

**LAND-USE/LAND COVER CHANGE AND ITS RELATIONSHIP TO
CHANGING CLIMATE AND CROP PRODUCTION IN THE LOWER
VOLTA BASIN, GHANA**

**THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN
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MPHIL ENVIRONMENTAL SCIENCE DEGREE**



**INSTITUTE FOR ENVIRONMENT AND SANITATION STUDIES (IESS),
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DECLARATION

I hereby declare that I have under supervision, undertaken this study herein submitted for the award of a Master of Philosophy in Environmental Science. This study is my own production and has not been presented anywhere for another degree whatsoever. The thesis report has been prepared and presented in accordance with academic rules and ethical conduct, I have fully cited, referenced and acknowledged all materials and results that are not original to this work.

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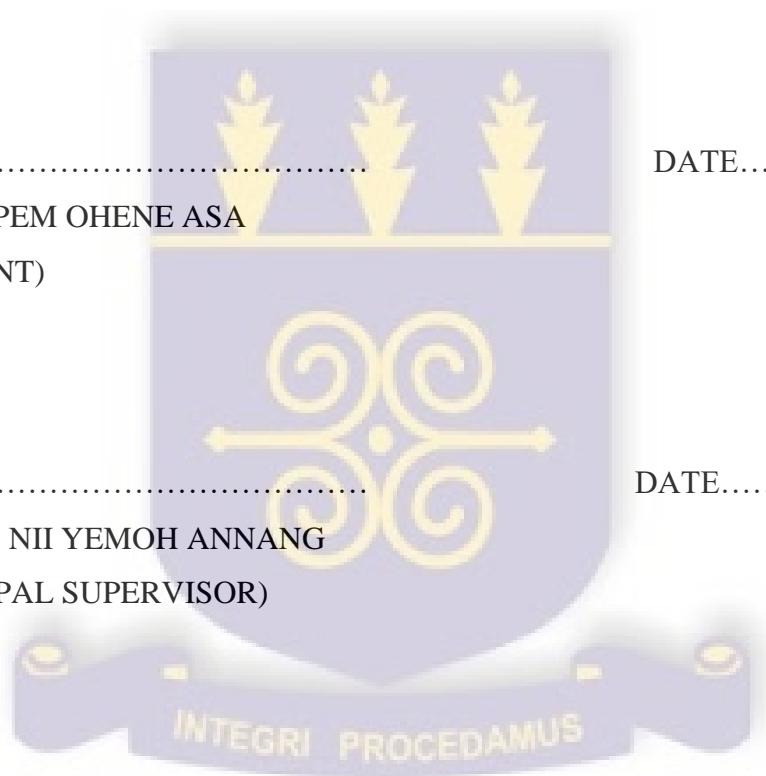
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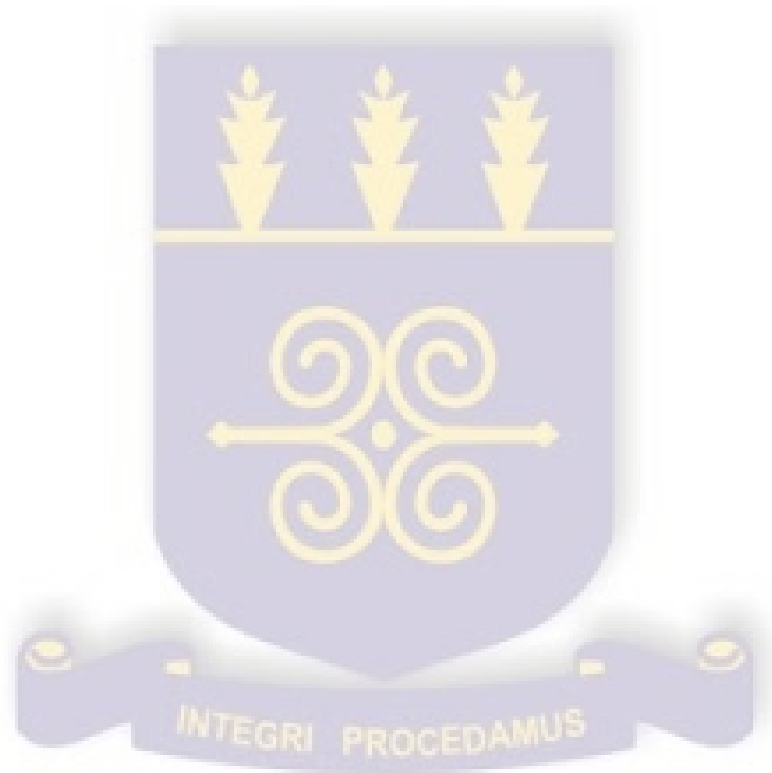
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DEDICATION

To My Family and Brenda Dzidzor Eleblu.



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ABSTRACT

The construction of the Akosombo and Kpong dams have led to a change in the watershed ecology which has in turn contributed to the change in land use and land cover of the Lower Volta Basin (LVB). Inevitable changing global climate has also played a role in the alteration of land cover and crop production which have affected livelihoods. In this study, a post-classification comparison change detection algorithm was used to determine changes in land use and land cover that have taken place from 2003-2015. A statistical analysis of rainfall and temperature variability for a period of five decades was studied as well as the perceptions and knowledge of farmers on climate change and land use/cover modification. The Diva GIS program was used to model and generate maps of crop suitability for current and projected future climatic conditions. The LUCC maps showed that between 2003 and 2015, the amount of mixed savannah vegetation, forest vegetation, grass lands and water decreased from 14.8% to 9.9, 35.1 to 32.3%, 3.6 to 3.2% and 6.1% to 4.3%, respectively of the total area, while farmlands (agriculture) and built up areas increased from 14.8% to 29.8% and 4.2% to 5.4%, respectively. The grasslands vegetation cover remains the largest and dominant land cover type and agricultural land use is second and increasing at a very fast pace. The small-scale shifting cultivation agriculture practiced in the LVB is the main factor responsible for the conversion of savannah and grassland vegetation into cropland. The changes in land cover is however a continuum which is influenced by changing climate. An increase trend in temperature and a decrease in rainfall have been identified with the Lower Volta Basin over the past five decades. These actual observed trends of rainfall and temperature affect crop yield in the area. However an increase in cropped area, application of fertilizer and the use of drought resistant seeds increases the general production of crops in the area.

Developed cropped suitability maps of the Lower Volta Basin, show that projected future climatic conditions will affect crop production and thus adaptation measures required.

TABLE OF CONTENTS

DECLARATION	i
DEDICATION	ii
ACKNOWLEDGEMENT	iii
ABSTRACT.....	iv
LIST OF TABLES	viii
LIST OF FIGURES.....	ix
LIST OF PLATES.....	x
LIST OF ABBREVIATIONS AND ACRONYMS.....	xi
CHAPTER ONE.....	1
INTRODUCTION.....	1
1.1 Introduction	1
1.2 Problem Statement.....	8
1.3 Justification.....	10
1.4 Research Questions.....	11
1.5 OBJECTIVES.....	12
1.6 Conceptual Framework.....	13
CHAPTER TWO	15
LITERATURE REVIEW.....	15
2.1 Volta Basin and Lower Volta Basin.....	15
2.2 Challenges associated to the Lower Volta Basin.....	16
2.3 Definition of Terms	19
2.4 Understanding Land-use Change (Theories of Land-Use/Cover Change).....	20
2.5 Land-use and cover change in Ghana and the Volta river Basin.....	23
2.6 Drivers of Land-Use/Cover Changes	24
2.7 Image classification	26
2.8 Change detection	27
2.9 Agriculture in the Ghana and the Volta River Basin.....	29
2.10 Climate change and rainfall variability	31
2.11 Exposure and sensitivity of crops to changing climate	32
2.12 Crop suitability mapping	33
CHAPTER THREE	36
MATERIALS AND METHODS	36

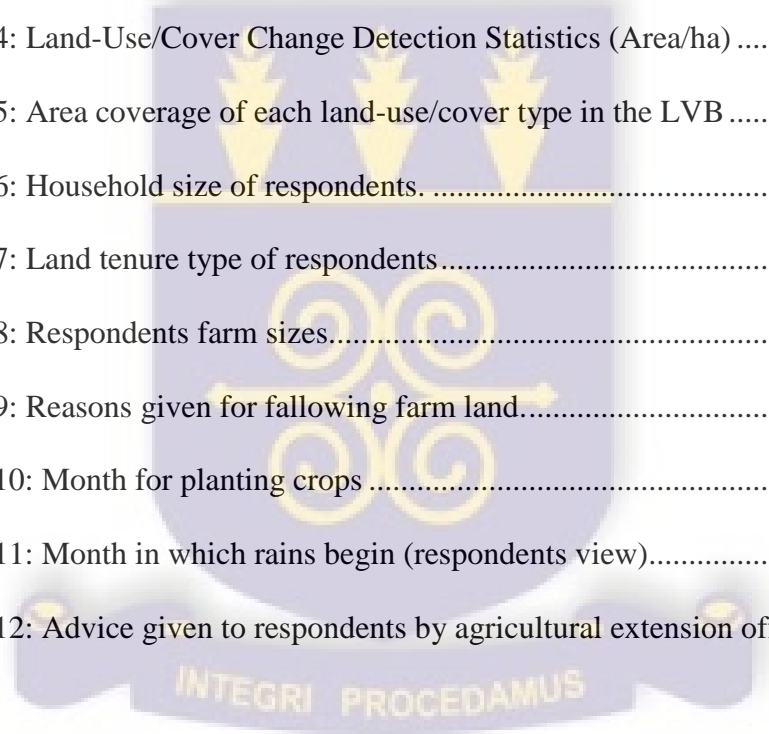
3.1	Study Area	36
3.1.1	Population.....	38
3.1.3	Climatic Conditions.....	39
3.1.4	Geology, Relief, and Soils.....	40
3.1.5	Land-use and Land Cover	41
3.1.6	Vegetation	42
3.2	Methods	43
3.2.1	Land-use/Cover Study.....	43
3.2.2	Climatic Study.....	51
3.2.3	Crop Suitability Study.....	53
3.2.4	Data	55
3.3	Socio Economic Study.....	56
3.3.1	Statistical Analysis	56
CHAPTER FOUR.....		57
RESULTS.....		57
4.1	Land-Use/Cover Classification and Change Analysis.....	57
4.2	Land-Use/Cover Change (Change Detection).....	61
4.3	Incidence and Trend of Climate Factors.....	76
4.3.1	Rainfall.....	76
4.3.2	Temperature	78
4.4	Crop yield in the Ada East & Lower Manya districts	80
4.5	Crop suitability (EcoCrop Model).....	84
4.6	Socio Economic Study.....	89
4.6.1	Background information from respondents	89
4.6.2	Population of the LVB	93
4.6.3	Perception, Knowledge and Observed LUCC.....	94
4.6.3.1	<i>Statistical Analysis</i>	96
4.6.4	Knowledge and Perceptions on Climate Change	97
CHAPTER FIVE.....		103
DISCUSSION.....		103
5.1	Land –Use/Cover Change of Lower Volta Basin	103
5.2	Incidence and Trend of Climate	111
5.3	Perception and Knowledge on Land Use	112

5.4	Perception and Knowledge on Climate Change	112
5.5	Crop Suitability.....	114
5.6	Socio Economic Study.....	115
5.7	Agriculture In the LVB.....	117
CHAPTER SIX		124
CONCLUSION AND RECOMMENDATIONS		124
6.1	Conclusion	124
6.2	Recommendations	127
REFERENCES.....		129
APPENDICIES		148



LIST OF TABLES

Table 3. 1 Distribution of the Basin among the six riparian countries.	36
Table 3. 2: Population of districts in the Lower Volta Basin.....	38
Table 3. 3: Typology of vegetation of the Lower Volta River Basin	42
Table 3. 4: Land-Use/Cover Classification Scheme and Description.....	44
Table 4. 1: Accuracy results for maximum likelihood classification 2003	59
Table 4. 2: Accuracy results for maximum likelihood classification 2015	60
Table 4. 3: Land-Use/Cover Change Detection Statistics (%)	66
Table 4. 4: Land-Use/Cover Change Detection Statistics (Area/ha)	67
Table 4. 5: Area coverage of each land-use/cover type in the LVB	73
Table 4. 6: Household size of respondents.	91
Table 4. 7: Land tenure type of respondents.....	91
Table 4. 8: Respondents farm sizes.....	91
Table 4. 9: Reasons given for fallowing farm land.....	92
Table 4. 10: Month for planting crops	98
Table 4. 11: Month in which rains begin (respondents view).....	99
Table 4. 12: Advice given to respondents by agricultural extension officers.....	101



LIST OF FIGURES

Figure 3. 1: Location Map of the Lower Volta Basin Showing Some Important Towns	37
Figure 3. 2 NDVI map of the two Landsat images	51
Figure 4. 1: Selected ROI's used for maximum likelihood supervised classification. 57	
Figure 4. 2: Selected ROI's used for maximum likelihood supervised classification .58	
Figure 4. 3 Land-Use/Cover map of the LVB (2003 & 2015). Source: (Author's Construct 2015).....	68
Figure 4. 4: Land-use/cover change over the period of study (2003-2015).....	69
Figure 4. 5: Land-Use/Cover change in Kpong area	70
Figure 4. 6: Land –Use/Cover Change detection (2003 and 2015)	71
Figure 4. 7: Commercial irrigation farming area at Asutuare.....	72
Figure 4. 8: Average annual rainfall totals, and trend in the Lower Volta Basin.	77
Figure 4. 9: Rainfall anomaly in the Lower Volta Basin	77
Figure 4. 10: Average temperature in the Lower Volta Basin	79
Figure 4. 11: Temperature anomaly in the Lower Volta Basin	79
Figure 4. 12: Cassava Production in Ada East.....	80
Figure 4. 13: Maize Production In Ada East.....	81
Figure 4. 14: Cassava Production in Lower Manya Krobo	82
Figure 4. 15: Maize Production in Lower Manya Krobo.....	83
Figure 4. 16: Crop suitability map for maize crop, current climatic conditions (1950-2010).	84
Figure 4. 17: Crop suitability map for maize crop, future climatic conditions (~2050).	85
Figure 4. 18: Crop suitability map for pepper crop, current climatic conditions (1950-2010).	86
Figure 4. 19: Crop suitability map for pepper crop, future climatic conditions (~2050).	86
Figure 4. 20: Crop suitability map for cassava crop, current climatic conditions (1950-2010).	87
Figure 4. 21: Crop suitability map for cassava crop, future climatic conditions (~2050).....	88
Figure 4. 22: Distribution of respondents in the study area	89
Figure 4. 23: Age groups of respondents	90
Figure 4. 24: Educational level of respondents in the study area.	90
Figure 4. 25: Number of years respondents have been farming.	92
Figure 4. 26: Type of tree used as fire wood by respondents	93
Figure 4. 27: Land-use change as observed by respondents.....	95
Figure 4. 28: Drivers of land-use change	96
Figure 4. 29: Knowledge level of respondents on climate change	97
Figure 4. 30: Respondents view on effects of rainfall and temperature on their yield and soil condition.....	100
Figure 4. 31: Factors that influence farmer crop yield.....	100
Figure 4. 32: Farmer adaptation methods to changing rainfall and temperature	101

LIST OF PLATES

Plate 3.1: Feature verification using “kml” overlay in google earth.....	47
Plate 3.2: Feature verification using spear tool in ENVI	47
Plate 3.3: False colour rendition image. Showing vegetation as bright red	47
Plate 4.1: Rice farms at Asutuare	72
Plate 4.2: Banana plantation (Golden exotics Co. Ltd)	72
Plate 4.3: Astruim imagery showing a section of irrigation scheme	73
Plate 4.4: Image showing some farms, reservoir and pump station	73
Plate 4.5: Astrium image showing a section of Dordoekorfe irrigation scheme	74
Plate 4.6: Reservoir at Dordoekorfe	74
Plate 4.7: Pump station at Dordoekorfe	74
Plate 4.8: Satelite image of Ada Foah area	75
Plate 4.9: Irrigation farms at Ada Foah	75
Plate 4.10: Irrigation farm at Ada Foah	75

LIST OF ABBREVIATIONS AND ACRONYMS

ABM LUCC – Agent-Based Model of Land-Use and Land Cover Changes

AWF – Africa Water Facility

CCSR – Canadian Centre for Remote Sensing

CSIR – Council for Scientific and Industrial Research

DN – Digital Number

ENVI – Environment for Visualizing Images

ETM – Enhanced Thematic Mapper

FAO – Food and Agricultural Organization

GCM – Global Climate Model

GDP – Gross Domestic Product

GIS – Geographic Information Systems

GLSS – Ghana Living Standards Survey

GMET – Ghana Meteorological Agency

GPS – Global Positioning System

HADCM3 – Hadley Centre Coupled Model version 3

IGBP – International Geosphere biosphere Program

IHDP – International Human Dimensions Programme

IPCC – Intergovernmental Panel on Climate Change

ISODATA – Iterative Self Organizing Data Analysis

ITCZ – Inter Tropical Convergence Zone

IWMI – International Water Management Institute

LUC – Land-use change

LULC – Land-use/land cover

LULCC – Land-use and land cover changes

LVB – Lower Volta Basin

MoFA – Ministry of Food and Agriculture

NAUTILUS - North East, Applications of Usable Technology in Land Planning for Urban Sprawl

NDVI – Normalized Difference Vegetation Index

NIR – Near Infra Red

OLI – Operational Land Imager

PCA – Principal Component Analysis

RMS – Root Mean Square

ROI – Region of Interest

SHS – Senior High School

SST – Sea Surface Temperature

TIRS – Thermal Infrared Sensor

UN – United Nations

UNFCCC – United Nations Framework Convention on Climate Change

UNEP GEF – United Nations Environmental Program, Global Environment Facility

UTM – Universal Transverse Mercator

VRA – Volta River Authority

VRB – Volta River Basin

WWAP – World Water Assessment Program

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Although dams have been built in the world since time immemorial, large dam construction was earlier not possible though needed, because of lack of adequate design knowledge, construction equipment, new materials like cement and concrete and technology of construction (Shultz, 2002). Moreover dams have solved many problems of communities served and have provided basis for economic development that has sustained itself. According to Gleick (2009), dams and reservoirs have long been used for various purposes which include, hydro power generation, irrigation, flood control and recreation.

Although the societal benefits gained from dams are immense, there exists a risk, particularly downstream, that needs to be addressed for public safety and infrastructure resilience (Woldemichael *et al.*, 2012). While some might argue that dam construction has reached the stage where the risk of structural failure is now almost non-existent, actual occurrences show that failures related to extreme hydrologic events (e.g., overtopping or unscheduled opening of spillways) still continue to occur (Saxena, 2005).

Research shows that there is also a potential impact of the reservoir on the local climate triggered by atmospheric feedback mechanisms that may physically modify the extreme hydro-climatology of the region (Woldemichael *et al.*, 2012). In some studies, (Degu *et al.*, 2011; Yusuf and Salami, 2009) it is indicated that the hydro meteorological variables like evaporation, precipitation and humidity are the first-order atmospheric

descriptors to show an increase in the post dam period while temperature and wind speed may also show a gradual decrease. Other changes occur in the post-dam era and are constituted as anthropogenic land-use and land cover changes (LULCC) around the dam. Factors responsible for the changes in the post dam era manifest themselves over a long period of time since anthropogenic (human-induced) alterations around dams, particularly of the land surface, take place continuously after the commissioning of the dam (Woldemichael *et al.*, 2012).

In Ghana the construction of the Akosombo dam in 1964 and Kpong dam 25km downstream in 1981 brought about hydro-electric power which has served as the backbone of Ghana's industrialization and social advancement. Both dams are of significant importance as they provide hydro-electric power to most parts of Ghana as well as neighbouring countries such as Togo. Lake transport, tourism, irrigation and flood control are other benefits that came with the construction of the dams, but the problems associated to the dam construction both upstream and downstream include water borne diseases such as bilharzia and guinea worm, disrupted farming and fishing activities and infestation of water weeds which hinders lake transport and fishing (Geker, 1999).

Apart from the construction of the Akosombo and Kpong dams affecting land-use and land cover changes (LULCC), these benefits and challenges associated to the post dam era have also contributed further to land-use/cover change (LUCC) in the Lower Volta Basin (LVB). The drivers of LUCC are both human induced and naturally caused, especially by change in climate. Land-use and land cover change is inevitable with changing climate and population as well as man's activities. According to Vitousek (1992), land-use/land cover change (LULCC) is a key driver of global change and has

significant implications for many international policy issues (Nunes and Auge, 1999). In recent years, LULCC has emerged as an important research question, because it has been identified as a key factor responsible for environmental modification worldwide (Xiao *et al.*, 2006). To understand how LULCC affects and interacts with global earth systems, information is needed on what changes occur, where and when they occur, the rates at which they occur and the social and physical forces that drive the changes (Lambin, 1997).

Amatekpor (1999), declared in his study that all categories of land-use occur in the Volta Basin, including rain fed and irrigated cropping, grazing, forestry, settlements, wildlife preservations, protected lands and many more. "But the current spatial distribution of these land-use types have not been mapped and published in a single document for easy reference and use by planners" (Amatekpor, 1999). However over the years some research studies including Koku (2002), Braimoh (2004), Codjoe (2004), Duadze (2004), Nyamekye (2010) and Akubia (2014), have been conducted on land cover and land-use types as well as its impact on the environment in the Volta Basin.

This study forms an integral part of an ongoing Lower Volta project, "Reoptimization of Operations of Akosombo & Kpong Dams on the Volta River in Ghana to Restore Downstream Livelihoods and Ecosystems". This project aims at restoring the natural flow of the Volta River, ecosystems and livelihoods which were changed after the construction of the Akosombo and Kpong dams and has also contributed to changes in land-use and land cover. This research study focuses on land-use/cover changes which influences and interacts with livelihoods and ecosystems.

Amatekpor (1999), points out that soil is the basis of all land-use planning. Moreover selecting a location for a specific land-use in an available space depend on the interpretation of the soil conditions as they relate to climatic and socio-economic conditions in the area.

Stretching from latitude 5° 30'N (Ghana) to 14° 30'N (Mali) and covering six West African countries in total, is the Volta Basin (Barry *et al.*, 2005). Two climatic zones are associated to the Volta River due to its length. The northern part having a single peak rainfall and the southern part having a bimodal rainfall pattern (Gordon, 1999).

Over the past several years, the Volta River Authority (VRA) had focused more on tackling the problems upstream of the dam. It is in recent times that attention has been shifted to the Lower Volta Basin (LVB) which has experienced major ecological and land-use changes.

The Lower Volta Basin which is defined as the area between the Kpong dam at Akuse and the estuary at Ada covering an area of about 68,600km² (Barry *et al.*, 2005), has undergone some changes because of the construction of the two dams (Akosombo and Kpong). There is a change in the normal flow regime of the river which has halted the periodic flooding of the Basin downstream. This has resulted in the change of the ecology and ecosystem services, thus having an impact on the livelihoods of people living here. Fishing and floodplain agriculture which were the main economic activities of the people living in communities downstream has due to the cessation of annual floods which deposited alluvial soils highly suitable for the cropping of pepper, cassava, okro and other crops collapsed. Also oyster, shrimps and tilapia which were in abundance before the construction of the dams are no longer available (Agbenyo,

2009). The characteristic in the flow regime created favourable conditions for plant growth. The plants hindered water transportation and created suitable habitat for other organisms which led to outbreak of diseases such as malaria and bilharzia.

With growing concerns on ecosystems and livelihoods, learning projects and research studies have brought about the need to explore possible re optimization of dams. Moreover the negative effects downstream of the two dams which include the loss of the dynamic interactions between the river and its floodplains, wetlands, deltas, estuaries and mangroves could possibly be improved with the possibility of a re-optimization project. Furthermore a probable re-optimization project looks at an enhancement of the benefits of dams which are hydropower generation, irrigation water supply, flood control and a restoration of ecosystems and livelihoods (Gregory, 2008). The Akosombo and Kpong dams when re optimized would create suitable conditions and minimize degree of the problems that were created downstream. Through a change detection analysis this study revealed how changed livelihood options as a result of the effects of the constructed dams is affecting land-use change. The impact of changing rainfall patterns on crop productivity was also evaluated.

Pertinent literature indicates that the agricultural sector is the largest contributor to the country's Gross Domestic Product (GDP). The Ghana Statistical Service (GSS) in 2010 reported that crops make up 66.2% of the agricultural subsector by GDP (GSS, 2010). According to Codjoe *et al.* (2005), rain-fed and some irrigated agriculture is the main economic activity of the majority of the population living in the Volta Basin region. This situation has however been reversed through rapid population growth and low economic standards of living with a lot of consequences for agricultural land resources in this region. An extensive engagement in crop farming coupled with variability in

rainfall and unreliable rainfall patterns in the Volta River Basin where poverty is predominant, has far reaching implications on the environment and food availability (Barry *et al.*, 2005).

Temperature and rainfall are known to be important climatic variables with considerable effect on crop yield. Titriku (1999) and MOFA (2011), reported that rainfall variability and unreliability is one important climatic variable that leads to moisture deficit that affects crop production.

According to the FAO (2000), crops have different optimal growing conditions with regard to temperature and rainfall. Codjoe (2004), reported that precipitation in the Volta Basin is characterized by large variability as expressed in periodic droughts. These suggest without doubt that rain fed agriculture and crop yield will be affected, because of the large variability in precipitation patterns, the development and optimum use of surface water resources is key to agricultural crop production in the area.

Moreover the interplay between land/atmosphere, energy, water, land-use and significant shifts in land-use patterns will cause spatio-temporal changes in weather patterns and rainfall characteristics. Concerns about land-use/cover change emerged in the research agenda on global environmental change several decades ago with the realization that land surface processes influence climate (Lambin *et al.*, 2003). It came to light in the 1980s that the land-use/cover change affected the terrestrial ecosystems which served as sources and at the same time sinks of carbon, and up until today decreasing vegetation (forests) remains a serious challenge (Woodwell *et al.*, 1983). Man and his activities are perceived to be the major drivers behind land-use/cover change and therefore have become essential in any land-use /cover change study

(Codjoe, 2004). Some of these drivers of land-use and cover change include increased population growth due to reduced infant mortality and migration (rural to urban or urban to rural), conversion of rural areas to urban areas, lack of value placed on ecological services, socio economic (jobs and poverty), and climate change/variability (Mallupatu and Reddy, 2013). Over the last few decades, numerous researches have improved measurements of land-cover change, the understanding of the causes of land-use change, and predictive models of land-use/cover change. These researches have been largely promoted through the auspices of the Land-Use and Land-Cover Change (LUCC) project of the International Geosphere- Biosphere Programme (IGBP) and International Human Dimensions Programme on Global Environmental Change (IHDP). Remote sensing is essential in documenting and analysing actual changes in land-use/land cover (LULC) on regional and global scales (Lambin *et al.*, 2003). Furthermore Geographic Information Systems (GIS) and Remote Sensing have proved to be useful tools for assessing the spatiotemporal dynamics of LULC (Hathout, 2002), and also assist decision makers to ensure sustainable development as well as to understand the dynamics of our changing environment (Iqbal and Khan, 2013).

It is therefore pertinent to note that, even in the absence of population dynamics, and in an attempt to improve upon livelihoods in the Lower Volta Basin which have been affected over the years due to the dam construction, land-use/cover change and variability in rainfall will continue to have a dynamic interaction which will in turn influence livelihoods. This study assessed the relationship that exists between livelihoods and land-use/cover changes as well as rainfall variability effect on rain fed agriculture which influences livelihoods. LUCC mapping using remote sensing and GIS techniques was carried out by conducting change detection analysis. Furthermore

the socio economic surveys, analysed climate data and crop yield data and crop suitability modelling was performed.

1.2 Problem Statement

By eliminating the annual floods in the Lower Volta River floodplain and estuary, the dams have devastated the livelihoods of the downstream communities and the physical ecosystem processes on which they depend (AWF, 2010). It is estimated that about 37% of freshwater-dependent species are on the verge of extinction as aquatic ecosystems worldwide and floodplain livelihoods in developing countries continue to be in a state of crisis. Furthermore recessional agriculture, estuarine fisheries and other land-uses have reduced and changed in the past several decades in Africa (Natural Heritage Institute, 2007).

According to Gyasi (1999) "*.....although the Akosombo and Kpong dams and their attendant artificial lakes have created significant economic opportunities, they also have created monumental national and international environmental, health and socio-economic problems that warrant greater attention*".

The ecological functions and livelihoods of people of the Lower Volta Basin have changed since the operation of the Volta and Kpong dams. According to Barry *et al.*, (2005), the establishment of the Akosombo dam has caused some of the soils in the Lower Volta Basin to become more acidic, and with a negative effect on yields from farms. Also human induced changes necessitated by the need to adjust to the change in ecosystem services especially in the provision of food resources have contributed to land cover change. As these land cover challenges have persisted over years there is no

doubt that changing rainfall patterns will also affect the currently existing agricultural land-use patterns and other land cover types downstream.

According to Duadze (2004), land-use and land cover information is not available for many areas of the Lower Volta Basin which is undergoing rapid and wide-ranging changes being contributed largely by slash and burn farming. Pre-dam land-use/cover in the Volta Basin have changed considerably and there is thus the need to map detailed land-use of the Lower Volta Basin periodically to enhance and support planning and decision making. Rain fed agriculture is one of the common types of land-use in the Lower Volta Basin and is based on the land rotation system known also as bush fallow system (Titriku, 1999). Titriku further explains that rainfall variability and unreliability which leads to moisture deficits are a major hindrance to agricultural production. Further, Barry *et al.* (2005), reports that rainfall is seen to becoming more variable and unreliable. “Extensive crop farming coupled with variable and unreliable rainfall patterns in a region where poverty levels are high has far-reaching implications for the environment and food security” (UNEP GEF, 2010).

Duadze (2004), further reported that many areas of the Volta Basin which are undergoing rapid and wide-range changes in vegetation and land-use due to the practice of shifting cultivation have no land-use and land cover information, suggesting the need to map land-use and perform change analysis more frequently due to the rapid changes that take place in the Lower Volta Basin.

1.3 Justification

The damming of the Volta River has caused a number of negative effects in the Lower Volta Basin, leading to massive changes in land-use/cover downstream. A re-optimization project could enhance the benefits of the dam which include increased hydro power output, irrigation water supply and flood control and a restoration of ecosystems and livelihoods. Mapping the land-use/cover changes that have occurred over the years just before the start of the re-optimization project is necessary because this is expected to inform policy makers and various stakeholders of how the implementation of the project has influenced land-use/ cover change and to what extent it can restore the terrestrial ecosystem. This study could help improve upon land-use planning and management which will also influence adaptation strategies to climate change (rainfall variability mainly).

