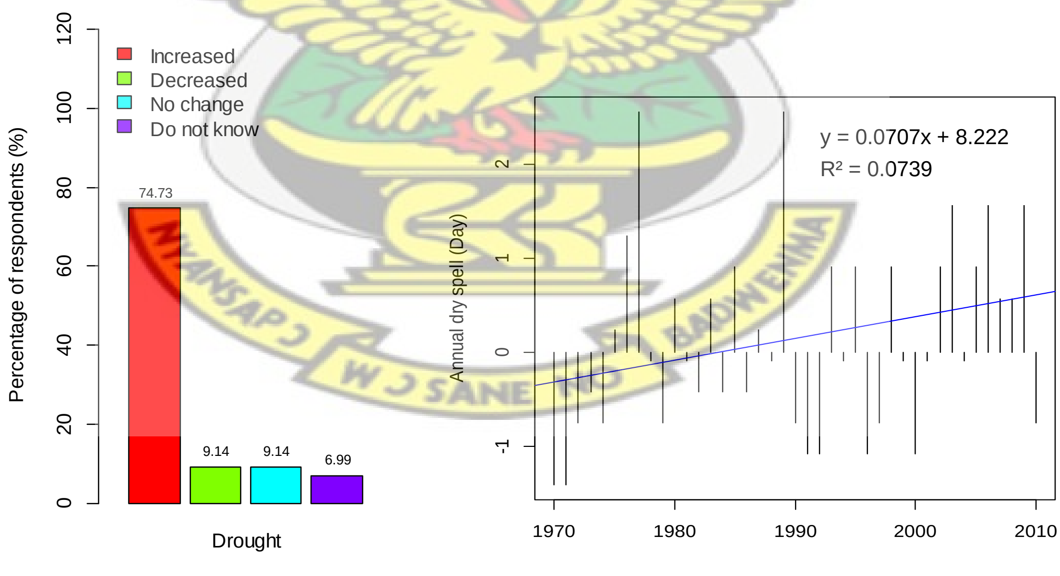
(b)

Figure 5.3: Duration of the rainy season in days as related to the dates of (a) onset and (b) cessation of the rainy season:

(a) Duration of the rainy season in days is highly correlated to the onset dates in Julian days (Julian days 100 correspond to the 9th April and Julian days 160 corresponds to the 8th June), (b) Duration of the rainy season in days is less related to the dates of the end of the rainy season in Julian days (Julian days 275 correspond to the 01st October and Julian days 295 correspond to the 21th October). The inter-annual variability is very high for the start of the rainy season (onset dates) varying from April to June during the last 40 years; unlike for the end of rainy season which is much more stable during the last 40 years varying only within one month (October).

5.3.3 Farmers' perception on long term changes of drought frequency versus climatological evidence

During the surveys, respondents claimed that the drought is a serious matter causing crop failure at the beginning of the growing period. For this reason, the stated concern was considered in the analysis by examining the number of days without rains (dry spells) for the first thirty (30) days after the average date of the onset (01 May) during the last 40 years in the study area (Table 5.1). There was an increased trend of dry spells during the next thirty days after the planting date (Figure 5.4b) which is in agreement with farmers' perceptions as illustrated in Figure 5.4a, which shows 75 % of farmers perceived an increase of drought frequency. Moreover, the area has experienced a continuous high frequency of dry spells during the last 10 years (2000-2010). This anomaly is not only in agreement with farmers' perception but also support their concern about the increasing crop failures during the last 20 years. On the other hand, 9 % of the respondents have reported that the frequency of drought has decreased.



(a) (b)

Figure 5.4: (a) Farmers' perception of drought frequency and (b) the trend of the dry spells of the next thirty days after the sowing date (date of onset). Note: The average date of onset during the last 40 years is stated at Julian day 122 which corresponds to 1st May

5.3.4 Determinants of farmers' perception

The empirical binary logistic sub-model which determines factors that influence farmers' perception of climate change and variability in the study area is depicted in Table 5.3. The likelihood ratio test showed that this sub-model is highly significant ($p = 0.001$) in exploring farmers' perception of climate change and variability. Among the explanatory variables, only two variables namely (Table 5.3); access to climate information from agriculture extension agent ($p < 0.036$) and elevation ($p < 0.000$) have significant association with a good perception of climate change and variability. These variables suggest that receiving climate information from agricultural extension services increases the odds of having a good perception of climate change by 101 % (2.011 - 1) and a 1 metre increase in terms of elevation (at the household location) also increases the odds of good perception of climate change by 4 % (1.040 – 1) (Table 5.3).

Table 5.3: Results of binary logit regression model for predicting farmers' perception of climate change and variability

Source	Value	Standard error	Wald Chi-Square	Pr > Chi²	Odds ratio
Intercept	-7.301***	2.319	9.911	0.002	
Gender	-0.480	0.460	1.089	0.297	0.619
Age	0.012	0.017	0.463	0.496	1.012
Experience	-0.024	0.016	2.125	0.145	0.977
Elevation	0.040***	0.010	14.327	0.000	1.040
Slope	-0.153	0.123	1.554	0.213	0.858
Clim-info	0.699**	0.333	4.405	0.036	2.011

Fitness and accuracy of the model
Likelihood test (chi-square statistics): 24.10 *df* = 6 p = 0.001
***, ** and * indicate the significance level at 1, 5 and 10% respectively

The sub-model has a good predictive power with an overall percentage of correct prediction of 65%. And this sub-model is much better at predicting farmers with good perception of climate change and variability because when the probability of good perception equals 1 the percentage of correct prediction reaches the 74% (Table 5.4).

Table 5.4: Percentage of correct prediction

from \ to	0	1	Total	% correct
0	48	39	87	55 %
1	26	73	99	74 %
Total	74	112	186	65 %

5.4. Discussion

5.4.1 Do farmers' perception of climate change agree with empirical climatological evidence?

The results presented in our study support the growing evidence that temperature is continuously increasing while rain becomes less predictable and shorter in duration (Maddison, 2006; Thornton et *al.*, 2006). As elsewhere in Africa, the majority of farmers in the study area believe that the climate has changed, including the three additional parameters (the onset of the rainy season, the end of the rainy season and the number of days without rains or droughts). The implication of these three characteristics of the rainy season in this study is related to their importance for farmers in terms of good start of the cropping system which is one of the key conditions for good crop production. Also the onset is the most important variable to which all the other seasonal characteristics are related (Laux & Kunstmann, 2008). For instance, the rainfall characteristics in terms of length of growing season have always been uncertain due to high variability of onset and cessation of the rainy season. In some years the rains start early while in others it arrives late. Hence, the inter-annual variability makes the planning of sowing and the selection of the crop type and variety rather difficult. In this context, farmers are very conscious that their production is suffering significantly with either a late onset or early cessation of the growing season, as well as with a high frequency of damaging dry spells with the growing season (Mugalavai *et al.*, 2008).

However, a number of farmers among the investigated communities reported that temperature has increased and rainfall has decreased. If the first farmers' assertion is in line with the trend of the historical maximum and minimum temperature of the weather station closest to the area (Figure 5.1b and c), the second assertion is not too much supported by the historical data since farmers are overestimating the decrease of the rainfall in the area (Figure 5.1d) given the very insignificant trend in terms of annual average of rainfall from the climatological evidence. In other words, though there is a high inter-annual variability in the amount of rainfall, the rainfall pattern in terms of average amount has not greatly decreased in the area which is in accord with the observation of Gbetibouo (2009) in the Limpopo basin of South Africa. In a recent research study in Kenya, Bryan *et al.* (2013) found that an overwhelming majority of farmers perceived an increase in average temperatures (94%) and decrease in average precipitation (88%) over the last 20 years. Some of the reasons explaining farmers' perception of long term decreases in rainfall may be based on their experiences with rainfall variability, increasing dry spells, and particularly shifts in timing through late onset and distribution of rainfall, rather than average quantities of annual rainfall. This may explain why farmers perceive a decrease in rainfall associated with climate change despite the fact that actual data have not shown a significant change in trend.

The analysis of the rainy season characteristics (onset dates, cessation dates, drought and the duration of the growing period) is also very relevant for farming systems since these characteristics are key factors in planning activities within the season. On this basis, majority of farmers believed that the rainy season starts late and ends early compared to the past twenty years (Figure 5.2a). Looking at the trends of these two parameters, though the rainy season starts late nowadays, it does not end early (Figure 5.2b, c) as claimed by the majority of the respondents. The end of the rainy season does not change too much and it is even coming slightly late since 1990 (Figure

5.2c). The previous statement is also supported by Figure 5.3b which shows that, for the last 40 years, the end of the rainy season is varying only within the month of October. Oladipo & Kyari (1993) investigated the fluctuation in the onset, cessation and length of the growing season in Northern Nigeria and reported that the length of the growing season is more sensitive to the onset of the rains than to the cessation. Mugalavai *et al.* (2008) also in their study on the analysis of rainfall onset, cessation and length of growing season for Western Kenya indicated that cessation of rainfall shows strong localised influences, mainly surrounding Lake Victoria and forested areas.

The results of the analyses on the relationship of the rainy season characteristics show that the early onset dates of rains results in a longer growing season and the late onset dates results in a shorter growing period (Figure 5.3a). In the study area, the average date of the onset of the rainy season is stated to be 122 Julian days which corresponds to the first (01) May and the average length of the growing season is 160 days during the last 40 years (Table 5.1). When the rainy season starts early (around Julian days 100 corresponding to the 09th April) then the growing period could reach the 180 days (six months) which effectively cover the cycle of the late varieties (Figure 5.3a). In contrast, for the late onset of the rainy season (Julian day 150 corresponding to the 29th May), the growing period could never reach the five months: which is too short for the local varieties with long cycle. This relationship between the onset and the duration of the rainy season is in line with the work of Sivakumar (1988; 1990) in the Sudano-Sahelian zone, particularly at the Niamey weather station using a longer historical database (1904-1984) with similar results. The relationship of later onset and shorter length of the growing period is also supported by Punyawardena (2002). Understanding the relationship among these characteristics of the rainy season is a key factor in land-use decision making and planning farming practices especially in the context of changing environment. However, this research found that climate change due to the changes in average climatic parameters used to define farmers' perception does not always attract the attention of most farmers. For instance, as discussed previously, due to the fact that farmers give much more importance to the intra-annual variability of rainy season characteristics such as rainfall intensity, they misperceived the duration of the growing season. As a result, farmers allocate the shortness of the growing season to the fact that the end is becoming early which is not supported by the records.

With regards to the results of the regression analysis, only two factors (information on climate and agro-ecological setting) influence significantly farmers' perceptions of climate change and variability. A positive relationship between the perception of climate change and access to information on weather and climate indicates that having extension advice is very likely to increase positively farmers' awareness of climate change and variability as hypothesised in this study and supported by studies of Gbetibouo (2009) and Deressa *et al.* (2008). Also, the farmers' perception of the local environment could be related to the topography of the area which determines a strong influence in the agro-ecology of the area. Accordingly, farmers living in the highlands are more likely to have a good perception of climate change and variability. This is in contradiction of the findings of Deressa *et al.* (2008) who indicated that farmers living in lowland areas are hypothesised to be more likely to have perceived climate change than farmers in the midlands and highlands. According to them the lowlands are already hotter and a marginal change in temperature can be perceived more easily. However, the limitation to this study is related to the fact that farmers were asked to indicate their awareness on the changes of five climatic parameters (temperature, rainfall, onset dates, cessation of the rainy season dates and the drought), which formed the basis for explaining their perception of climate change. The approach, however, discount the role of other drivers of climate change (economic, cultural, government, technological and environmental forces) which may amplify, negate or otherwise modify the impacts of climate on agricultural systems (Smit *et al.*, 1996).

5.4.2. Implications of adaptation to climate change and future research outlook

The findings of this work support the previous contributions in the area of adaptation research in the sense that it supports the collaboration between stakeholders, policy makers, development agencies and researchers in the understanding the multidisciplinary dimensions of climate variability. In this way, the contribution suggests the consideration of perception model in adaptation research in order to analyse appropriate adaptation measures stimulated by climate variability since the literature on adaptation also makes it clear that perception is a necessary prerequisite for adaptation (Smit *et al.*, 1996; Maddison, 2006). It was found that farmers adapted a range of practices in response to perceived climate change (Bryan *et al.*, 2013) and as a result, the most common responses included changing crop variety, changing planting dates and changing crop type. In this regards, about 41 % of farmers appeared to have changed their management in response to declining precipitation, with crop diversification and shifting the planting date being the most important adaptation measures (Fosu-Mensah *et al.*, 2010).

Consequently, an important issue related to adaptation to agriculture as pointed out by Bryant *et al.* (2000) is how these farmers' perceptions of climate change are translated into agricultural land use decisions, especially when it is recognised that farmers' responses can vary even when facing the same stimuli and within the same area. Accordingly, since perception of climate change itself is fundamentally determined by learning factors (Maddison, 2006), which include information on climate (learning by instruction), experience of farmers in other research (learning by doing) and the local environment (learning by copying), then it can be appropriately analysed using multidisciplinary approach such as MAS for technology diffusion and policy analysis (Maddison, 2006). Accordingly, research on the implications of climate change in agricultural land-use goes beyond crop yield modelling to estimate production and economic implications. Increasingly, the studies include adaptation, most commonly by assuming that farmers employ certain adaptive practices better suited to specified climate scenarios. There is clearly a need to test these assumptions by empirically examining actual adaptive behaviour of farmers, to identify the pertinent stimuli, the relevant constraints, and the general adaptive response functions to variations in climatic conditions over time (Bryant *et al.*, 2000; Vermeulen, 2014).

5.5 Conclusions

The findings of farmers' perceptions of climate change and variability in the study area show that farmers knowledge of past climate variability matches closely the empirical observations. A number of farmers in the study area (53 %) are aware of the increasing temperature, the late onset of rains and the increasing drought frequency which is in accordance with empirical climatological records. However, due to the fact that farmers give much more importance to the intra-annual variability of rainy season characteristics such as rainfall intensity, they misperceived the duration of the growing season; instead, farmers allocate the shortness of the growing season to the fact that the rainy season is ending earlier than before, which is not supported by the records. Also, the results of this research indicate that the local environment (i.e. topography) and access to climate information are the two main factors which influence the perception of climate change and variability in the basin.

The findings of this research are very relevant in agricultural land use decision analyses, since it contributes to answering the question of whether or not certain factors driving agricultural land use choice are beyond farmers' indicators and other assumed driving forces. This is in line with IPCC's policy objectives to improve tools for integrated assessment, including risk assessment, to investigate interactions between components of natural and human systems and the consequences of different policy decisions (IPCC, 2001). Accordingly, the study recognises that the role of climatic variations in promoting changes in agriculture cannot be understood without careful consideration of the role of other forces; economic, policy and environmental. Successful implementation of adaptation related policy is dependent on a decision-making framework that is informed by scientific and local knowledge. As observed by Howden *et al.* (2007), stakeholder perception serves to inform adjustment strategies to climate change impacts while simultaneously preserving cultural values that are meaningful to local communities.

6. SMALL-SCALE FARMERS' ADAPTATION TO CLIMATE CHANGE AND AGRICULTURAL LAND USE

6.1 Introduction

In much of sub-Saharan Africa, precipitation is inherently variable from year to year. This is often expressed by recurrent droughts and periodic flooding. Between 1991 and 2008, Ghana for instance experienced six major floods with greater than 2 million people affected by the floods in 1991. The northern savannah zone is exposed to floods as well as droughts. In 2007, floods followed a period of drought and affected more than 325,000 people. Because most agriculture is rainfed and rural populations in many countries lack the resources to moderate or adapt to drought, the agricultural sector is particularly vulnerable (Stanturf *et al.*, 2011). As a result, the Human System (HS) particularly the rural population is facing a permanent challenge. One response to this challenge is the concept of adaptive capacity that was built on the observation that some societies are better able to adapt, because of a combination of available resources, governance systems and ultimately better social learning processes (Smit & Wandel, 2006). Now efforts are still underway to include climate change adaptive capacity into socio-ecological models as a way of better forecasting future climate-related damages, and also as a way of suggesting immediate policies to improve adaptive capacity. However, one of the difficulties to cope with the social system is its complexity due to human behaviour. That is the reason why a proper assessment of adaptive capacity focused on an appropriate understanding of the micro- and macro-behaviours of societies exposed to the impacts of climate change is needed (Patt & Siebenhüner, 2005).