The inundation of the floodplain that could cause catastrophic damage or impinge upon settlements or specific land-use types to an unacceptable degree can and should be prevented. Moreover the pending change in the release of water from the Akosombo dam which will reintroduce annual controlled flow events into the floodplain is anticipated, as the re-optimization project seeks to identify scenarios that will increase water service benefit for all interests, including irrigation, fishery, flood control and hydro-electric power generation in the Lower Volta. Regional land-use patterns show the interaction between man and environment and the influence to mankind's basic economic activities. Hence land-use and land cover mapping is of great significance in scientific research, planning and management.

Furthermore changing climate might have possibly affected crop production in the Lower Volta Basin and thus affected livelihood. It is therefore necessary to investigate

to what extent rainfall pattern has affected crop production in the study area and what innovative measures could be put in place to improve crop production since the inundation of the flood plains have ceased as well. According to Gyasi *et al.* (2006), data for land-use planning seem inadequate and the increasing population as well as concomitant growing demands for land requires efficient use and management of land. This study therefore contributes to land-use and land cover data of the Lower Volta Basin needed for land-use/cover monitoring and effective land-use planning as well as management.

1.4 Research Questions

- What is the current land-use /cover pattern in the Lower Volta Basin?
- What are the types, patterns and aerial extent of land-use change?
- Which of the various land-use types in the Lower Volta Basin is predominant and why?
- What have been the changes in climate (rainfall and temperature) of the Lower Volta Basin over the past three decades?
- What is the trend of crop yield in the Lower Volta Basin?
- Which areas of the Lower Volta Basin are suitable for crop production based on rainfall and temperature parameters?

1.5 OBJECTIVES

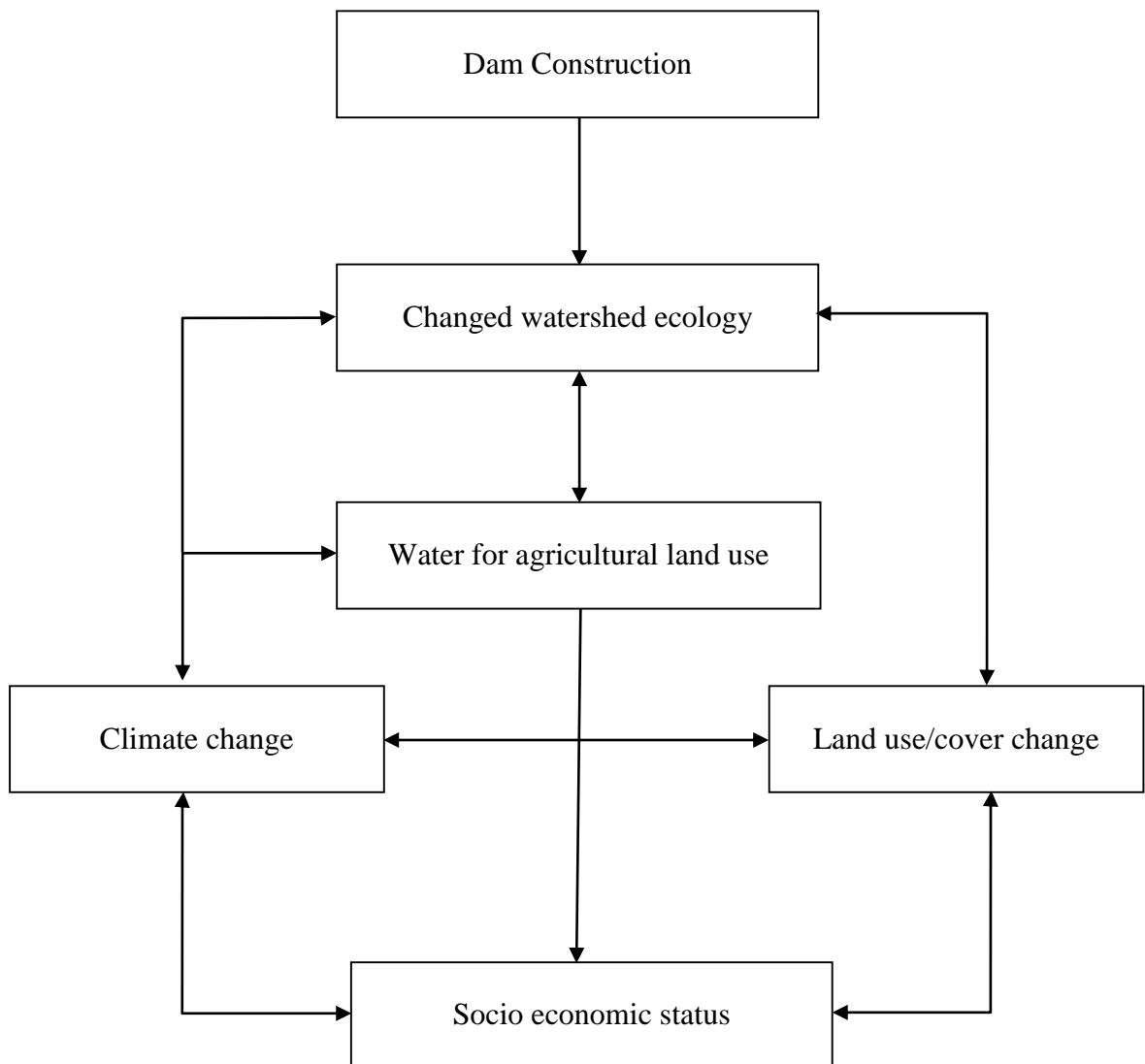
1.5.1 Main Objective

To study the relationship between changing land-use/cover using remote sensing and GIS techniques, changing rainfall patterns and agricultural crop production in the Lower Volta Basin.

1.5.2 Specific Objectives

1. To create a land-use/cover map of the Lower Volta Basin for the years 2003 and 2015.
2. To determine the types, pattern and magnitude of land-use/cover change.
3. Analyse rainfall and temperature variability and changing crop yield in the Lower Volta Basin.
4. Generate a crop suitability map for specific crops in the study area using different rainfall and temperature scenarios.

1.6 Conceptual Framework



Dam creation, which is meant for hydro-electric power production mainly but comes with some other benefits and challenges upstream and downstream of the River Basin (Agbenyo, 2009).

The dam creation has therefore affected the watershed ecology by altering the natural flow of the river. The natural annual flooding which occurs in the floodplain of the River Basin is affected and thus the creeks and wetlands which receive water annually become dry. Floodplain agriculture was also halted as the annual floods that replenished the floodplain with nutrients has ceased (Amatekpor, 1999).

Water for agricultural land use has been affected because creeks and natural reservoirs have dried up and climate change has and continues to influence rainfall.

The lack of access to adequate water for agriculture as well as changing climate has contributed to LUCC. Climate change affects water usage in five water demanding sectors namely; agriculture, industry, energy, municipal and reservoir (Yates and Strzepek, 1998).

With the lack of adequate water for agricultural land use, the socio economic status of the people in the LVB especially farmers who constitute majority of the economically active population there are affected.

CHAPTER TWO

LITERATURE REVIEW

2.1 Volta Basin

The Volta river Basin, located in West Africa covers an estimated area of 400,000 km² and stretches over six West African countries namely, Burkina Faso, Ghana, Togo, Benin, Cote d'Ivoire and Mali (Barry *et al*, 2005). In Ghana, the Volta River Basin covers nearly two-thirds (70%) of the land area and is divided into six sub-Basins namely, Black Volta, White Volta, Daka, Oti, Upper and Lower Volta. However studies conducted under the VBRP in 1997 suggested a revision of the geographic scope of the VRB to include the Tordzie/Aka Basin located south east of the Lower Volta in Ghana and Togo (UNEP-GEF, 2010). The basin therefore covers 8,500km² in size with a volume of 150 billion m³ and an average depth of about 18.8m with the deepest part going as far as 90m and a shoreline of 5,500km (Barry *et al.*, 2005).

The Lower Volta Basin is the 80km stretch of river between the Kpong head pond and the estuary at Ada Foah (Gordon, 1999). The Lower Volta has a range of vegetation from closed forest to humid savannah, mangrove and coastal strand vegetation and thicket. Short grasses occur more within the Lower Volta that enhances the rearing of herbivores such as cattle, goat sheep among others. Short Grass Vegetation, refers to the type of vegetation in which short grasses abound or are relatively more with occasional trees. This type of vegetation occurs at the Lower Volta where the soil is generally suitable for rangeland agriculture and water resources abound. The soil types include the "Chichiwere" (Oxyaquic Quartzipsamment), "Amo" (Vertic Dystropept), "Tefle" (Alic Dystraquert) and "Avyime" (Rhodic Paleustalf), Amatekpor (1999). The land is normally low lying and in a few cases slightly hilly. These unique features are

conducive for grazing and watering of livestock, crop production, industrial development and community development. (UNEP-GEF, 2010). The Lower Volta Basin falls within the coastal savannah and transitional zone.

2.2 Challenges associated to the Lower Volta Basin

The construction of the Akosombo dam brought about changes which can be categorized or presented as opportunities and challenges to the environment and people of the Lower Volta Basin. The impact of the dam on the environment has been found to be varied. These include enhanced fishing upstream and diminished fishing downstream, opportunities for irrigated farming downstream, proliferation of aquatic weeds upstream and downstream, increase in some water borne diseases such as bilharzia and malaria and reduction and elimination of other diseases such as Onchocerciasis in some areas. Also included are seismicity, sediment load changes, morphological changes and microclimatic changes (Amatekpor *et al.*, 1999).

Flooding

According to Yeboah (1999), the Volta River had its annual cycle before the dams were constructed. Naturally the dry season was characterized by low flow rates (1,000 cusecs) whereas the rainy season was characterized by high flow rates (125,000 cusecs), and this caused destruction of crops as well as property. He further reported that the annual floods did not only enrich the lands for cultivation but also the creeks, ponds and lagoons in these areas were filled with water for breeding fish which was exploited after floods had receded. Even though the construction of the dams completely cut out the annual flooding that occurred in the LVB, the opening of the floodgates of the Akosombo and Kpong dams occasionally causes flooding in certain areas of the Lower Volta Basin.

Flooding as observed in the Volta River Basin is blamed on extremely high rainfall rates and the creation of uncoordinated dams without appropriate management practices. Land-use conversions also exacerbate the problem as soils with significantly reduced vegetation cover that are exposed to atmospheric elements have little infiltration capacities to reduce storm water run-off (GEF-UNEP, 2002).

Sand bars formation

Before the dam construction, seasonal floods flushed out sandbars, which might have started during the dry season, thus the estuary was largely kept free of sandbars. However, after the construction of the dam, due to absence of annual floods, sandbars gradually formed at the estuary and in time virtually blocked it. The effect of this was that saline water, which during high tide flowed upstream into the river channel, completely ceased. Moreover, the absence of salt water in the river channel, made the areas even closer to the estuary prone to the presence of the schistosome snail and *Bilharzia* became prevalent (Yeboah, 1999). The VRA restored salinity to the river channel by placing a dredger permanently at the estuary to cut a channel through the sandbar. As a result, *Bilharzia* has been wiped out of these areas (Boubacar, 2005).

Diseases

All of the water-related diseases occurring in Ghana can be found in the Volta Basin. These include *Bilharzia*, which is very widespread in all four sub-Basins, except the Daka, onchocerciasis (except in the Lower Volta), Guinea worm, malaria, lymphatic filariasis, which is particularly common in the White Volta Basin, and diarrhoea (GEF-UNEP, 2002).

Poverty

In Lemoalle and Condappa (2010), it was reported that people are poor because of low agricultural productivity, limited access to markets, unstable prices, and insecure land tenure. Asante (2007) said, the three main causes of water related poverty in Ghana are low productivity of fishing, and agriculture, water insecurity (rainfall variability, poor access, health impacts, loss of labour) and water-related diseases (malaria, guinea worm and others). With regards to agriculture (Lachaud, 1998) the incidence of poverty was lower among cash crop farmers than among subsistence farmers.

Land degradation and Deforestation

The environmental problems arising from livestock production are becoming sources of great concern. The maintenance of large herds of livestock has tended to exceed the carrying capacity of the ecosystem (Barry *et al.*, 2005). Barry explains further, that as a result of trampling, soils are severely exposed to erosion. The watersheds are also exposed to rapid evaporation. The prolonged exposure of the soil renders it susceptible to erosion and reduces its regenerative capacity. In the northern parts of the Basin, large tracts of arable land have become infertile and crop yields have declined tremendously. Livestock is also taking a significant toll on soil productivity in the LVB region. Although there is little data on the specific effects of livestock, it is clear that livestock negatively influences the area (Barry *et al.*, 2005).

One widely held view is that dryland degradation or desertification is due to population growth and poverty which contribute to increased pressure on natural resources through overgrazing, over-cultivation, and over-harvesting of woodlands. These activities, in turn, lead to deforestation, soil erosion and poor land management which result in further environmental degradation and desertification (Mortimore, 1998).

An estimated 2 million people in Ghana depend on forests for subsistence uses and traditional and customary lifestyles. Forest-adjacent communities undertake a wide range of forest-related activities, including fuelwood and charcoal production, wood-carving, canoe carving, rattan production and chew stick-gathering (Tufouor, 2012).

2.3 Definition of Terms

Land cover is defined by the attributes of the earth's land surface and immediate subsurface, including biota, soil topography, surface and ground water and human structures as in the case for agricultural expansion or deforestation (Lambin, *et al.*, 2003).

Turner *et al.* (1995), defined land cover as “the biophysical state of Earth's surface and immediate subsurface.” He also defined land-use/cover change as “the sum of short and long term effects of global change and human transformation of the landscape”. Moreover according to the FAO (1995), land use can be described as the purpose for which land is used by a population.

Land-cover conversions (i.e., the complete replacement of one cover type by another) are measured by a shift from one land-cover category to another, as is the case in agricultural expansion, deforestation, or change in urban extent (Gonzales, 2009).

Land-cover modifications are more subtle changes that affect the character of the land cover without changing its overall classification (Lambin *et al.*, 2003).

GIS technology is a computer-based data collection, storage, and analysis tool that combines previously unrelated information into easily understood maps. GIS software

can perform complicated analytical functions and then present the results visually as maps, tables or graphs. This allows decision-makers to virtually see the issues before them and then select the best course of action (Parthasarathy *et al.*, 2008).

According to the Canadian Centre for Remote Sensing (CCSR, 1997), remote sensing is the science of acquiring information about the earth's surface without coming into contact with it. This is however done by, sensing and recording reflected or emitted energy and processing, analysing and applying the information obtained (Akubia, 2014).

2.4 Understanding Land-use Change (Theories of Land-Use/Cover Change)

Land-use change is a complex process that encounters sophisticated parameters Tayyebi *et al.* (2008) and Lambin *et al.* (2003), claims LULCC can be classified as either a progressive or episodic change. It is revealed through time series remote sensing data that land-cover changes may show periods of rapid abrupt change followed by a quick recovery of ecosystems rather than the known gradual change. Furthermore such changes caused by the interaction of climatic and land-use factors have an important impact on ecosystem processes (Lambin, *et al.*, 2003).

Lambin *et al.*, (1997) stated that, to understand how LULCC affects and interacts with global earth systems, information is needed on what changes occur, where and when they occur, the rates at which they occur and the social and physical forces that drive the changes. Research on land-use/cover change requires a combination of perspectives of understanding. These perspectives include the agent based, systems, and the narrative approaches (Lambin *et al.*, 1999).

The agent based perspective is centred on the general nature and rules of land-use decision making by individuals (Lambin *et al.*, 2003). These individuals who are agents of land-use/cover change have intentional and unintentional motives which are related to economic, traditional, emotional or biophysical factors (Leemans *et al.*, 2003). Parker *et al.* (2003), explains how economic models of land-use/cover change assume that land managers attempt to fulfil their needs and meet their expectations.

The systems perspective explains land-use/cover change through organizations and institutions of society (Ostrom, 1990). This perspective represents the dynamics of economy and environmental linkages which are operating at regional to global scales, and although some institutions are direct drivers of change, others, such as markets, are intricately linked to individual decisions (Lambin *et al.*, 2003)

Finally the narrative perspective provides an in-depth of understanding land-use/cover change through historical detail and interpretation (Crumley, 1994). It is important as well and might even be the most important as the historical analysis of landscape grasps all the complexity of events that affect LUCC (Klepeis and Turner, 2001). The narrative perspective is therefore able to avoid the simplifications and inaccurate interpretations that could result from a study focused on the present and immediate past (Batterbury, 1999). An integration of these perspectives as stated by Lambin (2003), will not only help to understand the dynamics of LUCC but will yield unequivocal results in LUCC studies.

According to Lambin *et al.* (2003), a major trend of global LUCC is the expansion of agricultural land. Currently, agricultural land covers about a third of the global land surface, and has expanded into forests to meet the growing demand for food. It is

important to know that climate-driven land-cover modifications interact with land-use changes. Land-use change is driven by synergetic factor combinations 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 organization and attitudes. Most importantly the changes in ecosystem goods and services that result from land-use change feedback on the drivers of land-use change (Lambin *et al.*, 2003). Furthermore understanding of the causes of land-use change has moved from simplistic representations of two or three driving forces to a much more profound understanding that involves situation-specific interactions among a large number of factors at different spatial and temporal scales.

Other forms of rapid land-cover change that are thought to be widespread are still poorly documented at the global scale. Local- to national-scale studies, however, demonstrate their importance and ecological significance (Lambin *et al.*, 2003).

In a study by Amanor and Pabi (2006), It was concluded that a collaboration between anthropological research within a regional economies perspective and remote sensing can be useful in providing framework for analysing the dynamics of localized patterns of change.

Remote sensing data highlight high temporal frequency land-cover modifications of great importance for earth system processes. In particular, data from wide-field of-view satellite sensors reveal patterns of seasonal and inter-annual variations in land surface attributes that are driven not by human induced change but rather by climatic variability (Eastman, 1993).

As reported in d'Aquino *et al.* (2002), researchers and experts in LUCC are developing a model "Agent-Based Model of Land-use and land cover changes (ABM LUCC) which will strongly compliment the already existing techniques of LUCC modelling. In this report, Parker and Berger discuss how ABM/LUCC can be used both as a means of implementing existing knowledge, thereby developing tools for scenario analysis, and for knowledge discovery, as integrated models are used to developed the process theory needed by the LUCC community. Finally, the editors discuss the potential for ABM/LUCC to integrate not only models, but researchers, across disciplines Berger *et al.* (2002).

2.5 Land-use and cover change in Ghana and the Volta river Basin

According to Agyarko (2001), Ghana's landscape has been categorized into land-use types including, small and large scale farming, forestry, grazing fields, urban areas, tree plantations of indigenous and exotic species and game/park reserves. To a very large extent the vegetative cover of an area is determined by climatic and edaphic factors. It is documented and also observable that the land cover of the Volta River Basin consists predominantly of sub-humid savannah; mainly tall grasses interspersed with fire resistant tress in the Black and White Volta Sub-Basins with some forest reserves found in the white Volta area. (GEF-UNEP, 2002).

With the latest developments in remote sensing and GIS technology, Ghana should now embark on mapping a detailed land-use map of the Volta Basin (Amatekpor, 1999). Amatekpor claims the use of Landsat TM or preferably SPOT-XS image is ideal for the production of the detailed land-use/cover map. Since the launch of the first Earth Resource Technology Satellite on July 23, 1972, the analysis of data has advanced from

simple visual observation to sophisticated interpretations based on first principles of spectroscopy and electromagnetic radiation (Ustin, 2004). Moreover, in present times the development of high resolution sensors such as Quick bird and Spot 5, provides high spatial resolution imagery which gives more accurate information about the earth's surface (Gumma *et al.*, 2010). Land-use/cover information is important because, it constitutes key environmental information required for many scientific, resource management and policy purposes, as well as for a range of human activities. This information is however currently not available for the Volta Basin even though it is undergoing rapid and wide-ranging changes in land-use and vegetation due to agricultural practices (Duadze, 2004).

It is very important to have continual, historical and precise information on LULC changes of the earth's surface for any kind of sustainable development program in which LULC serves as one of the major input criteria (Mei and Qing, 1999; El-Kawy *et al.*, 2010).

2.6 Drivers of Land-Use/Cover Changes

Land-use change is always caused by a multitude of interacting factors originating from different levels of organization of the coupled human-environment system (Lambin *et al.*, 2003). Land cover may change under the influence of biophysical conditions only but, most frequently; it results from human-induced land-use change (Briassoulis, 2000) At the local level, causes of land-use/cover changes involve a physical action on land cover such as agriculture, forestry and infrastructure construction (Lambin and Geist, 2006). Driving forces of land-use and land-cover change are not only highly interrelated, but also can vary both in time and space, whereby the strength of their

interrelations is also temporally and spatially variable (Schindler 2009). However, most importantly land-use dynamics, which involve decisions of land-users, are major determinants of land cover changes. Thus, the critical element in land-use is the human agent, who takes specific actions to his own calculus or decision rules that drive land-cover change (Lambin *et al.*, 1999).

There are proximate/direct causes of land-use change which constitute human activities or immediate actions that originate from intended land-use, which directly affect land cover (Ojima *et al.*, 1994). There are also the underlying (or indirect or root) causes which are fundamental forces that underpin the more proximate causes of land-cover change (Leemans *et al.*, 2003). The underlying causes are formed by a complex of social, political, economic, demographic, technological, cultural, and biophysical variables that constitute initial conditions in the human environment (Geist and Lambin, 2002).

Interestingly, Lambin *et al.* (2003), established that the five fundamental high level causes of land-use change are;

- i. resource scarcity leading to an increase in the pressure of production on resources,
- ii. changing opportunities created by markets,
- iii. outside policy intervention,
- iv. loss of adaptive capacity and increased vulnerability, and
- v. changes in social organization, in resource access and in attitudes.

However all known drivers of LUCC which are (multiple causes, economic and technological factors, demographic, institutional, cultural and globalization), are all

strongly linked within and between levels of organization of human-environment systems. This therefore places humans as the main drivers of land-use change. It is the agent (an individual, household, or institution) that takes specific actions according to its own decision rules which drive land-cover change (Berger *et al.*, 2002). Lambin *et al.* (2003), further conclude that, the various sectoral drivers of land-use change interact directly, are linked via feedback, and thus often have synergetic effects.

2.7 Image classification

An approach often used to derive main land-cover types is the analysis of satellite images via remote sensing using automatic classification methods. Such automatic classification methods extract land-cover types based on spectral information of the satellite image. But since some land-cover types display similar spectral properties, the accuracy of such automatic classification algorithms is often limited. These automated algorithms are therefore usually used in association with other information sources so as to interpret the automatically derived land-cover classes (Schindler, 2009). These other sources include, aerial photographs, a high-resolution satellite image, or ground-truth data.

Presently there are different image classification procedures used for different purposes by various researchers (Butera, 1983; Lo and Watson, 1998; Ozesmi and Bauer, 2002; Liu *et al.*, 2002; Dean and Smith, 2003; and Pal and Mather, 2003). The latest high resolution sensors and others which are yet to come, together with new existing data process environments have led to important changes in classification methodologies (Manakos *et al.*, 2000). According to Gumma *et al.* (2010), these techniques are distinguished in two main ways as unsupervised and supervised classifications.

Moreover, the supervised classification has different classification methods which are named as parallelepiped, maximum likelihood, minimum distance and fisher classifier methods. These are termed hard classifier.

The unsupervised classification also has two techniques namely K-Means and ISODATA classifier (Guide EUS, 2008). However both classification approaches have pros and cons, however supervised classification is likely to provide more accurate classification result than unsupervised classification (Peter and Michael 2003; Butt *et al.*, 2012). A Kappa coefficient is usually calculated after a classification process has been run on an image. Duadze (2004), recommends that an unmodified kappa index is utilized to report classification accuracy, primarily because it is documented and well known. Furthermore Duadze explains that errors of omission calculate the probability that a reference sample has been classified correctly whilst commission calculate the probability that a sample from the classified data actually represents that category on the ground. With the use of NDVI also aiding in image classification, (Tucker, 1979; Dawelbait and Francesco, 2011), acknowledged that NDVI has been mostly commonly used to map spatial and temporal variation in vegetation. However, it is limited in providing accurate estimates of shrub land cover in arid areas and limited utility in an arid ecosystem (Huette, 1992 and Asner, 2004).

2.8 Change detection

There are many techniques developed to detect changes in the environment (Wong *et al.*, 1997). But there is still no standard method for the quantitative estimation of land cover. Recent efforts have also been made and addressed improved methods of LULC change detection (Hurd *et al.*, 2001).

All the existing methods are based on different approaches which are suitable for specific locations or areas and satellite sensors (Purevdor *et al.*, 1998). Several techniques including, multi date classification, post classification change detection (Hurd *et al.*, 1992), cross correlational analysis (Hurd *et al.* 2001), multi date principal component analysis and RGB-NDVI colour composite change detection (Hoffhine, 2000) have been evaluated by North East, Applications of Usable Technology in Land Planning for Urban Sprawl (NAUTILUS) investigators (Civco *et al.*, 2002). According to Sunnar (1998), the most appropriate change detection procedure for a given situation has significant impact on the results. Moreover this depends on the type of application, environment, targets of interest and the amount of detail required. Several changed detection methods have been developed (El-Raey *et al.* 1999), however the most commonly used change detection techniques include, image overlay, classification comparison, image differencing, principal component analysis (PCA), image rationing, differencing of NDVI images, and change vector analysis (Sunnar, 1998).

With land cover change analysis, the most used approach is image differencing, which involves the subtraction of image brightness on a pixel-by-pixel basis (Duadze, 2004). The image differencing procedure involves the co-registration of two images of the same area taken at different times to assess the degree of change that has taken place between the dates of imaging and preparing a temporal difference image by subtracting the digital numbers (DN) for one date from those of the other date(s) (Lillesand and Kiefer, 1994). In this study, the classification comparison technique was used. This method makes use of two or more independent classifications of each satellite scene. In this method all classified satellite are classified into a single dataset and it identifies classes of pixels that have changed between dates (Richards, 1995).

In recent years, the developed satellite remote sensing techniques prove to be very useful for preparing accurate land-use/cover maps and monitoring changes at regular intervals of time and space (Zubair, 2006).

2.9 Agriculture in the Ghana and the Volta River Basin

Agriculture, including forestry, is the backbone of the Ghanaian economy. It provides 43% of the Gross Domestic Product, 50% of export earnings and 70% of total employment (Agyarko, 2010). Agriculture in Ghana is also predominantly on a smallholder basis, with about 90% of farm holdings being less than 2 hectares although there are some large farms and plantations, particularly for rubber, oil palm and coconut, and to a lesser extent, rice, maize, and pineapples. With the main system of farming being traditional, the hoe and cutlass are usually the main farming tools used and production varies with the amount and distribution of rainfall (MOFA-SRID, 2011). Published statistics of the MoFA reveal a vast amount of land that is potentially available for agricultural use. MoFA reports that of the total land area of 23.9 million hectares, 13.6 million hectares (57.1%) can be classified as agricultural land area but only 5.3 million (22.2% of all agricultural land area) were under cultivation at the last count (1995). With an economically active population between the ages 15 to 49, there are “424,458”, “531,635” and 145,034 people engaged in farming in the Volta, Eastern and Greater Accra regions respectively. The estimated annual population growth rate of Volta, Eastern and Greater Accra regions are 2.4, 2.0 and 2.8 respectively (MOFA-SRID, 2011). The soils of the Lower Volta flood plain which covers an area of 294.0sq km (29,280ha) is good for agriculture (Gordon and Amatekpor, 1999).

According to Fisher *et al.* (2002), suitable land and potential production for staple cereal crops will decrease markedly in sub-Saharan Africa. The paradox is that areas that are currently most food insecure will be most affected by climate change (Lane and Jarvis, 2007). However it should be asked if the area which falls within the Volta Basin of Ghana should be considered prone to low productivity due to changing climate. There is no doubt that with the available water provided by the lake rainfall should not hinder production even if temperature will increase and humidity will decrease. Fobil and Attaquayefio (2003), reported that “following construction of the Akosombo dam, there has been a steady decline in agricultural productivity along the lake and its tributaries, where inadequate soils have been exhausted.” The IWMI (2013), reported climate change will have an intense impact on water resources that could have serious effects for agriculture. A key message from the (WWDR3; WWAP, 2009a) states that, Adapting to climate change is a critical challenge, particularly for developing countries, whose capacity to adapt is low. For some, the incremental costs of climate change adaptation will soon approach the current value of aid inflows. Cassava and cocoa are the two most important crops in the coastal zone though their value are not as much as compared to those of the forest and savannah zones. Maize and yam account for more than half of the total crop harvest value in the savannah zone however maize is the least crop harvested in the coastal zone as compared to the savannah and forest ecological zones (GLSS, 2010). Cassava is reported a very significant crop in the coastal zone and has a higher capacity to withstand drought conditions.

The Ghana Statistical Service of Ghana reports livestock rearing is concentrated in the rural savannah areas, where 86 percent of drought animals, 63 percent of cattle and 80 percent of guinea fowls are being reared (GLSS, 2010).

2.10 Climate change and rainfall variability

According to the IPCC (2007), climate change is defined as a change in state of climate that can be identified by changes in the mean (using statistical tests) of its properties and persists for an extended period, decades or longer. This therefore refers to changes in climatic elements over time, be it due to natural variability or human induced. The IPCC further reports, average global temperature has increased by 0.74 Celsius in the last 100 years; rainfall has trended downward during 1960–2000; and sea levels have risen between 1 to 3 millimetres per year.

Rainfall variability is an inherent part of African climate and is deeply entrenched in West African society (FAO 2008). Moreover the impact of rising temperatures on rainfall distribution patterns in Africa remains far less certain (IPCC, 2007).

Over the past 50 years, declining rainfalls have been reported throughout West Africa as part of a general southward shift in seasonal migration of the Inter-tropical Convergence Zone (ITCZ) (Weldeab *et al.*, 2007)

Sea surface temperatures (SST) really influence climate change in Ghana. Studies conducted by scholars including Gu and Adler, (2003) show that, a high south Atlantic SST is associated with high rainfall in the Guinea coast (south of 8°N) and vice versa. In a national study conducted by Opoku-Ankomah and Cordery (1994) suggests that variability in the

Northern zone is distinct from the remainder of the country, due to the movement of the ITCZ and influence of Atlantic SSTs, as reported by Boateng (1967), as cited in Owusu (2009).

Climate models show that the probability of extremes of rainfall is likely to increase, resulting in more floods and droughts in regions already affected by these kind of events – often these are regions with low income levels per capita, widespread poverty, high population growth and rapid urbanization (WWAP, 2011).

Water-related climate change impacts are already being experienced in some river basins in the form of more severe and more frequent droughts and floods. Higher average temperatures and changes in precipitation and other climatic variables are projected to affect the availability of water resources through changes in rainfall distributions (UN Water, 2009)

2.11 Exposure and sensitivity of crops to changing climate

Many studies have confirmed that temperatures will rise and rainfall will increase in some places, while in others, rainfall will decrease (Rosenzweig *et al.*, 1993). However, there is general agreement among scientists that food crops are sensitive to the changing climate (Yumbya *et al.*, 2014).

According to Rosenzweig *et al.* (2001), altered and unpredictable weather patterns can increase crop vulnerability to pests, diseases and the effects of extreme climate events such as high temperatures, droughts and torrential rains. Sequential extremes, such as droughts followed by intense flooding rains, are catastrophic in themselves and are compounded by ecological effects such as the expansion of the ranges of pathogens, diseases, and pests that affect human populations and agricultural production. However the impact of climate change on production of various crops varies markedly depending mainly on the region, growing season, the crops and their temperature thresholds. Reilly *et al.* (1996), found that as temperatures move away from the favourable growing

temperature of crops, the growth of the crop is adversely affected. Similarly, if variability in temperatures is high, crop yields are lower. The authors therefore concluded that places that are too hot or are too close to the optimum temperature are likely to suffer the most in terms of crop production.

Porter *et al.* (2007) predict that if global temperatures do not increase more than 4°C over the next century, arable agricultural production can probably adapt to changes in mean global temperature using breeding, selection and management. Anecdotal evidence from farmers suggests that the onset of rainy season has been shifting forward in time over the past two generations. Recently, detailed atmospheric modelling over the region shows that in the near future too, the onset of rainy season will shift to later periods in the year, roughly from April towards May. The end of rainy season as well as the total amount of rainfall will remain more or less fixed (Van de Giesen *et al.*, 2010).

Climate change and its impact on agriculture may contribute to preventing strategic economic sectors and may further hinder the achievement of the Millennium Development Goal (MDG) 1 on poverty alleviation (Osman-Elasha, 2010)

2.12 Crop suitability mapping

The value of Geographic Information Systems (GIS) for assessing climate change impacts on crop productivity cannot be over-emphasised (Yumbya *et al.*, 2014).

Agriculture is a climate-dependent activity and hence is highly sensitive to climatic changes and climate variability (Ramirez-Villegas *et al.*, 2013). Several authors report

that agricultural production could suffer progressive yield losses in the next hundred years (Challinor *et al.*, 2009; Challinor *et al.*, 2010; IPCC, 2007; Lobell *et al.*, 2008; Thornton *et al.*, 2011). Acknowledging the gap of non-availability of production of minor crops data and models, Ramirez-Villegas *et al.* (2013), integrated the current expert knowledge reported in the FAO-EcoCrop database, with the basic mechanistic model (also named EcoCrop), originally developed by Hijmans *et al.* (2001).

The Diva GIS program houses this model and is used to generate crop suitability maps based on the evaluation of the likely impacts of climate change on agricultural production. Ramirez-Villegas *et al.*, (2013) furthermore highlighted the considerable opportunity of using EcoCrop to assess global food security issues, broad climatic constraints and regional crop-suitability shifts in the context of climate change. The model was named EcoCrop since it was based on the FAO-EcoCrop database (FAO, 2000). The modeling of the crop's suitability is a process that involves the evaluation of the model and the usage of the selected parameter set(s) to run the model using a certain (set of) climate scenario(s) (Ramirez-Villegas *et al.*, 2013). Furthermore, in the model, there are two ecological ranges for a given crop. Each defined by a pair of parameters for each variable (i.e. temperature and rainfall). There is the absolute range (minimum and maximum absolute temperature and rainfall), optimum range (minimum and maximum optimum temperatures and rainfall respectively) and an additional temperature parameter (T_{KILL}) used to illustrate the effect of a month's minimum temperature (Ramirez-Villegas *et al.*, 2013).

In many studies (Yumbya *et al.*, 2014; Lane and Jarvis, 2007; Geerts *et al.*, 2006), scientist have used the EcoCrop model to predict suitable areas of crop production under current and future climatic conditions. Other methods using other GIS platforms

such as ArcView and ArcGIS are also used to model suitable geographical areas for crop production (Geerts *et al.*, 2006).

In Parthasarathy *et al.*, (2008) the thirty years area and production curves of ginger growing states were compared with the Eco-crop suitability model which indicated that suitability has direct impact on production.

CHAPTER THREE

MATERIALS AND METHODS

A background and general information about the subject and study area which guided the methodology of this research is provided. Pertinent literature has identified some major occurrences as drivers of land cover and land-use changes in the Volta Basin. Thus the need to study these drivers and their effects in relation to the environment and peoples livelihoods. Furthermore the need to look at the relationship between changing climate (rainfall and temperature) and farming, a major livelihood option of the people in the Lower Volta Basin is relevant to this study.

3.1 Study Area

The Lower Volta Basin is a sub Basin of the Volta River Basin which covers six West African countries with an estimated area of about 400,000km² and considered the 9th largest in sub-Saharan Africa (UNEP GEF, 2002). The widest stretch of the Volta Basin is longitude 5^oW to 2^oE along latitude 11^o N, it becomes narrower towards the coast of the Gulf of Guinea. In Ghana the Volta Basin is about 167,298 sq km representing about 70% of the total land area of Ghana and 40% of the entire Volta Basin as seen in table 3.1.

Table 3. 1 Distribution of the Basin among the six riparian countries.

Country	Area of Volta River Basin (km ²)	% Basin	% Country In Basin
Benin	17,098	4.10	15.2
Burkina Faso	178,000	42.65	63.0
Côte d'Ivoire	12,500	2.99	3.9
Mali	15,392	3.69	1.2
Togo	26,700	6.40	47.3
Ghana	167,692	40.18	70.0
Total	417,382	100%	

Source: UNEP GEF, 2002

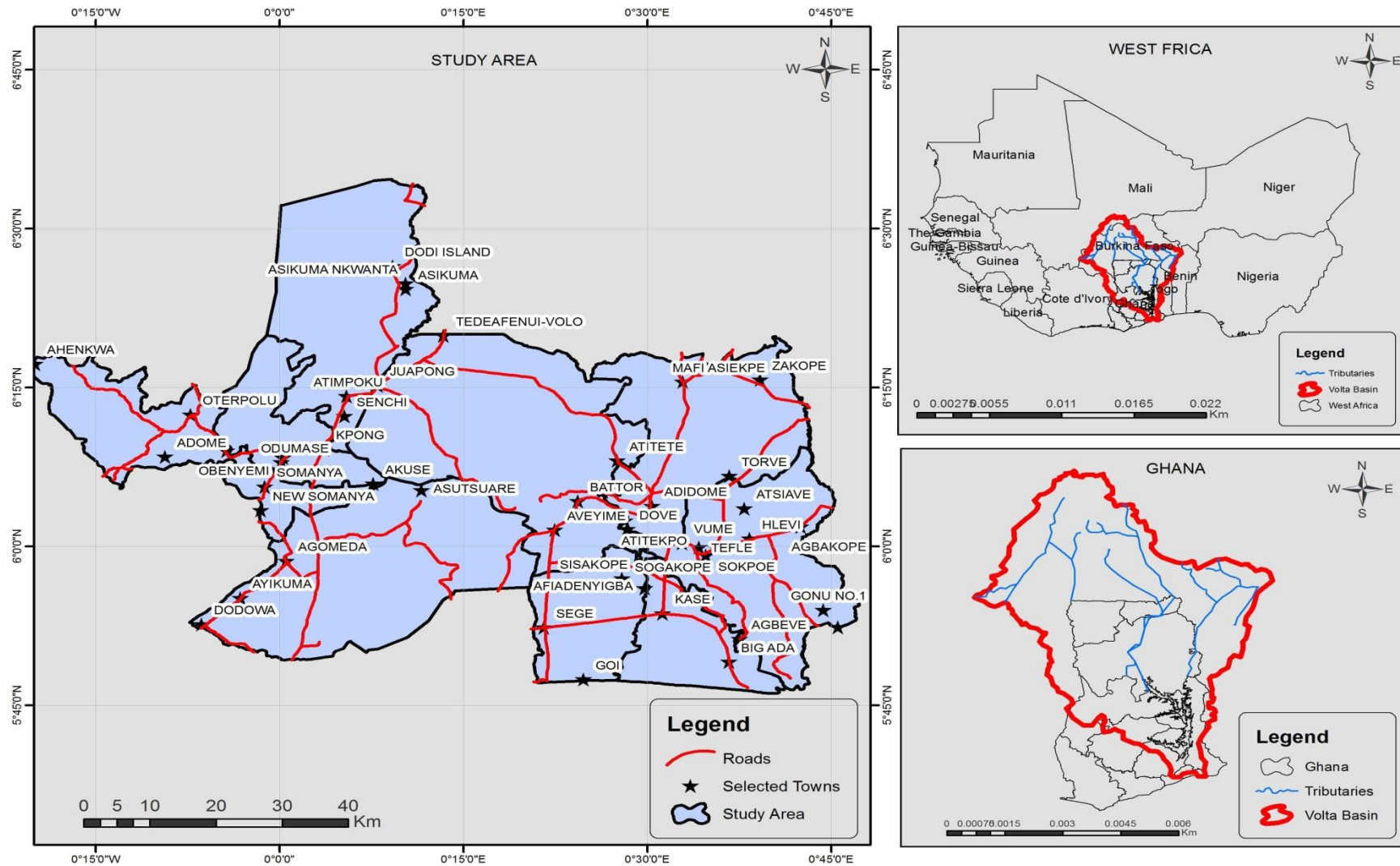


Figure 3. 1: Location Map of the Lower Volta Basin Showing Some Important Towns

3.1.1 Population

The Lower Volta Basin traverses six districts of Ghana, including, Lower Manya Krobo, Shai Osudoku, North Tongu, Central Tongu South Tongu and Ada East. These districts fall within three regions of the country, namely; Greater Accra, Eastern and Volta region.

The Volta Basin has an estimated population of about 8.85 million (2010) people and supplies close to eighty percent of the staple food requirement of the country. The population growth rate for these regions, Greater Accra, Eastern and Volta for the period, 2000 to 2010 are 3.1%, 2.1% and 2.5% respectively (UNEP GEF, 2010).

Using the population of the various districts that fall within the Lower Volta Basin area, the total population for the study area is computed in the Table 3.2.

Table 3. 2: Population of districts in the Lower Volta Basin

Region	District	Population
Greater Accra	Ada East	130,795
Eastern	Shai Osudoku	122,836
Volta	North Tongu	149,188
Volta	Central	59,411
Volta	South Tongu	87,950
Eastern	Lower Manya Krobo	89, 246
Total		639,426

Source: GSS, 2010, population and Housing Census.

3.1.2 Location and Administrative Area of LVB

The six districts that are captured in the extent of the Lower Volta Basin as defined by the coordinates (0°45"E to 1°00"E and 6°15"N to 5°45"N) of the Volta Basin Research Project (VBRP).

The Ada East district is located in the Eastern part of the Greater Accra region and forms part of the Accra plains.

North Tongu district lies within the Tropical Savannah Grassland, with a large tract of grassland which is suitable for large scale livestock rearing. The Volta River runs from the north to the south of the district roughly dividing it into two equal parts (MOFA, 2015)

South Tongu district, was carved out of the Tongu district, the district is drained mainly by the Volta River, which runs along the district's western boundary with Dangme East District.

The Central Tongu district forms part of the (25) MMDAs in the Volta Region of Ghana. The district is drained by the Alabo, Kolo, Aklakpa, Gblor, and Nyifla streams and their numerous tributaries into the Volta River, which runs North – South through the District.

The Shai Osudoku District formerly Dangme West. The general pattern of drainage in the district is dendritic with most of the streams taking their source from the Akwapim range which is also serves as a watershed, and flows from northwest to southwest into lagoons on the coast.

The Lower Manya Krobo district is relatively flat to the southeast with isolated hills to the northwest. Landscape is generally undulating with several streams, most of which drain into the Volta River.

3.1.3 Climatic Conditions

The climate of the Volta Basin is controlled by two air masses namely, the North-East Trade Winds and the South-West Trade Winds, which meet in a zone referred to as the Inter-Tropical Convergence Zone (ITCZ). The ITCZ moves northwards and southwards across the Basin from about March to October when rainfall is received in

the region (Barry, *et.al*, 2005). In the southern and middle parts of the Basin two rainy seasons are experienced with a double maxima regime in May to August (major peak) and September to October (minor peak) (Codjoe, 2004).

Temperature

Mean daily temperature in the LVB ranges from 32–44°C, whilst night temperatures can fall to as low as 15⁰C. Temperatures in the South could fall as low as 18⁰C under the influence of sea breeze, particularly during the months of July and August when marine coastal upwelling occurs (UNEP-GEF, 2010). CSIR-WRI (2000), projected a temperature increase by 2.5-3.2°C by 2100 across the country.

Rainfall

Furthermore three types of climatic zones can be identified in the Volta Basin: the humid south with two distinct rainy seasons; the tropical transition zone with two seasons of rainfall very close to each other; and, the tropical climate, north of lat 9° N, with one rainfall season that peaks in August. The average annual rainfall varies across the Basin from approximately 1500 mm in the south eastern section of the Basin in Ghana, to about 360 mm in the northern part of Burkina Faso. The Lower Volta Basin has two wet seasons, one from March to July, and a shorter wet season from September to November, corresponding to the northern and southern passages of the ITCZ across the region (Rodgers *et al.*, 2007).

3.1.4 Geology, Relief, and Soils

The (UNEP-GEF, 2010) report, indicates that the geology of the main Volta is dominated by the Voltaian system, which consist of consists of Precambrian to

Paleozoic sandstones, shales and conglomerates. The other geological formations include the Buem formation, Togo series, Dahomeyan formation, and *Tertiary-to-Recent* formations. However the Dahomeyan formation which consists of mainly metamorphic rocks, including hornblende and biotite, gneisses, migmatites, granulites, and schist occurs mainly in Southern portion of the Lower Volta. The Basin has on its western side a chain of mountains, the Akwapim Togo Ranges, Fazao mountain and Atakora ranges in Benin.

The relief of the Lower Volta is generally low with an average elevation of (0-150m) above sea level, with the average mean altitude of the main Volta Basin approximately 257m (Barry *et al.*, 2005). The soils in the Volta Basin and Lower Volta Basin for that matter are related to the agro-ecological zones within the Basin (UNEP-GEF, 2010). The agro ecological zones of the Volta Basin includes Coastal savannah, Sudan savannah, Guinea savannah, Forest savannah transitional zone, Semi-Deciduous forest and High rainforest. The geological formations have given rise to different parent materials from which most of the soils in the Lower Volta Basin and Ghana are derived (Ministry of Lands and Forestry, 2002). Amatekpor (1999), reported that the soils developed over the Lower Volta Alluvium, Coastal Savanna Zone include; Chichiwere, Amo, Tefle and Aveyime. The soils of the Lower Volta flood plain which covers an area of 294.0sq km (29,280ha) is good for agriculture (Gordon and Amatekpor, 1999).

3.1.5 Land-use and Land Cover

All categories of land-use occur in the Volta Basin, including; rain-fed and irrigated agriculture, grazing, forestry, settlements, public services, wildlife preservation,

reservoirs (manmade and natural), protected lands and many more (Amatekpor, *et al.*, 1999).

Rain-fed agriculture which is based on the land rotation farming system, also known as bush fallow system, is the most common type of land-use in the area. (Titriku, 1999).

The land cover of the Volta River Basin consists predominantly of sub-humid savannah; mainly tall grasses interspersed with fire resistant trees in the Black and White Volta Sub-Basins whereas the Lower Volta has a range of vegetation from closed forest to humid savannah, mangrove and coastal strand vegetation and thicket. Short grasses also occur more within the Lower Volta that enhances the rearing of herbivores such as cattle, goat sheep among others (UNEP-GEF, 2010).

3.1.6 Vegetation

Climatic and edaphic factors are known determinants of vegetation cover of an area. The dominant tree species in the area is the "Neem" tree. It can be found everywhere in the Lower Volta Basin. Generally, the Lower Volta has a composite vegetative cover of moist semi deciduous forest, short grasslands with some mangrove zones (UNEP-GEF, 2010)

Table 3. 3: Typology of vegetation of the Lower Volta River Basin

Northern section	Mixed savannah woodland, tall grassland with fire resistant trees.
Central section	Derived savannah interspersed with semi deciduous rain forest
Southern	Semi-deciduous rain forest with patches of derived savannah with short grasses and mangroves

Source: GEF-UNEP (2010)

The area is predominantly a coastal savannah grassland and scrub, and the predominant vegetation type is grass with trees such as neem, sheanut, baobab and dawadawa in the north with acacia species and mangroves in the south (Ayivor, 1999).

3.2 Methods

3.2.1 Land-use/Cover Study

For this study, satellite imagery captured by LandSat 8 (OLI & TIRS) and LandSat 7 ETM+ of different dates was obtained from the United States Geological Survey (USGS) website, (<http://earthexplorer.usgs.gov/>) and "*global visualization viewer*".

The path and row of the LandSat 8 2015 images from the USGS website are *wrs_path* = 193 and *wrs_row* = 056 respectively. The acquisition date of this image was 4th January 2015. The 2003 LandSat 7 ETM+ images was also downloaded from the USGS website from *wrs_path* = 193 and *wrs_row* = 056. The acquisition date of this image was 12th February 2003.

These two images were selected based on the quality of the satellite image and the amount of cloud cover in the image. Therefore a final decision was made after carefully considering these factors and how they could interfere with the accuracy of mapping land-use/cover for this study. The selected datasets were cloud free images acquired in between January and March, i.e, for the dry season.

Table 3. 4: Land-Use/Cover Classification Scheme and Description

Land-Use/Cover Classes	General Description
Waterbody	Rivers, Inland waters and reservoirs, creeks, permanent lakes and other intermittent ponds
Farmlands (Rain fed/Irrigation)	Land prepared for growing agricultural crops, covered with crops and land under preparation. This category includes rain fed and irrigation agriculture.
Grassland/Shrub	Areas covered with natural grass and small shrubs.
Mixed savannah/Coastal veg	Areas covered with patches of trees, bushes and woodlots. Riverine vegetation as well as mangroves and some species of water weeds.
Semi Deciduous Forest/Protected Area	Areas covered by trees with minimum size of 0.5ha. Dominated by natural high forests which are deciduous.
Bare/Burnt Area	Areas burnt by fire (bush burning) and exposed soils due to erosion and or misuse, especially overgrazing.
Built Area	Built-ups (buildings) in both rural and urban areas.

Source: Adapted and modified from UNEP-GEF, 2010

Remote Sensing and GIS Data Processing and Analysis

Pre-processing

The time series satellite images obtained between (2003 and 2015) and were processed using *Environment for Visualizing Images* (ENVI) and ArcGIS softwares.

Georeferencing and co-registration

The obtained Landsat images used for this study had been already corrected to the Universal Transverse Mercator UTM 30 N based on the WGS 84 projection. There was however no need to georeference the images.

Radiometric Calibration

Radiometric calibration was used since it's essential for the analysis of multi-temporal images acquired on different dates and by different sensors. Each sensor has its' own calibration parameters in recording digital numbers. These digital numbers recorded will thus represent different radiance and reflectance values (Mantey and Tagoe, 2013). As mentioned earlier this study was meant to detect change by comparing multi-temporal satellite images. For calibration of the obtained satellite images, the equations presented by Chandler *et al.* (2009) for converting calibrated Digital Numbers to absolute units of At-sensor spectral radiance and Top- of Atmosphere (TOA) reflectance were done. Firstly the calibrated digital numbers (DN) of both images (TM and ETM+) were converted to absolute units of At-sensor spectral radiance using equation (1). Secondly the At-sensor spectral radiance values (L_λ) were then converted to Top-of-Atmosphere (TOA) reflectance (ρ_λ) using equation (2).

Equation (1)

$$L_\lambda = G_{\text{rescale}} * Q_{\text{cal}} + B_{\text{rescale}}$$

Equation (2)

$$\rho_\lambda = \frac{\pi * L_\lambda * d^2}{ESUN_\lambda * \cos\theta_s}$$

Where;

L_λ = The spectral radiance

G_{rescale} = Band specific rescaling gain factor

B_{rescale} = Band-specific rescaling bias factor

Q_{CAL} = The quantized calibrated pixel value in digital number of each band

ρ_λ = The top-of-atmosphere reflectance

d = The distance from the earth to the sun in Astronomical Units (AU)

$ESUN\lambda$ = The mean solar exoatmospheric irradiance

θ_s = The solar zenith angle

Layer Stacking and Spatial subset

All bands (band 1-band 8) of the two satellite images (2003, 2015) were put together through a process called “layerstack”. This was performed using the ENVI software under the tools tab.

“Spatial Subsetting”, was performed by using the “Resize data (spatial/spectral) tool in ENVI. This tool was used to extract the area of interest from the obtained satellite images.

The spatial subset was carried out using the coordinates of what the VBRP used in defining the Lower Volta Basin.

Analysis Using ENVI and ArcGIS software’s

The methods of analysing the data included, image classification using ENVI, change in vegetation cover using the normalized difference vegetation index (NDVI), development of land-use land cover classes, change detection and other GIS based processes such as on screen digitizing of different land-use features from the satellite images.

Band 4, 3 and 2 of the Landsat 8 image was loaded into the ENVI software to obtain the true/natural colour. Subsequently other bands were selected to give a false colour and/or infrared imagery to aid with classification and further analysis. Other band combinations which were used included (5 4 3 Color Infrared (vegetation), 6 5 2

Agriculture, 7 6 5 Atmospheric Penetration, 6 5 4 Vegetation Analysis) The Landsat 7 ETM+ followed a similar process to aid with the image classification.



Plate 3. 1: Feature verification using “kml” overlay in Google Earth



Plate 3. 2: Feature verification using Spear tool



Plate 3. 3: False colour rendition image. Showing vegetation as bright red, crops as pink and water as black.

Land-Use/Cover Classification and Change Detection

Two image classification processes were used in this study (Supervised classification and Post classification). However unsupervised classification which is the identification of natural groups, or structures, within multispectral data (Rai *et.al*, 2010) was employed and compared to the supervised classified images. This was done to verify and select the method which yielded the best result.

Unsupervised classification

The *Iterative Self Organizing Data Analysis* (ISODATA classification) technique was used under the unsupervised classification method. This technique automatically created as many classes as justified by the data. It merged all classes for which there was a minimum distance between means and split classes for that which had high standard deviation within a group.

Unlike the K-means method which required that a specific number of classes is chosen, this method provides a range. A range of classes (15 minimum and 30 maximum) therefore was selected for classification. 27 classes were generated after running the statistical process. These classes were combined until 7 classes were left. For the purpose of this study, and to avoid having so many classes of vegetated land cover, a classification scheme adopted from (UNEP-GEF, 2010) was used (See Table 3.4).

Supervised classification

The supervised classification method is used to cluster pixels in a dataset into classes corresponding to user-defined training. This classification type requires that training areas are selected for use as the basis for classification. In selecting the training areas the ENVI software enables the user to make use of what is known as region of interest (ROIs).

Different ROIs were carefully selected as training areas for both 2003 and 2015 Landsat images. Various comparison methods were then used to determine if a specific pixel qualifies as a class member. With the broad range of different classification options provided under ENVI's supervised classification namely "Maximum Likelihood

classifier” was used because it produced the best result for the study area and it has been used and recommended by other researchers who have worked in the Volta Basin.

Change Detection

The Post classification method provides classified images with evaluation of classification accuracy through post processing. An extra feature of the post classification method is that it allows for the extraction of statistics from the image that were used to classify the satellite image (Exilis, 2014). Accuracy assessment was done for both classified images in this study by using the confusion matrix tool under this post classification process. Classes were combined, sieved and lumped using this process as well to clean up the classified land-use/cover images that were created. The minority/majority analysis in ENVI was conducted to remove all unclassified pixels from the final classified image.

Change detection statistics

A change detection statistics was run on the two final classified images. With the 2003 image set as the initial state and the 2015 image set as the final state, the change detection computed class/pixel change, area change and percentage change for all classified land-use/cover types. The classes were then converted to vector layers and saved as a shape file. It was opened in ArcMap for finalization of the land-use/cover map.

Ground Truthing/Verification

Ground truth verifications was conducted in the study sites with the aid of a Global Positioning System (GPS) (*Garmin Etrex GPS 20*) to confirm and help check the accuracy of land cover and use classification process. All the six study areas were

visited with GPS coordinates taken at specific places to aid in accuracy of classification. Some of the coordinates taken of features include, cleared farmlands, cultivated farm lands, bare land, bushes, partially bare grounds, grass lands, burnt fields and built up areas (markets, residential areas). Some of the ground control points were taken at converging points of certain features such as the intersection points of roads (major road junctions).

The use of Google Earth Pro was also used in confirming some land cover/use features. There are two procedures that were employed in using google earth as a post verification tool. The employment of the "SPEAR" tool in "ENVI" was used in the classification process. This tool takes the coordinates of a selected cover type in ENVI and plots to the exact location (coordinates) in google earth. This helps verify a feature found in the satellite image. After classification was done for both satellite images further verification was done by;

- Exporting the image to ArcMap.
- Created polygon using the draw tool over the area (class) to be verified.
- Converted polygon feature to kml file type and saved.
- The “kml” file type was opened in Google Earth.

Normalised Difference Vegetation Index

The analysis of vegetation cover changes was done using the Normalized Difference Vegetation Index (NDVI). This method is used to analyse the amount or extent of change in vegetation. It is calculated by

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

Where RED is the visible red light portion (band 3) (620-750nm) of the electromagnetic spectrum and NIR is the invisible radiant energy (band 4) (750nm -1mm). The NDVI itself has an index varying between -1.0 to +1.0.

It was used to determine the extent to which vegetation cover had changed in the two satellite images.

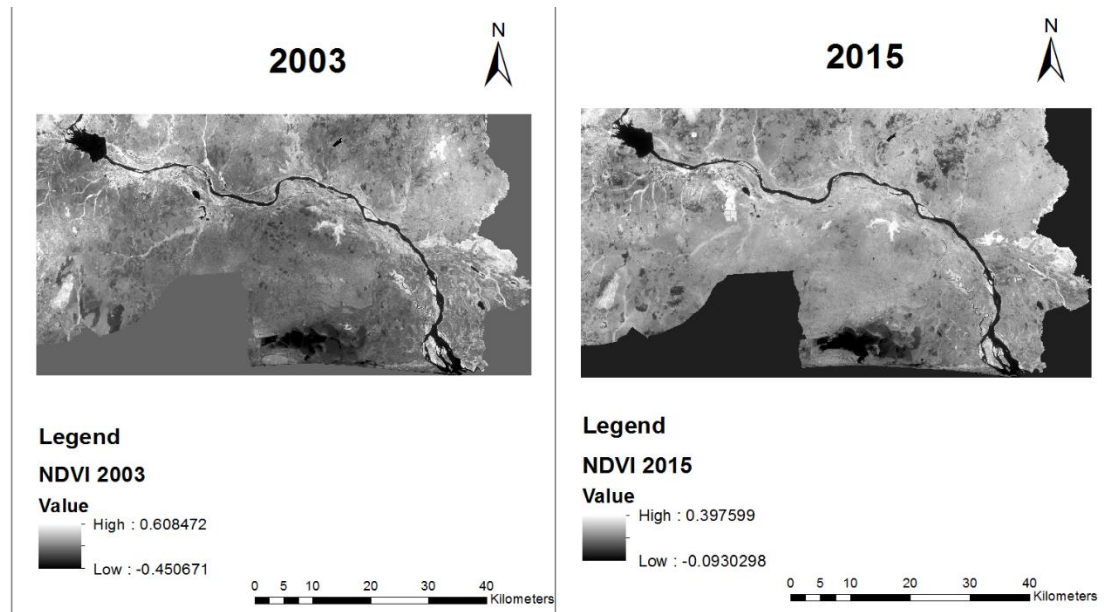


Figure 3. 2 NDVI map of the two Landsat images

The NDVI generated map was compared to the generated LULC map of the study area. It was used as a check to assess which of the Landsat images had a higher vegetation cover.

3.2.2 Climatic Study

Monthly climatic data for the past five (5) decades (1960-2013) was acquired from the Meteorological Services Agency of Ghana (GMet). Units of climatic data used in this study were rainfall and temperature. This data was from weather stations of the various districts of the study area.

Thiessen Polygon Method

In calculating the average rainfall and temperature for the Lower Volta Basin, the values for the various weather stations in the above mentioned districts were calculated by using the Thiessen Polygon method.

The Thiessen Polygon interpolation algorithm embedded in ArcGIS 10.2.2 was employed to calculate the areal average annual temperature and rainfall for seven weather stations Kpong, Akuse, Sogakope, Ada, Asutuare, Asuogyaman and Adidome. This method is based on the true assumption that rainfall is never uniform over the entire area of the Basin or catchment. But it varies in intensity and duration from place to place. Thus the rainfall recorded by each rain gauge station should be weighted according to the area, it represents (<http://www.yemenwater.org>, 2015). The method is suitable under these conditions;

- Areas of moderate size,
- when rainfall stations are few compared to the size of the Basin and
- In moderate rugged areas.

The polygons were constructed in ArcMap and each area was calculated as well as the whole area.

The formula used is presented below.

$$P_{av} = \frac{(P1 \times A1) + (P2 \times A2) + \dots + (P7 \times A7)}{A1 + A2 + \dots + A7}$$

Where P_{av} is Precipitation average

$P1$ is Rainfall measured at station 1 and

$A1$ is area in km^2 of the area in which the weather station 1 is located.

The formula below was used in calculating for the average temperature for the Lower Volta Basin as well.

$$T_{av} = \frac{(T1 \times A1) + (T2 \times A2) + \dots + (T7 \times A7)}{A1 + A2 + \dots + A7}$$

Where T_{av} is temperature average

T1 is the temperature measured at station 1 and

A1 is area in km² of the area in which the weather station 1 is located.

Trend line analysis of climatic data was analysed using a linear regression model.

Graphs were drawn, and rainfall and temperature anomaly analysis were performed.

3.2.3 Crop Suitability Study

EcoCrop Model

The EcoCrop module in the DIVA GIS programme was used to create a crop suitability map for *Zea mays* (maize), *Capiscum annuum longus* (pepper), and, *Manihot esculenta* (cassava). These crops were selected because they are grown in all districts of the Lower Volta Basin.

This EcoCcrop module uses FAO's database of environmental requirements for plant species which is used to identify possible crops that can grow in a particular environment or geographic area (Hijmans *et al.*, 2005).

In using the EcoCrop module in the DIVA GIS programme to determine the suitable areas for growing these food crops, precipitation and temperature were the two main climatic variables that were used.

The temperature parameters considered in determining the suitability of a growing season for the crops are presented below;

KTMP: absolute temperature that will kill the plant.