However, the term adaptation is still little understood by the broader public, and the topic adaptation to climate change also remains poorly understood. In the climate change community, the term "adaptation" has been used since the early 1990's, but no single definition has been generally adapted. The concept, as it is presently used in the global change field, has its origins in natural sciences, particularly evolutionary biology (Smit & Wandel, 2006) where the concept adaptation broadly refers to the development of genetic or behavioural characteristics which enable organisms or systems to cope with environmental changes in order to survive and reproduce (Winterhald, 1980).

Today, numerous definitions of adaptation are found in climate change literature (Malik *et al.,* 2010; Patty *et al.,* 2009; Smit & Wandel 2006; Smit *et al.,* 2000). However, most of them vary by the phenomena of interest. The Intergovernmental Panel on Climate Change (IPCC) for instance has defined climate change adaptation as "adjustments in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderate harm or exploit beneficial opportunities" (IPCC, 2001). However, various types of definition can be distinguished including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation (Smit *et al.*, 2000, Smith & Lenhart, 1996). These definitions of these concepts have much in common. As indicated by Smit *et al.* (2000), they all refer to adjustments in a system in response to climatic stimuli, but they also indicate differences in scope, application and interpretation of the term adaptation. Therefore, based on the previous definitions, coping with this concept refers to the question of knowing "how does adaptation occur?", "who or what adapts? and "adaptation to what?".

Looking at the study area, climate change, population pressure and land degradation remain the major factors affecting the agricultural land-use systems resulting in further impoverishment for small-scale farmers. In this situation, farmers have diversified their livelihoods to adapt to uncertain environmental conditions in various ways including diversification of production, migration to urban areas and introducing irrigation (Laube *et al.*, 2012). However, few studies have been conducted to date to identify factors that influence the choice of indigenous climate related strategies by smallholder farmers in northern Ghana (Al-hassan *et al.*, 2013). Hence, this research comes in as a contribution to the understanding on the adaptation strategies to climate change and variability in this area. Therefore, the specific objectives developed in this chapter were to:

(1) Analyse the changes in farming systems due to long term changes in temperature and rainfall and the strategies introduced in farming;
(2) Identify barriers to the adaptation strategies and;
(3) Determine factors explaining the choice of the adaptation strategies.

6.2 Methodology

6.2.1 Research background

A number of adaptation methods were identified by the adaptation studies among which the most commonly cited in the literature include new crop varieties, livestock species, irrigation, crop diversification, mixed crop livestock farming systems, change of planting dates, diversification from farm to non-farm activities, increased use of water and soil conservation techniques, changed use of capital and labour and trees planted for shade and shelter (Al-hassan *et al.*, 2013; Maddison, 2006; Nhemachena & Hassan, 2007; Deressa *et al.*, 2008). Generally, the different strategies used to adapt the agricultural land-use system against the negative implications of climate change and variability found in the literature can be summarised by the following five broad farming strategies:

(1) Intensification of production;
(2) Diversification of agricultural activities to increased output values;
(3) Expanding farms and herd size;

(4) Increasing off-farm income and;

(5) Complete exit or departure from the farming system or migration in general.

All the aforementioned strategies are the same which Dixon *et al.* (2001) identified as farm household strategies. The authors, judged the five broad farm household strategies to have greatest potential for poverty and hunger reduction and economic growth in the next few decades. For them, these five broad possible farm household strategies are considered to help farmers to escape from poverty and hunger and improve livelihoods. Moreover, they used these farm household strategies, as a basis for defining the major farming systems throughout the developing regions of the world in order to offer a framework within which appropriate agricultural development strategies and interventions can be determined. Thinking in this way arise the critical question of whether or not the adaptation methods reported by farmers are only stimulated by climate change. The impacts of climate change are there, especially those of climate variability which are the main concerns of farmers, but there is a strong influence of non-climatic factors such as economic, cultural, government, technological or environmental forces which may amplify, negate or otherwise modify the impacts of climate on agricultural land-use systems (Smit *et al.*, 1996). This is an empirical issue faced in this area of adaptation research especially because farmers themselves seem to be more concerned about socio-economic change rather than climate change meaning that adaptation measures reported by farmers may be profit driven rather than climate change driven (Deressa *et al.*, 2008; Nhemachena & Hassan, 2007). The process seems to be complex by the fact that the other forces which are the non-climatic factors are also often as variable and unpredictable as climate conditions (Smit *et al.*, 1996), which may lead to the design of assumptions and scenarios via simulations on the land-use systems, climate hazards, decision-making and strategies in order to capture the impact of climate change and variability on the agricultural system independently of the non-climatic forces. This may be one of the contributions of SKY-LUDAS in this area since, it aimed to explore the implications of adaptation decision making in agricultural land-use system and small-scale livelihood strategies.

6.2.2 Research approach

As introduced in the previous sections, the process of adaptation depends on many factors, including who or what adapts, what they adapt to, how they adapt and what and how resources are used (Wheaton & Maciver, 1999). For these reasons, in order to explicitly investigate the implications of adaptation in agricultural land-use system, this study, adapted the approach of adaptation research. This approach showed clearly the dimensions of adaptation through a conceptual framework of adaptation research (Figure 6.1). With respect to the framework, adaptation research is represented as a process driven by a broad range of multi-dimensional determinants characterised by four core questions (Preston & Stafford-smith, 2009):

(1) Who or what adapts?

(2) What do they adapt to?

(3) How do they adapt? and;

(4) What do they want to achieve?

The adaptation cycle is iterative, dynamic, interconnected, non-linear and likely chaotic (Wheaton & Maciver, 1999). However, barriers and limits as shown in Figure 6.1 are the main factors of disturbance of the relationship between determinants and the adaptation process. For the purpose of this study, four main core factors which are highlighted in blue in Figure 6.1 represented the key responses to the determinants of adaptation research in this area of agricultural land-use system in the study area.

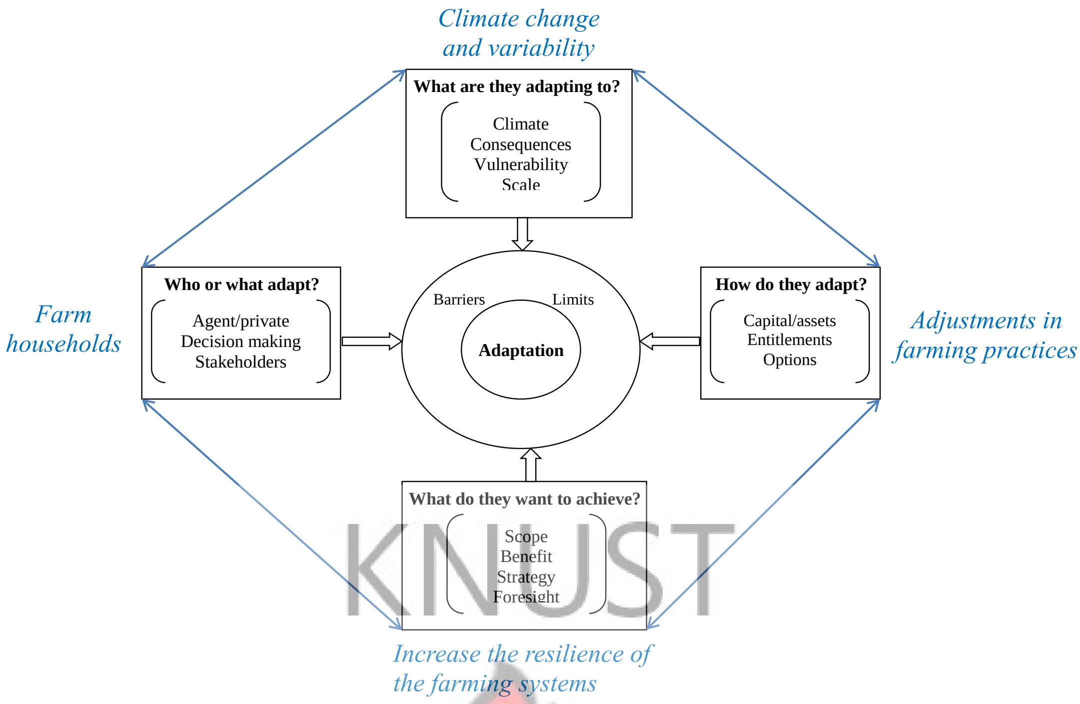


Figure 6.1: Framework of adaptation research approach (Adapted from Preston & Stafford-Smith 2009)

6.2.3 M-logit variable specifications for modelling adaptation

The aim of this section is to determine a set of options which represents the categorical dependent variable (adaptation to climate change and variability). Twelve (12) adaptation practices related to climate change have been collected in the study area during the surveys (2012) on farming system: New crops, New varieties, Intercropping/Mixed cropping, Early sowing, crop rotation, Soil conservation technique, Extend land, Irrigation, Planting trees, Non-farm activities, livestock and Migration. All these adaptation practices were subjected to the Principal Component Analyses (PCA) in order to condense and reduce the number of these options from a large number of original variables into new composite components with minimal loss of information. For the principle of the PCA, see Chapter 3. For the selection of these adaptation practices, Kaiser-Meyer-Olkin (KMO) was used as a measure of sampling adequacy. As a result, and following practices with KMO less than 0.5 three have been removed from the PCA analysis: crop rotation, migration and non-farm. Then, only the variables with higher loadings per identified component were selected to name the first five principal components (adaptation option factors) as follow (Table 6.1):

(1) Early sowing and planting trees;

(2) Crop diversification;

(3) Land use diversification;

(4) Crop-livestock integration and;

(5) Land use intensification.

In reality, adaptation strategies are not mutually exclusive. In fact, even at individual household level, almost every farm household pursues a mixed set of strategies depending on its capability (Dixon *et al.*, 2001). Also in terms of the use of the concepts land-use intensification and diversification, there is no real consensus in the literature because of overlapping that often occurred between approach concerning which practices should be considered as intensification or diversification. For instance, on one hand cultivation of different crops under certain management practices is considered as System of Crop Intensification (Berhan *et al.*, 2011), on the other hand FAO grouped a number of broad practices as land-use diversification including: intensification of livestock in mixed farming systems, improvement of agroforestry systems, increasing off-farm employment and income generating activities, etc.

However, the approach used in this study, discriminated land-use diversification and land-use intensification which is in accordance with the method used by Lambin *et al.* (2003). Accordingly, the mixed cropland expansion was separated from agricultural intensification (Lambin *et al.,* 2000, 2003). With respect to the above discussion, the adaptation option factors early sowing/planting trees and crop diversification constituted also a form of land-use intensification and crop-livestock integration as land-use diversification. These selected adaptation options are described as follow:

Land-use diversification

Crop-livestock integration is one of the common practices in the study area (Figure 6.2). This option refers to farmers with at least one cow in the house. Owning the cows gives farmers, the possibility of having manure, the use of ploughing, and the transportation of manure to the field. Irrigation was also practiced in the area. In this case, farmers used either one of his plots during the rainy season or a different plot (which could be rented or was unused during the rainy season because of flooding) for dry season farming. This explained the positive correlations of variable irrigation and extended land to the principal component land-use diversification (Table 6.1). The selection of this activity as adaptation option is also supported by the fact that it has been introduced in the study area not longer than the mid-1990s when small farmers started to develop their irrigation facilities and established vegetable gardens along the dry riverbeds because they were facing decline of rainy season farming which increased poverty (Laube *et al.*, 2012).

Figure 6.2: Best example of fertility management in the study area where integrating crop-livestock with the aim of recycling soil nutrients is very well understood by farmers.

Land-use intensification

Maize and soybeans were the two variables mentioned so far by farmers whenever a question was referred to new crops introduced in the study area. The correlations of these variables to the factor Crop diversification (Table 6.1) helped to understand that the new crops are more adapted by farmers who were already in the use of new varieties. The selection of these two practices of adaptation options is supported by the participatory meeting with stakeholders organised during the field work. The introduction of these crops was understandable in the sense that new practices in the area helped to face the decrease of rain-fed production in the area where selling cereals like millet and guinea corn is a taboo.

No adaptation: The variable No adaptation referred to those farm households who were not doing any of the selected options to support their farming system.

Table 6.1: Grouping the selected adaptation options based on the PCA

Variable	Early sowing and Planting trees	Crop diversification	Land-use diversification	Crop-livestock integration	Land-use intensification
	PC1 (25.06 %)	PC2 (15.29 %)	PC3 (12.94 %)	PC4 (12.17 %)	PC5 (11.22 %)
New crops	-0.025	**0.866**	0.041	0.013	-0.036
New varieties	0.189	**0.840**	-0.042	-0.076	-0.002
Mixed cropping	-0.053	0.060	0.208	-0.252	**0.803**
Early sowing	**0.990**	0.083	0.051	-0.044	-0.032
Extended land	0.129	0.132	**0.564**	0.486	0.092
Irrigation	0.025	-0.062	**0.823**	-0.129	-0.008
Soil conservation	0.013	0.144	0.244	-0.382	**-0.665**
Livestock	-0.106	-0.072	-0.053	**0.818**	-0.055
Planting trees	**0.990**	0.083	0.051	-0.044	-0.032

6.2.3.1 Dependant variable

The dependant variable is the choice of adaptation options by the farm households. This categorical variable is composed by the following options: Crop-livestock integration; Irrigation; Soybeans farming; Maize farming and No Adaptation.

6.2.3.2 Independent variables

Research in adaptation studies cited a number of factors as explanatory variables hypothesised to influence farmers' adaptation choice. These factors were varied and can be grouped in the following three categories:

(1) Farm households' characteristics;

(2) Environmental attributes of land plots and;

(3) Institutional or policy related factors.

The most commonly cited in the literature of adaptation studies include: age, education, farming experience, gender of the household head, and wealth for the household characteristics; then farm size, fertility, and slope for the environmental attributes; and access to extension, credit, distance to input and output markets for the policy related factors (Deressa *et al.*, 2008; Gbetibouo, 2009; Hassan & Nhemachena, 2008; Maddison, 2006). Similar factors were used in adaptation studies to climate change in Ghana (Al-hassan *et al.*, 2013, Fosu-Mensah *et al.*, 2010).

Based on the aforementioned review on adaptation studies, the surveys conducted the monitoring of the farming practices during the rainy season (2013) and the observations in the study area, the explanatory variables hypothesised to influence the farmers' adaptation choices (Table 6.2) are described next.

Characteristics of the household head

Household head age and Farming experience: It was assumed that, the older the farmer, the more experienced he is in farming activities. With respect to the results of the surveys, the variables age of the household head and experience in farming have a positive relationship. But whether the more experienced farmer is likely to adopt methods especially to climate change, there are some divergences in the point of views of authors. Whereas Shiferaw and Holden (1998) cited by Deressa *et al.* (2008) indicated a negative relationship between age and adopting improved soil conservation practices, Maddison (2006) and Nhemachena & Hassan (2007) have indicated that experience in farming increases the probability of uptake of adaptation measures to climate change. Therefore, there is no agreement in the literature on adaptation studies about the effect of age. Gbetibouo (2009) summarised that the effect of age is generally location or technology specific. According to him, the expected result of age is an empirical question. Age may negatively influence the decision to adopt new technologies. It may be that older farmers are more risk-averse and less likely to be flexible than younger farmers and thus have a lesser likelihood of adopting new technologies. In another case, age may positively influence the decision to adopt. It could also be that older farmers have more experience in farming and were better able to assess the characteristics of modern technology than younger farmers, and hence a higher probability of adopting the practice.

Household size*:* It is admitted that the farm households with more labour are better able to take up adaptation in response to changes in climate (Hassan & Nhemachena, 2008). Although farmers can hire extra labour which is money consuming and they can also organise a communal labour which is also relatively more money consuming, most rural farmers were not able to do this, which limited their ability to take on labour intensive farming activities. For that reason and since crop diversification and intensification of the cropping system are more labour intensive; then family size is expected to have a positive influence on the adaptation strategies to climate change.

Education level*:* Evidence from many adaptation studies accepted that there is a positive relationship between the education level of the household head and the adoption of improved technologies and adaptation to climate change (Maddison, 2006). In this regards, Deressa *et al.* (2008) has found that education can significantly increase soil conservation and changing planting dates as an adaptation method. Also, educated and experienced farmers were expected to have more knowledge and information about climate change and agronomic practices that they can use in response (Hassan & Nhemachena, 2008, Maddison, 2006). Therefore, educational level is expected to positively influence farmers' decisions to take up adaptation measures to climate change even though most old farmers in the area have never been to school.