TMIN: minimum average temperature at which the plant will grow

TOPMN: minimum average temperature at which the plant will grow optimally

TOPMX: maximum average temperature at which the plant will grow optimally

TMAX: maximum average temperature at which the plant will cease to grow

The rainfall parameters considered are presented below;

RMIN: minimum rainfall (mm) during the growing season

ROPMIN: optimal minimum rainfall (mm) during the growing season

ROPMAX: optimal maximum rainfall (mm) during the growing season

RMAX: maximum rainfall (mm) during the growing season

The climatic data used for this mapping was downloaded from the www.worldclim.org website. This is because the DIVA GIS program uses a specific file format known as “CLM” which it refers to for climate data.

The source of the current (1950-2010) climate files downloaded was **WorldClim version 1.4** from the www.worldclim.org website.

The data resolution was 2.5 arc minutes

The source was downscaled GCM outputs based on the HADCM3 model of the projected future conditions (~2050). Also at a resolution of 2.5 arc minutes. (Available at <http://www.worldclim.org/futdown.htm>)

The source of the projected future conditions (~2050) climate files downloaded was Govindasamy *et al.*, (2003). These data were subsequently downscaled and matched to the *WorldClim* estimates of current climate also at a resolution of 2.5 arc minutes.

The downloaded files include (precipitation, minimum temperature, maximum temperature, and altitude) “BIL” files which are extracted and converted into “GRD” files using ArcGIS. These are also further converted into CLM files using the DIVA

GIS program. The process includes Importing and converting BIL files into GRD files in DIVA-GIS and Creating CLM files in DIVA-GIS (Ramirez and Bueno, 2009).

"In EcoCrop, the growing period is defined in days between Gmin and Gmax (start of growth and end of growth respectively). In DIVA-GIS, 12 possible growing seasons are considered, starting on the first day of each month. The length of the growing season is defined as the average of Gmin and Gmax" (Hijmans *et al.* 2005).

To predict the suitable areas for crop areas for the Lower Volta Basin using the Ecocrop model in GIS, the rain during growing season and interaction (temperature times precipitation scores).

3.2.4 Data

Ghana district map

An outline of the Ghana district map and Volta River ("shp" file format) was obtained from the Remote Sensing and GIS laboratory of the Geography and Resource Development Department, University of Ghana.

Crop production data

Crop production data for rain fed agriculture over the past decade (2003-2013) was also obtained from the district offices of the Ministry of Food and Agriculture (MOFA) at Lower Manya Krobo and Ada East.

Additional data was obtained from books, thesis, journals, articles and internet sources to review in-depth literature. Reports were also collected from various institutions such as the District offices, Volta River Authority (VRA) and Ministry of Food and Agriculture (MOFA).

3.3 Socio Economic Study

A total of 200 questionnaires were administered specifically to farmers who engaged in rain-fed agriculture only using the Purposive and random sampling technique. The questionnaires was pretested in the study area before they were finally administered.

A face to face interview was conducted with farmers from the Ada East and Lower Manya Krobo district, with the aid of structured questionnaires made up of open and closed ended questions.

The purpose of this was to assess the farmer's knowledge on land-use and cover changes, climate change (rainfall and temperature), on their crop yield. Other Information sought were related to the influence of rainfall variability on planting times, crop productivity for the previous years (2013 and 2014) and their view on what they (farmers) think has been the major influencing factor of crop yield was inquired. As part of the social appraisal, the educational levels of the respondents were sought.

3.3.1 Statistical Analysis

The variables and responses from the questionnaire were subjected to statistical analysis. Descriptive statistics including frequencies gave a result of comparisons, means, sums and standard deviations. Cross tabulations, regression and Chi square tests were performed as well.

CHAPTER FOUR

RESULTS

Results of the study focused on Land-use/cover change as well as climate conditions and its relationship to crop productivity and crop suitability conducted in the Lower Volta Basin are presented below.

4.1 Land-Use/Cover Classification and Change Analysis

A combination of methods were used to carefully classify both (2003 and 2015) Landsat images. The images (Figure 4.1 & 4.2) below shows the Landsat images (2003 and 2015) of the Lower Volta Basin with region of interests (ROIs) selected for the process of supervised classification.

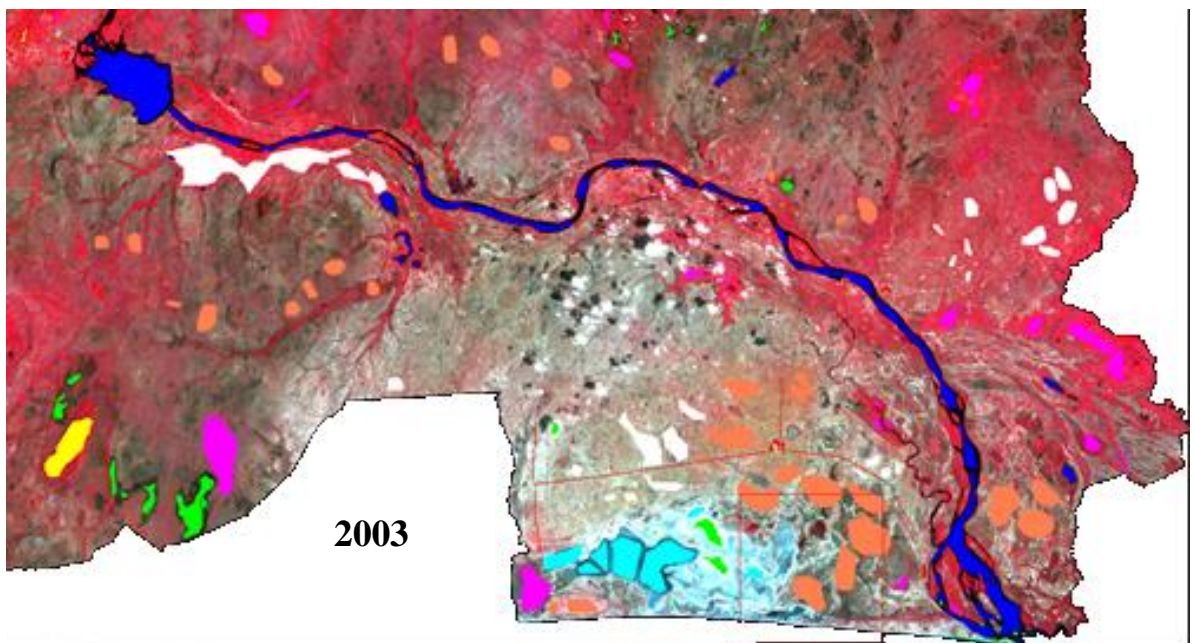


Figure 4. 1: Selected ROI's used for maximum likelihood supervised classification.

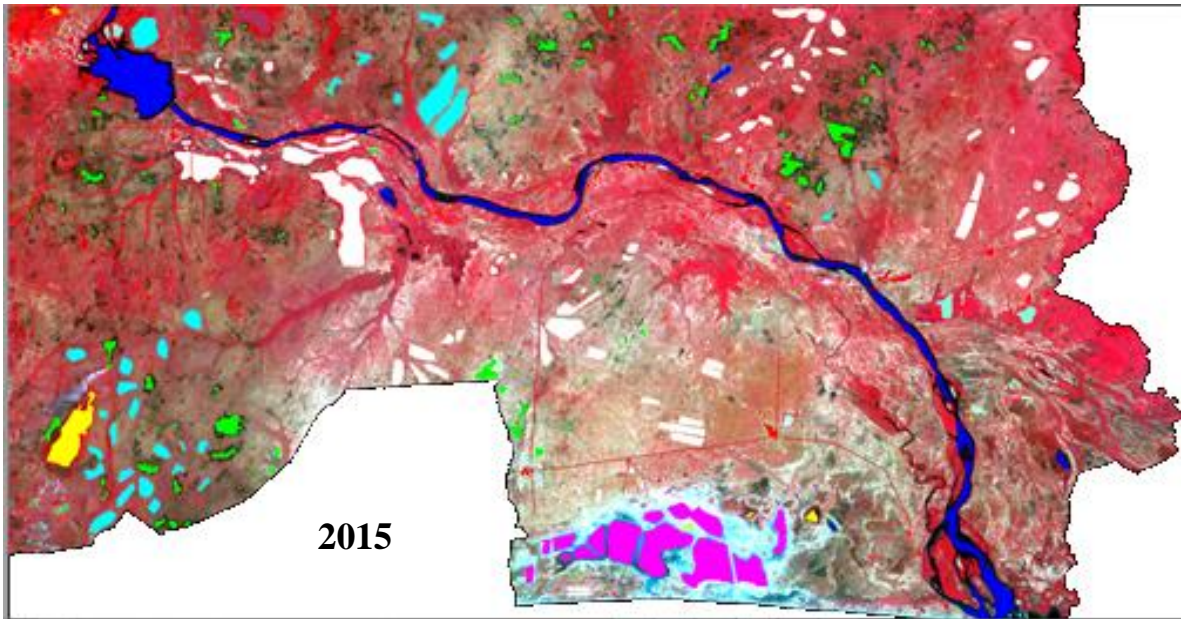


Figure 4. 2: Selected ROI's used for maximum likelihood supervised classification

The selected regions of interest were carefully done to produce an accurate classification representing what was on the ground.

4.1.1 Accuracy Assessment

Statistics of Supervised Classification (2003 and 2015)

Table 4. 1: Accuracy results for maximum likelihood classification 2003 Image

Class	Water	Built Area	Forest/P.A	Farm lands	Mixed Savannah	Grass/Thicket	Burnt/Bare land	Salt wining	Pixel Total	User Acc. %
Water	61169	0	0	5	0	35	0	30	61239	99.89
Built Area	3	3454	1	2661	46	8446	30	40	14681	69.53
Forest/P.A	0	0	6920	1650	2181	251	4	0	11006	62.87
Farm lands	0	283	141	20998	417	8621	0	0	30460	68.94
Burnt/Bare	156	63	0	33	2	1567	14777	845	17443	84.72
Salt wining	1479	0	0	21	0	81	54	19469	21104	92.25
Mixed Savannah	1	4	380	15099	16374	3118	0	0	34976	46.81
Grass/Thicket	5	715	38	9171	516	51691	381	0	62517	82.68
Total	62813	4519	7480	49638	19536	73810	15246	20384	253426	
Producer Acc. %	97.38	76.43	92.51	72.3	83.81	70.03	96.92	95.51		

Source: Author's Computation, 2015

Overall Accuracy = (194852/253426) **76.8%**

Kappa Coefficient = **0.7185**

Table 4. 2: Accuracy results for maximum likelihood classification 2015 Image

Class	Water	Built Area	Forest/PA	Farm lands	Mixed Savannah	Grass/Thicket	Bare/Burnt	Salt wining	Pixel Total	User Acc.%
Water	231929	0	27	35	0	0	0	1793	233784	99.21
Built Area	0	18265	7	8440	5699	246	3932	9	36598	59.91
Forest/PA	64	9	36794	3381	17610	2168	284	0	60310	61.01
Farm lands	16	997	72	244026	5742	6278	1785	0	258916	94.25
Bare/Burnt	1777	1093	271	9665	1766	1182	114706	1717	132177	86.78
Salt wining	3838	0	0	4	0	0	33	182743	186618	97.92
Mixed Savannah	8	1084	1416	15827	27243	5415	858	52	51903	52.49
Grass/Thicket	0	618	368	59311	8769	133946	975	0	203987	65.66
Total	237632	22066	38955	340689	66829	149235	122573	186314	1164293	
Producer Acc.%	97.6	82.77	94.45	71.63	40.77	89.76	93.58	98.08		

Source: Author's Computation, 2015

Overall Accuracy = (989652/1164293) **85.03%**

Kappa Coefficient = **0.8191**

The error/confusion matrix in Table 4.1 indicates classification accuracy of eight classes for the 2003 image classification. The producer's accuracy percentage ranges from 97.38% (water body), 76.4% (built up), 92.5% (Forest/Protected Area), 72.3% (Farm lands), 83.8% (Mixed Savannah) 70.0% (Grass Thicket), 96.9 (Bare/Burnt land), 95.51 (Salt wining, Songaw Lagoon). On the other hand, the percentage of the user's accuracy varies from 99.89% (Water), 69.53% (Built Area), 62.8% (Forest/PA), 68.9% (Farm lands), 84.7% (Bare/Burnt Area), 92.5% (Salt wining), 46.8% (Mixed savannah vegetation) and 82.6% (Grass/Thicket). The overall accuracy of the classification is 76.88% for the eight classes that were accurately classified with a Kappa statistic of 0.7185.

For the 2015 image classification, the error/confusion matrix in Table 4.2 indicates classification accuracy of eight features as well. The producer's accuracy percentage ranges from 97.6% (water body), 82.7% (built up), 94.4% (Forest/Protected Area), 71.6% (Farm lands), 40.7% (Mixed Savannah) 89.7% (Grass Thicket), 93.5 (Bare/Burnt land), 98.0 (Salt wining, Songaw Lagoon). On the other hand, the percentage of the user's accuracy varies from 99.2% (Water), 59.9% (Built Area), 61.0% (Forest/PA), 94.2.9% (Farm lands), 86.7% (Bare/Burnt Area), 97.9% (Salt wining), 52.4% (Mixed savannah vegetation) and 65.6% (Grass/Thicket). The overall accuracy of the classification is 85.0% for the eight classes that were accurately classified with a Kappa statistic of 0.8191.

4.2 Land-Use/Cover Change (Change Detection)

The tables 4.3 and 4.4 shows change detections statistics for the initial state (2003) classes seen in the columns and the final state (2015) classes seen in the rows. This was used to determine the distribution of classified pixels that changed classes. For each

“initial state class” (in each column), the table indicates how these pixels were classified in the “final state image” (in each row).

Farmlands (Rain-fed and Irrigation)

As shown in Table 4.3 and Table 4.4, about 51.12% (29597.6ha) of farmlands area was maintained in the study area. A total of 14,699.9ha representing 25.39% of grass/shrub area changed into farmlands, indicating the extent to which land with vegetation cover i.e. grass, bush and thickets are being turned to farmlands. Also about 8.29% (4799ha) of mixed savannah vegetation had been turned to farmland. Furthermore about 6.31% (3,654.9ha) of bare land/burnt area (in 2003) changed to farmlands in 2015. Burning of vegetation in the LVB is done for two main reasons, to prepare land for cultivation and secondly to enhance the growth of new grass for grazing purposes. The area, bare/burnt area is more likely to change significantly to either farmlands or grasslands. Overall, a total area of 57896ha of land classified as farmland in 2003, whilst about 95,099ha of land was also classified as farmlands in 2015. The class change for the farmlands was 48.9% (28298.7ha), implying that other land-use/cover categories had been converted to farmlands. The image difference between 2003 and 2015 was 64.3% (37202.5ha) which indicates that there has been a considerable positive change or gain in farmlands over the period of study.

Waterbody

Waterbody which consist mainly of the Kpong head pond and Volta River had 87% (14,801 ha) retained after the image time difference analysis. In table 4.3, (8.64%) representing 1,469ha of bare land was gained from water. This is due to the fact that the salt which is mined in the Songaw lagoon, reflected more like the bare/burnt area land cover type and was thus classified as such. In table 4.3 (2.13%) representing

362.3ha was converted to farmlands. Forest/PA, Grass/Shrub and Mixed Savannah had 1.05% (177.9ha), 0.25% (42ha) and 0.65% (114ha) changed respectively to waterbody. A total class of 19,610ha ha was classified as waterbody in the year 2003 whilst about 17,007ha had been classified as waterbody in 2015. The class change for the waterbody was 7,5603ha.4ha (13%). The image difference between 2003 and 2015 was -5.4% (2,206ha), which shows that there has been some change (reduction) of water coverage over the years mainly accounted for by changes in the Songaw lagoon.

Bare/Burnt Area

This feature had 4,024ha of land area maintained. A total of 77,042ha was gained. This was mainly due to an increase in the area of salt which was classified under Bare/Burnt area at the Songaw lagoon. Other reasons accounting for this change include the increase in the number of manmade (built) water reservoirs for irrigation farming. 6.9% of bare/burnt area (6,325ha) was gained from grass/shrub land-use/cover type. Also 3.1% representing 2,925.3ha was changed to farmlands. 0.3% (299ha) and 0.3% (278ha) was changed to Built-up area and Forest/PA respectively. About 1% (840) was also gained from the Mixed savannah in 2015. A class total of (41163ha) was classified in 2003 and 91734ha was classified as Bare/Burnt area. The class change for the bare/burnt land was 55.1% (87,709.2) telling that this land-use/cover had gained from other land-use/cover types. The image difference between the two images was 55.1% (50571ha), which indicates that the bare/burnt area had increased in coverage over the period of study.

Forest/PA

From Table 4.3 and 4.4, 27.5% (2,982.6ha) was maintained as Forest/Protected areas.

The computed statistics show that Forest/PA had a class change of 48.8% (87,709.2). Generally, an overall total class of (12,535ha) in 2003 and (11,411.9) in 2005 was classified as forest and protected area. This feature lost 27.6% (3,462.5) to grass/shrub land-use/cover. 18.6% (2337.1ha) was also lost to the mixed savannah land-use/cover type. Also 23.7% (2,982.7) was lost to farmlands which show encroachment by farmers. Finally 1% (128.3ha) was converted to Built-up area. The image difference between the years was -8.9% (-1123.5) which shows a reduction or loss in Forest/PA, to other land-use/cover types, especially, grasslands and farmlands.

Grass/Shrub

40.3% (55,536.0) of grass land and shrub did not change for the period 2003 to 2015. A total of 27.1% (37,320ha) had changed or been converted to farmlands. As mentioned earlier, farmlands area has increased and grassland and shrub had decreased. 16.7% (22,968ha) is also lost to Bare/Burnt area. It is to be noted that there is burning done especially in grassland areas by Herder's. 10% (13,810ha) though quite small has been transformed to Mixed Savannah land cover type. Again, 4.3% (5854ha) was converted to Built-up Areas in in 2015. 0.6% (121.7ha) had also been converted to water. Probably from water standing in less permeable areas. A total class of 137,690.5ha was classified as Grass land/Shrub land-use in 2003 and 103,128.9 in 2015. The class change for the grassland /shrub is 59.6% (82154.4ha). The image difference between the two years was -25.1% (82,154.43ha) showing that there has been a reduction in the grassland area in the LVB over the period 2003 to 2015.

Mixed Savannah

In the mixed savannah class classification, 13% which is (7,589ha) area coverage approximately had not change over the period of study (2003 to 2015). However 31%

representing (18,129ha) was lost to farmlands. 37.4% (21,924.5ha) of this cover type was also converted into grasslands and shrub. 8% (4634ha) of the mixed savannah land cover type had also been changed to forest areas. This is as a result of some smaller vegetation which have reflectance characteristics similar to that of forest type vegetation. Also, 8.3% (4,887ha), was changed to bare/burnt area. Finally 1.6% (967.8ha) and 0.6% (388.7ha) representing built area and water respectively also gained from the loss of some portions of mixed savannah. Though almost insignificant it contributes to the change occurred in the LVB. A total class of 5,8520ha was classified as mixed savannah in 2003 and 31,425.5 in 2015. Total class change for the mixed savannah was 87% (50,931.7ha). The image difference between 2003 and 2015 was -46.3% (-27,095.9ha) which indicates that quite a considerable area had been lost to other land-use/cover change.

Built- Up Area

For the built up area, 32.7% remained unchanged in the change detection statistical analysis. The overall class total for the year 2003 was 16,647.48ha and 17,181ha in the year 2015. 23.9% representing (3,986ha) of Bare/Burnt area was changed into the Built up class. Indicating that, some form of construction had taken place on the bare land. 6.8% (1,139ha) of grass lands/shrub had also been lost to built-up area. Farmlands lost to built-up area also represented 22.7% (3,781.8ha). Also 11.6% (1,935ha) of mixed savannah vegetation had been lost to the built area class. The image difference between 2003 and 2015 was positive, indicating 3.21% (534.3ha) had been gained from other classes.

Table 4. 3: Land-Use/Cover Change Detection Statistics (%)

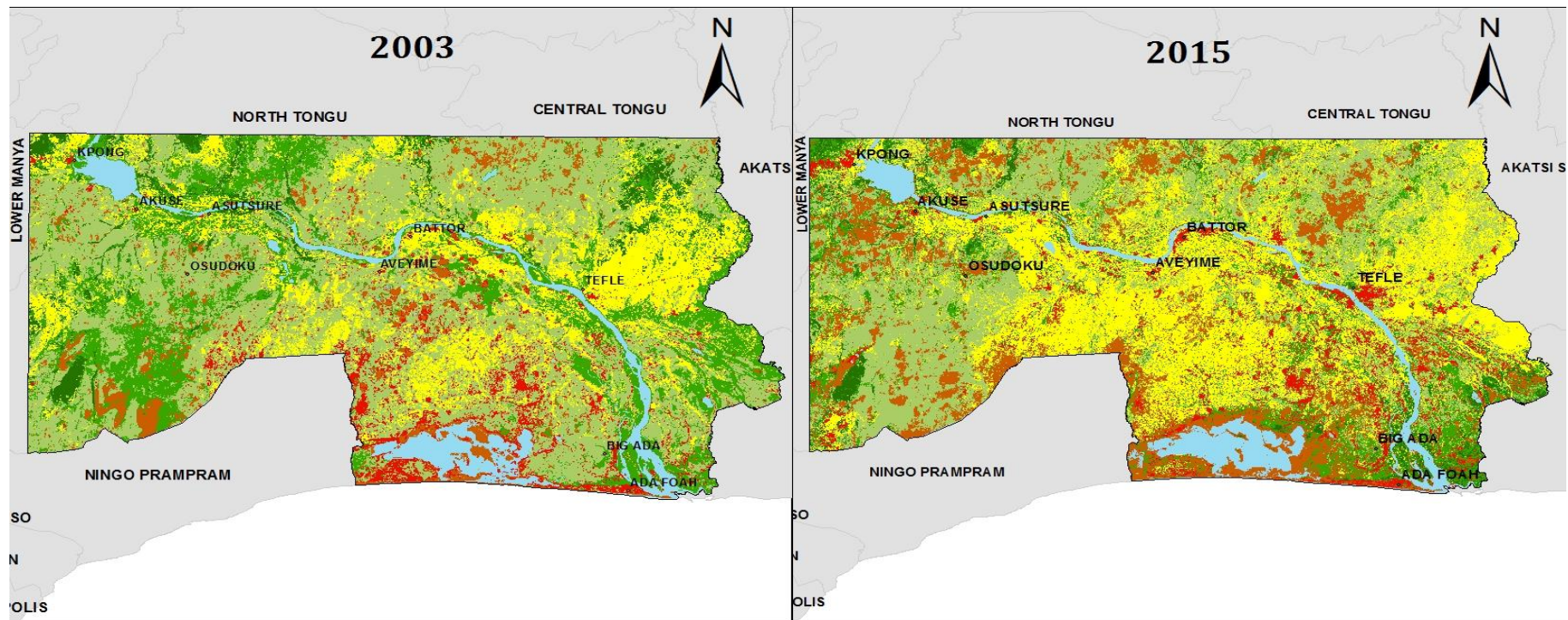
	Initial State (2003)							
	Water	Built Area	Forest/P.A	Farm lands	Burnt/Bare land	Grass/Thicket	Mixed Savannah	
Final State (2015)	Water	87.03	1.44	0.09	0.01	6.03	0.09	0.66
	Bare/Burnt	8.64	23.95	1.38	6.31	83.39	16.68	8.35
	Forest/PA	1.05	0.70	27.45	1.19	0.30	1.51	7.92
	Grass/Shrub	0.25	6.84	27.62	25.39	6.90	40.33	37.46
	Farm lands	2.13	22.72	23.79	51.12	3.19	27.10	30.98
	Mixed Savannah	0.67	11.62	18.64	8.29	0.92	10.03	12.97
	Built Area	0.24	32.72	1.02	7.68	0.33	4.25	1.65
	Class Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
	Class Changes	12.97	67.28	72.55	48.88	95.61	59.67	87.03
	Image Difference	-5.45	3.21	-8.963	64.257	55.128	-25.101	-46.3

Source: Author's Computation, 2015

Table 4. 4: Land-Use/Cover Change Detection Statistics (Area/ha)

		Initial State (2003)							
Final State (2015)		Water	Built Area	Forest/P.A	Farm lands	Burnt/Bare land	Mixed Savannah	Grass/Thicket	Row Total
	Water	14800.68	239.22	11.07	7.11	12.41	388.71	121.77	15580.97
	Bare/Burnt	1469.25	3986.55	172.71	3654.90	4024.89	4886.82	22968.00	41163.12
	Forest/PA	177.84	115.92	3440.79	688.41	278.19	4633.92	2076.84	11411.91
	Grass/Shrub	42.03	1139.04	3462.48	14699.97	6324.75	21924.54	55536.03	103128.84
	Farm lands	362.34	3781.80	2982.60	29597.67	2925.36	18129.06	37320.03	95098.86
	Mixed Savannah	114.12	1935.18	2337.12	4799.07	840.33	7589.25	13810.41	31425.48
	Built Area	40.77	5446.44	128.34	4445.10	299.07	967.86	5854.23	17181.81
	Class Total	17007.03	16647.48	12535.47	57896.37	91734.12	58520.97	137690.46	0.00
	Class Changes	2206.35	11201.04	9094.68	28298.70	87709.23	50931.72	82154.43	0.00
	Image Difference	-14001.06	534.33	-1123.56	37202.49	50571.00	-27095.49	-34561.62	0.00

Source: Author's Computation, 2015



LAND USE/COVER MAP OF LOWER VOLTA BASIN

Legend



Figure 4. 3 Land-Use/Cover map of the LVB (2003 & 2015). Source: (Author's Construct 2015).

The map (Figure 4.3) shows the land-use/cover map for the years 2003 and 2015. This is the result of the two carefully classified images of the Lower Volta Basin. By visually comparing both images, changes in classes are noticeable without difficulty. In 2003 35.1% of the LVB was covered with grasslands/shrub whereas farmlands took 14.8% of the total area in the LVB. However In 2015 grasslands/shrub covered 32.3% and farmlands covered 29.8%.

Figure 4.3 shows the area of change for the seven classified land-use/cover classes in the LVB over the 13 year period (2003-2015)

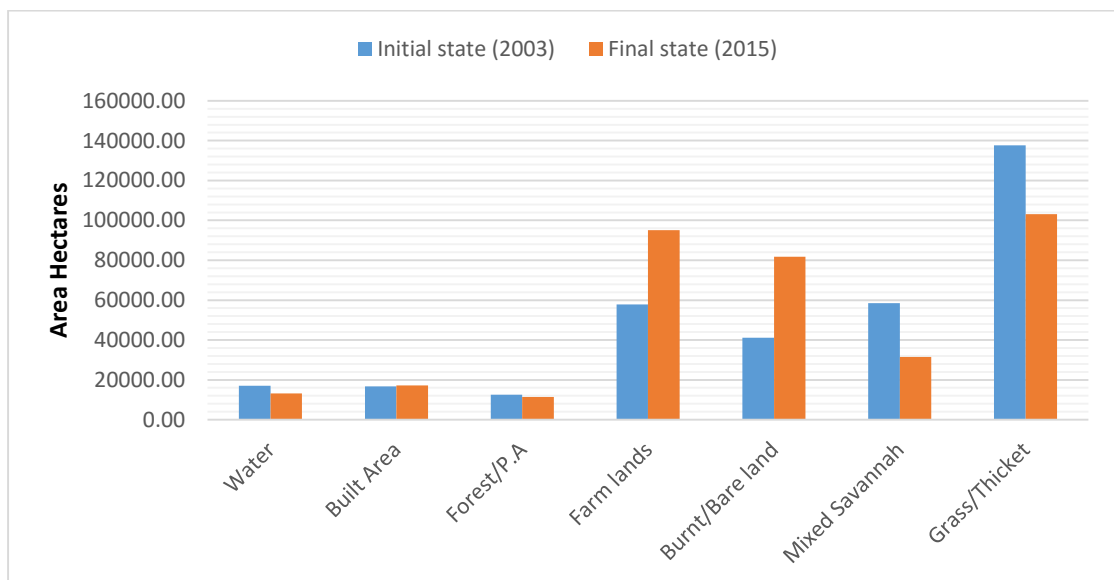


Figure 4. 4: Land-use/cover change over the period of study (2003-2015)

From the Figure 4.4, one can tell that farmlands have increased considerably over the years. Bare/Burnt areas have decreased also. The mixed savannah land cover type and the grass/thicket have also decreased extensively. From figure 4.4, it is noticed that all vegetation classes have decreased considering the time period under study. However farming area and crops have gained more coverage area over the years. Even though the classified forest/protected area has decreased, it is quite marginal. The same can be said about the built area as well as the waterbody land-use/cover features.

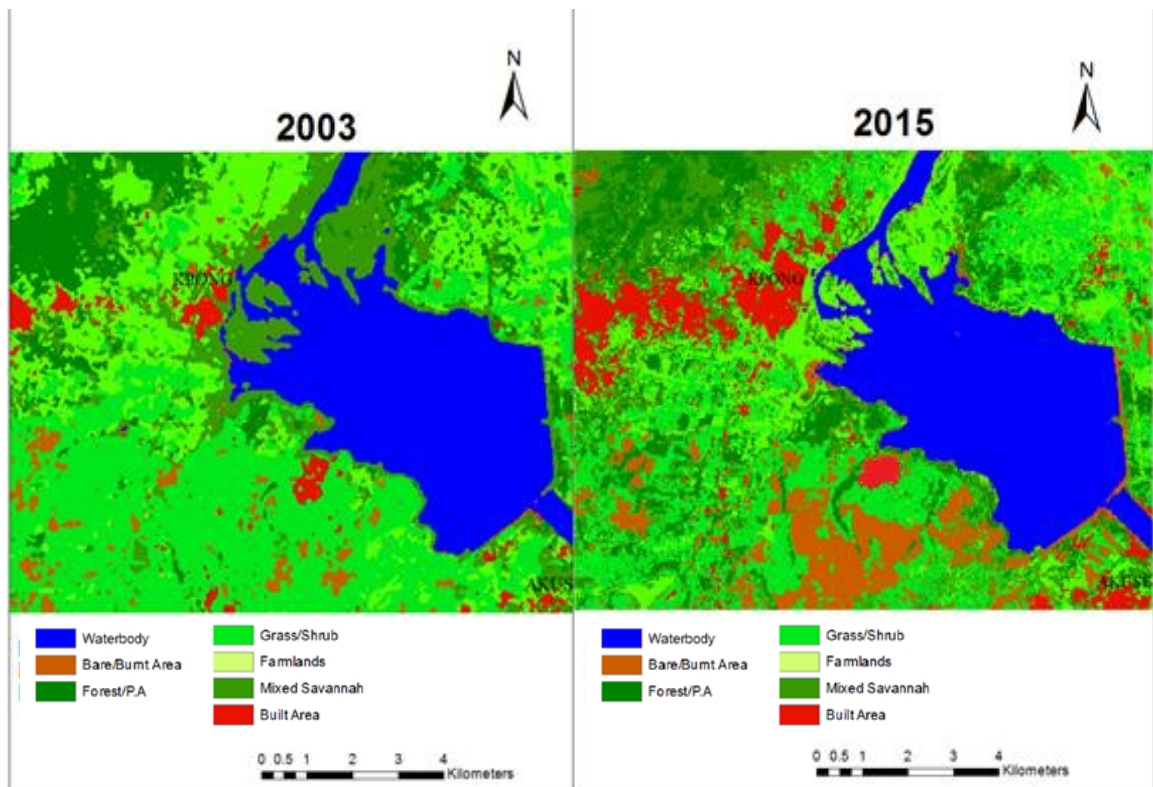


Figure 4. 5: Land-Use/Cover change in Kpong area

Source: Author's Construct, 2015

From the classified map figure (4.5), the built-up area (colour red) showing the Kpong Township has increased over the years. As it can be seen from the map, the built-up area replaced another land cover feature (vegetation). The 2015 image (right) also shows an increase in the area of bare land.