Gender: A number of studies in Africa have shown that women have lesser access to critical resources in terms of access to assets, education and other critical services such as credit, technology and input supply (Hassan & Nhemachena, 2008) which can undermine their ability to carry out agricultural innovations. Nevertheless, Nhemachena & Hassan (2007 found that in Southern Africa, female-headed households were more likely to take up climate change adaptation methods. According to them, the possible reason is that in most rural smallholder farming communities in the region, men are more often based in towns, and much of the agricultural work is done by women. Therefore, women have more farming experience and information on various management practices and how to change them, based on available information on climatic conditions and other factors such as markets and food needs of the households. Therefore, as elsewhere in this part of West Africa, based on our investigations in the study area, male and female headed households differed significantly in their ability to conduct farming activities and adapt and it is hypothesised that being a male-headed household will likely increase the ability to adaptation to climate change given the major differences between them.

Income and Non-farm activities: Farm and non-farm income represent wealth of the households. As mentioned by many researchers in adaptation studies, it is hypothesised that the adoption of agricultural technologies including coping methods to climate change requires sufficient financial resources, based on the accessibility to the necessary farm inputs and other associated equipment (Deressa *et al.*, 2008; Gbetibouo, 2009). Therefore, these variables were assumed to influence the adaptation to climate change since farmers themselves considered poverty and insufficient financial resources as constraints to make adjustments in their farming systems.

Number of plots: Number of plots (or size of plot in some papers) owned by the household seemed to be a key variable in adaptation especially when the plots of lands are located in different places. Accordingly, the coefficient on farm size is significant and positively correlated with the probability of choosing irrigation as an adaptation measure (Gbetibouo, 2009). Despite the above factor, large-scale farmers are more likely to adapt because they have more capital and resources which is in line with the investigations of this study when farmers themselves mentioned that "land is a problem" for adjustment to climate change.

Livestock index*:* Livestock is often considered as a coping measure in the case of food shortage that may occur as a result of droughts or floods. Because these hazards always occurred in the rainy season before harvest, in many poor households, animals were sold to purchase food items during these times (Laube *et al.*, 2012). Moreover, in addition to some socio-cultural values such as sacrifice, livestock provides also manure and traction which improves labour demand especially during the ploughing and transportation (manure, compost, farm products, etc.). For these reasons, livestock index was assumed to be a reliable indicator in soil fertility management by creating crop-livestock integration which is a very common practice adopted in the study area as indicated in section 6.2.3.

Institutional or policy related factors

Extension services and information on climate change*:* Extension services on crop and livestock and information on climate represent access to information which may strongly help to uptake the right decision to adapt to climate change. Studies in this area have reported a strong positive relationship between access to information and the adoption behaviour of farmers and that access to information through extension increases the likelihood of adapting to climate change (Maddison, 2006; Nhemachena & Hassan, 2007; Deressa *et al.*, 2008). Therefore, these variables were hypothesised to increase the adaptation to climate change even though in our study area only few farmers claimed having extension services.

Subsidy and Credit Access*:* Access to credit and subsidised prices play a very important role as institutional support in increasing the farmers' ability when choosing the adaptation options to adjust the land-use systems and to be able to escape from the negative impacts of climate change. Hence, it is clear that any adoption of coping method or technology requires an important initial investment based on either an owned or borrowed capital which is not always easy for farmers to get (Gbetibouo, 2009). In our study area, only few farmers are getting farm inputs which are subsidised and very few are having credit for their farming activities.

Access to Water*:* Access to water facilities was included in these analyses because during the surveys, farmers reported that access to water facilities as a factor that constrains adaptation to climate change especially for dry season farming. Also farmers cited as example the two medium-scale irrigation schemes at Tono and Vea, constructed in the late 1960s until 1985 which influenced irrigation development in the region (Laube *et al.*, 2012). Learning from this experience, the neighbouring areas which are not benefiting from these water facilities started to develop their own irrigation facilities where the water is harvested from wells and dugouts along the stream. For these reasons, access to water was assumed to influence positively adopting dry farming as adaptation to climate change. Therefore, the effect of this variable was captured by the distance from house to the main streams.

Environmental attributes

Agro-ecological setting (Elevation, Slope): In addition to the climatic variables (rainfall and temperature), agro-ecological factors such as elevation, slope, etc. could also vary across different agro ecologies, influencing farmers' perception of climate change and their decisions to adapt. If the climate attributes (temperature and rainfall) were assumed to be quite uniform given the small size of the study area, the agro-ecological factors were assumed to be more spatially sensitive and variable, and may likely influence the likelihood of the adaptation strategies choice, especially in this area where the farm households are very scattered within the landscape.

Table 6.2: Dependent variable and independent variables used in m-logit for modelling adaptation decision

Variable	Description	Expected value	Data source
Dependent variable:			
Adaptation to climate change	Categorical variable through a choice set of five options in farming system		Interview during the surveys
Independent variable			
Characteristics of the Household head			
Household head age	Age of the head of the farm household	Continuous	Interview during the surveys
Household size	Number of household members	Continuous	Interview during the surveys
Experience	Number of years in farming activities	Continuous	Interview during the surveys
Education	Number of year of formal schooling attained by the household head	Continuous	Interview during the surveys
Gender	Gender of the farm household head	Dummy, takes the value of 1 if household head is a male and 0 otherwise	Interview during the surveys
Gross farm income (%)	Revenue coming from farm products	Continuous	Interview during the surveys
Nonfarm activities	Dummy variable indicating whether the household head is doing nonfarm activities or not	Dummy, takes the value of 1 if the household head is doing off-farm activities and 0 otherwise	Interview during the surveys
Number of plots	Number of different plots of land owned and rented by the household	Continuous	Interview during the surveys
Plot size (ha)	Total land area	Continuous	GPS area calculation
Livestock index	Number of animals of the household estimated as livestock index	Continuous	Interview during the surveys

Institutional or policy related factors			
Extension	Whether the household has access to extension services	Dummy, takes the value of 1 if the farmer is having extension service and 0 otherwise	Interview during the surveys
Subsidy	Whether the household is having subsidy on the farm inputs	Dummy, takes the value of 1 if the farmer is having subsidy and 0 otherwise	Interview during the surveys
Information on climate change	Dummy variable on whether the household is getting information about weather or climate	Dummy, takes the value of 1 if the farmer is having information on weather and 0 otherwise	Interview during the surveys
Distance to stream (km)	Extracted values of the distance from each household to the main stream	Continuous	GIS based on the DEM process
Environmental attributes			
Elevation (m)	Extracted values of the elevation at the geographic household location	Continuous	GIS based on the DEM process
Slope (degree)	Slope values (in degrees) extracted at the geographic household location	Continuous	GIS based on the DEM process

6.2.4 Analytical framework of the m-logit used to develop the adaptation decision sub-model

Based on the assumption that the strategic selection of human behaviour is based on preference function, the major approach under consideration is a random utility approach. By far the easiest and most widely used discrete choice model is Multinomial logit (m-logit) MNL model. Its purpose is to estimate probability of each categorical outcome from multiple choices (Train, 2009). Then, maximising sum of logarithm of likelihood leads to the estimation of the coefficients. Also, the most important feature of multinomial logit model is to set a “base category”. It is needed because multinomial logit estimates probabilities of shift from base to other categories. In short, it estimates relative probability of outcomes. MNL was actually used in several adaptation studies. For instance, the model has been used to analyse the determinants of farmers’ decisions to adaptation (Deressa *et al.*, 2008, Gbetibouo, 2009, Hassan & Nhemachena, 2008, Tafesse *et al.*, 2013). It was also applied to analyse crop choice selection (Kurukulasuriya & Mendelsohn, 2007) and livestock (Seo & Mendelsohn, 2006). In this study also the m-logit model was used to explore the determinants of farm household adaptation options' decisions. As indicated in section 6.2.3.1, adaptation is a dependant variable with five categorical responses: Crop-livestock integration, Irrigation, Soybean farming, Maize farming and No Adaptation where No adaptation was used as base category. The analytical framework of m-logit was described with more details in Chapter 3.

6.3 Results

6.3.1 Changes observed in farming systems and farmers' responses

Farmers within the study area reported a number of changes they have realised in their farming practices as a result of the historical changes observed in terms of temperature and rainfall. In order for them to cope, many adjustments have been innovated over time and introduced in the farming systems depending on the type of climate stimulus (rainfall or temperature change). Table 6.3 summarised the adequate adjustments corresponding to the type of changes in farming practices which could be categorised in three different groups as: (1) Reduction of production, (2) Damage caused on crops and farmland and (3) Changes in timing.

(1) **Reduction of production**: This type of change observed in farming activities is characterized by low production and slow crop growth as reported by 74.7 % and 1.1 % of farmers respectively while 2.2 % of respondents claimed that they do not know about any change. Based on the reduction of production, some farmers claimed, there is nothing to do about it. This is the case of 36.6 % and 62.4 % of respondents who are not doing any adjustments (No adaptation) due

respectively to long term changes in terms of rainfall and temperature. For this group of respondents, the change is especially either related to God or other in-respect of tradition. On the other hand, some spontaneous adjustments are still taking place in the area. In this regards, the coping measures against low production related to change in rainfall included: introduction of new crops (4.8 %), use of fertilizer (1.1 %) and practice of dry season farming (0.5 %). For the same negative impact (low production) related to the change of temperature as stimuli, the only measure for farmers is to avoid practicing bush burning (2.7 %).

(2) **Damage caused to crops and farmlands**: As changes observed in farming activities farmers have reported some damages caused to crops and farmlands as a result of changes in temperature and rainfall. For 9.1 % of respondents, farmlands are nowadays very dry. According to them, soils of farmlands are becoming very hard and difficult for tillage especially at the beginning of the rainy season. The damage concerns also the crops either because of drought frequency or flooding as indicated by 3.2 % and 2.7 % of farmers respectively. During the sowing period, farmers (1.1 %) used also to observe germination failure due to drought and or heating. A number of spontaneous reactions as adjustments due to the aforementioned damages in farming are still ongoing in the area. With respect to Table 6.3 for the changes related to rainfall, the coping measures included the practice of manure application (4.3 %), ploughing (3.2 %), mulching (0.5 %) and planting trees (1.6 %). Against changes related to temperature, planting trees (10.2 %), drought resistance varieties (8.1 %), mulching (1.6 %), early weeding (1.6 %) and manure application (0.5 %) are applied.

(3) 5.9 % of respondents reported that **the change in timing** is essentially due to the late onset of the rainy season. As a result, the delay in sowing influences the whole **timing** of the farming practices. In this case, farmers practiced early planting and use early maturing varieties (Table 6.3).

Table 6.3: Changes realised by farmers in farming practices due to long term changes in temperature and rainfall. Adjustments still ongoing in the study area by farmers based on the corresponding changes in farming practices

Type of change	Changes realised in farming activities	Percentage of respondents (%)	Adjustments due to long rainfall change	Percentage of respondents (%)	Adjustments due to long temperature change	Percentage of respondents (%)
Reduction of production	Low production	74.7	No adaptation	36.6	No adaptation	62.4
	Slow crop growth	1.1	Introduce new crops	11.8	Avoid bush burning	2.7
	Do not know	2.2	Fertilizer application	1.1		
			Dry season	0.5		
Damage on crops and farmland	Dried farmland	9.1	Manure application	4.3	Planting trees	10.2
	Crop damage due to drought frequency	3.2	Ploughing	3.2	Drought resistant varieties	8.1
	Germination damage	1.1	Mulching	0.5	Mulching	1.6
	Crop damage due to floods	2.7	Planting trees	1.6	Early weeding	1.6
					Manure application	0.5
Changes in timing	Delay in farming	5.9	Early sowing	23.1	Early sowing	12.9
			Early maturing varieties	17.2		

6.3.2 Barriers to adaptation measures

Farmers in the study area reported a number of factors that constrain adapting their farming systems' strategies against the negative effects of climate change and variability. With respect to Figure 6.3, these factors included: insufficiency of capital, insufficiency of information, insufficiency of accessibility to farm inputs, insufficiency of water facilities, insufficiency of land and insufficiency of labour. All these constraints are related either to poverty, local policy or to the weakness of the availability of infrastructure in the local area. The insufficiency of capital for instance, which was mentioned by many farmers is a consequence of a very weak access to financial facilities like credit in the study area. Though it still exists, but through random sampling procedure, it is yet difficult to select a farmer who is having access to credit in the study area. The insufficiency of information is also claimed by many farmers saying not to be aware of any coping measures and not having information on climate forecast and change. In this case, there is a need to develop programmes on climate change issues and train the agricultural extension agents by improving their capacities since they work close to farmers. Insufficiency of accessibility to farm inputs and water facilities are also serious issues in the area. Subsidy on farm inputs which is very rare in the area and infrastructure could be the best local politics for the development of market access and water facilities. Despite the above factors, issues on land and labour are also pattern to social issues, but still associated to the lack of financial facilities like credit. Access to credit can enable farmers to efficiently engage land-use intensification whereby on small plots of land farmers can produce a lot by using equipment/facilities that can reduce labour demand while the production will be less dependent on rainfall.

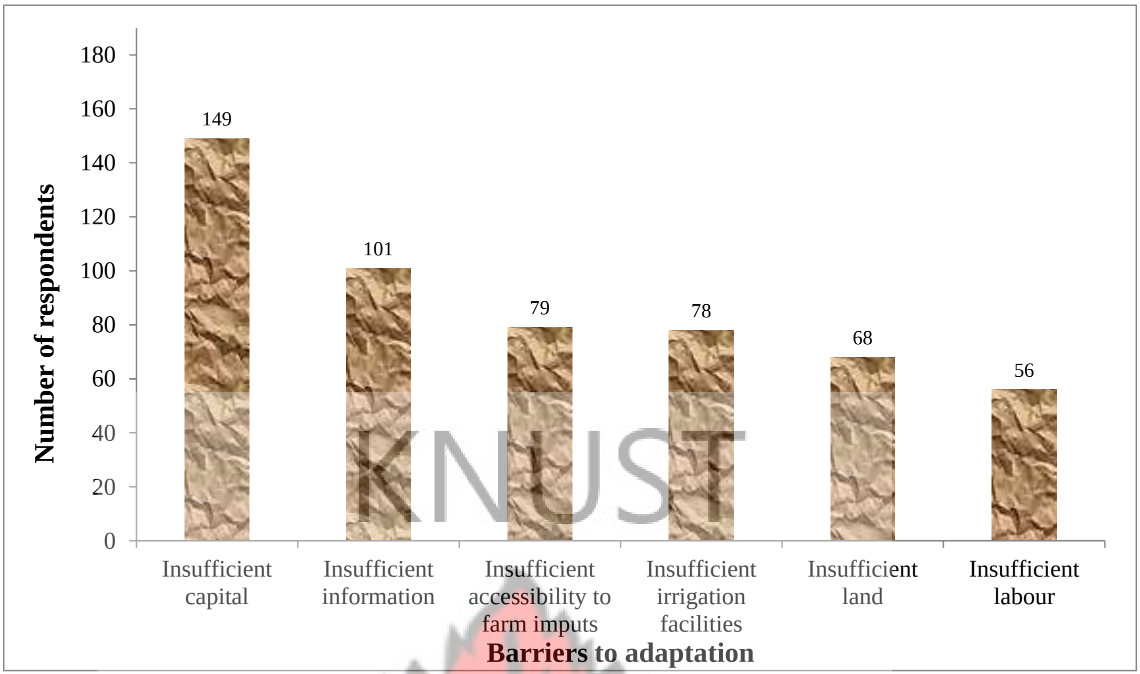


Figure 6.3: Barriers to the implementation of adaptation measures

6.3.3 Results of m-logit for modelling adaptation decision

The estimation of preference coefficients of the m-logit was undertaken with *No Adaptation* as a base category. Therefore in all cases, the estimated coefficients should be compared with the variable *No Adaptation* in order to measure the expected change in terms of probability of a particular choice being made with respect to a unit change in an independent variable. The likelihood ratio statistics as indicated by the Chi-square statistics ($P < 0.0001$) showed that the empirical model is highly significant indicating strong explanatory power in explaining the climate change adaptation options' choice of farm households (Table 6.4). Also, based on the value of the Nagelkerke R square (0.604), we can state that 60 % of the total variation is explained by the selected explanatory variables. Accordingly, the choice of the adaptation options will be described as follows:

- With respect to the results of the m-logit model (Table 6.4), four variables determine the choice of "crop-livestock integration": size, total land area, access to extension service and livestock index. This adaptation option is undertaken by farmers owning animals as shown by the significant variable of livestock index. Suggesting that for each unit increase of livestock index, the odds of choosing this option will also increase by 31 % in comparison with No adaptation option. The choice of "crop-livestock integration" option requires also enough family labour and available land in terms of area. Hence, the higher the number of family members and land surface, the more likely the farmer practice the integration of crop and livestock as adjustment to counter the negative impact of the implications of climate change and variability on his cropping systems. For each unit increase of an active member in the household and one hectare of land, the odds of adopting "crop-livestock integration" will also be increased respectively by 22 % and 110 %. This adaptation option is widely adopted in the study area, as shown by Figure 6.3 whenever the rainy season is about to start, farmers are used to transport a lot of manure and compost to the farms. The practice does not necessarily need the advice of an extension agent as shown by the significant variable extension.