Figure 4.5 is a classified map showing a section of the Lower Volta Basin which has undergone considerable change. This area is right below the Kpong head pond, between Akuse and Asutuare.

The map shows how farmlands have developed along the stretch of the Volta river in 2015 (Figure 4.6). Also apart from the statistical difference mentioned earlier, a visual comparison of the two images shows a change in farmlands and waterbody. As can be seen the natural ponds at the Lower right corner of the 2003 classified image has reduced in the 2015 classified image.

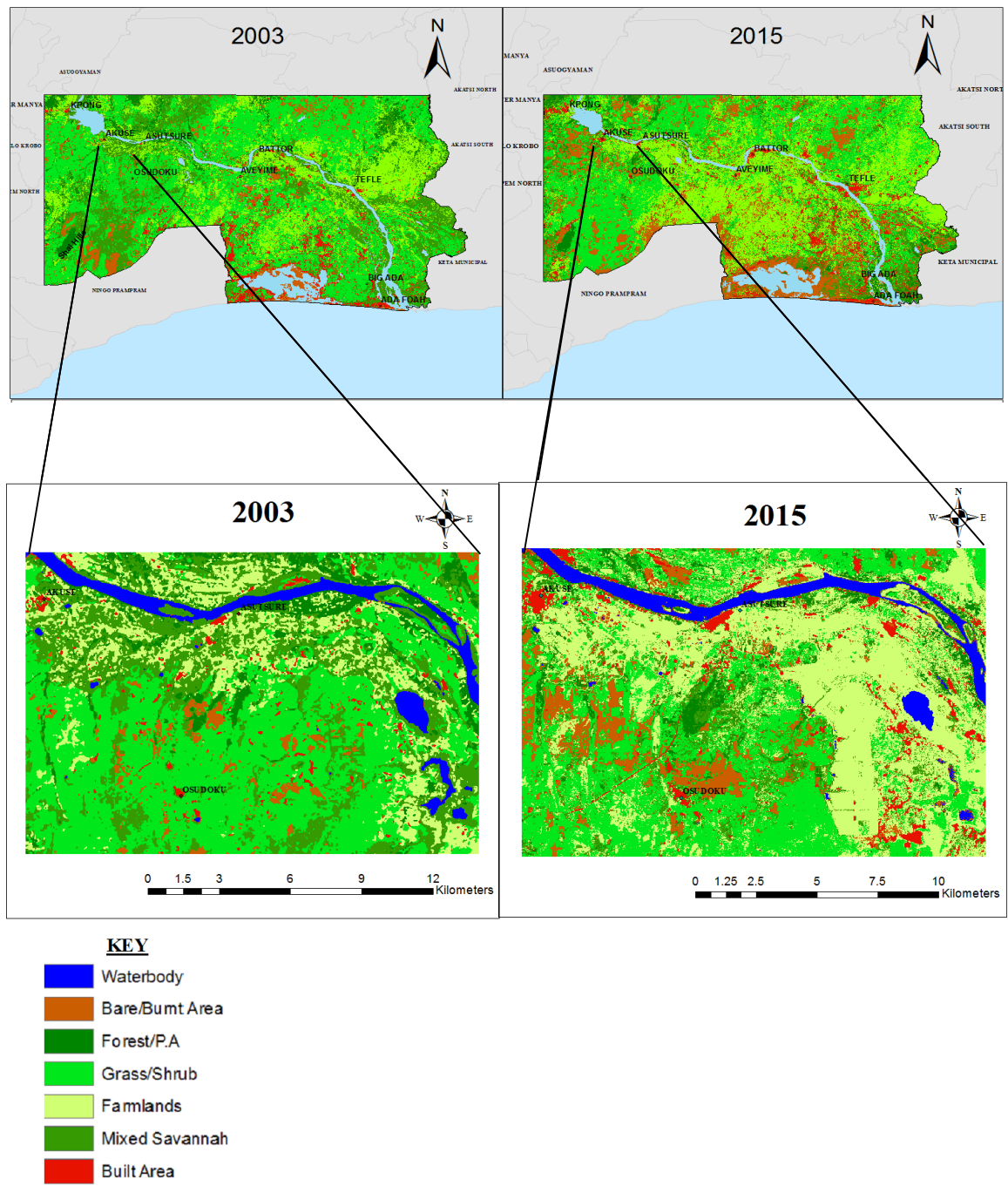
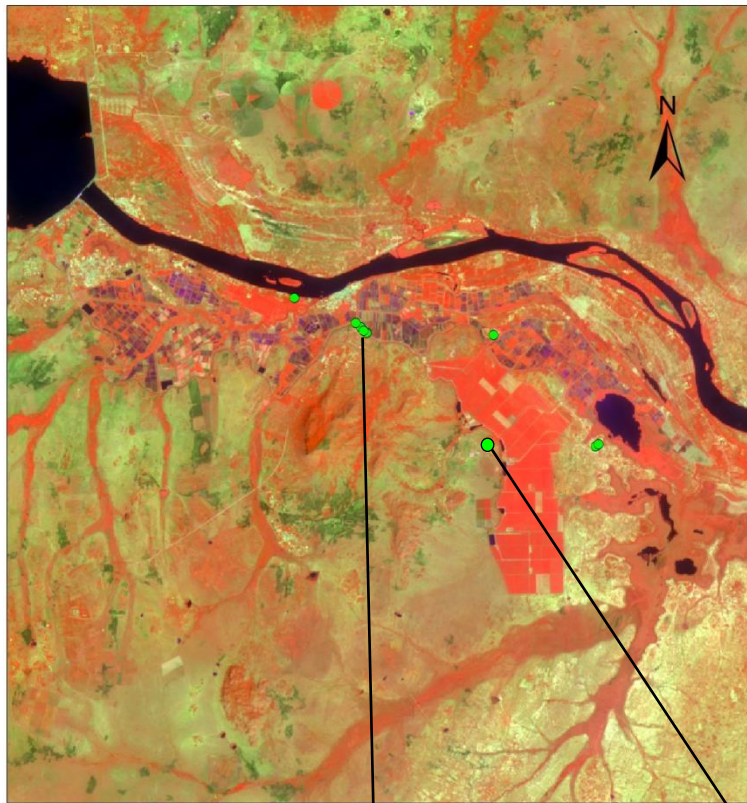


Figure 4. 6: Land –Use/Cover Change detection (2003 and 2015)



Legend

● GPS points

Figure 4. 7: Commercial irrigation farming area at Asutuare.



Plate 4. 1:1 Rice farms at Asutuare



Plate 4. 2: Banana plantation (Golden Exotics Co. Ltd).

The Ada small farm irrigation scheme was established to provide small holder farmers on the stretch between Kasseh and Big Ada with an alternative source of water for farming.

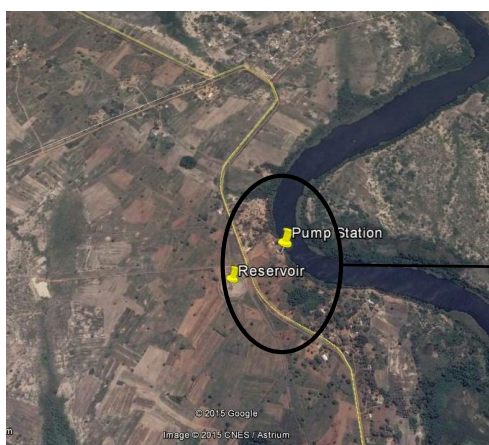


Plate 4. 3: Astrium imagery showing a section of irrigation scheme.

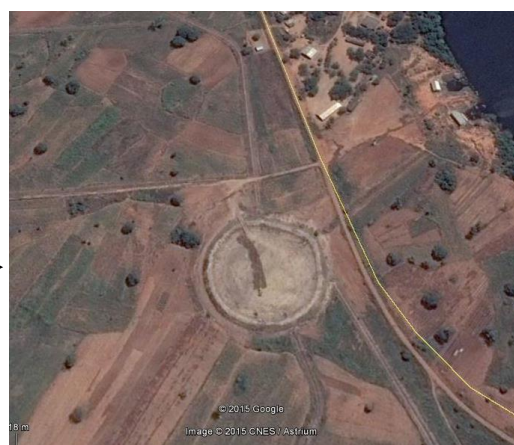


Plate 4. 4: Zoomed image showing some farms, reservoir and pump station.

Source: Astrium image. Google earth, (2015)

Table 4. 5: Area coverage of each land-use/cover type in the LVB

Land-use/cover type	Area (ha)	Percentage covered in LVB
Water	19610.09	6.1
Bare/Burnt	41163.1	12.9
Forest/PA	11411.9	3.6
Grass/Shrub	103129	32.3
Farm lands	95098.9	29.8
Mixed Savannah	31425.5	9.9
Built Area	17181.8	5.4

Table 4.5 shows the classified types of land-use/cover types and their coverage area in the LVB for the year 2015. Currently Grass lands and farmlands constituting 32.3% and 29.8% respectively dominate more than half of the LVB. These two are the most dominant land-use types in the LVB currently.



Plate 4. 5: Astrium image showing a section of Dordoekorfe irrigation scheme.

Source: Astrium image. Google earth, (2015)



Plate 4. 6: Reservoir at Dordoekorfe



Plate 4. 7: Pump station at Dordoekorfe

Source: Author's Photograph, (2015)

An interesting phenomenon which began in the year 2005 has considerably changed or altered the land-use type in the Ada Foah Township. This phenomena could be referred to as urban gardening. Vegetable farming, which includes mainly carrots, pepper and tomatoes as well as watermelon fruit are grown using a simple irrigated

system. This has led to a reduction in the rate at which buildings are constructed.

While some land owners are leasing out their parcels of land for farming, others are themselves farming on their lands which were initially meant for building (see Plate 4.9 and 4.10).



Plate 4. 8: Satellite image of Ada Foah area

Source: Astrium image. Google earth, (2015)



Plate 4. 9: Irrigation farm at Ada Foah



Plate 4. 10: Irrigation farm at Ada Foah

Source: Author's photograph, (2015)

The pictures (Plate 4.9 and 4.10) show irrigated (underground water) vegetable farm fields in the Ada Foah town of the LVB from. Plate 4.8 shows an overview of Ada

Foah Township. As can be seen from the satellite image (Plate 4.8), there are many small farmlands that have sprung up among this fast growing urban town.

4.3 Incidence and Trend of Climate Factors

4.3.1 Rainfall

The average annual total rainfall in the Lower Volta Basin for the period under study (1960-2013) was 871.4mm (Appendix 2). The minimum and maximum rainfall recorded over the period was 633.3mm and 1,272.8mm respectively.

Figure 4.8 shows the average annual rainfall pattern from 1960 – 2013 in the LVB calculated using the *Thiessen Polygon* method. From the chart, the first 10years (1960-1970) experienced generally high rainfall above 1,000mm with the highest rainfall recorded (1272.8mm) for the entire 53years period which occurred in 1963.

The regression equation of the rainfall data revealed between the periods 1960 and 2013 (53years) shows that there is a reduction in rainfall amount at the rate of 3.59mm/year. From early 1970s to 1980s low rainfalls are noticed which fall below the average rainfall. Despite a considerable increase in 1981, the year 1983 recorded the lowest rainfall for the entire period. Up until the 1990s, the period between 1982 and 1992 experienced shortfalls in rainfall. Rainfall amounts from this year (1992) to the early 2000s has hovered around the average, with 1996 recording 1008.3mm and 1999 recording 871.4mm. Most of the years from 1983 to the mid-2000s generally recorded low rainfall averages. From 2005, rainfall interestingly increases sharply and drops again sharply after 2008.

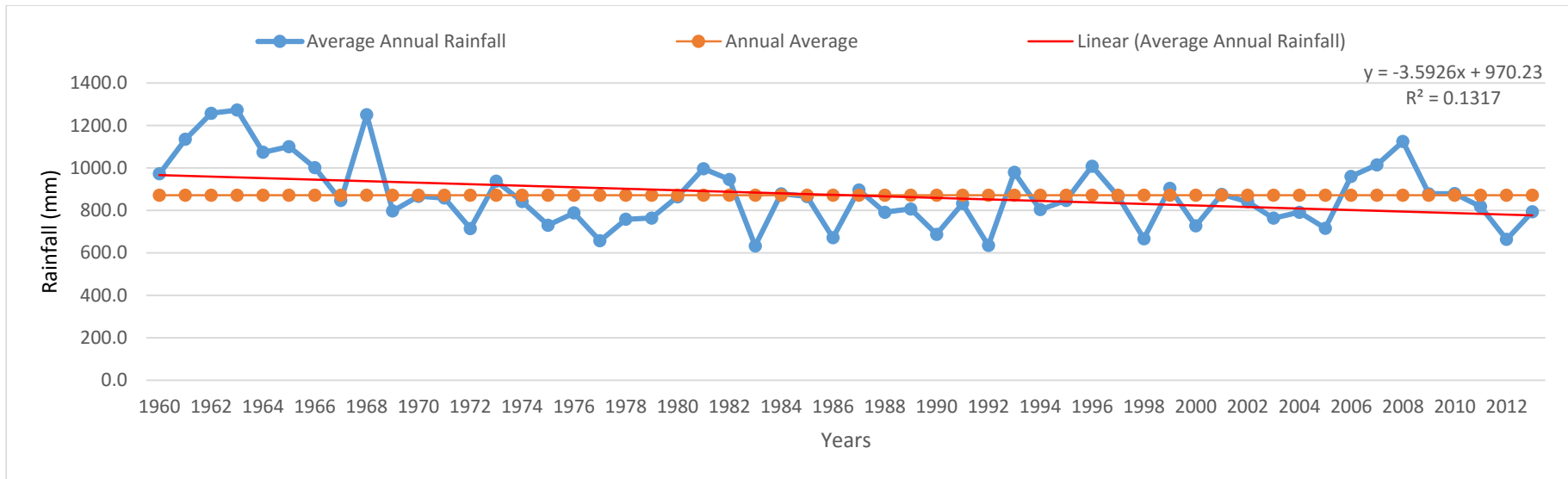


Figure 4. 8: Average annual rainfall totals, and trend in the Lower Volta Basin.

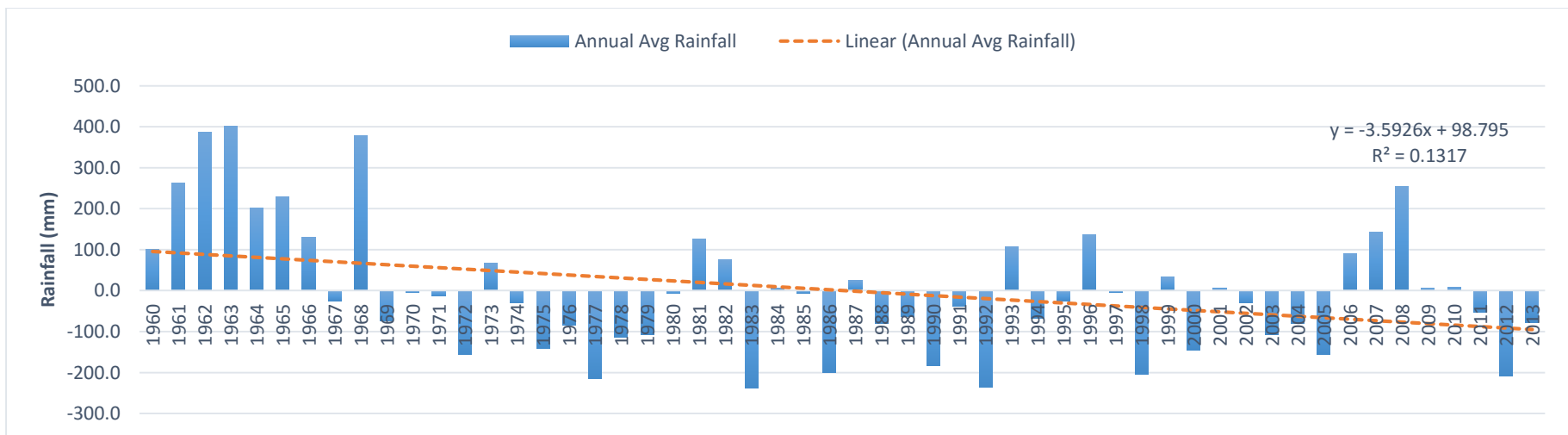


Figure 4. 9: Rainfall anomaly in the Lower Volta Basin

From the Figure 4.9, the anomaly in rainfall pattern of the Lower Volta Basin is evident that there were dry and wet periods in the area. Apart from 1963 being the wettest year, the period between 1960 and 1969 were relatively wet years with rainfall values well above the normal (annual average). The period 1970 to 1995 were dry years as most of the years for the period had rainfall values which fell below the normal average. Indicating that there were rainfall deficits in the area. 1996 to 2013 has been characterized by an interesting mix of dry and wet periods.

4.3.2 Temperature

The average annual temperature of the Lower Volta Basin ranged from 28°C to 34°C. The minimum temperature was 28.3°C and the maximum temperature was 34.8°C. The value for the average annual temperature is also 32.7°C (Appendix 2).

From Figure 4.10, the minimum temperature value of 28.3°C was recorded in 1979. The maximum temperature of 34.8°C was also recorded in 1965. The period between 1962 and 1980 recorded temperatures below the average annual temperature (32.7°C), indicating that those years were relatively cold years. However in this same period (1962-1980) 1965 recorded the highest temperature value of 34.8°C. Again the period from 1962 to 1980 can be generally regarded relatively cold with three sharp drops in temperature for the years 1969 (29.2°C), 1970 (29.4°C) and 1979 (28.3°C). In the succeeding years, from 1982 to 2013 has experienced generally warm temperatures. Almost all the values in this period have recorded values above the annual average temperature, leading to an increasing level in temperature as indicated by the trend line in figure 4.10. There was a generally increasing trend in average annual temperature for the study area at a rate of 0.0292°C/year.

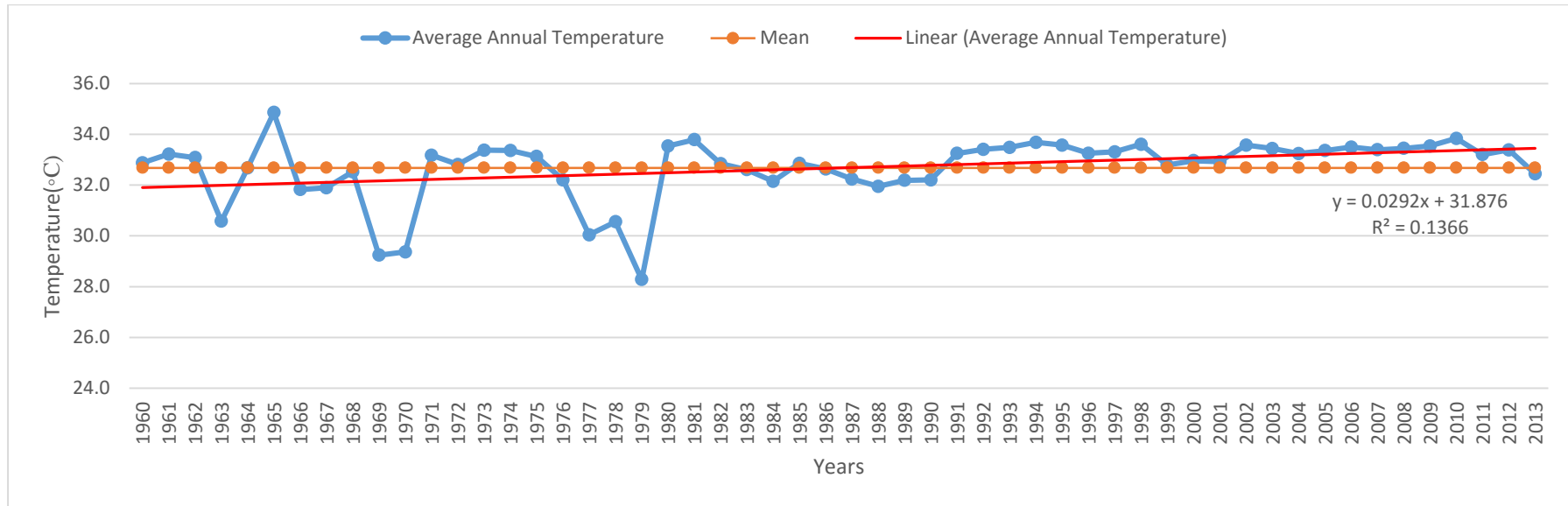


Figure 4. 10: Average temperature in the Lower Volta Basin

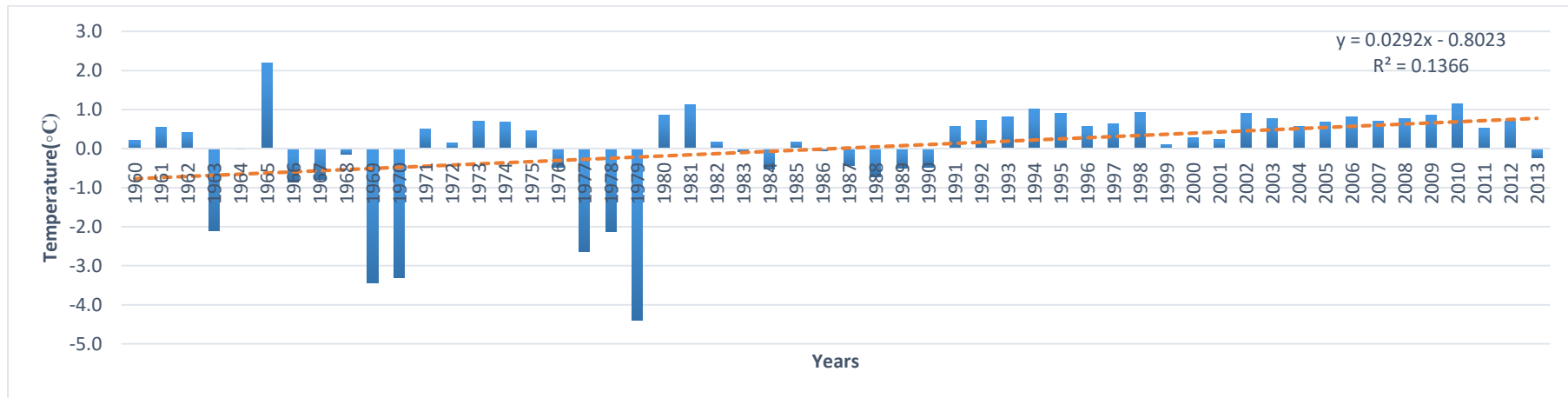


Figure 4. 11: Temperature anomaly in the Lower Volta Basin

From figure 4.11 the average annual temperature anomaly shows negative and positive temporal patterns of change from the period 1960 to 1990. The period 1960 to 1962 recorded positive values whereas there was a (-2.1°C) value in 1963. Then again a rise in 1964 and 1965. An increase and decrease trend is observed until 1990 when temperature becomes quite steady. The period 1971 to 1975 shows positive values with negative values before and after that period. So after the 1990s most years had positive values except for 2013 which had a -0.2°C value and 1999 which was very close to 0°C with a value of (0.1°C).

4.4 Crop yield in the Ada East & Lower Manya districts

Data on crop yields from Ada East and Lower Manya Krobo districts, are presented below. Cassava and maize were used because out of all the crop yield data collected from Ada East and Lower Manya Krobo, they are the only two crops which were grown in both districts. Figure 4.12 is shows crop production and area (ha) cultivated for cassava in the Ada East District for 2005 to 2013.

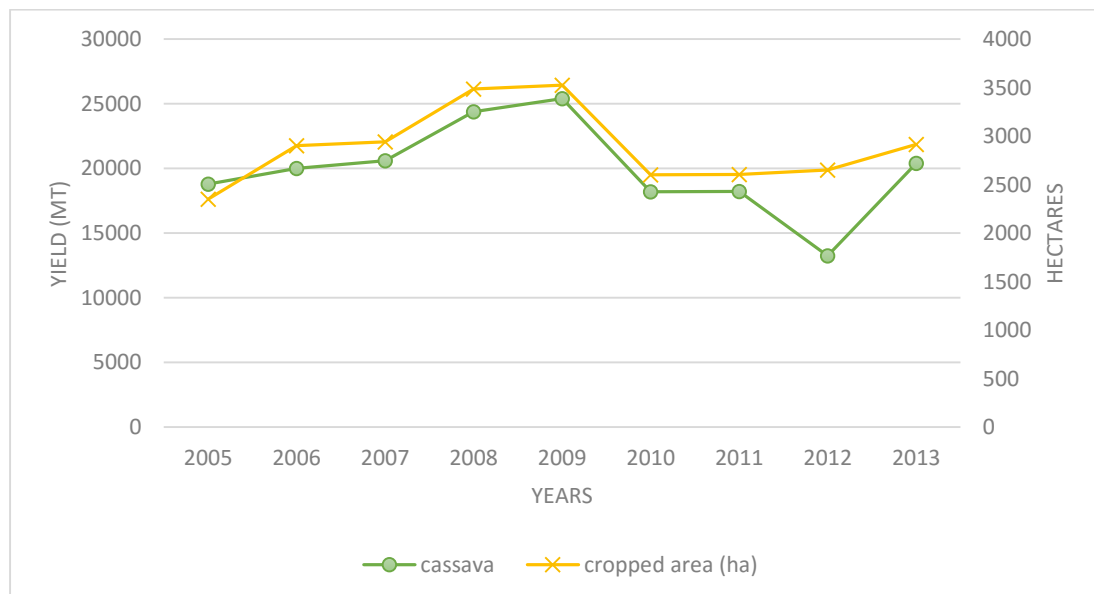


Figure 4. 12: Cassava Production in Ada East

The figure 4.12 shows that the production/yield of cassava corresponds to the area cultivated. A correlation analysis reveals that there was a strong positive correlation (0.82) between cassava yields and area cultivated.

Figure 4.13 also shows maize production in the Ada East for the same period (2005 to 2013). A positive correlation (0.65) was recorded. It is observed in figure 4.13 also that production/yield had a corresponding relationship to area under cultivation. The period of 2005 to 2009 showed a significant increase in area cultivated which corresponded with increase in yield (Mt/ha). However there was a maize production decline with cultivated area still increasing for the period (2011 to 2012). In 2013 there was an observed increase in yield as cultivated area also dropped.

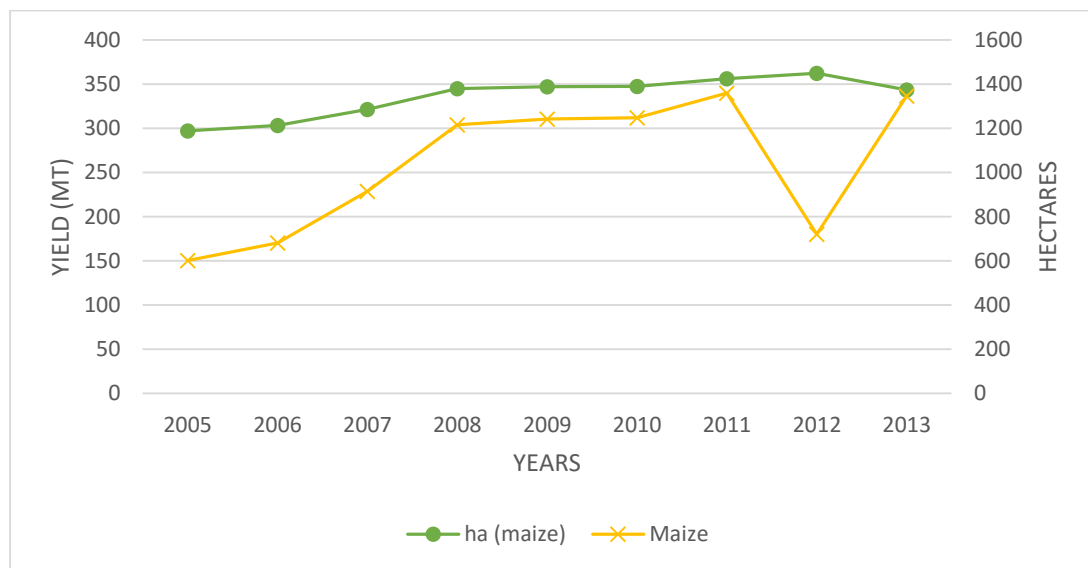


Figure 4. 13: Maize Production In Ada East

Figure 4.14 and 4.15 also show yields of cassava and maize in the Lower Manya Krobo District

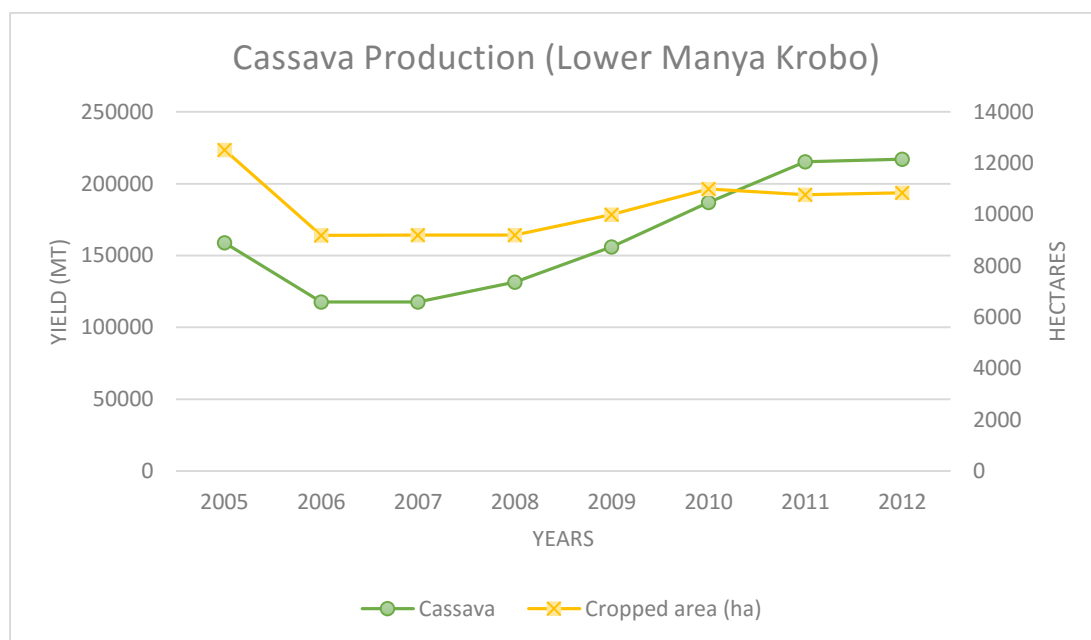


Figure 4. 14: Cassava Production in Lower Manya Krobo

In this district (Lower Manya Krobo), a similar relationship between crop production/yield and cultivated area is noticed as was in the Ada East district. A correlation coefficient of (0.63) was computed. It is therefore visually observed that crop yield increases with increased cultivated area and decreases with a decrease in cultivated area (see figure 4.14).



Figure 4. 15: Maize Production in Lower Manya Krobo

Again in figure 4.15, maize yields increases and decreases with an increase and decrease in cultivated area over the period. A correlation coefficient of (0.96) was computed, indicating a very high positive relationship between yield and area cultivated. A decrease in yield in 2006 followed by a steady increase from 2006 till 2011 (peak) is observed.

In the Ada East District, it is noticed in figure 4.12 and 4.13, that the yield of cassava and maize increase and decrease with the area of land cultivated. Furthermore, the Lower Manya Krobo Districts also experienced a similar trend in the relationship between crop yield and the area under cultivation. The yield per hectare for both crops, in both districts by year can be seen in Appendix 5

4.5 Crop suitability (EcoCrop Model)

Below shows the crop suitability map of various crops (Maize, Pepper and Cassava) for current climatic conditions (1950-2010) and future climatic conditions, 2041-2060 (~2050) in the Lower Volta Basin.

The suitability map for both climatic periods was based on rainfall and temperature parameters only.

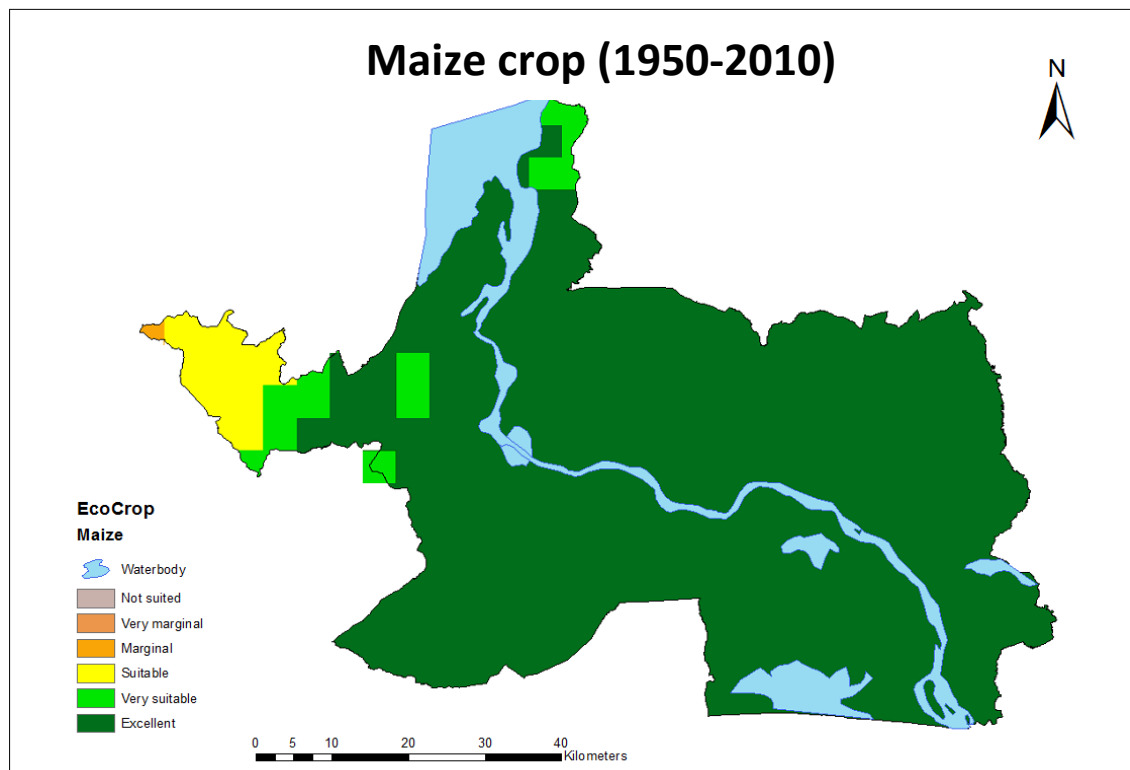


Figure 4. 16: Crop suitability map for maize crop, current climatic conditions (1950-2010).

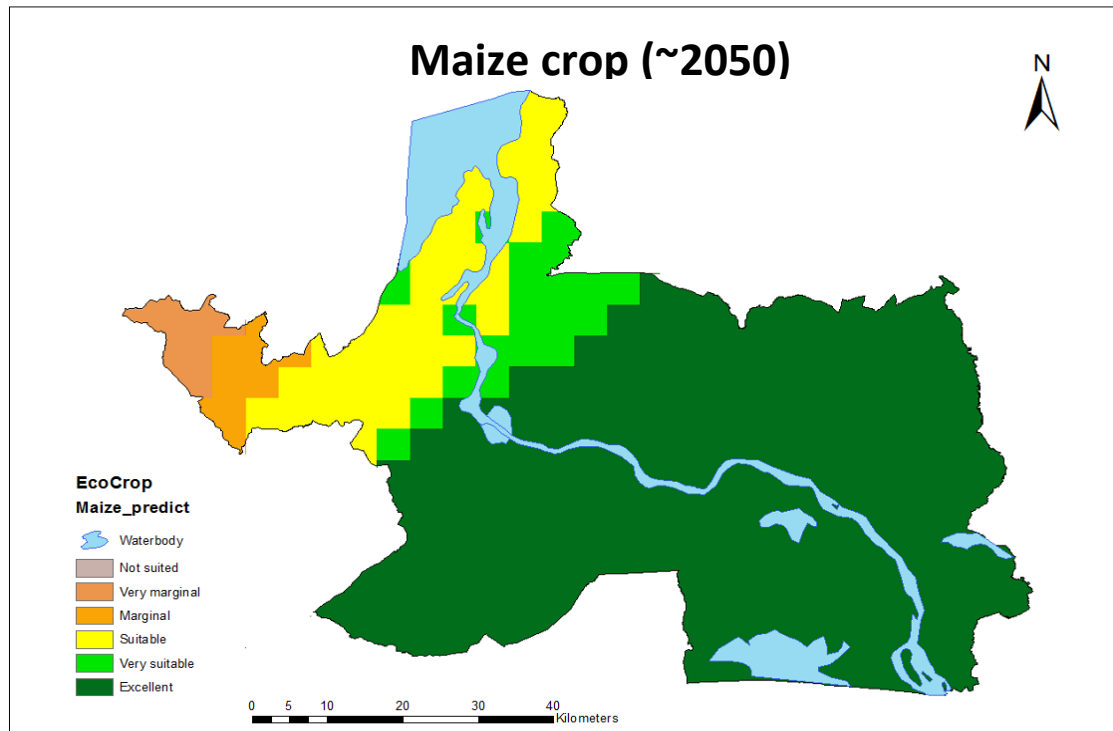


Figure 4. 17: Crop suitability map for maize crop, future climatic conditions (~2050).

A clear difference can be seen between Figure 4.16 and 4.17. Figure 4.17 shows the North Western part of the Lower Volta Basin having a wider coverage being very marginal, marginal and suitable as compared to Figure 4.16 which has almost the whole area being excellent for growing the maize crop.

Figure 4.18 and Figure 4.19 show the crop suitability maps of the Lower Volta Basin for the pepper crop for both current and future climatic conditions respectively.

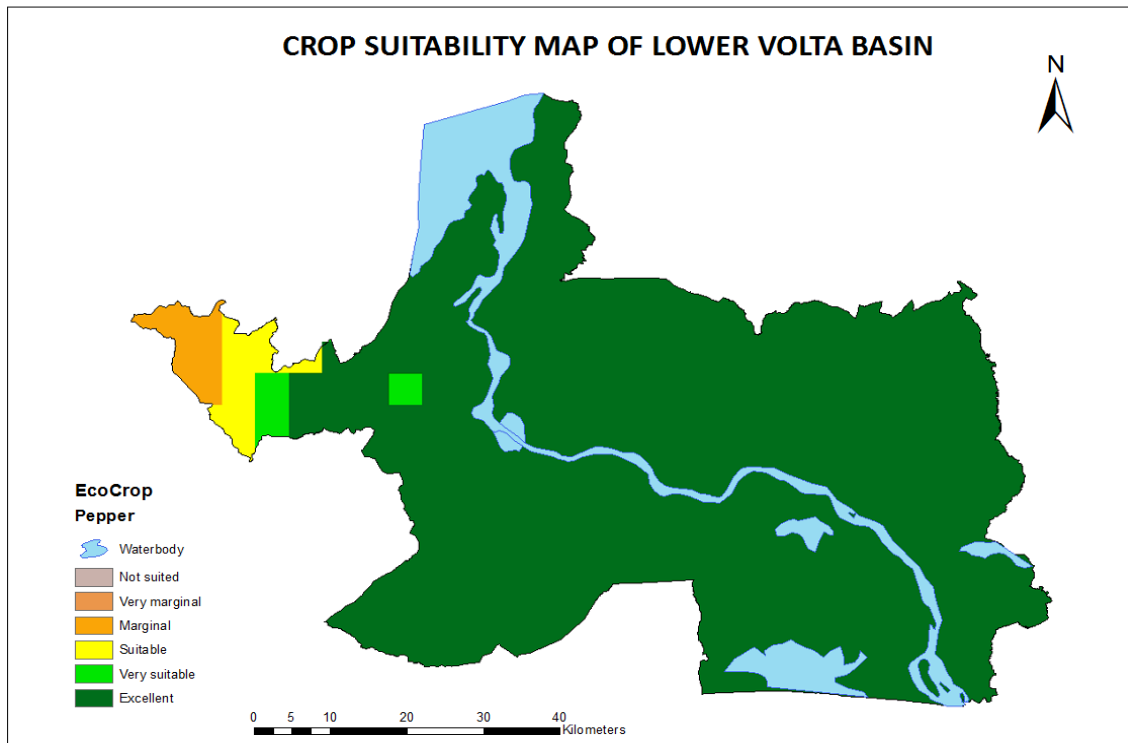


Figure 4. 18: Crop suitability map for pepper crop, current climatic conditions (1950-2010).

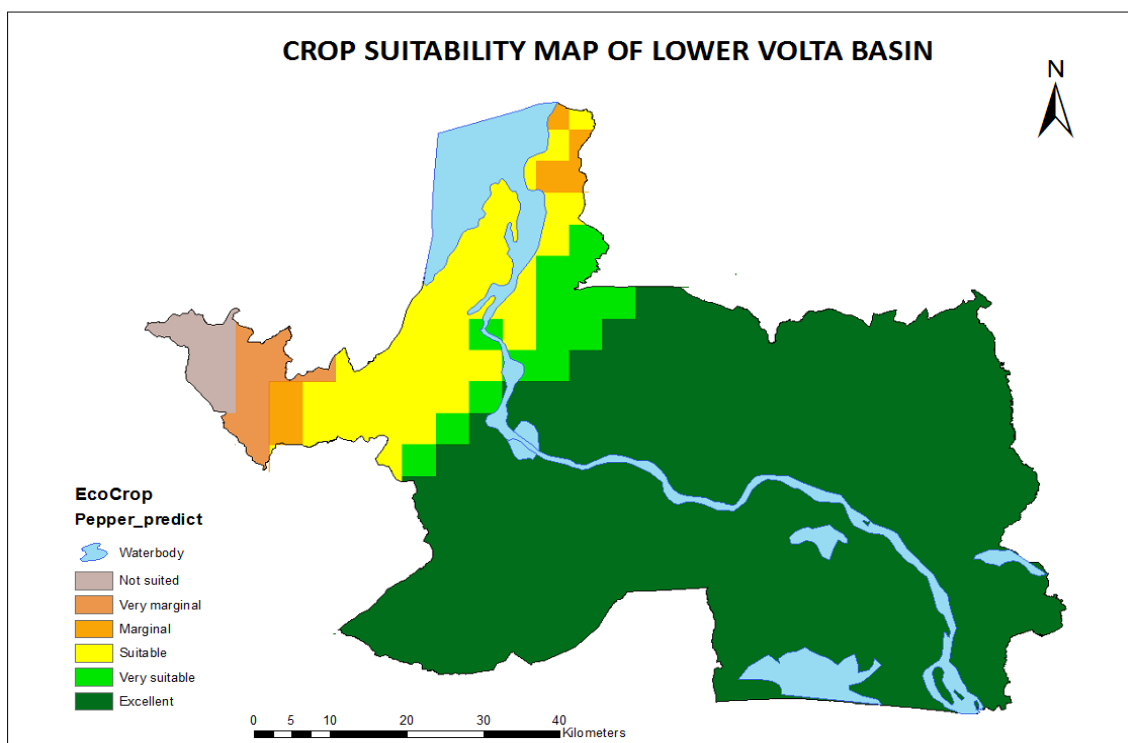


Figure 4. 19: Crop suitability map for pepper crop, future climatic conditions (~2050).

Figure 4.18 shows that the Lower Manya Krobo (north western side) area has a small portion being marginal. Comparing it to Figure 4.19, which shows future suitability

conditions it is found that some areas have become non suitable for crop production. The area being excellent for current climatic conditions (Figure 4.18), has reduced for future climatic conditions as shown in Figure 4.19. However a very large portion of the LVB still remains excellent for pepper crop production based on rainfall and temperature parameters.

Figure 4.20 and 4.21 also shows crop suitability maps for the cassava crop. Figure 4.20 shows that the current climatic parameters provide suitable and excellent conditions for the cassava crop. Figure 4.21 also shows that the future climatic parameters provide excellent conditions for cassava. There is no much difference for the cassava crop for both current and future periods as compared to the other two crops (Figures 4.16, 4.17 and 4.18, 4.19).

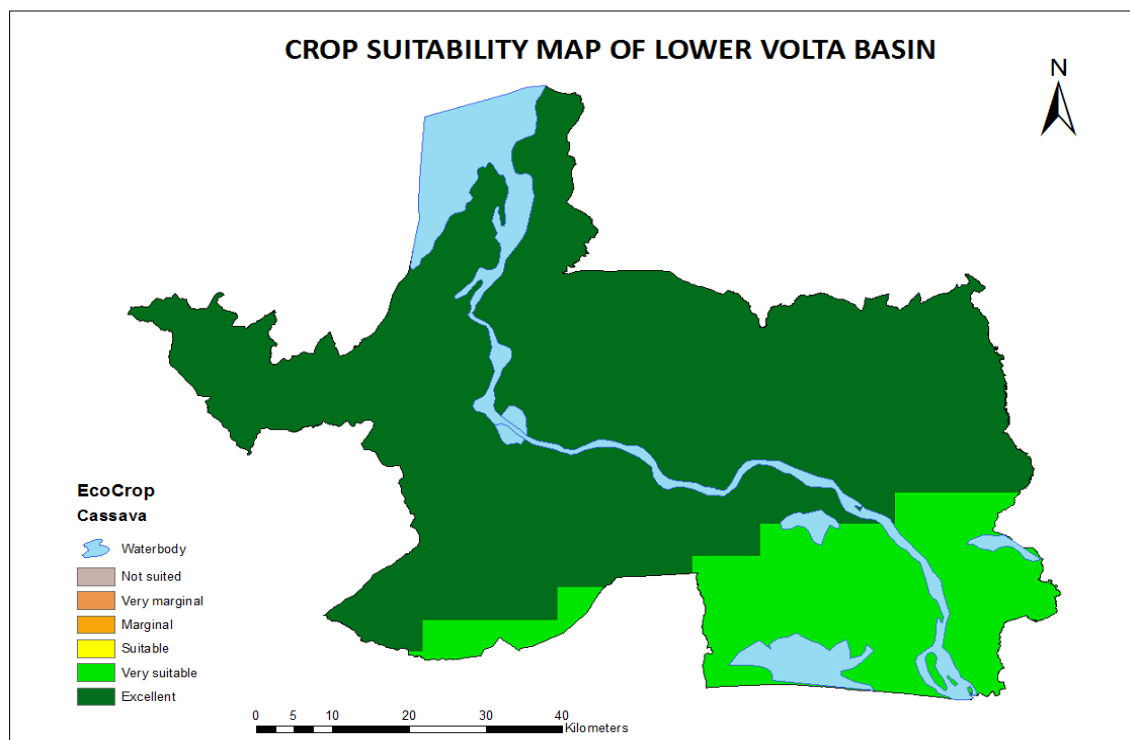


Figure 4. 20: Crop suitability map for cassava crop, current climatic conditions (1950-2010).

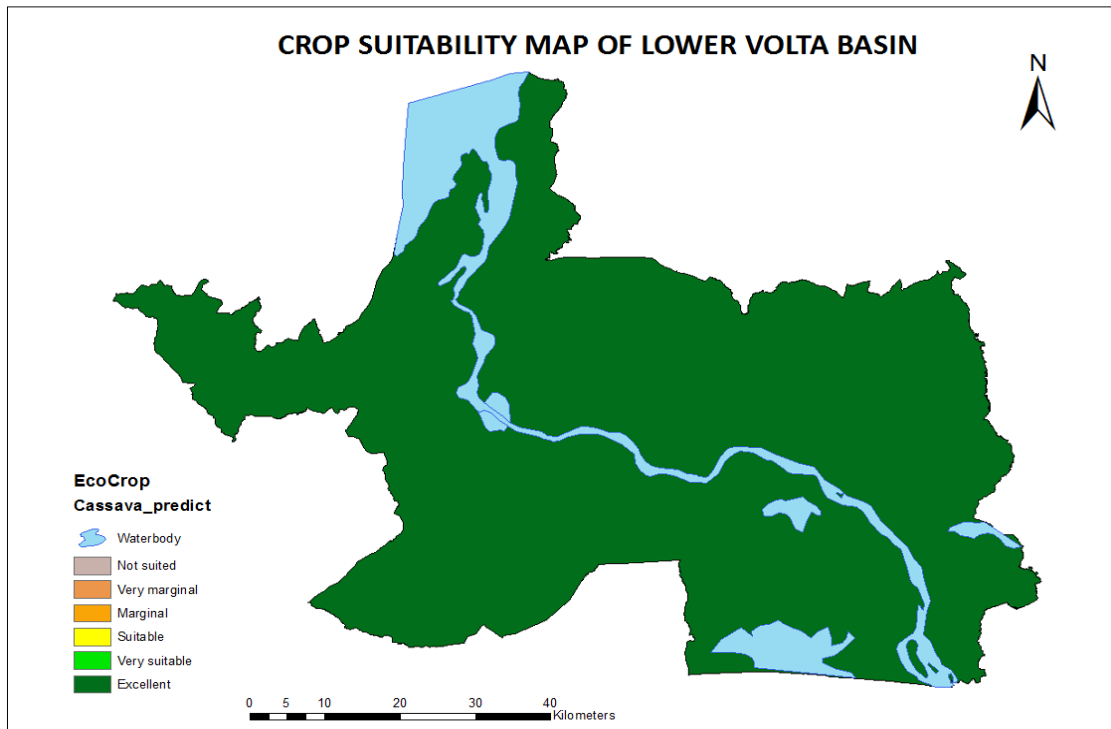


Figure 4. 21: Crop suitability map for cassava crop, future climatic conditions (~2050).

4.6 Socio Economic Study

4.6.1 Background information from respondents

This section presents the outcome of interviews and questionnaire administered to individuals (farmers) in communities within the study area. A total of 200 respondents from twelve (12) randomly selected communities namely; Dorgobom (20%), Tojeh (10%), Manaikpo (10%), Big Ada (10%), Bedeku (5%), Kasseh (5%), Dogo (5%), Korleykope (5%), Bueyonye (15%), Oborba West (5%), Yongase (5%) and Kabose (5%) were interviewed. The figure 4.22 illustrates the distribution of respondents in the study area.

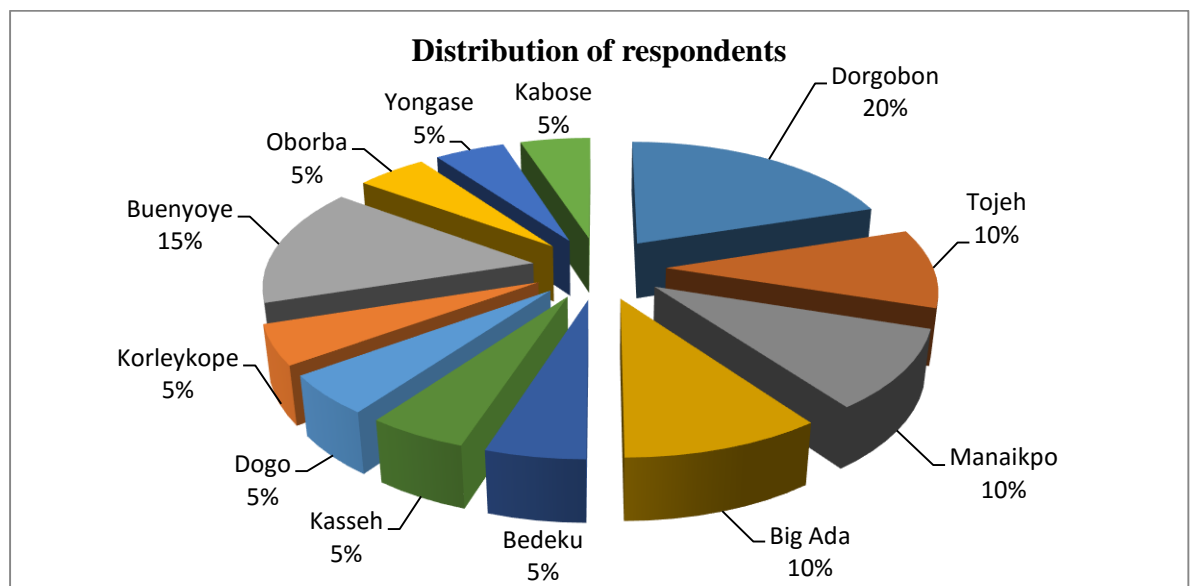


Figure 4. 22: Distribution of respondents in the study area

With respect to sex of the respondents 67% were males whilst 33% were females.

Figure 4.22 presents the age distribution of the respondents in the study area. Thirteen percent (13%) of the respondent were between the ages of 18-25 years, 17% and 38 % were between the ages of 26-35years and 36-45years respectively whilst 32 % were above 45 years at the time of the interview.

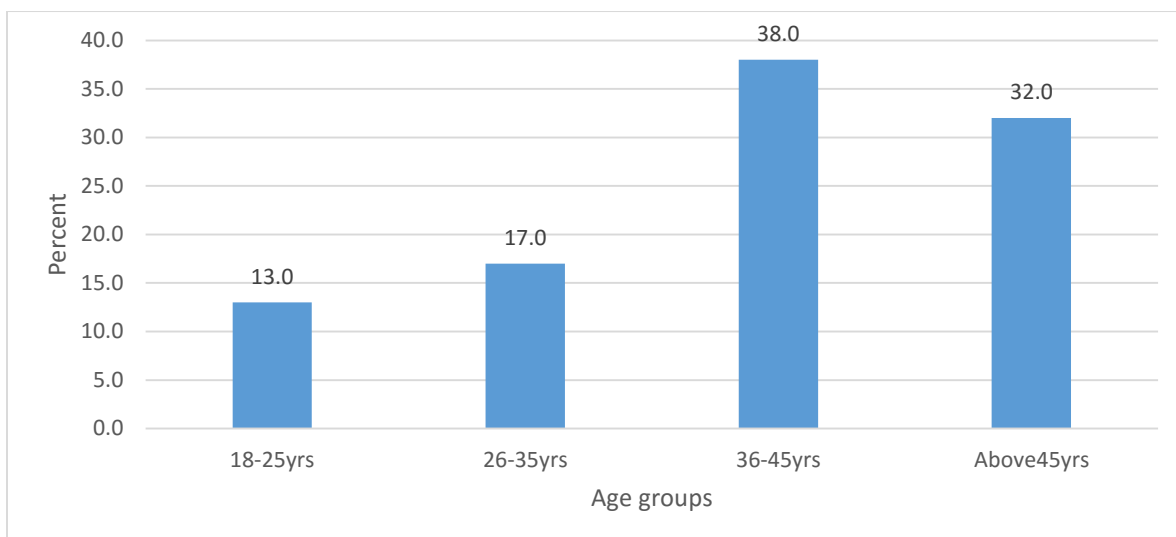


Figure 4. 23: Age groups of respondents

The crops grown by farmers in the study area included vegetables such as pepper and tomatoes as well as cassava among others. Fourteen percent (14%) of the sampled population had had SHS/6th form education, Primary (33.5%), JHS (38%) with 14.5% having no formal education at the time of the interview. The figure 4.24 illustrates the educational background of respondents in the study area.

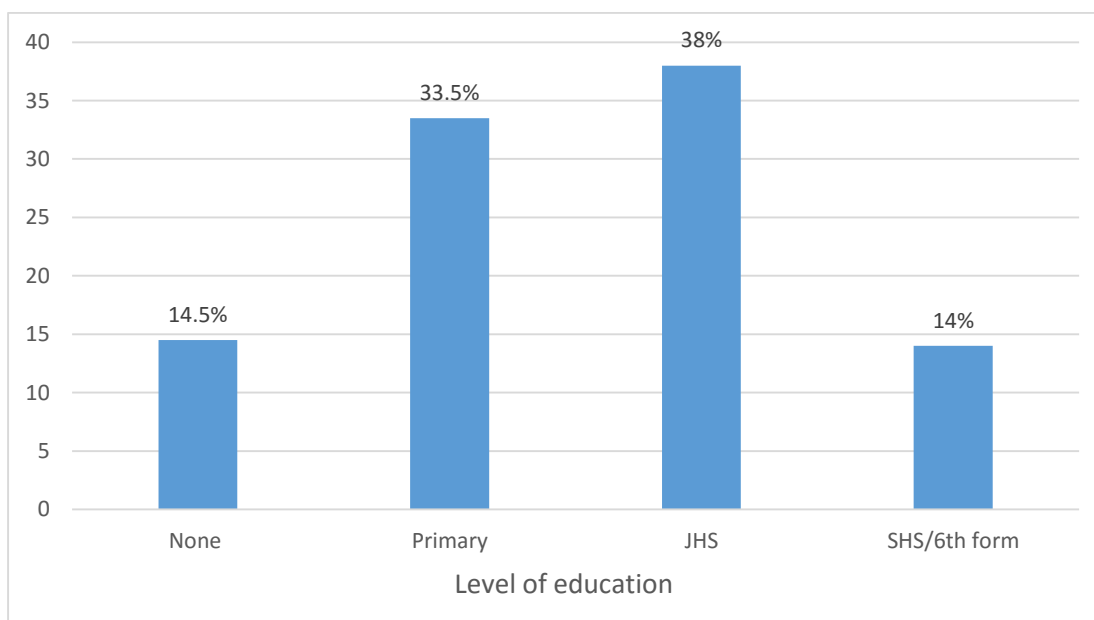


Figure 4. 24: Educational level of respondents in the study area.

The household size of the respondents were grouped into three categories, 1-5, 6-10, and more than 10 people. Majority (57%) of the respondents had household size in the 6-10 people category.

Table 4. 6: Household size of respondents.

Household size	Frequency	Percent
1-5	34	17
6-10	114	57
10 and above	52	26
Total	200	100

With regards to land tenure system, 51% of the respondents owned their farm lands through inheritance from families whilst 37.5% are acquired their lands through lease. One hundred and twenty five the respondents owned their lands and 75 of them said they had rented the land. Out of this, 102 of them had inherited the parcels of land while 13 of them said they had bought them and 10 of them said they shared the land with others, thus group ownership.

Table 4. 7: Land tenure type of respondents

Land Tenure type	Frequency	Percent
Inherited	102	51
Bought	13	6.5
Shared ownership	10	5
Leased/Rented	75	37.5
Total	200	100

Table 4.8 shows grouped farm sizes and the number of respondents that have lands falling within these groups. From the table 4.8, it is clear that majority of the farmers interviewed had farmlands with sizes ranging from 1.2 to 8.1ha. Very few had land over 8.1ha.

Table 4. 8: Respondents farm sizes.

Farm size (Ha)	Frequency	Percent
0-2.0	44	22.0
2.4-4.0	60	30.0
4.5-6.1	44	22.0
6.5-8.1	47	23.5
>8.1	5	2.5
Total	200	100.0

Majority of the respondents have farmed these lands for 10 to 22 years, while a few (7.5%) had been farming for just less than 5 years.

Figure 4.25 shows that most of the respondents that were interviewed had been farming for more than 10 years. A total of 148 respondents had been farming for more than 10 years at the time of the interview.

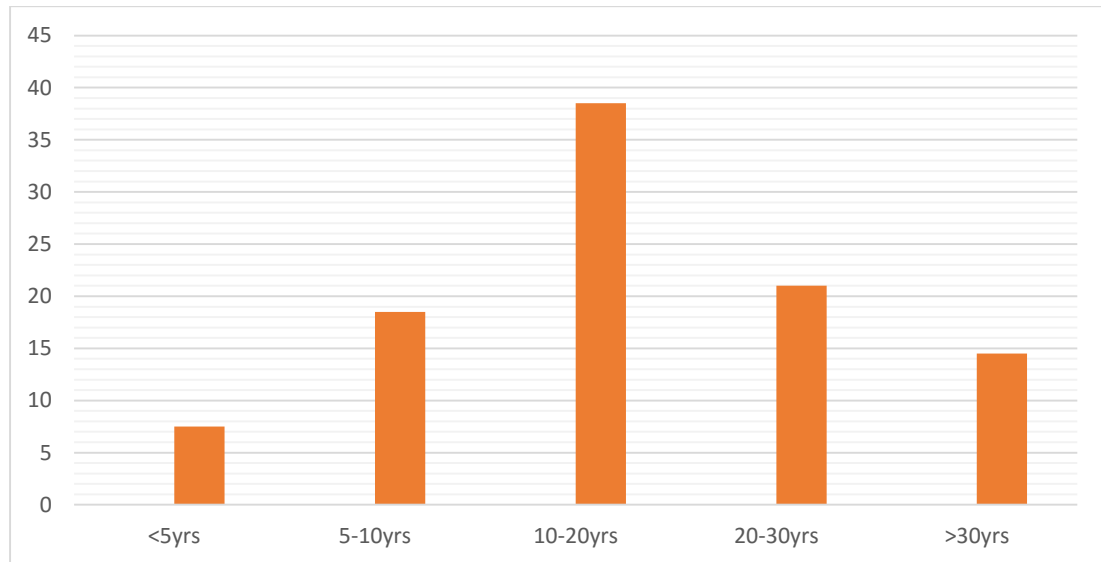


Figure 4. 25: Number of years respondents have been farming.