- Three variables determine the choice of irrigation as adaptation to climate change and variability: size, number of farms in different locations and distance from house to stream. The explanatory variable "distance from house to the main stream" is highly significant; indicating that the distance to the stream plays a very important role in the choice of dry season farming (irrigation) as adaptation option. Suggesting that the bigger the distance from the house to the stream, the less likely the farmer will practice dry season farming. In this case, farmers themselves claimed that access to water and water facilities is a constraint in practicing dry season farming as adaptation to climate change and variability (Figure 6.2) which is increasingly supported by this explanatory variable. In this regards, each unit (km) increase in the distance from house to stream, the odds of practicing dry season farming will decrease by 86 %. The number of plots of land is also another key variable in terms of having many farms in different locations since dry season farming is only possible in the lowlands. The higher the number of plots, the more likely the farmer adopts dry season farming. The fact that the irrigation practice is also labour demanding was also shown by a significant explanatory variable of family size, where a unit in terms of increase of an active member in the household, increases the odds of adopting dry season farming by 31 %.

- None of the explanatory variables is significant in the choice of soybeans farming as adaptation option. This is likely because of the very small number of farmers involved in this activity.
- With respect to Table 6.4, the following variables determine the choice of maize as adaptation option: size, gender, number of plots, total area of land, livestock index, topography and distance to the stream. The number of plots of land for a farmer is a key variable for choosing "Maize farming" as an adaptation option. The bigger the number of plots, the more likely the farmer is involved in farming maize as an adaptation option. And the same interpretation is given to the total land area. The household size increases the odds of adopting this option by 28 %. The explanatory variable "distance to stream" is significant with negative value in the choice of this option, indicating the longer the distance to the stream the less likely to adopt (No adaptation) this option (decrease of odds 58 %). Because maize is demanding in terms of farm inputs and soil fertility. It is grown in the lowlands where soils are quite fertile even though sometimes, because of stealing as reported by farmers, some plots of maize are located not far from the house. The previous statement is also supported by the significant

value of elevation in the sense that this option is most of time undertaken on the upland. The aforementioned explanation is also supported the variable gender suggesting the implications of female in this activity, since most plots owned by women are located in the compound vicinity.

This empirical adaptation sub-model has satisfactory predictive power where the choice of crop-livestock integration, irrigation, soybean, maize and no adaptation is correctly predicted for 74 %, 31 %, 100 %, 36 % and 73 % of the sample respectively. The overall percentage of correct prediction is 64% (Table 6.5).

Table 6.4: M-logit estimations of adaptation strategies' choice

Variable	Climate change adaptation options											
	Crop-livestock integration			**Irrigation**			**Soybeans farming**			**Maize farming**		
	Coefficient	Error	P level	Coefficient	Error	P level	Coefficient	Error	P level	Coefficient	Error	P level
Intercept	-4.334	3.605	0.229	-0.434	88.424	0.996	0.946	66.753	0.989	-11.835***	4.325	0.006
Size	0.200**	0.091	0.028	0.273**	0.134	0.041	0.863	3.395	0.799	0.244**	0.102	0.017
Gender	-0.640	0.600	0.287	-10.564	88.091	0.905	18.010	14.255	0.206	-1.290*	0.755	0.087
Age	-0.012	0.023	0.617	0.009	0.050	0.855	-0.143	0.779	0.854	-0.003	0.030	0.912
Education	-0.052	0.085	0.541	-0.091	0.120	0.448	1.689	2.841	0.552	-0.071	0.093	0.446
Nonfarm	-0.646	0.539	0.231	0.166	0.799	0.836	-9.472	13.776	0.492	0.082	0.595	0.890
Number of plots	0.431	0.361	0.232	1.311**	0.543	0.016	-7.114	11.874	0.549	1.405***	0.382	0.000
Area_plots	0.746***	0.214	0.000	-0.272	0.435	0.532	0.330	4.848	0.946	0.413*	0.243	0.089
Experience	0.010	0.022	0.655	-0.053	0.052	0.303	-0.073	0.751	0.923	-0.039	0.029	0.175
Info.on climate	0.537	0.654	0.412	0.150	1.064	0.888	20.383	29.842	0.495	0.456	0.747	0.541
Extension	-0.878*	0.498	0.078	0.650	0.960	0.498	-16.911	16.306	0.300	-0.944	0.592	0.111
Subsidy	0.693	0.768	0.367	1.720	1.061	0.105	23.014	15.485	0.137	0.183	0.886	0.837
Livestock index	0.274***	0.066	< 0.0001	0.108	0.093	0.246	-0.875	2.535	0.730	0.136*	0.074	0.067
G_income %	-0.753	0.616	0.222	0.212	0.791	0.789	6.155	12.143	0.612	-0.842	0.670	0.209
Elevation	0.012	0.016	0.445	0.040	0.035	0.260	-0.118	0.279	0.673	0.049**	0.019	0.010
Slope	-0.137	0.162	0.399	0.091	0.281	0.745	0.284	4.094	0.945	0.066	0.190	0.726
Dist_to_stream	-0.325	0.292	0.266	-1.942***	0.652	0.003	-0.687	7.098	0.923	-0.873**	0.363	0.016

Fitting and accuracy of the model: Chi-Square = 179.778; df = 64; Sig = Pr < 0.0001

Pseudo R Square: Nagelkerke = 0.604

The reference category is: No Adaptation

***, ** and * indicate the significance level at 1, 5 and 10 % respectively.

Table 6.5: Classification table of the correct prediction among the adaptation options

From\to	Crop-livestock integration	Irrigation	Soybeans farming	Maize farming	No Adaptation	Total	Correct prediction
Crop-livestock integration	67	3	1	6	14	91	74 %
Irrigation	6	5	0	2	3	16	31 %
Soybeans farming	0	0	4	0	0	4	100 %
Maize farming	16	2	0	15	9	42	36 %
No Adaptation	17	1	0	0	48	66	73 %
Total	106	11	5	23	74	219	64 %

6.4 Discussion

Due to changes in terms of temperature and rainfall over time in the study area, farmers realised many changes in their farming practices. These changes are categorised into three groups (Table: 6.3): Reduction of production; Damage caused to crops and farmland and Changes in timing. When the changes in farming practices are related to the long term change in rainfall, only 36.6 % of farmers reported having nothing to do about it (No adaptation). Similarly, when the changes in farming practices are due to long term change in temperature, 62.6 % of respondents claimed not to have taken any adjustments. The reason is that, rainfall seemed to be more perceived by farmers than temperature, also because of many barriers to adaptation (Figure 6.2), a great number of farmers are not able to take any adaptation method as supported by Deressa *et al.*, 2008. PCA was used to reduce the number of initial adaptation practices to a few number of adaptation option factors. As a result, five options have been selected and used as categorical dependent variables for the m-logit model in order to explore and analyse the factors that determine the choice of each option. The categorical dependent variable comprises the following options: Crop-livestock integration; Irrigation; Soybeans farming; Maize farming and No Adaptation.

The results of the m-logit model (Table 6.4) indicated four variables which influence the choice of crop-livestock integration as climate change adaptation strategy to support the resilience of cropping system: livestock index, plot area, extension and family size. Apart from access to extension service, these explanatory variables positively and significantly influence the probability of adopting crop-livestock integration as adaptation to climate change. It is found that the family size increases the probability of adaptation to climate change by 1.8 % (Deressa *et al.,* 2008) in the sense that the large family size is normally associated with a higher labour endowment which would enable a household to accomplish various agricultural tasks. Livestock index referring to the ownership of livestock play a key role in the interaction between crop and livestock in the sense that it provides the possibility of manure application, traction especially in transporting manure and compost to the field and all activities related to soil fertility maintenance. It was said that, developing crops and livestock that are more suited to hot and dry conditions will help countries adapt to many current climate zones as well as future ones (Kurukulasuriya & Mendelsohn, 2006). Plot area in terms of farm size which is most of the time associated with greater wealth, increase positively and significantly the probability to adapt, since large scale farmers are more likely to adapt because they have more capital and resources (Gbetibouo, 2009). The distance from house to stream which reflect in this research the access to water, shows a strong explanatory power via the way it negatively and significantly influences the probability of adopting irrigation. Also having many plots of land in different locations is reliable as well in adopting irrigation. Talking about irrigation in this area, for a farmer to start irrigation, he needs to own or rent land where shallow groundwater can be tapped easily, as land used for shallow groundwater irrigation is usually along rivers or in floodplains and not all farmers own such suitable lands (Laube *et al.*, 2012). Land resource in terms of number of plots and farm size which is likely associated with greater wealth as indicated earlier impacts positively on the probability of adopting of maize cultivation as climate change adaptation option.

A number of factors reported by farmers (insufficiency of capital, insufficiency of information, insufficiency of accessibility to farm inputs, insufficiency of water facilities, insufficiency of land and insufficiency of labour) were considered as barriers for adapting to climate change and variability (Figure 6.2). But the fact that most of the constraints are related either to poverty, or to the local policy or to the insufficiency of availability of infrastructures in the area raises the question of whether the adaptation measures reported by farmers are profit driven or climate driven. The discussion in the next chapter will provide some contributions for the understanding of the issue. However, Gbetibouo (2009) has stated that understanding the likely adaptive responses of farmers to anticipated climate change represents serious challenges for researchers. According to him, in this area of research, the challenge is to isolate the climate stimuli response from other stimuli like market, policy and others that farmers face in the real world. Moreover, farmers are more concerned about climate inter and intra annual variability than climate change. Also the fact that humans can react in a number of ways to similar or different external stimuli make the task of researchers in this area of adaptation more complicated. As a result, there is a need to better understand the responses of agricultural land-use system to climate variations, including identifying rather than assuming the climate attributes to which farmers are sensitive and adapt (Smit *et al.*, 1996). Accordingly, to improve estimates of climate impacts on agricultural land use, there is a need to know more about how farmers perceive climate and how they respond, in both the short and long term, to variable climate conditions, including the magnitude and frequency of extreme conditions.

6.5 Conclusion

This research worked out the perception of farmers vis-a-vis climate change and the adaptation strategies undertaken to cope with the changing environment. Farmers are conscious of the severe environmental change taking place in the area. Moreover, degradation comes in partly as a result of the local dynamics of population growth, poverty and unsustainable resource exploitation. Accordingly, this study worked out a number of measures inovated by farmers to increase the resilience of the farming system. Also, many barriers reported by farmers as factors of disturbance between adaptation and factors determining its choice were explored and analysed. In this context, there is a need for integrated analyses in the situation where the complexity due to land degradation and dynamics of the population are complicated by the implications of the global changes affecting the local environment.

7. DEVELOPING AN OPERATIONAL SKY-LUDAS FOR SIMULATING AGRICULTURAL LAND-USE ADAPTATION

7.1 Introduction

Multi-Agent System (MAS) is a relatively a new approach in agricultural land-use system management (Latynskiy, 2014). In recent years, adaptation models have included more and more sophisticated human behaviour explicitly, addressing the interactions between human agents represented in this study by the farm households as actors in land-use decision making and the environment system of which they are part (Schouten, 2013). Therefore, modelling human decisions by means of MAS approach has become a popular tool that has been used over the past decades to understand complexity and non-linear behaviour in exploring the dynamics and management of human and natural systems (Bharwani, 2004, Latynskiy, 2014, Le, 2005, Martin, 2006, Schindler, 2009, Schouten, 2013, Villamor, 2012). As a result, a growing number of MASs were built for analysing farm decision making in agricultural land-use system, especially in simulating the adaptation of agricultural land-use to climate change in order to understand the interactions between the heterogeneous population and the agro-ecological resources (Schreinemachers & Berger, 2011, Troost *et al.*, 2012). In addition, climate change policy can no longer be addressed separately from a broader context of adaptation and sustainability strategies (Balbi & Giupponi, 2009). Thus, this study aimed to explore the implications of climate change and variability in the adaptation of agricultural land-use system through the following specific objectives:

- To parameterise SKY-LUDAS as an integrated MAS model that simulates the socio-ecological components of the landscape using empirical data;
- To implement the two-step decision making sub-models for simulating the effects of farmers' perception of climate change and variability in the adaptation of agricultural land-use system.

7.2 Methodology

7.2.1 Operational SKY-LUDAS as an integrated model using empirical data

The SKY-LUDAS as described in Chapter 2 was specifically designed for the research area within Atankwidi basin. The model was designed to assess the consequences of adaptation strategies on the socio-economic indicators of the farm households (e.g. farm gross income, livelihood strategies, etc.) and the land-use pattern (e.g. land-use types).

7.2.1.1 Graphic and user interface

The user interface of SKY-LUDAS is composed of the following (Figure 7.1):

- User's input and global (experimental) parameters : through the slider, the user can externally adjust the values of parameters to be tested in the model;
- Digital land-use/-cover map navigation window: land-use/-cover map is depicted in the viewer of NetLogo platform, and display the land-use/-cover pattern. The map can be exported at any time of the simulation to analyse changes, which can occur annually.
- Time-series graphs of performance indicators of both biophysical and human systems: These graphs allow users to visualise the real-time changes in the predefined indicators. These include the land-use pattern, household agent-group pattern, etc.
- Monitors along with specific time-series graphs are included for further related calculations of indicators.

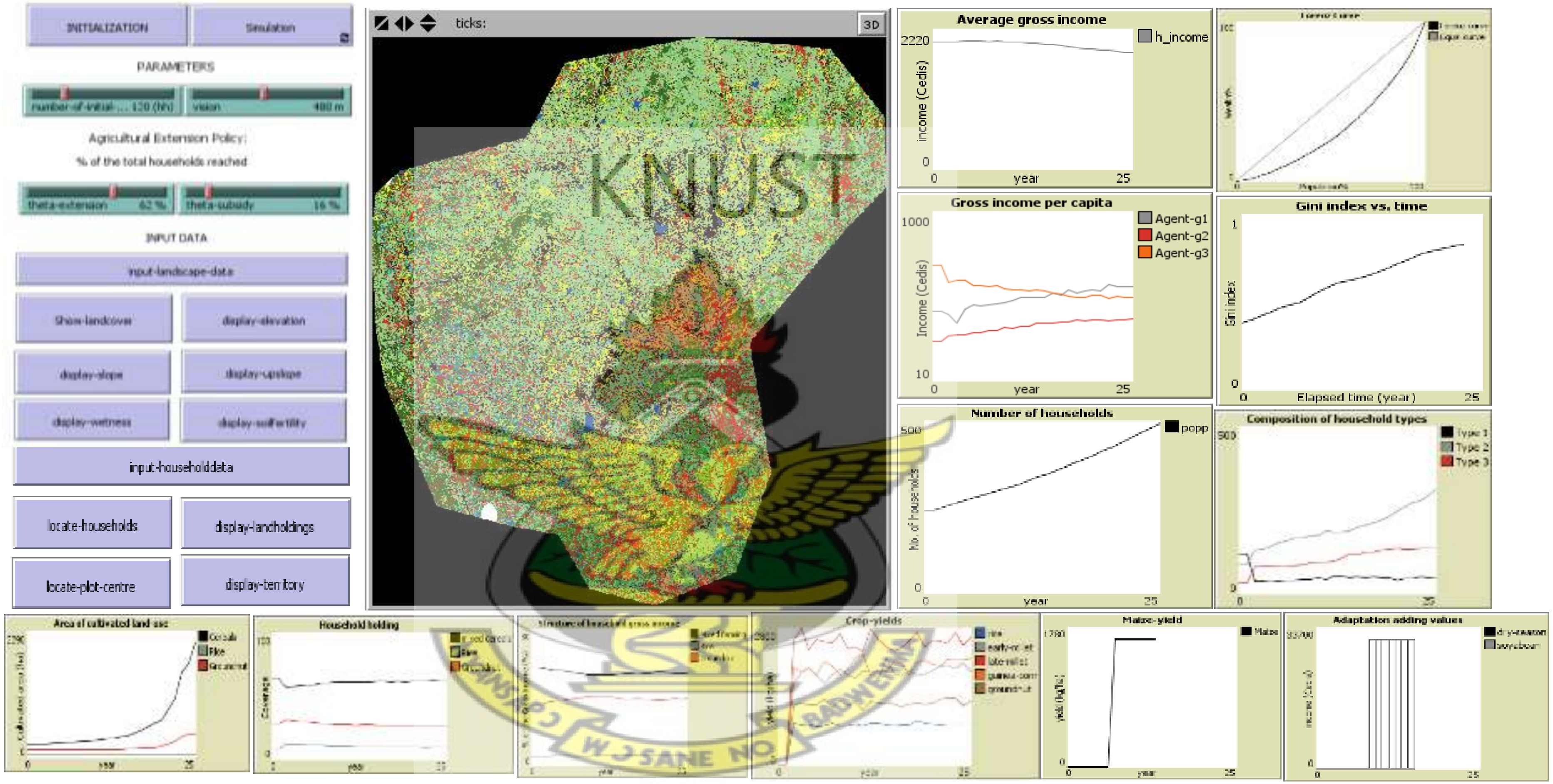


Figure 7.1: Interactive model interface, map and graphs tracking simulated model data over time

SKY-LUDAS is implemented in NetLogo version 5.0.3, which is a multi-agent modelling environment (Wilinsky, 1999), in the sense that it provides components where modellers can use a convenient language to programme agents and their interactions and also the possibility to visualise and export the results.