Out of the 200 respondents, 159 of them said they had fallowed their farm lands for one of the following reasons;

- i. Because they had no labour to help cultivate their farm lands
- ii. So their lands could regain its soil nutrients.

Moreover 49 of the respondents gave both of the above mentioned reasons which are lack of labour and to regain soil nutrients as the reasons why they fallow their farm lands.

Table 4. 9: Reasons given for fallowing farm land.

Reasons				Total
To gain soil nutrients	Lack of labour	Both	Not Applicable	
97	13	49	0	159
0	0	0	41	41
97	13	49	41	200

Table 4.9 shows the number of respondents who practiced fallowing and the reasons why they did so.

Twenty six of the respondents said they planted trees for the following reasons; providing shade on their farm land and for the purpose of harvesting the fruits for consumption.

Moreover *Azadirachta indica* (Neem) and *Acacia auriculiformis* (Earleaf Acacia) trees are the two trees the respondents used for fire wood.

Figure 4.26 shows the types of trees and the percentage of respondents who used these trees as fire wood.

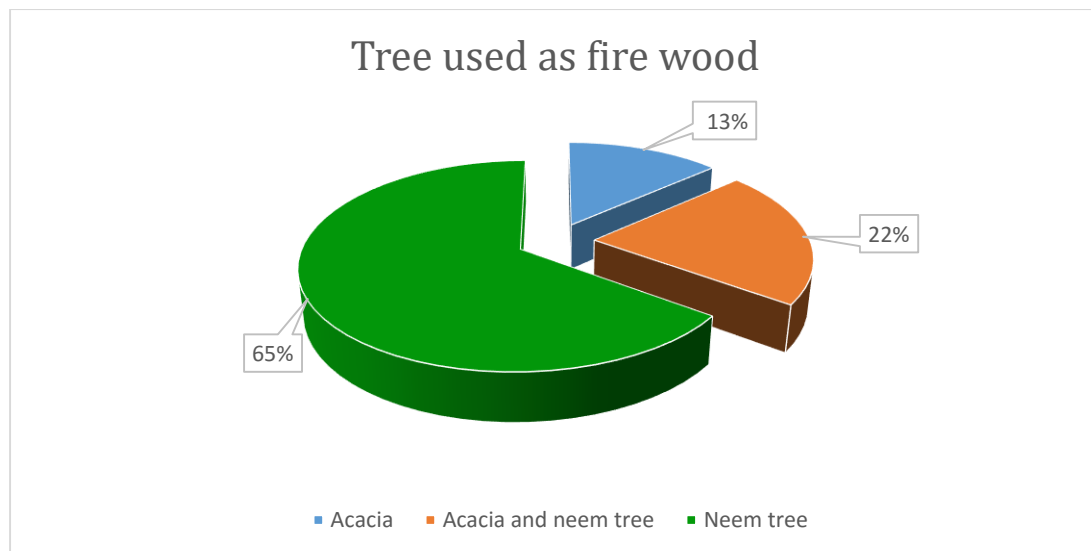


Figure 4. 26: Type of tree used as fire wood by respondents

4.6.2 Population of the LVB

The population (876,146) of the Volta Basin in 1960, rose sharply to 3,032,857 in 2000. It recorded an increase of 62% in the population between 1960 and 1970, compared to a 45% increase in 1970-1984; the period 1984-2000 experienced a 48% increase in population. Today the population calculated based on the districts that make up the LVB is 585,640.

The Ada East district director explained, an increase in population over the years had contributed to the changes in land-use and land cover. He further mentioned that the influx of people in the district during the “Asafutufiami” festival which takes place in the month of August has led to the building of hotels, guest houses, restaurants and fuel stations in recent times. This he acknowledged as a form of land-use change, as the Ada area, especially Big Ada and Ada Foah is growing its coverage of built areas. The island communities are experiencing some cover changes as well in terms of clearing vegetation for farming and clearing of mangroves to be used as fuel wood and smoking of fish.

4.6.3 Perception, Knowledge and Observed LUCC

The interviews revealed that all respondents have knowledge on land-use/cover changes. All respondents were aware of changes taking place in their environment. They had observed land related changes such as increasing farmlands while decreasing vegetation cover and increasing infrastructure while decreasing vegetation cover. The observations made by the respondents with regards to land-use change shows that majority of them had observed an increase in farmlands and decrease in vegetation. 52.5% of the then respondents agreed to the fact that they have observed increasing farm lands and decreasing vegetation cover as major land-use change. Figure 4.27 gives a representation of the people’s response to land-use changes.

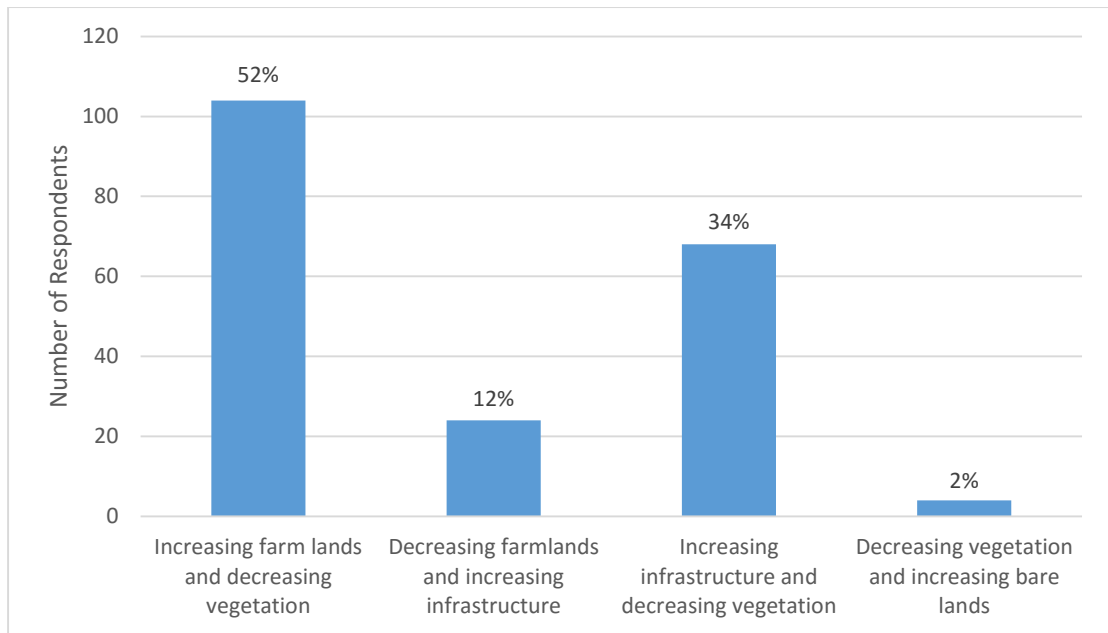


Figure 4. 27: Land-use change as observed by respondents.

116 farmers would seek to acquire land in a different area of the same district. Out of these 166, 123 would use it for farming while 43 claimed they would use it to build houses for themselves and for rent.

According to the respondents, the major drivers of land-use change considered were; population, socio economic issues like (jobs and income) rainfall variability and soil condition. They ranked the drivers based on the knowledge they have on land-use/cover change in the chart (Figure 4.28).

Land-use conflict is a challenge in the district. Lands on which people had their farms are being sold by family heads and chiefs to companies for purposes such as recreational centres. Furthermore the estuary had been sold to a real estate company which sought to develop hotel/housing units there. This he said has led to a disagreement between the people residing there and the land owners as they had not been relocated nor compensated (*Source: District Director*).

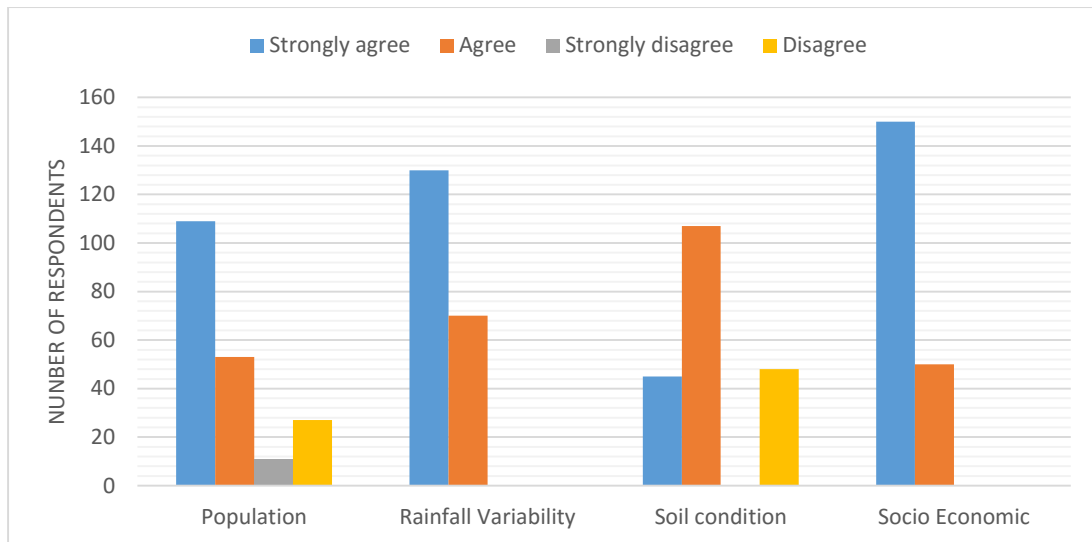


Figure 4. 28: Drivers of land-use change

Most respondents (54%) agreed that all four drivers were actually causing land-use change. However for the “socio economic” and “rainfall variability” drivers, none of the respondents disagreed. Further, a few respondents (10.7%) disagreed to population and soil condition as drivers of land-use change in the area.

4.6.3.1 Statistical Analysis

Regression analysis conducted to establish the causality between land-use change and drivers of land-use changes, revealed that there is a significant relationship between land-use change and Population, rainfall variability, socio-economic conditions and soil condition as shown by the global test of significance ($F=21.5$, $P<0.05$)(Table 4.5). This means population, poor soil condition, rainfall variability and socio-economic conditions jointly determines or influences the kind of land-use adopted. An adjusted R-Square of 0.794 obtained from the analysis means population, rainfall variability, soil conditions and socio-economic conditions jointly determines 79% of the variance in land-use change.

However when the t-test was used to conduct an individual test of significance; population, rainfall variability and socio-economic conditions significantly influenced

the type of land-use change ($P < 0.05$) but soil condition did not ($P > 0.05$) (see Appendix 4). The regression analysis that was used to determine the drivers of land-use change ascertained from the socio economic data showed a significant relationship between land-use changes and the independent variables population, rainfall variability, socio economic conditions and soil condition. This analysis showed that there was 21% of other factors unaccounted for, which influenced land-use change.

4.6.4 Knowledge and Perceptions on Climate Change

Majority (64%) of respondents had knowledge in climate change whilst the remaining 36% had no knowledge. The respondents level of knowledge on climate change were then sought to ascertain their level of understanding of issues related to climate change. 36% of them had no knowledge, limited knowledge (53%) and 11% had some knowledge at the time of the interview. Figure 4.29 shows the knowledge levels of the respondents on climate change.

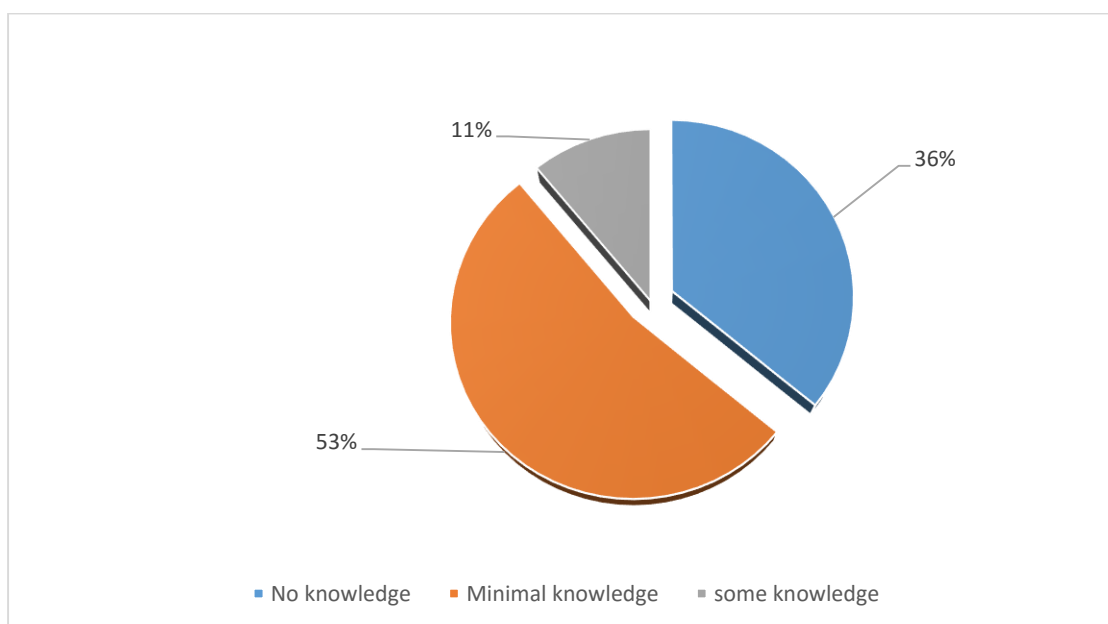


Figure 4. 29: Knowledge level of respondents on climate change

All respondents had observed an increase in temperature. However 121 said they had observed a decrease in rainfall and 79 had observed a fluctuating pattern.

According to the respondents, the earliest month in which they start planting is March. In early March, some of them grow watermelon in preparation for the planting major crops. Thus majority of the farmers start planting in March and April. Table 4.10 illustrates this.

Interestingly some older farmers, (32 of them) claimed they could tell if it was going to rain or not in the near future (days ahead) by looking up at how the sun appeared in the atmosphere.

Table 4. 10: Month for planting crops

Month	Frequency	Percent (%)
April	52	26.0
April and May	1	0.5
June	21	10.5
March	78	39.0
May	48	24.0
Total	200	100.0

All respondents had changed the month in which they planted their crops in certain years. The major reason given for this change in planting time was because of the change in the onset of rains. Other reasons however included, not being able to purchase seeds and ploughing farmland (economic reasons).

Even though there is a general planting month for the growing season every year, a fruit such as *Citrillus lanatus sp.* (water melon), which is mainly grown very close to the coastal areas has a different planting month. The Ada East district is the largest watermelon producer in the LVB.

Table 4.11 illustrates the month in which respondents considered beginning of the rainy season.

Table 4. 11: Month in which rains begin (respondents view)

Month	Frequency	Percent
February	29	14.5
March	62	31.0
April	46	23.0
April and May	2	1.0
May	56	28.0
June	5	2.5
Total	200	100.0

The respondents claimed that the onset of the rainy season was the months of February, March, April and May.

Almost all of the respondents affirmed, that there was a change in the length of rainy season. 116 said it was decreasing, while 84 of them said it was fluctuating. Further, out of the 181 who responded yes to a change in their crop yield, 126 had experienced a decrease in their yield whilst 55 had experienced a fluctuating nature of crop yield over the past 10 years. The reasons the respondents gave for the changes in their crop yield included low soil fertility, less rain, diseases and application of fertilizers.

The farmers who claimed had experienced a decrease in yield all said the changed rainfall pattern and quantity was a major contributing factor. Other farmers who had experienced a fluctuating nature claimed to have gotten high yields in certain years due to the application of chemical fertilizer.

Figure 4.30 shows, the respondents view on how rainfall and temperature have affected their crop yield and soil condition.

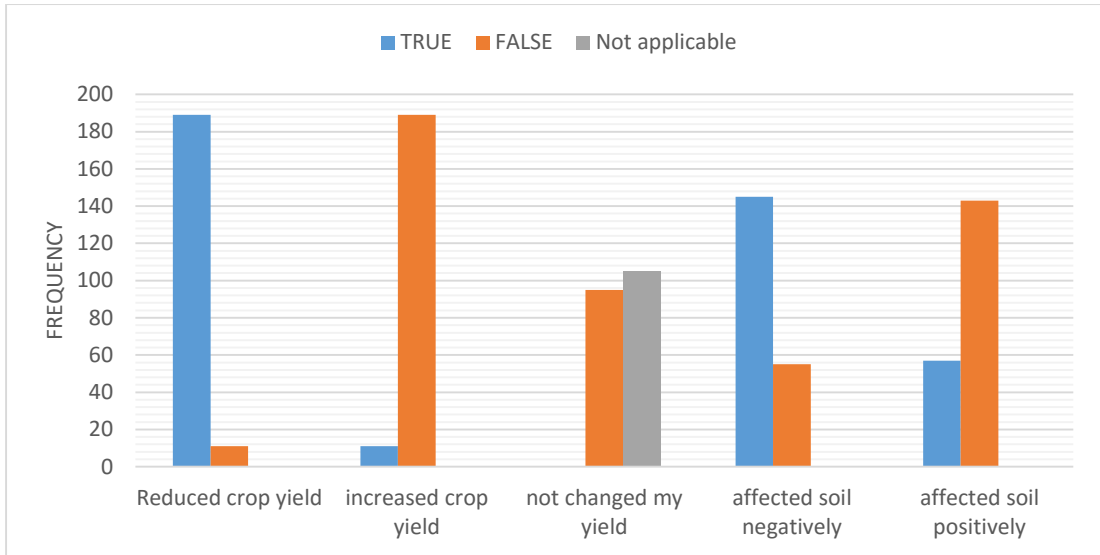


Figure 4. 30: Respondents view on effects of rainfall and temperature on their yield and soil condition

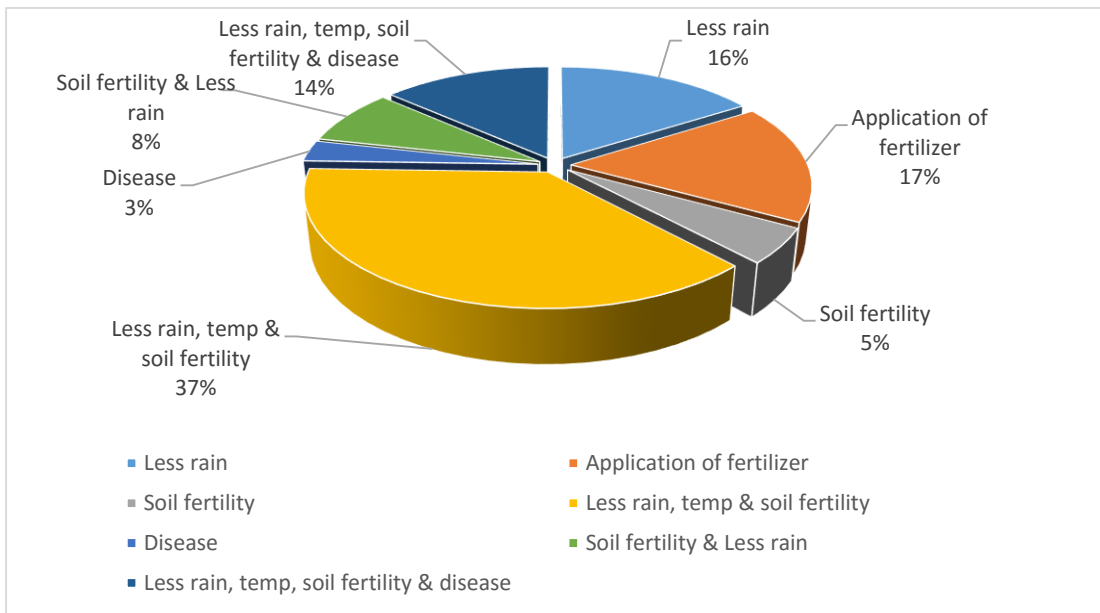


Figure 4. 31: Factors that influence farmer crop yield

110 respondents had received professional advice from agricultural extension officers.

Table 4.12 shows the interventions proposed by agricultural extension officers to the respondents.

Table 4. 12: Advice given to respondents by agricultural extension officers

Advice	Frequency	Percent
Mulching	66	33.0
Proper use of fertilizer	30	15.0
Use of drought resistant seeds	72	36.0
Make sunken beds	26	13.0
Construction of reservoir	6	3.0
Total	200	100

The table (4.12) shows that the most frequent advice given to farmers by extension officers are mulching and the use of drought resistant seeds.

158 farmers had made changes to their farming methods.

Figure 4.32 shows the different methods adopted to help reduce vulnerability to changing rainfall and temperature.

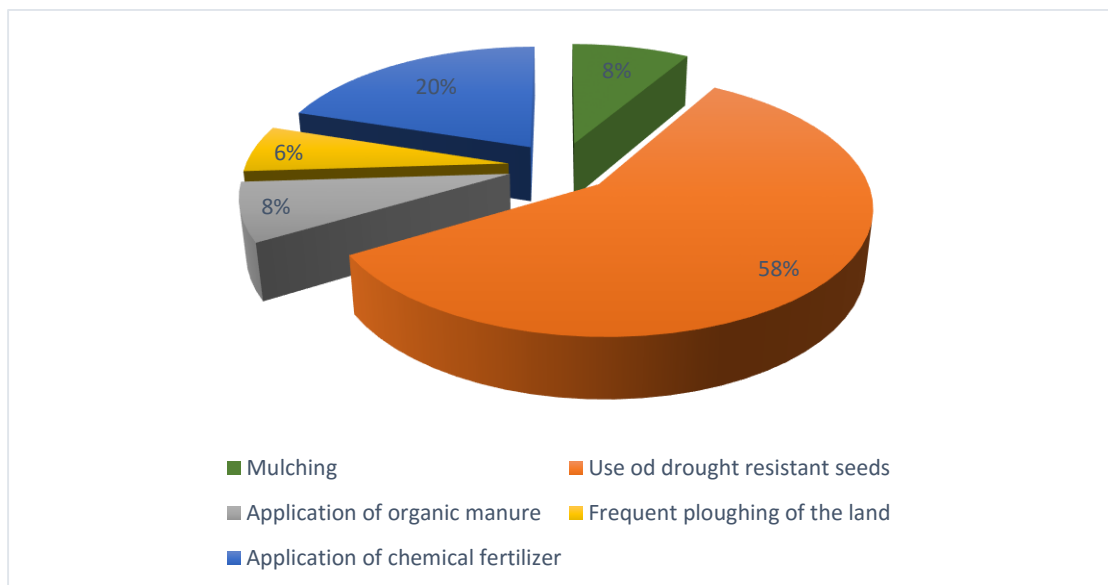


Figure 4. 32: Farmer adaptation methods to changing rainfall and temperature

The use of drought resistant seeds appears to be the most used method amongst the other methods the respondents engaged in. Some of the drought resistant crop varieties grown include “pectomech” and “nema giant” for tomato, “mamaba” for maize, “bankye hema” for cassava pepper and tomato.

4.6.4.1 Statistical Analysis on relationship between farmers knowledge of climate change and adaptation measures.

The chi square test was used to establish the relationship between the farmers knowledge on climate change and the adaptation measures or changes they have made to their farming practices due to change in rainfall and temperature. The test revealed that there was no significant relationship (chi square =1.27, $p>0.05$).

CHAPTER FIVE

DISCUSSION

Studies on Land-use/cover change as well as climate conditions and its relationship to crop productivity and crop suitability was conducted in the Lower Volta Basin to provide additional information which could help solve challenges and bridge the knowledge gap in studies conducted in the LVB. This chapter presents further insight into the results obtained from this study and a linkage to other studies conducted in the LVB and Volta Basin as a whole.

5.1 Land –Use/Cover Change of Lower Volta Basin

The land cover type of the Lower Volta Basin is generally savannah shrub characterized by many "neem" trees, shrubs and coastal savannah lands (Koku, 2002). This naturally has associated to it an interesting ecosystem. From this study, the land-use types that can be found in this area today includes grazing lands (pasture), farmlands (rain fed and irrigated), built-up areas which include houses, schools, hospitals, hotels guest houses, a few industries, roads lorry stations and markets.

Despite the changes that have taken place in the Lower Volta Basin, these land-use changes have remained the same. Though there has been an increase in some and a decrease in some of the land-use types. According to Andah *et al.*, (2003), the main land-use of the Lower Volta Basin is short bush fallow cultivation along the banks of the river, animal grazing and fishing. They also mentioned of how the cutting of wood had become an extensive economic activity in the southern transitional zone.

Using remote sensing techniques to develop land-use classification mapping for this study was useful and presented a detailed way to improve the selection of areas designed to agricultural, urban and/or industrial areas of a region as reported in (Rai *et al.*, 2011). Despite the different methods for classifying satellite imagery, this study employed the maximum likelihood classifier (supervised classification) method. According to Stemmler and Su (1993), it is a primary algorithm for supervised classification of image data and offers best results. While some researchers such as Tutu (2008) and Plantier *et al.*, (2006), concluded in their study that unsupervised classification had demonstrated improved accuracy of land-use/cover classification, others (Richards, 1995; Akgun *et al.*, 2004), have also claimed that the maximum likelihood method is found to be more applicable and reliable for (especially Landsat) satellite image classification purposes. In this study, the maximum likelihood method under the supervised classification system produced very good results. In a similar research by Duadze (2004), in the Volta Basin of Ghana, supervised classification proved to derive accurate land-use and land cover maps for the savannah ecosystem in the Volta Basin of Ghana. Duadze went on to say that the maximum likelihood classification of LANDSAT images for a large area can be done successfully with high level accuracy.

However in classifying the satellite images for this study, the ISO data unsupervised classification method was employed prior to field visit, in order to determine strata for ground truth (Torahi and Suresh, 2011) and to analyse also, how the mixed pixels of certain features in the image would best fit when combined to other land-use features.

NDVI is mostly used as a greenness parameter which indicates biophysical activity of a land surface (Hansing and Wittich, 1995). It is well known that there is a direct correlation between NDVI and the amount of stress vegetation experiences (Travis, 2006). Research conducted by Travis reveals that NDVI could be used to determine drought effects on specific land use/cover types.

After classification was done a statistical analysis was run to check the accuracy of the classified image to the original Landsat image. Important features such as farmlands and built up-areas had 68.9% and 69.5% producer accuracy respectively and 93.65%, 71.71% for farmlands and built-up areas user accuracy respectively. Duadze (2004), indicates that, an overall statement of accuracy is useful, but it does not say anything about the accuracy of the classified image as a whole and thus the need to look at the producer and user accuracies. Gumma (2010), reported that in African countries, it is generally difficult to map land-use and land cover classes because there are no large agricultural delineations in agriculture forms. Implying that agriculture and other land-use and land cover areas are very similar because of the nature of small-holder agriculture which dominates. Furthermore, in Ghana and most parts of Africa, a single plot of land is usually occupied by different land-use types. This usually gives rise to mixed pixels. It is for this reason that ground truthing and supervised classification methods are suitable for this kind of study.

Several change detection methods have been developed using conventional image differencing (consider change in reflection), using image ratio, normalized difference vegetation index, principal component analysis, multi-date image classification, post-classification comparison, manual onscreen digitization (El-Raey *et al.*, 1999). In a

comprehensive study conducted by Civco *et al.* (2002), it was concluded after studying all the change detection methods, that there is no single best way in which to perform change analysis. They further suggested that for any method being used, the accuracy depends heavily on each of the input maps. In this study the main method employed to identify land-use changes in the Lower Volta Basin was the image differencing and post classification comparison method. However Muttitanon and Tripathi (2005), reported that the most common approach used for change detection is digitizing and overlaying to compare the data sets from two dates in order to detect land-use changes of the first date data that have been replaced by the new land-use in the second date. In Turner *et al.* (1993), it was made clear that there are two forms of land-use/cover change. This they said was conversion and modification. In this study the change detection analysis was specifically focused on land-use/cover features that had been converted or replaced by another land-use/cover type rather than changes that affected the character of land cover and land-use type.

The change detection analysis in this study revealed that, farm lands had increased. Implying that farming activity and/or the surface area of both rain fed and agricultural activities had increased over the time period studied. Increasing farmlands also meant that some type of land cover was being converted. Crop data obtained from Lower Manya Krobo and Ada East districts revealed that indeed the area cropped per farmer increased over the years (Figures 4.12, 4.13, 4.14 and 4.15). This study showed that grass lands, mixed savannah and some burnt areas were changed into farming fields. This meant that grass lands and other sparsely vegetated areas had decreased as they had been converted to farmlands. On the contrary it should be noted that farmlands, when abandoned, could possibly be converted into grasslands or bushes as reported by

(Shindler, 2009). There is also no doubt that though the bush fallow system is still practiced in the area. An abandoned farm field could remain bare due to environmental conditions such as topology as well as changing rainfall patterns. Mantey and Tagoe, (2013) in their study, showed that there had been a decrease in sparse vegetation from 3,604.71km² (1985) to 2,784km² (2013) around the Lower Volta River Basin which is similar to results obtained for mixed savannah vegetation in this study.

With regards to burnt areas, the Lower Volta Basin is characterized by a random increase and decrease of burnt areas annually. This is mainly because of the herders who burn grass lands so as to gain fresh grass for their cattle to feed on and farmers who burn sparsely vegetated areas to prepare land for farming. So even though some burnt area has been lost to farmlands, it should be noted that these burnt areas keep increasing and decreasing. Bush burning is used to clear land for agricultural purposes, hunting, creating fire belts at the onset of the dry season, and inducing rapid re-growth of rangeland during the dry season, which often results in enormous damage to vegetation, wildlife, and properties because it is typically are not controlled (Boubacar, 2005). Furthermore, increasing temperatures and dry spells as recorded from the climate data obtained could influence increased burnt areas and bare lands.

The UNEP-GEF (2010), reports that regular burning, grazing of livestock and cultivation have resulted in the survival of relatively few trees. The vegetation in these areas is thus quite open and is dominated by short grasses. Andah *et al.* (2003), mentioned that annual bush burning takes place since grazing lands are poor. Forests and protected areas (densely vegetated areas) have reduced according to the change detection statistical analysis.

From the classified image (Figure 4.3), it is evident the forested area in the Kpong area has reduced. The protected area in and around the Shai hills which is quite a distance from the river can be said to have been maintained quite well. However a careful look at (Figure 4.3) shows that some bare and burnt lands have developed close to the forest reserve. Development of land by putting up structures is one land-use type which has also increased in the LVB. This is due to an increase in population and commercial activities in certain major towns like. Kpong, Aveyime, Akuse, Tefle and Big Ada. Barry *et al.* (2005), reported that urban land-use is limited to a few towns like Kpandu, Kwamekrom, Akuse, Sogakope and Ada Foah, however this study's results shows that other towns in the Lower Volta Basin including Kpong, Tefle, Kasseh and Big Ada are growing in size. Urbanization can be ranked as one of the well-known LUCC. However, since urban areas occupy a relatively small fraction of the earth's surface (Gruebler, 1994), it may lead to a misconception that the growth of urban areas can be ignored in land-use studies (Heilig, 1994). Urbanization in reality affects land-use change elsewhere at large scale, especially through strong linkages between urban and rural areas (Lambin *et al.*, 2001).