7.2.1.2 Description of the two-step decision making mechanism

The two-step decision making sub-models were developed for SKY-LUDAS for simulating adaptation strategies. This method was designed in accordance with the decision-making developed in LB-LUDAS to capture process-based decision-making (Villamor, 2012). Accordingly, the *Perception-of-Climate-Change* and the *AdaptationChoice* sub-models were integrated in the decision module of LUDAS particularly within the *FarmlandChoice* procedure as a household decision-making mechanism (Le, 2005). The first step simulates farmers' perception of climate change, while the second step simulates the choice of adaptation strategies if only the farmer has perceived the climate change (Figure 7.2). These two steps decision-making routines developed under decision programme as two different procedures are taken by each household agent in each time step, independently of its agent group.

- **First step**: this step was developed based on the results of binary logistic regression as shown in Chapter 5. The probability P_hij-perception is a binary outcome of *Perception-of-Climate-Change* represented in the model through a dummy variable taken value 1 (Yes) when the farmer has perceived climate change and 0 (No) otherwise (Figure 7.2). When the value of probability P_hij-perception is 0, the decision programme skips the adaptation procedure to the common *FramelandChoice* routine: in this case, only the baseline runs for this particular household. In contrast, when the value of the probability P_hij-perception equals 1, then the decision programme runs the *AdaptationChoice* routine to compute the probability of choosing an adaptation option. Meaning that the household is engaged in the procedure of multiple choices.

- **Second step**: the second step sub-module is designed in the model based on the results of the m-logit through the probability of five following adaptation choices: Crop-livestock integration; Irrigation; Maize farming; Soybean farming and No adaptation, which is used as base category in the m-logit analysis (see Chapter 6). When the household chooses a particular adaptation option, then the option is executed in the *FarmlandChoice* routine especially during the *moving phase* (Figure 7.2). This second step involves many indicators especially labour force to make up a particular selected option. This is in accordance with what was found during the field work in the study area: labour was the main factor which determines the implementation of the household decision taken at the beginning of the rainy season.

7.2.2 Scenarios

Based on the identified range of land-use related factors and livelihood indicators, three specific scenarios were systematically tested:

(1) Baseline scenario (Baseline);

(2) Perception of climate change and variability (PCC) scenario and;

(3) No perception of climate change and variability (NO-PCC) scenario.

Each scenario was run five times for 20 time steps (years).

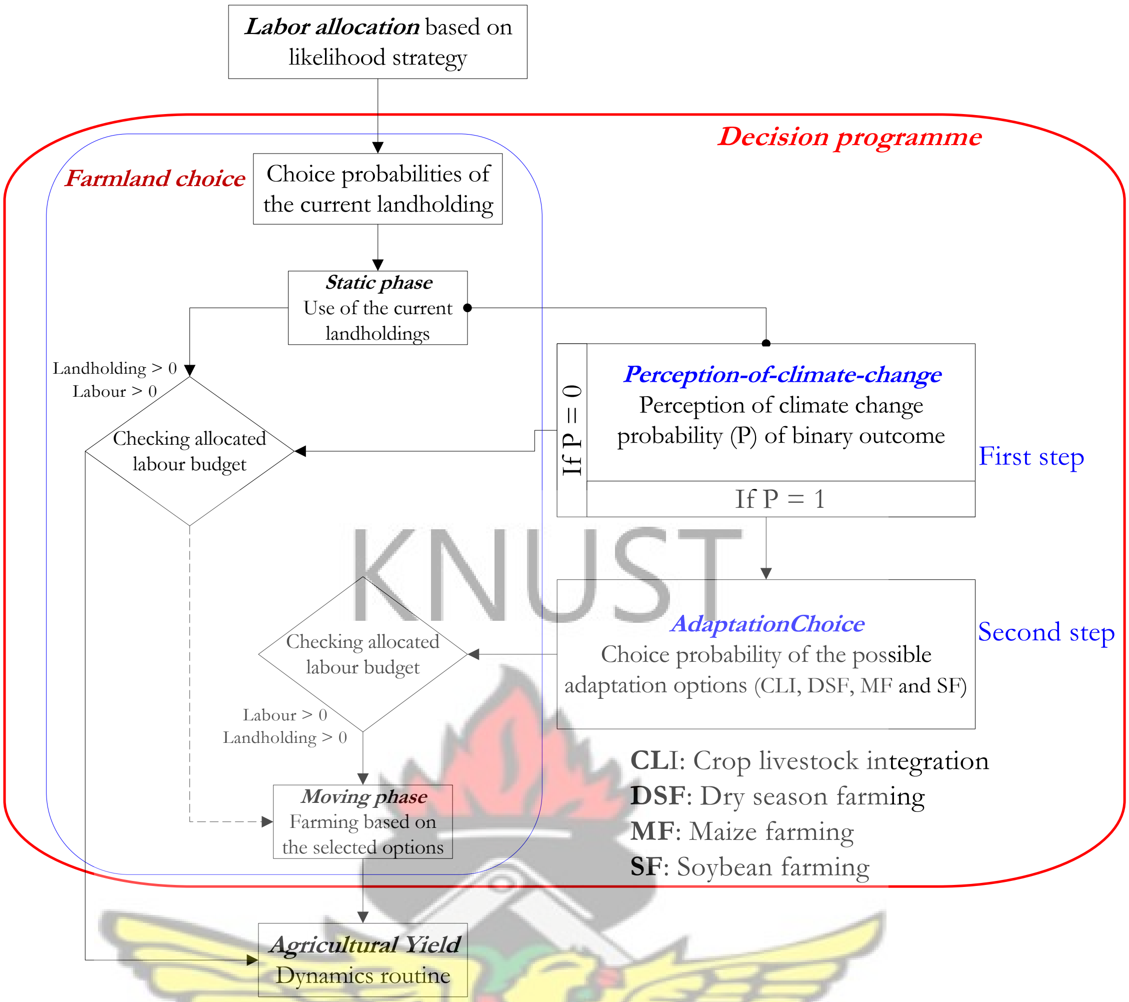


Figure 7.2: Schematic representation of the two-step decision making routine integrated in the decision programme

7.2.2.1 Baseline setting

The baseline setting corresponds to the business as usual where the decision-making programme follows the empirical land-use choice model as the benchmark (Le *et al.*, 2008). The socio-ecological parameters used under this scenario were developed in Chapter 3. The land-use pattern and other key socio-economic conditions of the baseline are stated in the following:

- The land-use/-cover of 2012 (Chapter 4) was the initial state of the study area. The patterns of land-use/-cover in terms of percentages are given in Table 4.2;

- The initial simulated population amounted to 1500 individuals which correspond to 250 farm households;
- The human population growth rate was 2.5% according to the 2010 population and housing census in Ghana (PHC, 2012);
- The statistics of crop yields are reported in Table 4.3 and the livelihood indicators are in Table 3.5.
- The descriptive statistics of the sampled households showed that 51% of the total households were reached by extension services.

Since the baseline is likely to determine the current trend, it can be used to evaluate the implications of farmers' perception in the adaptation of agricultural land-use.

7.2.2.2 Setting the perception of climate change and variability scenario (PCC)

The "perception of climate change and variability scenario" (PCC) was set in the program in addition of the baseline scenario which is described in the previous section. Accordingly to Figure 7.2, the PCC scenario goes through two procedures: first step and second step. As explained in the description of the two-step decision, the values (0 or 1) of the farmers' perception probability in the first step and the available labour budget determine the implementation of the second step which refers also to the relative probabilities calculated for the adaptation options.

7.2.2.3 Setting the No perception scenario (NO-PCC)

Using the baseline alone and the two-step decision making in simulating the adaptation strategies is not enough to give the understanding of the implications of climate change (*Perception-of-Climate-Change*) in the adaptation choice (*AdaptationChoice*). For a better understanding of the two-step decision making, the scenario of No perception (NO-PCC) was developed in the decision programme. This scenario consisted of stopping the routine of the first step which is *Perception-of-Climate-Change*. By doing so, no more restriction related to the *Perception-of-Climate-Change* existed again in the decision programme. In this case, the decision programme runs the second step (*AdaptationChoice*) for all the farm households if ever they still have a positive balance of the labour budget which will give them the possibility of making up a chosen option.

7.2.3 Socio-ecological interactions of the adaptation options

The socio-ecological interactions of the five adaptation options selected (see Chapter 6) for the simulations were described in the following:

Option 1 = Crop-livestock integration: referred to those households who owned livestock especially cattle. These households have the possibility for manure production, means of manure and compost transportation to the fields and means for ploughing. By doing so, they were able to enhance the soil fertility of the land, and this happens mostly in mixed and inter-cropping system of cereals where many crops are grown on the same plot of land. In order to consider the interactions in this option for households who choose this option, the following values were improved stochastically by the random values bounded by the correspondent standard deviations: livestock index (*h_livest*), manure application (*h_manure*) and fertility management (*h_fertiliser*).

Option 2 = Irrigation option refers to households who were involved in dry season farming due to climate change. In the moving phase (Figure 7.2), the household "open new land" based on the following condition:

(1) The land-cover type should be rice farmland and;

(2) The wetness index should be greater than zero in order to avoid those rice farmlands located on the uplands, since irrigation was ongoing along the river side.

Then the ecological sub-module built in landscape agents (agricultural yield) hold for tomatoes which is the main crop in the dry season.

Option 3 and option 4 = maize and soybean farming were the two crops introduced in the area because of climate variability according to farmers and stakeholders (see Chapter 6). Therefore, the ecological sub-module (Agricultural yield) for these two crops was integrated in the moving phase.

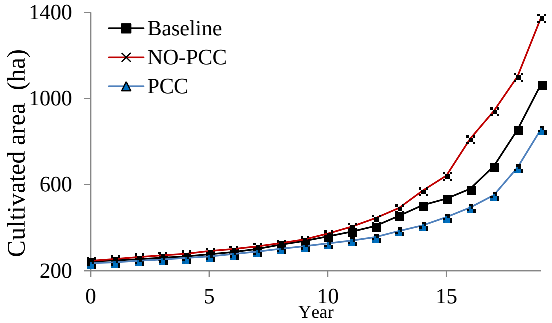
7.3 Simulation Results:

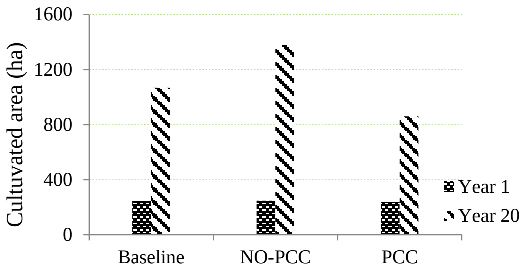
7.3.1 Impact of climate change and variability on land-use pattern and household typology

The simulation results of cultivated land areas (ha) of the main land-use types (mixed cereals, rice and groundnut) and the changes between the first and the twentieth year under the three scenarios are reported in Figure 7.3. The percentage of landholding (%) and the pattern of the categorised household-agents simulated under the three scenarios are depicted in Figure 7.4. Each plot presented the output of the three scenarios for a better analysis of the temporal performance. From Figure 7.3 (a), regardless of the three scenarios, an increasing trend of the cultivated land area of mixed cereals was shown. For the same land-use type, similar trend of the percentage of landholding was also simulated (Figure 7.4.a), which became relatively constant for the last three years (year 18 to 20). A clear rapid increase was also observed in the trend of the simulated cultivated land area of rice up to the year 7 (Figure 7.3 c) then it became relatively constant over time. Presented in Figure 7.3 e, groundnuts also showed a slight increasing trend in cultivated areas, which became important in the last four years. With regard to the landholding, the percentage of mixed cereals remains the main important component of the cropland (Figure 7.4 a) followed by groundnuts (Figure 7.4 c) and then rice (Figure 7.4 b). Based on the results, when the landholding of mixed cereals showed an increase due to rapid upward trend in the cultivated land area, that of rice and groundnuts revealed a slight decrease over time.

In terms of land-use change, for both cultivated land areas and landholding, the three scenarios (i.e. Baseline, NO-PCC and PCC) developed the same pattern during the next 20 years. The main factor of difference remains the magnitude of the effect of each scenario on the land-use decision. In this regard, the magnitude of the simulated cultivated area for mixed cereals and rice in the scenario NO-PCC was the highest among the three scenarios with respectively an average change of 1113 ha (Figure 7.3 b) and 2 ha (Figure 7.3 d). Similar behaviour in terms of magnitude of the simulated landholding for these two land-uses was observed (Figure 7.4 a and Figure 7.4 b). The high magnitude of cultivated area for mixed cereals for the next 20 years reflects the extensive characteristics of the farming system in the study area which is supported by the high cultivated area under the baseline accentuated by the NO-PCC scenario (Figure 7.3 a). In the case of PCC scenario, household-agents have not emphasised on increasing the cultivated land area of mixed cereals, instead they were more involved in different alternatives for their livelihood strategy such as groundnuts or other adaptation options. This justified the lowest magnitude in terms of trend of cultivated area of mixed cereals (Figure 7.3 a) and also a lowest change of 624 ha (from 235 at year 1 to 859 at year 20) under PCC scenario (Figure 7.3 b). In contrast, this scenario (PCC) has the highest magnitude (Figure 7.3 e) with a change of 70 ha compared to the baseline (57 ha) in the cultivated area of groundnuts under PCC scenario (Figure 7.3 f) where groundnut was used as cash crop especially in the case of mono-cropping system. An opposite behaviour was observed in the case of rice (Figure 7.3 d) suggesting that even if this crop is grown as cash crop the reason behind would be stimulated by another purpose different from climate stimuli.

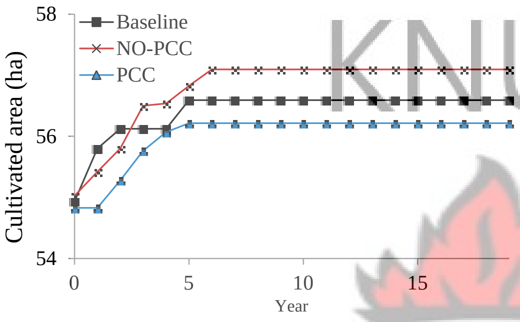
From Figure 7.4, even with the three scenarios, the categorised household agents followed the same pattern within each group over time (Figure 7.4 d, e, f). This is understandable in this research since the two scenarios developed (NO-PCC and PCC) were used for exploring the undergoing adaptation of agricultural land-use in the study area without adding any assumption (e.g. credit), which was expected to change the lifestyle of the communities. These communities were categorised based on the approach of the capital asset (Chapter 3), and each household-agent group followed the same typological pattern independently of the scenarios. Accordingly, SKY-LUDAS reflects the characteristics of the *real-world* households and based on these characteristics, the model mechanism simulates households-specific responses to the different scenarios.

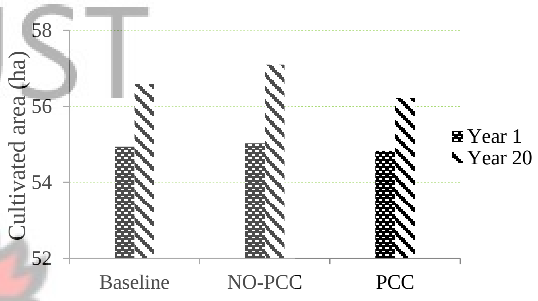




(a) Mixed cereals

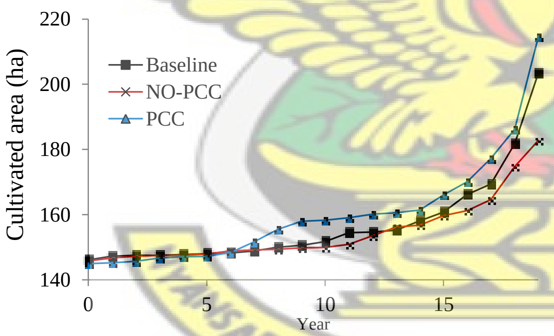
(b) Change of mixed cereals area

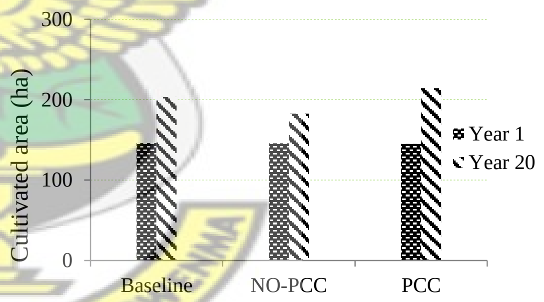




(c) Rice

(d) Change in rice area

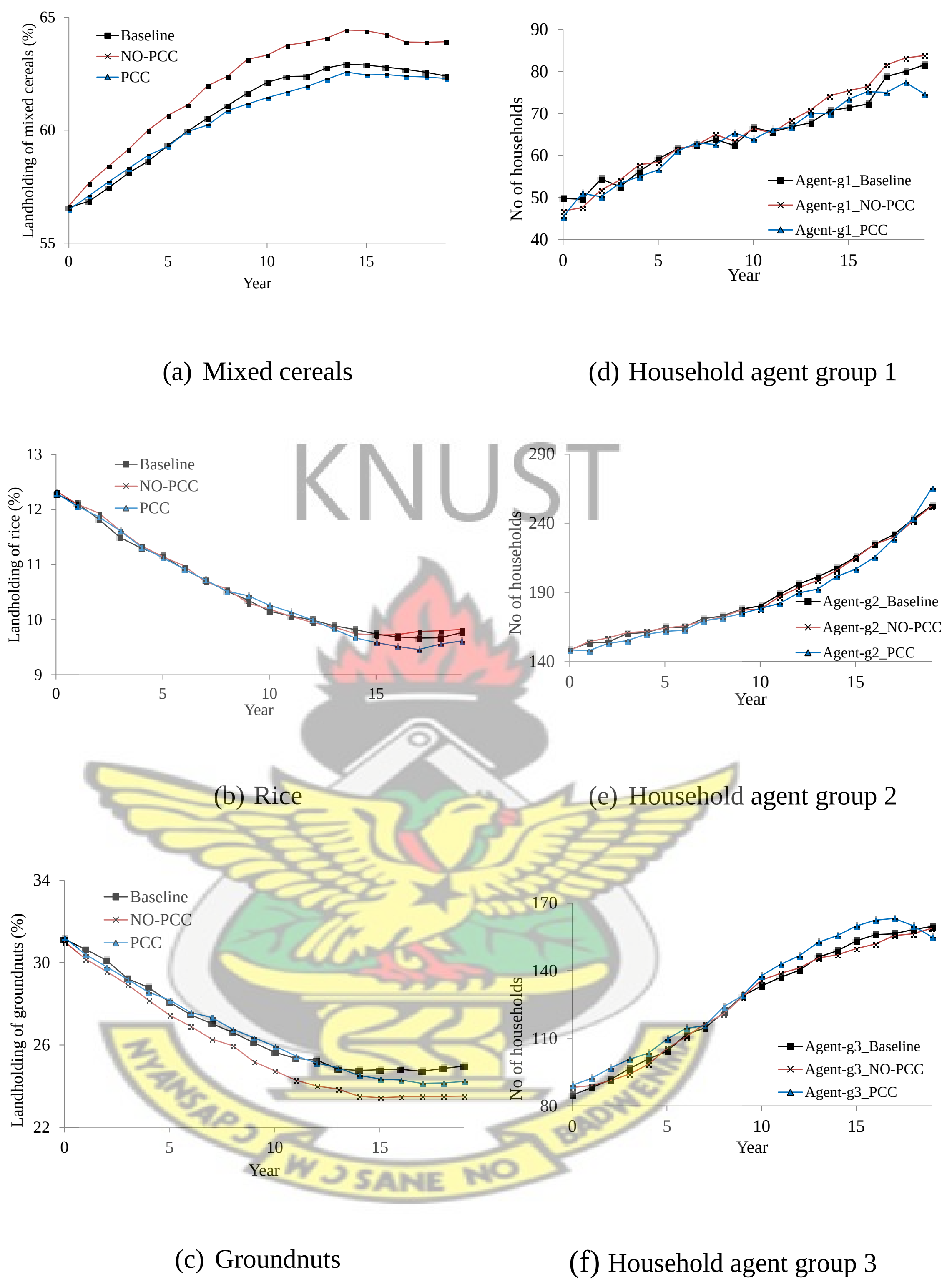




(e) Groundnuts

(f) Change of groundnuts area

Figure 7.3: Simulated cultivated areas of the three main agricultural land-use types: (a), (b) mixed cereals); (c), (d) rice and (e), (f) groundnuts under perception (PCC) and No perception (NO-PCC) scenarios compared to the baseline



(a) Mixed cereals (d) Household agent group 1

(b) Rice (e) Household agent group 2

(c) Groundnuts (f) Household agent group 3

Figure 7.4: Simulations of landholdings and household patterns

7.3.2 Impact of climate change and variability on livelihood strategy

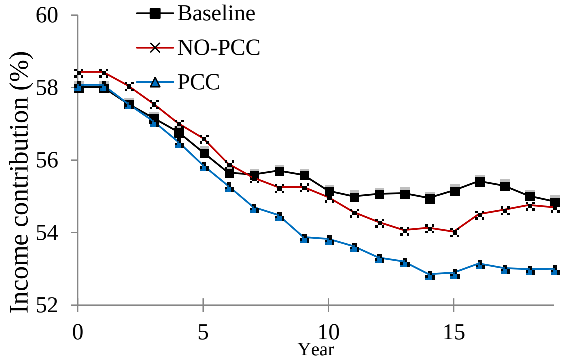
Figure 7.5 presents the simulated percentage of income contribution of each land-use type under the three scenarios. Generally, mixed cereals represent the main contribution for all the three household agent groups (Figure 7.5 a). This reflects in addition to the extensiveness, the subsistence oriented behaviour of agricultural land-use system in the study area which is supported by the highest magnitude of the income contribution trend of mixed cereals under baseline scenario. Also another important point was that even though the cultivated area of the mixed cereals was increasing (Figure 7.3 a), but in terms of income contribution, this land-use type was experiencing a downward trend over time, which suggests also a change in livelihood strategy. An interesting point was also the lowest magnitude of the scenario PCC (Figure 7.5 a) which indicated that the income contribution of mixed cereals-based was less important for farmers with good awareness of climate change and variability. The reduction of the income contribution percentage between the first and the twentieth year of mixed cereals under PCC scenario is the greatest (-5 %) comparing to the NO-PCC and baseline scenarios with respectively - 4 % and - 3 % (Figure 7.5 b). As a result, the better farmers' climate perception is, the less they are involved in cultivating mixed cereals the more they are involved in other alternatives.

From Figure 7.5 c and Figure 7.5 e, it is clearly shown that the magnitude of the increasing trend of rice and groundnut under NO-PCC and PCC scenarios was greater than the baseline. In terms of income structure change, the increase of the income contribution of rice under NO-PCC scenario is greatest (0.5 %) in comparison with the increase of the percentage of rice income under PCC and baseline scenarios, with both 0.2 % (Figure 7.5 d). In accordance with the above, it was explicitly shown that farmers with good awareness of climate change are more involved in choosing groundnuts as livelihood strategy than rice. This was due to the fact that rice farming was more demanding in terms of labour, water, farm inputs and care, and for these reasons this land-use type (rice) could not be the choice of the majority of small-scale farmers as a diversification option. Despite these factors, a net difference was observed in the increase of percentage of income contribution of groundnut under PCC scenario (Figure 7.5 e). In view of that, the change of the income contribution of this land-use type under PCC scenario is the greatest with 5 % comparing to the NO-PCC and baseline scenarios with respectively 4 % and 3 % (Figure 7.5 f). It is also important to note that even though both rice and groundnuts are experiencing lower landholding percentage compared to mixed cereals; they all showed a growing upward trend in terms of income contribution. This suggests that the new generation of farmers were more interested in farming rice and groundnuts as cash crops in the study area in diversifying their livelihood strategy.

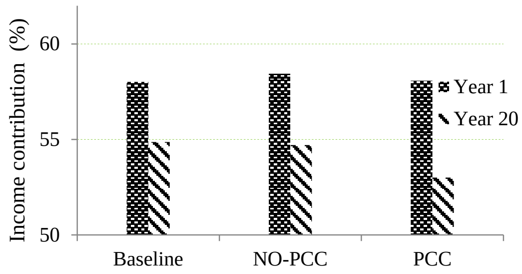
7.3.3 Implications of climate change perception in household revenue

The development of the simulated gross income and the gross income per capita of the households-agent groups is depicted in Figure 7.6. From Figure 7.6.a, the simulated average of gross income showed a slight increase for the first 10 years and then declined. This downward trend of the average gross income was similar for all the 3 scenarios. However, while the lines of the baseline and NO-PCC scenarios have relatively steady movement over time, the line of PCC showed considerable oscillations leading to an increase in the magnitude of the overall gross income for the last decade. This was due to relative probabilities of the *AdaptationChoice* sub-model in choosing an option among the multiple choices of the adaptation options.

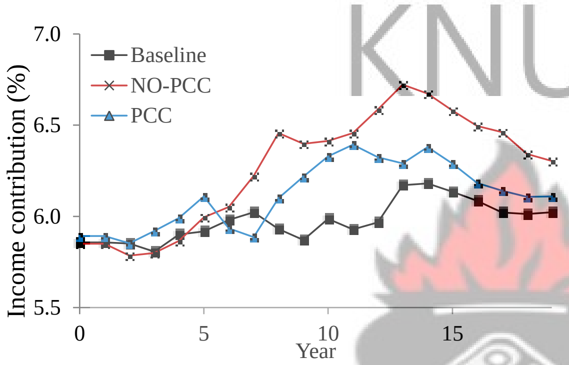
To explore the dynamics of the average gross income within the community, the gross income per capita was plotted for the categorised household-agents under the three scenarios. Generally, the trend of the average gross income decreased slightly over time (Figure 7.6.a) as introduced earlier.



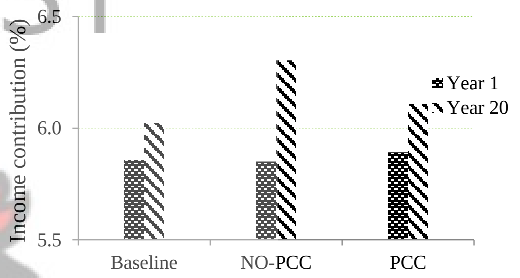
(a) Mixed cereals



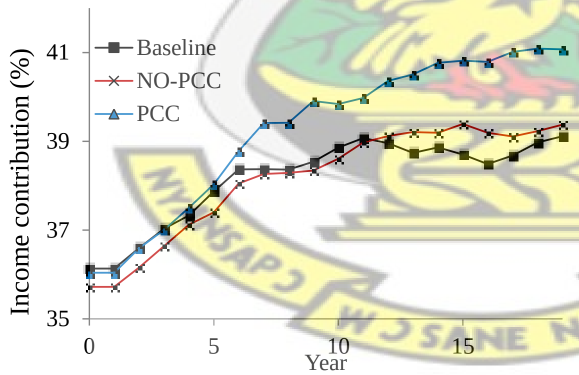
(b) Change of mixed cereals income



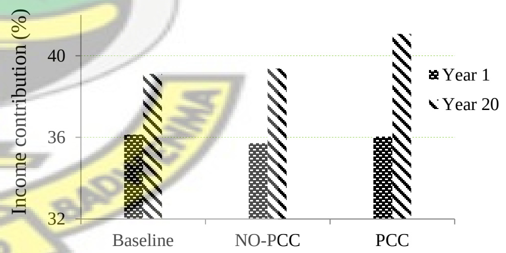
(c) Rice



(d) Change of rice income



(e) Groundnut

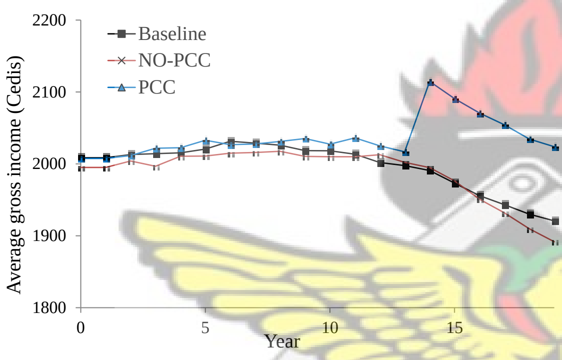


(f) Change of groundnut income

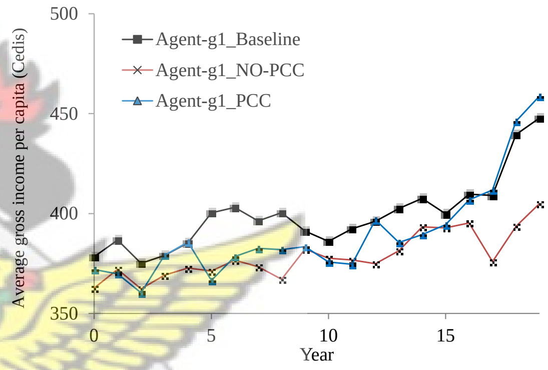
Figure 7.5: Simulated income structure of the three main agricultural land-use types (a), (b) mixed cereals, (c), (d) rice; and (e), (f) groundnuts.

When it comes to the gross income per capita the following was observed: the gross income per capita was relatively constant over time (Figure 7.6.b) for the agent group 1 (moderate households); a steady increase of the income per capita was observed

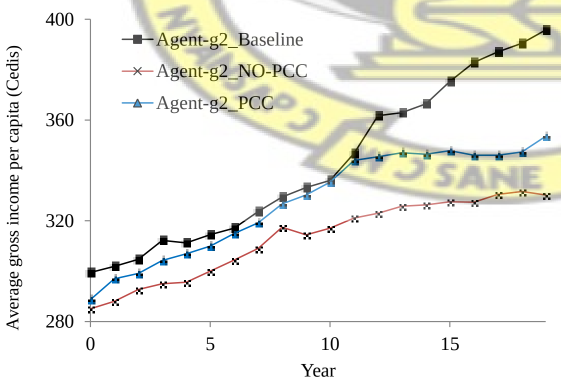
(Figure 7.6.c) for the agent group 2 (poor households) while the trend of the income per capita was declining (Figure 7.6.d) for the agent group 3 (rich households). It is important to note that the income simulated here represented the average gross income within the whole population which is independent of the household agent group. The gross income per capita even though still average, gave an idea of the distribution of the income within the household agent groups. For instance, the average of the increasing gross income per capita for the agent group 2 even at the 20th year of the simulation (Figure 7.6.c), did not reach the lowest values of the decreasing income per capita for the agent group 3 (Figure 7.6.d).



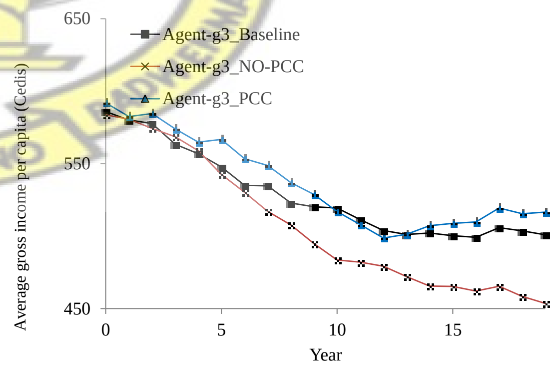
(a) Average gross income



(b) Income per capita of agent group 1



(c) Income per capita of agent group 2



(d) Income per capita of agent group 3

Figure 7.6: Simulations of (a) gross income and income per capita of (b) agent group 1, (c) agent group 2 and (d) agent group 3

7.3.4 Implications of climate change perception on crop production

The simulated average crop yields from the mixed cereals (a, b and c), rice (e) and groundnuts (d) are presented in Figure 7.7. With the exception of rice, SKY-LUDAS overestimated the yields of cereals. Comparing the simulated crop yields to the historical yield data recorded by the regional Ministry of Food and Agriculture (MOFA) in Bolgatanga from the period 1992 to 2009, the following were observed: the mean yields for millet and sorghum, were 958 kg/ha/y and 1052 kg/ha/y respectively which were lower than the simulated means. Groundnut was also overestimated by the model since the simulated average (1267 kg/ha/year for the baseline scenario) was greater than the recorded mean (933 kg/ha/y). In contrast, SKY-LUDAS underestimated the yield of rice since the recorded mean amounted to 2106 kg/ha/y. The three cereals (early millet, late millet and guinea corn) and groundnut were quite sensitive to the developed scenarios with improved yields for the NO-PCC (a and b) and PCC (c and d) because they were grown in the cropping system where crop and livestock were integrated, which is not the case of rice where the yield is not at all sensitive to the two scenarios (Figure 7.7.e).

7.4 Discussion and Conclusions

With respect to Figure 7.3.a, a clear increase of cultivated areas of mixed cereals farming was simulated by SKY-LUDAS which was also supported by the high proportion of simulated percentage of landholding for the same land-use type (Figure 7.4.a). As a result, the land-use behaviour reflected a tendency of subsistence farming which is in line with the findings of the previous research in the study area. For instance, it was found that the increased income from farming activities was generally due to higher yields, cultivation of more valuable crops, and/or an extension of cropped area, or a combination of these (Schindler, 2009). Moreover, the increased food demand due to the rapid growing population is another factor of increasing the importance of improving productivity of land (Hageback *et al.*, 2005).

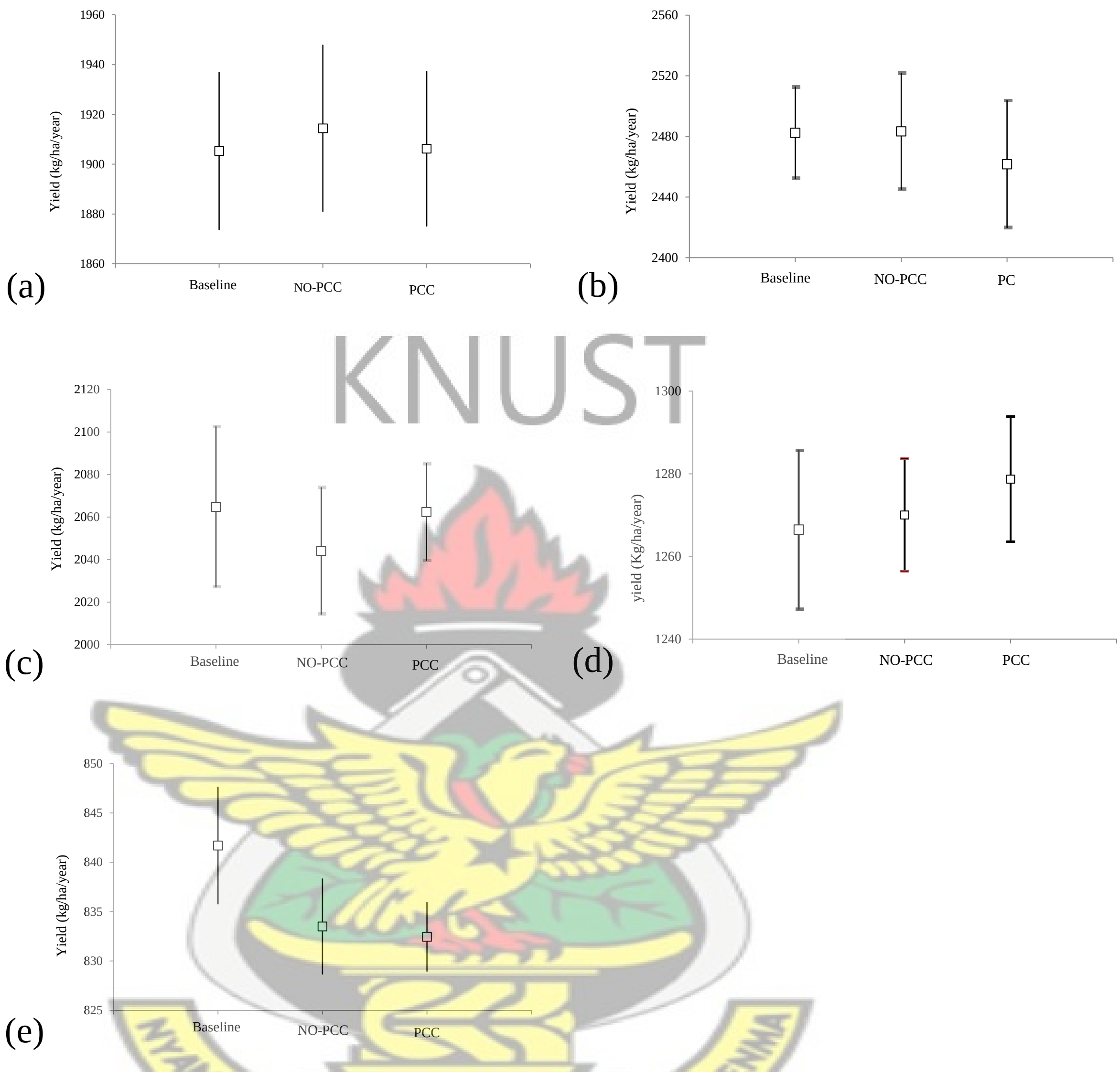


Figure 7. 7: Simulated crop yield of (a) early millet, (b) late millet, (c) sorghum, (d) groundnut and (e) rice . The bars are bounded by the values of the confidence interval at 95 % level

Rice and groundnuts have shown an upward behaviour less important than mixed cereals in terms of cultivated areas. However, the percentage of landholding for these two land-uses still showed a slight decline due to high proportion of mixed cereals. Despite the aforementioned factor, when it comes to livelihood strategy especially the structure of the gross income, there was a growing contribution of rice and groundnut. One of the main reasons for this was that the younger generations tend to prefer cash crops such as rice and groundnuts to traditional crops. This was supported by the empirical data set, which showed a much higher percentage of such crops among younger farmers (Schindler, 2009). Also, the importance of the magnitude for the PCC scenario could also be supported by the fact that the younger farmers were more educated, therefore more interested in having information on weather conditions which was one of the main determinants of *Perception-of-ClimateChange* sub-model (Chapter 5). Accordingly, it was well said, in general, individuals with higher levels of education were more aware about change (Zube, 1987). Therefore, as education is admitted to improve farmers' perception, then it will definitively influence responses to the landscape. In view of that, the perception of any system, has a great deal of influence on how to go about dealing with that system (Ellis & Swift, 1988).

With regards to the results of this research, SKY-LUDAS has revealed a gradual shift among land-use types from traditional cereals' farming to the cultivation of rice and groundnuts which was also observed during the last decades (Schindler, 2009) in the study area. In order to adapt to environmental changes, transformation of traditional small-scale agriculture has taken over in many parts of the Upper East Region where agricultural production was intensified mainly through adoption of irrigation practices and the adoption of new crop varieties (Laube *et al*., 2012). Moreover, because farmers with good awareness of climate variability were more into groundnut farming (Figure 7.3.f) than rice (Figure 7.3.d), thus we can conclude that groundnut farming (especially in mono-cropping) as cash crops is considered as another adjustment (alternative) to climate change for farmers in the study area. However, the hypothesis of this finding was not considered at the beginning of this work. Number of studies focused the adaptation strategies adopted by local households in the research area when environmental change threatened their agricultural livelihoods. Traditional small-scale agriculture has never been severely affected in its patterns (Laube *et al.*, 2012) as a result of an increasing delay of onset dates which has been suspected by local farmers themselves since the mid-1980s (Laux & Kunstmann, 2008). Consequently, new crops such as maize and soybeans were introduced in the area (see Chapter 6), also local cereals like millet or guinea corn that have long growth period are substituted by other types that mature faster and the same is true for local types of groundnuts which were replaced by fast-growing varieties (Laube *et al.*, 2012: 761).

The simulation results of SKY-LUDAS also demonstrated that farmers in the study area have adapted their land use to climate change based on the income source and gradual change in the cultivated land-use with the purpose of being less dependent on vulnerable farming systems and therefore the climate. This reflected the complex nature of land-use change in its interaction of behavioural and structural factors associated with the demand, technological capacity, social relations affecting demand and capacity, and the nature of the environment in question (Verburg *et al.*, 2004a). Similar farmers' behaviour was found in the work of Hageback *et al.* (2005). As a result of the aforesaid, farmers are less involved in cultivating mixed cereals but rather into other alternatives. In the shift from traditional cereals farming to the cultivation of more valuable crops, farmers planted crops that are less resistant to droughts such as maize which is considered in this study as new crop introduced in the area because of climate variability (Chapter 6). One reason could be that their living situation has changed drastically during the last 20 years, mainly due to economic changes as they have indicated during the group discussions. This adaptive response of farmers was for them to improve their living conditions. Therefore one will wonder whether climate variability could be an additional reason, even though it is hard to distinguish the extent of influence (Hageback *et al.*, 2005). In the same point of view, climate change is considered as only one of many factors that will affect world agriculture over the next several decades. The broader impacts of climate change on world markets, on hunger, and on resource degradation will depend on how agriculture meets demands of a growing population (Reilly & Schimmelpfennig, 1999).

Through the two-step decision making sub-models, SKY-LUDAS was also able to capture the profit coming from the diversification as adaptation options. The approach has been used as two-stage decision-making routines in LB-LUDAS (Villamor, 2012) where it showed its importance in better incorporating the decision making process. However, because of the highest proportion of farmers involved in crop livestock integration (option 1) which frequently lead to highest probabilities of selecting this option after each time step, the frequency of capturing all other adaption options (irrigation, soybeans and maize farming) was very low.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

The aim of this study was to develop an integrated land-use model for small-scale area in the Upper East Region of Ghana that enables policy-makers and other stakeholders to explore alternative scenarios on adaptation to climate change. The study was also supposed to give more insights into the understanding of the interactions between rural communities and their local environment. As a result, the understanding and anticipation of rural future land-use and land-cover change can provide a basis for potential proactive land management, by trying to find strategies to mitigate future climate impacts and possibly improve the sustainability of resource use. With respect to the above introduction, four key aspects were provided by this research:

- First of all, this thesis begins with a review of the coupled human-environment system as a new modelling paradigm and focuses on multi-agent system by using a standard approach for documenting such models. The reason behind it was to clarify the basis of this research for a better understanding of this approach on LUCC processes which are often challenged by the complex nature and unexpected behaviour of CHES drivers.
- Secondly, a typology of agricultural land use was developed in order to deal with the high heterogeneity of the mixed cropping systems in the area. Also, based on the approach of the capital asset, meaningful indicators were identified and used to describe the differences in local livelihood typologies. Since it is a common assumption that land-use decisions are related to livelihood strategy of farming household, the diversity of agents regarding land-use decisions can be achieved by a categorisation of these household agents into groups, each having an individual livelihood strategy. Then the decision-making sub-models which

represent choices among discrete sets of options were developed based on multinomial logistic regression models of the categorised households and landscape. Hence, this method used for this household decision-making captured considerable heterogeneity in terms of land-use choice behaviour. Generally, households choose land use based on the considerations of a range of individual characteristics, natural conditions of the landscape and particular policy factors. Therefore, this developed model of land-use choice has provided a basis for coupling human and environment system under particular circumstances when simulating land-use changes.

- Thirdly, this study has the merit of developing and integrating the two step decision making sub-models in the decision programme of LUDAS model and created SKY-LUDAS. As a result, it explicitly explored the implications of perception of climate change and variability in the decision of adapting agricultural land use. The first step was developed based on the results of binary logistic regression with binary outcomes: the probability of *Perception-of-Climate-Change* was represented in the model through a dummy variable taken with value 1 when the farmer has perceived climate change and 0 otherwise. The second step (when the probability in the first step equals 1) used the results of the m-logit model through the probability of the following five adaptation choices: Crop-livestock integration; Irrigation; Maize farming; Soybean farming and No adaptation. This integrated approach helped to capture the adding values of the different adaptation options with often discrete advantages.
- SKY-LUDAS was able to represent the dynamics and interactions as well as process between human and landscape system of the rural communities in the study area. This model quantified and estimated possible impacts of climate variability on land-use change through the perception local rural communities

have on climatic parameters (see chapter 5). Thus, supporting the perception of how particular ecological systems operate determine the approaches that are advocated in attempting to modify or manipulate those ecosystems (Ellis & Swift, 1988).

8.2 Limitations

It has been clearly mentioned in the earlier versions of LUDAS that the first limitation in this approach is related to the fact that some substantial interactions in both human and biophysical system have been implemented only in the limited extend (Le, 2005, Schindler, 2009). For instance, on the one hand, processes like conflicts, negotiations on land, realistic networks as well as quantification of the more qualitative benefits farmers gained from network memberships were also not captured in this study. On the other hand, the neighbourhood interactions which could determine the influence among land-use types (Verburg *et al.*, 2004b, Villamor *et al.*, 2014a) and the land-use intensity were also not explicitly considered. Knowledge in current levels of agricultural land-use intensity has its importance, especially when it comes to assessing the long-term potential of further yield growth and to be able to make projections about future land-use developments (Dietrich *et al.*, 2012). Further limitations including long running speed of the simulation time and large amount of data coming from various disciplines were also indicated (Villamor, 2012). In addition to the above factors, the following aspects could also be considered:

SKY-LUDAS cannot be transferred easily to other areas. Only the approach through the framework of LUDAS in general could be reused because all the variables and the calibration of the sub-models (e.g. agricultural crop yields) should be area specific due to the heterogeneity of the decision-making and the ecological processes.

Also one of the limitations of this work lies in the difficulty of the validation of the results due to the limited time frame of the study. Actually the validation of the MAS model is currently a debatable (Le, 2005). However, some validation strategies were discussed including comparing simulated data versus observed data or differential equations (Bousquet & Le Page, 2004), sensitivity analysis (Schouten, 2013), and use of Role Playing Games theory with MAS which was found as efficient tool for multiple stakeholders to reach collective decision making in land-use (Suphanchaimart *et al.*, 2005, Villamor & Noordwijk, 2011). In the case of this study, two-step decision sub-models were used for simulating the adaptation strategies in agricultural land-use. These sub-models integrated in the decision making mechanism represented an important process that reflects the characteristics of the real system. Moreover, the strength of this approach resides in the fact that its outputs in terms of livelihood strategy are in line with previous research work implemented in the same study area (Schindler, 2009). Also, one land-use pattern (groundnuts in mono-cropping) which was usually considered as simple livelihood strategy and was not intentionally modelled for that purpose has emerged as strategy related to climate change. As a result, this research brought more insights by answering the question on whether an adaptation strategy is climate stimuli or not. However, the non-farm activities were not considered in this study.

8.3 Recommendations

Multi-Agent System (MAS) cannot predict the real-world human-environment system in the most realistic and fully integrated manner and no modelling approach can. However, it makes the representation of agricultural land-use system more realistic due to the high flexibility of the model and the possibility of integrating human decision-making and ecological processes. Therefore, it can offer insights into the relationship between features of CHES and the range of possible future adaptations that will be likely in response to climate change (Patt & Siebenhüner, 2005). Given the aforesaid, the following points are recommended:

First, given the complexity of human-environment systems (HESs), studies using an approach of MAS models in agricultural land-use requires a researcher to have a broad combination of various knowledge domains and technical skills in information technology (e.g. GIS and remote sensing). Instead, implementation of such studies within a multidisciplinary team should be the best.

Second, SKY-LUDAS model as an integrated MAS model was able to represent the dynamics and interactions as well as the processes between human and landscape system of the study area. Due to the two-step decision making sub-models, SKY-LUDAS was also able to capture the implications of farmers' perception of climate change and variability in agricultural land-use adaptation; therefore, this modelling approach can be repeated in different areas since it opened the way for considering all stakeholders' opinion in the design of the policies in the agro-ecosystem management.

Third, desertification of the savannah and land degradation has been mentioned by a number of respondents during the field surveys as a constraint for adopting many adaptation options in their farming systems. Since these complex processes are also the results of human-induced factors (e.g. over-cultivation) and other natural factors such as climate change and soil erosion, therefore, there is a need to build and integrate a land degradation sub-model in the SKY-LUDAS framework.

Finally, since it is shown that a mixed approach would lead to a better understanding of the model's behaviour, and also determine and integrate the various types of knowledge and values of different actors can contribute to a more comprehensive understanding of social-ecological system (Villamor *et al.*, 2014b), therefore, valuable tools like Role-playing games should be developed and played with stakeholders in order to validate the model and help stakeholders relate better to the outcomes of the model.

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KNUST

HOUSEHOLD QUESTIONNAIRE

Dry season survey

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PhD Research title:

Simulating agricultural land-use adaptation under changing climate using Multi-Agent System model in the Upper East Region of Ghana

Negative impacts of Climate Change on Agriculture are expected IPCC (1997). Your responses will certainly help to better understand the Impact of Climate Change on the Crop production systems and the adaptation strategies in Northern Ghana and in Africa in general. Your responses will be anonymous

Compound No: ....

Name of the household head: .... Village: ....

Date of the interview: ....../....../2013 / Time start: ....Time end: ....

Section 1: Demographic structure of the household

1.1 Household size __________ Wives number ________________

1.2 Household characteristics

	1.2.1 Gender	1.2.2 Age	1.2.3 Matrimonial status	1.2.4 Educational level (years)	1.2.5 Farm occupation	1.2.6 Off-farm activities occupation
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
	1. Male **2. Female**		**1.Maried 2.Divorced 3.Separate** **4.Widow 5.Single** **6.Yung member less than 16 years**		**1.Yes 2.Non**	**1.Yes 2.Non**

1.3 Ethnic group of the household head? ____________________

1.4 Religion of the household head?________(**Use the key : 1. Muslim 2. Christian 3.Non believer. 4.Animist 5.Others (to specify)**)

1.5 Does the household have access to the electricity? ________________ (**1.Yes 2. Non**)

2

Section 2: Occupation — All questions concerned the last 12 months

2.1	2.2	2.3	2.4	2.5	2.6	2.7
The main activity of the household head	Further activities of the household head	Number of days/week allocated to the main activity	Number of months allocated to the main activity during the last 12 months	Number of days/week allocated to the secondary activity	Number of months allocated to the secondary activity during the last 12 months	Number of days lost due to the disease during the last 12 months
1.Agiculture 2.Traide 3.Teaching 4. Artisan 5.Office job 6.fonctionnaire 7.farm waged 8.Nurse 9.Of farm work 10.Student 11.Unemployed 12.Other to specify		Please check the definition of one day of work = 6-8 hours of work		Please check the definition of one day of work = 6-8 hours of work		

Section 3: Land tenure and different activity steps — All questions concerned the last 12 months

3.1 How many farms are exploited by the household_________ **(A farm corresponds to a parcel referring to the parcels' section)**

3.2 Note the land surface cultivated by the household during the last 12 months and the GPS position of the household

(The measurement of farm surface with the GPS will be done after the interview)

Farm	Area of the farm (Farmer estimation)	Area unit	GPS		
			Farm area	Household location	
				Latitude (Y)	Longitude (X)
1					
2					
3					
4					
5					
6					

3.3 Answer the questions on the land farming referring to the total area and the farming system type implemented by the household members

	3.3a	3.3b	3.3c	3.3d
Number of parcels	Land farming system	Land tenure of the cultivated parcel	During how many years you cultivated this parcel?	Fees by year if the parcel has been lend
1				
2				
3				
4				
5				
6				

Key for 3.3a

1. Change farming system with fallow
2. Continuous farming without fallow
3. farming with multiple rotation
4.area allocated to livestock
5.Other to specify

Key for 3.3

1.Landowner
2.Owner lands and lend to other farmers
3.Landholding (rented land)
4.community land
5. other to specify

NB: Please allow multiple answers in this case

3.4 Cropping season's period

Rainy season	Cropping season	Start:	End:
Dry season	Cropping season	Start:	End:

3.5 Activities' division: estimation of the number of persons and days on each parcel according to the labour type

Season and activity type per parcel		Total number of employed labours and total number of work days (per activity and per season) (1 day = 6 – 8 hours of labour)													
		Household labour						Rented labour						Communal labour	
		Male adult		Female adult		Young (< 16ans)		Male adult		Female Adult		Young (< 16 ans)		All participants	
		No	Days	No	Days	No	Days	No	Days	No	Days	No	Days	No	Days
Rainy season: **Parcel 1**	Land cleaning														
	Ploughing														
	Sowing														
	Weeding														
	Pesticide, fertilizers, etc														
	Transport manure														
	Harvesting														
	Gathering and storage														
Rainy season: **Parcel 2**	Land cleaning														
	Ploughing														
	Sowing														
	Weeding														
	Pesticide, fertilizers, etc														
	Transport manure														
	Harvesting														
	Gathering and storage														
Rainy season: **Parcel 3**	Land clearing														
	Ploughing														
	Sowing														
	Weeding														
	Pesticide, fertilizers, etc														
	Transport manure														
	Harvesting														
	Gathering and storage														
Rainy season: **Parcel 4**	Land clearing														
	Ploughing														
	Sowing														
	Weeding														
	Pesticide, fertilizers, etc														
	Transport manure														

	Harvesting														
	Gathering and storage														

Season and activity type per parcel		Total number of employed labours and total number of work days (per activity and per season) (1 day = 6 – 8 hours of labour)													
		Household labour						Rented labour						Communal labour	
		Male adult		Female adult		Young (< 16ans)		Male adult		Female Adult		Young (< 16 ans)		All participants	
		No	Days	No	Days	No	Days	No	Days	No	Days	No	Days	No	Days
Rainy season: **Parcel 5**	Land cleaning														
	Ploughing														
	Sowing														
	Weeding														
	Pesticide, fertilizers, etc														
	Transport manure														
	Harvesting														
	Gathering and storage														
Rainy season: **Parcel 6**	Land cleaning														
	Ploughing														
	Sowing														
	Weeding														
	Pesticide, fertilizers, etc														
	Transport manure														
	Harvesting														
	Gathering and storage														
Dry season: **Parcel No?**	Land clearing														
	Making ridges														
	Sowing/transplanting														
	Irrigation														
	Digging														
	Pesticide, fertilizers														
	Weeding														
	Harvesting														
Dry season: **Parcel No?**	Land clearing														
	Making ridges														
	Sowing/transplanting														
	Irrigation														

	Digging														
	Pesticide, fertilizers,														
	Weeding														
	Harvesting														

3.6 Farm remuneration

Farm remuneration rate	Rented labour			Communal labour
	Male adult	Female adult	Young	Money spent by the household for one day of work
Daily average salary for all activities per labour				

Section 4: Details on Crop productivity and Livestock — All questions concerned the last 12 months

4.1 Details on crop productivity and sale for these last 12 months?

Please use the keys for 4.1.2 (if the crop dose not part of the list, please specify it as other)

1. Early Millet
2. Late Millet
3.Guinea Corn
4.Corn
5.Groundnuts
6.Beans
7.Bambara Beans
8.Rice
9.Potatoes
10.Pepper
11.Okro
12.Tomatoes
13.Tobacco
14.Soybeans
15.Leafy vegetables
16.Onion
17.
18.
19.
20.

season	No of parcel	Crop type	Sowing date	Harvesting date	Surface occupied (%)	Amount harvested (kg)	Amount consumed by the HH (kg)	Amount consumed by the livestock (kg)	Amount lost because of disease (kg)	Amount sold (kg)	Cost of kg of sold product	To whom the production has been sold	Quantity of seeds used (kg)	Cost of kg of seed
Rainy season	1													
	2													

	3													

season	No of parcel	Crop type	Sowing date	Harvesting date	Surface occupied (%)	Amount harvested (kg)	Amount consumed by the HH (kg)	Amount consumed by the livestock (kg)	Amount lost because of disease (kg)	Amount sold (kg)	Cost of kg of sold product	To whom the production has been sold	Quantity of seeds used (kg)	Cost of kg of seed
Rainy season	4													
	5													
Dry season	?													
	?													

You can also use key for 4.5 to 4.9 : 1. Big basin; 2. Small basin; 3. Bowl; 4. Standard crate; 5. Big crate; 6. Bag; 7. Other to specify

Key for 4.9a: 1.local consumer, 2.Speculators, 3.Local markets, 4.Others

If the dry season parcel is not one of the parcels used in rainy season, please note 6, 7, 8, ….

4.2 Water, fertilizers and pesticides

Season	No of parcel	Water source	If irrigation, which system are you using?	Fertilizers use (kg/year)	Pesticide use (kg/year)	Use of Manure or compost (**Please check the unit**)
Rainy season	1					
	2					
	3					
	4					
	5					
	6					
Dry season	?					
	?					
	?					
		Use the Key: 1.rainfall 2.irrigation	**Use the Key:** 1.gravity 2.Irrigation under public scheme/dam 3.Dugout with motor pomp 4.Hand dug well 5. ground water Irrigation 6. Drip irrig. Syst. 7. Others to specify			

Cost of 1 kg of fertilizer 1: ________________ Cost of 1 kg of fertilizer 2:__________________

Cost of 1 kg of pesticide: _________________ Cost of 1kg of manure: ____________________

What did you do with the crop residues in your farms: ……………..

4.3 Information on ploughing and other materials

Tools/Engines/Instruments	Number	Who is the owner of the equipment?	How much you paid for rented tools?	Duration of your own instrument (year)
1. Sowing machine				
2. Bullock Plough/				
3. Animal traction				
4. Pulveriser/Knapsack				
5. Motor pump				
6. Tractor				
7. Motoking				
8. Motorbike				
9.				
10.				
11.				
		Key for 1.Household 2.Sharing 3. Renting 4. Support project		

4.4 Information on the storage rooms and market

Storage rooms	Use	Value of the room
Room 1		
Room 2		
Room 3		
	Key for 4.17.4b 1.Farm product storage 2.Animals management 3.Farm equipment storage 4.Other	

4.5 How far is the nearest market where you sell your production?________________________ (**km or hours, please check the unit and add the name of the market**)

4.6 By which means of transport are you going to the market?___________________________

Key for 4.6 : 1. Walk 2. Animals 3. Cart 4. Car 5. Motoking, 6.Other

4.7 How far is the market where you buy your provisions? _____________________________**(km or hours, please check the unit and add the name of the market)**

4.8 Livestock and Poultry

Do you have animals? __________ 1. Yes 2. No (**If No, then go to the section 5**)

Type of animal	Number owned	Number born the last 12 months	Number bought the last 12 months	Price of each bought animal	Number of month during which you fed the animals			Number sold the last 12 months	Price of each sold animal
					On community land	On household land	In the bush		
1.Sheep									
2.Goat									
3.Cow									
4.Pig									
5.Poultry									
6.Other									

4.9 Livestock Products

Household livestock Products	Quantity used by the household (kg/year)	Quantity sold (kg/year)	Price per unit
1.Milk products			
2.Meat			
3.			
4.			
5.			

Section 5: Agricultural Extensions and Training Access — All questions concerned the last 12 months

5.1 Agricultural Extensions

Have you received some advices from Agric office or NGO service? **1: Yes, 2: No (If No, go to 5.3)**

	For the farming activities	For livestock activities
The extension advices come from which organisation? Code for 5.1.4 1. Agric officer 2. NGO 3. Crop research institution **4.** Other		
Which kind of advices have you get?		
How many time do you receive their visit per year?		
Do you pay for the advices? **1:Yes, 2: No (If No go to 5.2)**		
How much do you pay per year for the advices?		

5.2 Did they give you information on the upcoming rainfall?________________________1: Yes 2: No

5.3 If no advices from Agric office or NGO services, then where do you receive some technical advices? ____________________

Key for 5.3: 1.Media 2.Neighbours 3. Shop man 4. Other to specify 5. Not at all

Section 6: Further farming cost and farming subventions — All questions concerned the last 12 months

6.1 How much your household has paid for the following rubrics the last 12 months?

Income taxes	
Ownership taxes	
Market taxes for selling	
Further costs (to	

precise__________________)	
Further costs (to precise__________________)	

6.2 Did your household get credit for the farm activities during the last 12 months? (If No then go to 6.3)

Get from (Source)	Amount received	Annual interest rate	Disbursement period (month/year)
________	______________	________________	_________________
________	______________	________________	_________________
________	______________	________________	_________________

Code : 1.Relatives, 2.Association/cooperative, 3.Traide Bank, 4.credit society, 5.Others (specify)

(**Please check if more than one household member got different credit**)

6.2.1 In which farm activities did you invest the credit? ____

6.2.2 Why did you invest the amount in this activity/these activities? ________________________________

6.2.3 Which profit did you realise? ____

6.3 Have you got subsidy during the last 12 months?

	Code: 1: Yes 2: No	Source	Market price	Subsidised price
1.Subsidy on crops				
2.Subsidy on farm inputs				
3.Subsidy on livestock				
3.Cash				
4.Other (to specify)		**Key:** 1.Goverment 2.NGOs 3.Private 4.Other		

Section 7: Climate change and Adaptation options

7.1 Have you noticed any long term changes in the mean temperature over the last 10, 20, 30 years:? (Please explain if the number of hot days stayed the **same, increased or declined**)

……………………………………………………………………………………………

7.2 Have you noticed any long-term changes in the mean rainfall over the last 10, 20, 30 years? (Please explain if the number of rainfall days stayed the **same, increased or declined**)

…………………………………………………………………………………………

7.3 What did you notice for the following characteristics of the rainy season over the last 10, 20 30 years?

Rainfall characteristics	Farmer perceptions
1. Onset	
2. End of the rains	
3. Drought within the season	

Code for 7.2.2 : **1. Earlier 2. Late 3. No change 4. Increase 5. Decrease 6. Do not know**

7.4 Then what change did you realise in your farming activities due to these changes in temperature and rainfall? (please explain)

………………………………………………………………………………………………

7.5 What adjustments in your farming have you made to these long-term shifts in rainfall? (if it is the case) Please list below:

____

____

7.6 What adjustments in your farming have you made to these long-term shifts in temperature? (If it is the case) Please list below:

____

____

7.7 Have you introduced news crops in your farming system?

If No why?
:____

If yes, fill the following table:

Name of the introduced crop	Duration	What is the main reason?	Adding value

7.8 Have you introduced new crop varieties?

If No why? :____

If yes, fill the following table:

Name of the new varieties	Duration (year)	What is the main reason?	Adding value

7.9 Have introduced a new mixed cropping (intercropping) in your farming system?

If No why? :____

If yes, fill the following table:

Give the type of the mixed cropping	Duration (year)	What is the main reason?	Adding value

7.10 Have you change your planting date?

If No why? :____

If yes, fill the following table:

From when to when?	Duration (year)	What is the main reason?	Adding value

7.11 Have you started extended your land farming?

If No why? :____

If yes, fill the following table:

Indicated the parcels extended	Duration (year)	What is the main reason?	Adding value

7.12 Have you started dry farming?

If No why? :____

If yes, fill the following table:

Indicated the parcels used	Duration (year)	What is the main reason?	Adding value

7.13 Have you implemented some soil conservation techniques in your farms?

If No why? :____

If yes, fill the following table:

Indicated the techniques	Duration (year)	What is the main reason?	Adding value

7.14 Have introduced livestock?

If No why? :____

If yes, fill the following table:

Type of livestock system	Duration (year)	What is the main reason?	Annual income

7.15 Have started off-farm (**cutting tree, trade**,) activities?

If No why? :____

If yes, fill the following table:

Type of off-farm activity	Duration (year)	What is the main reason?	Annual income from this activity

7.16 How many members of your household migrated to the town?

If No why? :____

If yes, fill the following table:

Number of members and the name of the town	Duration (year)	What is the main reason?	Annual income due to this migration

7.17 are you doing land rotation or crop rotation?   (Explain)

Type of rotation	Duration	What is the main reason?	Adding value

Key from 7.7 to 7.16: 1: lack of money; 2. Lack of information; 3. Shortage of labour; 4. Other (write into the lines provided above)

7.18 What were the main constraints/difficulties in changing your farming ways?

7.19 Have you seen changes in the vegetation cover the last 10 20 30 years? (Please explain)