Since farming is the main economic activity of the people in this region, majority of the people are farmers and would farm on more available lands if they have the means.

Recent developments in land use, particularly below the Akosombo dam include irrigated rice, sugar cane and vegetable cultivation in the areas immediately adjoining the Volta River (Andah *et al.*, 2003). They further proclaimed that, with increasing population and growing demand for food, the economy can no longer depend on rain fed agriculture. For the past twenty years Ghana has experienced drought periods and erratic rainfall. Irrigation is therefore the way forward in agriculture if the country is to

solve the food security problem. This study confirms that rain fed agriculture is not sustainable and thus the needed shift to irrigation to help keep and improve upon crop production.

Moreover, private companies, such as Golden Exotics Co. Ltd. have taken over lands from the locals and established large scale irrigated plantations. Even though local small scale farmlands have been overtaken by these private companies, employment has been created for the people (locals) in the area. The government has invested in large scale irrigated rice farms which is leased to local farmers to help them improve upon their livelihood and reduce poverty. However this is arisen due to the lack of capacity of the local farmers to engage in large scale irrigated farming. Even though irrigation development in sub-Saharan Africa has remained well below its physical potential, international donors have shown renewed interest in irrigation investments due to the far reaching benefits of irrigation farming, several investments in sub-Saharan Africa have been directed towards irrigation development. These investments have been driven by government policies (colonial and postcolonial), multinational donor agencies, private investors, markets, and by technological innovations such as, drip, motorized pumps and treadle pumps (Ofosu, 2011).

Further downstream, towards the Big Ada area to Ada Foah, farming activities have been affected. (Agbenyo 2009), says the hydropower schemes have made farming more difficult and expensive in the study communities. This problem was attributed to the seizure of regular seasonal floods that deposited silts on farmlands and wetted the farmlands for easy cultivation on the floodplains. Farmers in the communities now

maintain soil fertility through application of chemical fertilizers and also hire the services of tractors for tilling farmlands.

In a study by Ofofu (2011), in the Upper East region of Ghana, it was reported that the major contributor to the expansion of irrigation in the study area is the rising demand for vegetable products in the urban centres of southern Ghana. This is very true as almost all the vegetable farmers in the Ada East area especially of the LVB claim to produce vegetables for the city (Accra). A social survey conducted in this study confirms that there is a high demand for vegetables in the city. This is one of the major reasons (high demand) why there is an upsurge of vegetable irrigation farming in the Ada Foah township (see plate 4.8, 4.9 and 4.10).

Furthermore Ofofu (2011), points out that there are three major sources, of vegetables (especially tomatoes) for urban centres in Ghana (coastal area, middle-belt and Upper East Region). The increasing rate of urbanisation in Ghana, coupled with increasing population has both contributed to the increasing demand for vegetables (Ofofu, 2011).

Interestingly, according to Rosegrant *et al.*, (2001) and Hussain (2005), in areas such as South-East Asia and East Asia investments in irrigation have yielded significant impacts in terms of improving food security and poverty reduction, however the same cannot be said for sub-Saharan Africa. The FAO (2006), reports that Regions such as South-East Asia have almost exhausted their irrigation development potential, making the potential irrigable land in Sub-Saharan Africa a major hope for the world in terms of feeding the future population.

5.2 Incidence and Trend of Climate

"Similar to the Sahel and Mid-Ghana, the Volta Basin have experienced significant downward trending rainfall since the 1970s" (Owusu, 2009). Owusu further mentions in his research that the southerly areas of the Volta Basin have experienced shifts in their bimodal regimes. He says, the dry spell (July-August) that separated the two rainy peaks has experienced increases in both the average total rainfall and the number of rainy days. And he goes on to discuss how food security could be threatened and household incomes eroded due to declining rainfall in nations of West Africa who have their economies being highly dependent on rain.

It is known that a country such as Ghana, in the area of agriculture provides a high percentage of employment but with declining rainfall totals there is higher risks for rain-fed agriculture.

The analysed rainfall data in this study is similar to what Lemoalle and Condappa (2010) reported. They reported that "The decades of the 1950s and 1960s were relatively wet, while the 1970s and 1980s were drier". In Owusu (2007), there was a general observation of declining mean annual rainfall and the zone B in which the LVB falls was reported to have seen a reduction from around 1200mm to about 1000mm.

It is to be noted however that, land surface changes can affect local precipitation and temperatures. Vegetation patterns and soil composition can influence cloud formation and precipitation through their impact on evaporation and convection (the rise of air) (De Sherbinin, 2002).

5.3 Perception and Knowledge on Land Use

With all the respondents having observed changes in land-use/cover in their vicinity, majority of them had observed an increase in farmlands to which they had contributed to. The figure (4.23) shows clearly that majority had observed an increase in farmlands and decreasing vegetation. This suggested that many more lands were being cleared for cultivation of crops.

The major drivers of land-use change considered included population, socio economic status (poverty/job), rainfall variability and soil conditions. The study revealed that the farmers did not consider poor soil quality as a major cause or drive land-use change in the area. According to Braimoh (2004), soil quality which is a biophysical variable, does not directly influence land cover/ use change but can influence land-use decisions. For instance a decline in soil fertility might cause farmers to move to uncultivated areas to farm. Rainfall variability and Socio economic factors were considered the highest by the farmers as the most influencing drivers of land-use change. This is not surprising as the main economic activity of the LVB is agriculture (rain fed) and majority of the population are into farming.

5.4 Perception and Knowledge on Climate Change

Normally the rainy season begins in May/June with some rains earlier in April. There is however a dry spell in August. The rainy season continues from September till the month of November. In the south, rainfall is distributed bi modally with long rains from April to July and short rains from September to November. The risk of within-season dry spells influences cropping choices (Lemoalle and Condappa, 2010). Owusu (2009), reported in his study that there are striking differences (including onset of rains,

intensity of rains and duration of rains) in the rainfall regimes and the regional strengths of the causal mechanisms of variability in the Sahel and the Guinea coast regions.

The uni-modal regime of the Sahel seems to have suffered declines throughout the short rainy season (June-September), while the more southerly areas have experienced shifts in their bi-modal regimes. The short dry spell (July-August) that separated the two rainy peaks has experienced increases in both the average total rainfall and the number of rain days. The response from farmers showed that the earliest planting month was in March with some planting in April and others in May and June.

All farmers involved in the survey reported that they change the month in which they plant sometimes. Some of the farmers planted early because they claimed they had noticed the rains starting early during the year in recent times. However many also planted (nursed) early in the month of March and April and transplanted the seedlings to their farms during the main rainy season month (June). The farmers interviewed also believed that the month of the start the rainy season had changed from early March to late March and April, with some others saying May. Recently, detailed atmospheric modelling over the region shows that in the near future too, the onset of rainy season will shift to later periods in the year, roughly from April towards May (Van de Giesen *et al.*, 2010). Jung and Kunstmann (2007), also predicted that the change in the onset of rainy season may continue to move forward. Furthermore Laux *et al.* (2007), used principal component analysis to show that there is, indeed, a statistically significant shift forward in several components of 0.4–0.8 days/year.

It is clear that rainfall variability in recent times is making it difficult for farmers to develop a systematic means of growing crops with regards to planting (Van de Giesen *et al.*, 2010). It was agreed by 58% of farmers that there was a decrease in the length of the rainy season whilst 42% said they had observed a fluctuating trend.

5.5 Crop Suitability

This study presents the first use of the EcoCrop model to map crop suitability in the Lower Volta Basin and Ghana as a whole. It has however been used in different countries to map out suitable areas for growing crops based on climatic factors. In a study by Parthasarathy *et al.* (2008), the EcoCrop model was used to map out suitable areas for growing ginger in some states (Orissa, West Bengal, Mizoram and Kerala) of India. Literature reveals that most of the studies conducted using the EcoCrop model have been done using large geographical areas such as states and especially countries.

The model maps presented in Chapter 4 of this study reveal how future projected rainfall and temperature are going to affect areas suitable for growing crops (maize, cassava and pepper). For instance the *Zea mays* (maize) crop is suitable in almost the whole area of the LVB under current climatic conditions, but projected future conditions renders some areas marginal and very marginal (see figure 4.18 and 4.19). In each of the suitability maps, the coastal areas are shown to have excellent conditions for crops to grow. However it is to be noted that this model makes use of climate parameters only and thus does not take soil into consideration. Moreover the EcoCrop model provides an opportunity for agriculturist, spatial analysts and policy makers to analyse the effect of climate change on crop productivity to inform development of adaptive strategies and policy to minimize the negative impact of climate change on

crops (Yumbya *et al.*, 2014). Yumbya further stated that this model provides opportunities for further potential research to fine tune the model and communicate model predictions better.

The DIVA GIS programme was used in a study on model comparison for the distribution of crops by Villordon *et al.*, (2006). It was reported in their study, that detailed information on the geographic distribution of a crop is important in planning efficient conservation strategies, but is often not available, particularly for minor crops. The modelling of species distribution has become an important tool in biogeography, evolution ecology, conservation and invasive species management (Anderson *et al.*, 2003 and Williams 2005).

5.6 Socio Economic Study

Agriculture is the main economic/livelihood in the Lower Volta Basin just as in the whole Volta Basin (Codjoe, 2004). It was noticed that about 86% of the farmers were educated.

The population of the main Volta sub-Basin more than doubled between 1960 and 1984, a period of 24 years, and had been projected to reach 4,268,927 in 2010, based on annual inter censal growth rate of 2.5% during the period 1984-2000 (Codjoe 2004). In Mantey and Tagoe (2013), it was also stated that according to Ghana Statistical Service, the population in the Basin is expected to increase by 80% within a twenty-five year period (2000-2025) due to the high average population growth rate of 2.54%. Lemoalle (2007) said, the combination of demography and climate change defines new pressures on the environment. This sets the scene for an evolving and increasing food demand,

and for the necessary adaptation of the agricultural production, productivity and water uses.

Household size mostly fell within 6-10 based on the survey conducted. The traditional rural settlement of Ghana usually has a larger household size as compared to urban settlements. A number of reasons, including the need to get more hands to work on farming fields as well as the extended family system (living together with relatives) leads to an increase in household size. A study conducted in the Volta Basin of Ghana by Braimoh (2004), showed that a change in house hold size influenced land-use change (farm size), confirming that land–use change is driven by increase in demand for food.

Land ownership in the LVB is usually passed on from one generation to the next as most of the land is owned by families/clans and Chief's. From the survey, 51% of respondents had inherited their lands. Furthermore, it was noticed during the field survey, through interaction with the local farmers and what was captured in the questionnaire interview that most of them did not own just one parcel of land. The reason being that the most of the land in the study area belongs to families and chiefs which have been passed on from generation to generation. This means families have very large plots of land. The availability of land as compared to the population tells why one family could have very large (larger than 10 hectares) plots of land. Farmers therefore have parcels of land in different locations.

Most of the farmers interviewed had not less than 3 acres (2.1ha) for a parcel of land. With such large tracts of land, some of the farmers mentioned that one of the reasons for leaving their land to fallow is because of lack of labour to cultivate the fields. Also

the survey revealed, that all those who had not fallowed their farming fields before are those that had less than 5 acres of land.

Field observations during field visits supported by responses to questions reveal that the *Azadirachta Indica* (neem tree) is very dominant in the LVB. It grows everywhere and could be considered the most dominant tree species in the LVB. In this region most thickets are made up of this kind of tree. However there has been very little mention of this in literature as most studies and research are much more concerned with the economically valuable trees such as Shea and Cocoa. Acacias were also another species the local people fetch for firewood. Most of the people did not plant trees, however efforts have been made through various programmes such as, Project for Improving Water Governance in the Volta Basin (PAGEV) and the Greening Basin Initiative (GBI) to encourage tree planting. In some other parts of the Volta Basin, Barry *et al* (2005), reported of an afforestation project funded by the VRA, with the aim of encouraging fishermen to plant wood lots and adopt the use of improved stoves, which use less fuel wood for fish smoking. Almost all of these programmes have not been sustainable as bush burning and animal grazing had been identified as major causes of unsuccessful tree planting projects (Okine and Nyarko, 2008).

5.7 Agriculture In the LVB

Many of the interviewed farmers had experienced a decline in crop yield over a 10 year period whilst others said they had experienced an increase and decrease trend.

From the figure 4.21, it is obvious that there wasn't one person who claimed that rainfall and temperature had not affected their yield. Figure 4.22, shows the various factors the farmers said affected their crop yield. From this chart it is noticeable that a lot more

farmers didn't think rainfall only was the reason for the change in their yields. Moreover the "application of fertilizer" factor was considered the best intervention method by those who had experienced an increase in crop yield.

In each district of the LVB there are agricultural extension officers who are however usually not adequate in terms of number. Field visits revealed that the extension officers in the Lower Manya Krobo district and Ada East district were inadequate in number as compared to the number of farmers in the district. The extension officers, educate, and aid the farmers with challenges they face to help achieve higher yields. More than half of the farmers engaged in the use of drought resistant seeds which cost a little higher than the normal seeds. The farmers claimed the extension officers encouraged them to use these seeds. Some other farmers explained, ploughing the field helped in keeping the soil moist for a longer period as run off was reduced. Furthermore some of the farmers said they could not afford to buy fertilizer and drought resistant seeds.

Moreover from this study, farming practices adopted by farmers due to changes in temperature and rainfall patterns does not depend on their knowledge of climate change. Even though recent research has suggested a possible shift to groundwater for agriculture because of the unreliable nature of rainfall (Masiyandima and Giordano, 2007; Tuinhof *et al.*, 2011), efforts are being made to maintain crop yields and reduce poverty.

Public and private owned irrigation systems have been setup in the Ada East district. The Ada small farm irrigation scheme was established to provide small holder farmers on the stretch between Kasseh and Big Ada with an alternative source of water for

farming. Moreover, as in most other regions of Africa, the irrigated area in the Volta Basin is only a small fraction (<0.5%) of the total cultivated area, and is also only a small fraction of the irrigation potential (2%) Lemoalle and Condappa, (2010). Furthermore, the authors pointed out that even though the areas for which irrigation water is available from the Akosombo and Kpong dams, they have not been fully exploited. It has become clear from this study that farmers do not have any laid down adaptation measures put in place to address the issue of changing climate and thus practice what the extension officers tell them.

It is projected that agricultural production and access to food in many African countries would be severely affected (UNFCCC, 2013). The northern region of Ghana has started experiencing this phenomenon and if nothing is done about it, food security would seriously be affected and the problem of malnutrition would be exacerbated Source: (<https://mofafoodsecurity.wordpress.com/food-security-situation-in-ghana>).

It is an issue of major concern (Obeng, 2000) that agricultural production in Ghana is a terrible recurring cycle of poor farmer incomes irrespective of production outcomes. Thus when the weather is good and output levels are high, gluts force prices down and farmers are confronted with low incomes. On the other hand, when bad rains lead to low production outcomes, there is nothing to sell and production outcomes are limited to subsistence.

According to the Ghana Statistical Survey (GSS) (2014), a little over half (51.5%) of households in Ghana own or operate a farm. Even though, farming is mostly rural and

engages about 83% of rural household, it is much common in rural savannah areas with about 93% of households involved.

Research by Sivakumar and Hatfield (1990), showed that rainfall is spatially heterogeneous, and so farmers scatter their fields around their vicinity to minimize risk. Field visit, interaction with the farmers as well as the classified satellite imagery confirmed what Sivakumar and Hatfield had stated in their study. Granaham (2012), reported that since agricultural practice is dependent on the availability and distribution of rainfall, farmers suffer significant loss when rain fails. The Volta Basin is also noted for livestock production as it happens to be almost entirely within the savannah grassland belt of the country. The natural grass serves as grazing fields providing food for cattle, sheep and goats (UNEP-GEF, 2010). GSS also informs that livestock rearing is concentrated in the rural savannah where 86% of drought animals can be found. Out of this, 63% they said, are cattle.

A discussion with the older farmers of the Dorgobom community revealed that the area (Dorgobom) used to be the hub of grazing fields for cattle. One of the farmers explained that as a teenager he could clearly recall how cattle came all the way from as far as Ningo Prampram to graze in the Dorgobom area and neighbouring communities. According to the older farmers the district agricultural office was setup there in Dorgobom.

Regardless of the rainfall variability and trend in both districts, yields are kept generally high. Apart from the large cropped area contributing to increased yields, Sagoe (2006), said, improved farming technologies which includes planting more than two types of

varieties of root crops and planting improved varieties that are drought tolerant help keep yields high. Also Lemoalle and Condappa (2010) claim, fertilizer and small-scale irrigation can improve the yields of rain fed crops and alleviate poverty. It is to be noted that rainfall is relatively abundant in the Lower Volta Basin, however the temporal and spatial distribution of rainfall influences agriculture more than total rainfall (Lemoalle and Condappa, 2010).

The maize crop follows a very similar trend. A direct relationship between maize production and area cultivated is observed figure 4.13. Area cultivated for maize was generally higher in Lower Manya Krobo for the period (2005-2013) as compared to Ada East. The highest recording yield for the said period in Ada East was 25,387.2 in 2009 and 28,887.1 in 2012 for Lower Manya Krobo district. Ada East district recorded a decline in yield for both crops (cassava and maize) in 2012. It was also the lowest recorded yield for the period (2005-2013). Lower Manya Krobo, also experienced a sharp decline in yield as well as cultivated area, for both crops in 2013. This is because the district was split into upper and Lower Manya Krobo.

According to Terrasson *et al.* (2009), simulation modelling showed that fertilizer (N40, P13 kg/ha) can increase yield potential of most soils of the Volta Basin. Moreover Lemoalle and Condappa (2010), reported that if the climate trend remains constant, the greater production of food required cannot be achieved only by increasing area of cultivation. Furthermore an increase in area is not always in proportion with the increase in production (Parthasarathy *et al.*, 2008). An increase in input systems to maximize production to necessary levels will be needed.

From analysed climate data and crop yield it is established that rainfall amounts could be high for a particular year, however low yields. This could be due to reasons such as, the rains not falling during the growing season but rather outside of it or the rains falling heavily and for long periods during the growing season, thus destroying some of the crops due to flooding. Interactions with the agricultural extension officers and farmers confirmed that there could be a high amounts of rainfall in certain periods which destroys crops. Information from farmers reveal that deceptive rains which start well in the beginning of a growing season and ends abruptly during the growing season destroys crops and thus low yields. Despite the unreliable rainfall pattern and intensity, the dry spells also pose a threat to yield as it has been observed to be increasing in certain areas and fluctuating in other areas, (Owusu, 2009)

According to Barry *et al.* (2005), poor water resources management has resulted in an inability to bridge intra-seasonal dry-spells, which often causes reductions in yield. They further mentioned, low yields could be avoided with better water management for agriculture in the tropical drylands.

An interview with the planning director of the district Ada East district informed that there was no recorded database nor maps of showing the nature, trend and rate at which the land cover and land-use is changing in the district. The land-use of the district, he claimed, is changing very fast from the coast as observed. The nature of change as observed is a decrease in farming activities and clearing of bushes (vegetation) for construction of buildings (houses and hotels mostly), fuel stations, tourist sites and roads.

The vegetable irrigation farming has got so much attention and has created part time jobs as well as full time employment for the unemployed youth. Because of this activity, cow dung which was a nuisance initially and a challenge with regards to how to dispose of it has now become useful to all those engaged in this farming activity. The cow dung is collected and composted. It is bagged and sold to those who need it. Moreover everyone engaged in this activity uses the compost because of the nature of the soil (sandy loam) in this area. With an initial start-up cost of approximately 2,500 Ghana cedis, almost all of those engaged in this activity greed to making enough profit out of the venture.

Although efforts are being made in water management, groundwater resources are poorly understood and under exploited as indicated by Martin and Van de Giesen (2005), and Lemoalle and Condappa (2010). This study's findings however tells otherwise in the Ada Foah area of the Ada East district.

Challenges and Constraints

A major challenges faced during the study included the type of satellite imagery used. Due to the nature and quality of satellite imagery used in this study, the details of certain land-use features fell under the mixed pixels category and were thus generalized and could not be mapped appropriately. This is because these features cover a very small area and the 30x30 resolution Landsat imagery used could not capture such detail in developing the land-use maps.

However the cost involved in getting such imagery is very high and usually purchased by Institutions and/or companies.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

From the two satellite images studied through LUCC mapping and NDVI analysis, it is observed that various land use types have been changed from one type to another. Rainfall especially impacts on vegetation cover in this area. In as much as changing climate is affecting vegetation cover and agricultural crop production, the quest to increase crop yield influenced by a growing population of farmers is the chief driver of land use change in the Lower Volta Basin.

The largest and dominant conversion of land use in the LVB over the last 12 years has been the expansion of agriculture at the expense of grasslands/shrub (grazing land) and mixed savannah vegetation. Moreover the dominant land use/cover type in the LVB currently, is grasslands/shrub constituting 32.3%. Farmlands and grasslands together, cover 62.1% of the whole LVB. Structure and composition of vegetation of the Lower Volta Basin is changing rapidly. The patterns of land use in the LVB are highly determined by rainfall amounts and soil characteristics. However, vegetation, especially grasslands (grazing fields) increase and decrease annually due to the wet and dry seasons experienced every year in the LVB.

This study has shown that the maximum likelihood classification method is indeed good for mapping Land use/cover changes that take place in large areas such as the LVB.

In the LVB, it is established from this study that there has been a decrease of rainfall over the years. This study also indicates how rainfall amounts and pattern could affect vegetation and agricultural crop production. Temperature, another climate parameter was shown to have increased over the years in the LVB with implications for vegetation cover and crop productivity as well.

The decreasing trend of rainfall and increasing temperature will have adverse effects on all land based productive systems in the LVB. These changes are likely to cause big challenges on efforts to alleviate poverty and promote food security. It is therefore necessary to consider interventions to prepare the communities on how to adapt to climate change.

This study also shows that crop yield from the two study districts in the Lower Volta Basin had experienced an increasing trend. However the production was associated to the increased tracts of farmlands. The increase in crop production was due to a number of reasons which includes, an increase in cropped area, expansion of private and state owned irrigation farming along the Volta River and the use of drought resistant seeds as well as the application of fertilizers. The growing of large scale irrigation farming especially along the river from Akuse to Asutuare has led to small scale farmers losing their farm fields. This growing phenomenon is however creating employment opportunities for many people in the area.

The crop suitability models in this study shows that current climatic conditions provide excellent, very suitable and suitable conditions for crop production in the LVB. But projected future climatic conditions (~2050) showed that most of the southernmost parts of the LVB which includes the Ada East and South Tongu areas remain excellent

and suitable whilst the Lower Manya Krobo area (North western parts) is expected to have marginal, very marginal and not suitable conditions.

6.2 Recommendations

Most of the land use/cover research that has been done in the Volta Basin of Ghana focuses on the Northern part of the Basin with very little attention given to the LVB. It is however important to track, frequently map and document land use/cover changes that occur in the LVB through remote sensing techniques for proper land management planning and other policy interventions. It would therefore be necessary for researchers to conduct Land Use/Cover change studies often using Landsat satellite images which do not cost yet gives accurate information.

- A further detailed crop suitability modelling should be conducted by academic researchers. In a rain fed agricultural region, areas suitable for growing crops under changing climatic conditions are usually not known. There is therefore the need to use climate crop suitability models such as the one used in this study to determine which areas will be suitable for growing specific kinds of crops in the future.
- The Ministry of Food and Agriculture (MoFA) should ensure records and databases of crop production are archived properly to help improve research findings.
- There is also the need to increase the number of agricultural extension officers in the various districts of the Lower Volta Basin. The agricultural extension officers should educate the farmers on the issues of climate change, its impacts and adaptive measures as well as assist them.

- The cost of drought and disease resistant seeds should be subsidized by the government and made accessible to small holder farmers at moderate prices.
- The Ghana Irrigation Development Authority should collaborate with local irrigation schemes within the LVB to assist small holder farmers so as to mitigate the impacts of climate change and increase crop production.
- There is an urgent need for a regional framework and guidelines for sustainable land management including all sectors of land use like cropping, grazing and urbanization in the LVB. This should be carried out by all relevant stakeholders including the VRA, MoFA, Forestry Commission, Lands Commission, Local Government and Local Authority.

REFERENCES

- Africa water facility (AWF). (2010). Reoptimization and reoperation study of Akosombo and Kpong dams.
- Agbenyo, P. K. (2009). Effects of the Akosombo and Kpong power schemes on six selected Mafi-communities in the Volta region.
- Agyarko, T. (2010). Forestry Outlook Study for Africa (FOSA): Ghana, Accra: FAO <http://ftp.fao.org/docrep/fao/003/AB567E/AB567E00>. Date Accessed 21st. April 2015
- Agyarko, T. (2001). Country Report. In: G.M.A.L.A Forestry (Editor) Forestry Commission, Ghana, 2010. Annual Report.
- Akgun, A., Eronat, A., H. & Türk, N. (2004). Comparing Different Satellite Image Classification Methods: An Application In Ayvalık District, Western Turkey. In International Congress for Photogrammetry and Remote Sensing, Istanbul, Turkey.
- Akubia, J. E., K. (2014). Geo-Information Technology Application to Changing Climate and Land-Use-Cover Impacts on Water Resources and Socio-Economic Conditions in the Lower Volta Basin, Ghana. Unpublished thesis submitted to the Institute for Environment and Sanitation Studies, for the award of a MPhil degree.
- Amanor, K., S. & Pabi, O. (2007). Space, time, rhetoric and agricultural change in the transition zone of Ghana. *Human Ecology*, 35(1), 51-67.
- Amatekpor, J., K. (1999). Soils and land use in the Volta basin: State of the art. The Sustainable Integrated Development of the Volta Basin in Ghana Volta Basin Research Project, Accra. Gordon, C., and Amatekpor, J. A., (editors)
- Andah, W. E., van de Giesen, N. & Biney, C. A. (2003). Water, climate, food, and environment in the Volta Basin. Contribution to the project ADAPT, Adaptation strategies to changing environments. ADAPT, Accra.

- Anderson, R. P., Lew, D. & Peterson, A. T. (2003). Evaluating predictive models of species. Distributions: Criteria for Selecting Optimal Models, *Ecological Modelling*, 162.
- Asante, F.A. (2007). Analysis of water-related poverty in the Volta Basin of Ghana. Accra: Institute of Statistical Social and Economic Research (ISSER), University of Ghana.
- Asner, G. P. (2004). Biophysical remote sensing signatures of arid and semiarid ecosystem, in: S.L. Ustin, (Ed.), *Remote Sensing for Natural Resources Management and Environmental Monitoring*. Third ed., Hoboken, New Jersey, pp: 53-109.
- Ayivor, S. J. (1999). Small-Farmer Management of Floodplain Distributed by Damming: A case study of the Lower Volta Basin of Ghana; An Unpublished Thesis submitted to the Department of Geography and Resource Development, University of Ghana, for the Award of MPhil Degree
- Barry, B., Obuobie, E., Andreini, M., Andah, W., & Pluquet, M. (2005). The Volta River Basin, Comprehensive Assessment of Water Management in Agriculture, Comparative study of river basin development and management. Report. IWMI Publication, 33.
- Batterbury, S. P. J. (1999). Environmental histories, access to resources and landscape change: an introduction. *Land Degradation. Dev.* 10(4):279–89
- Berger, T., & Ringler, C. (2002). Tradeoffs, Efficiency Gains and Technical Change: Modeling Water Management and Land Use within a Multiple-Agent Framework. *Quarterly Journal of International Agriculture* 41(1/2):119–144.
- Boateng, E. A. (1967). *A Geography of Ghana*. Cambridge University Press: Cambridge.
- Boko, M., Niang, I., Nyong, A., Vogel, C., Githeko, A. & Medany, M. (2007). Africa. In M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, & C. E. Hanson (Eds.), *Climate change 2007: Impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the*

intergovernmental panel on climate change. Cambridge: Cambridge University Press.

- Braimoh, A. K. (2004). Modelling Land use Change in the Volta Basin of Ghana. Ecology and Development Series, No. 14, Cuvillier Verlag, Gottingen.
- Briassoulis, H. (2000). Factors influencing land-use and land-cover change. Encyclopedia of Life Support Systems (EOLSS).
- Butera, M. K. (1983). Remote sensing of wetlands. Geoscience and Remote Sensing, IEEE Transactions on, (3), 383-392.
- Butt, M. J., Waqas, A., Iqbal, M.F., Muhammad, G. & Lodhi, M.A.K. (2012). Assessment of urban sprawl of Islamabad metropolitan area using multi-sensor and multi-temporal satellite data. Arab. J. Sci. Eng. 37, 101–114.
- Canada Centre for Remote Sensing/Natural Resources Canada (CCSR), (1997). GlobeSAR2 Radar Image Processing and Information Extraction Workbook Version 1.2. Ottawa, Ontario, Canada.
- Challinor, A. J., Ewert, F., Arnold, S., Simelton, E. & Fraser, E. (2009). Crops and climate change: progress, trends, and challenges in simulating impacts and informing adaptation. Journal of Experimental Botany, 60 (10): 2775-2789.
- Challinor, A.J., Simelton, E.S., Fraser, E.D.G., Hemming, D. & Collins, M. (2010). Increased crop failure due to climate change: assessing adaptation options using models and socio-economic data for wheat in China. Environmental Research Letters, 5 (3): 034012.
- Civco, D. L., Hurd, J. D., Wilson, E. H., Song, M., & Zhang, Z. (2002). A comparison of land use and land cover change detection methods. In ASPRS-ACSM Annual Conference.
- Civco, D.L. & Hurd J.D. (1999). A hierarchical approach to land use and land cover mapping using multiple image types. Proc. 1999 ASPRS Annual Convention, Portland. pp. 687-698.

- Codjoe, S. N. A, Eckart Ehlers & Paul L. G. Vlek. (2005). Effects of Change in Population, Household Conditions and Farming Practices on Agricultural Land Use in the Volta River Basin of Ghana, 1984–2000.
- Codjoe, S. N. Ardey. (2004). Population and land use/cover dynamics in the Volta River Basin of Ghana, 1960-2010. Ecology and development series no. 15.
- Crumley, CL, eds. (1994). Historical Ecology: Cultural Knowledge and Changing Landscapes. Santa Fe: Sch. Am. Res. 304
- CSIR-WRI (Council for Scientific and Industrial Research-Water Research Institute). (2000). Climate change vulnerability and adaptation assessment on water resources of Ghana. A UNFCCC/EPA/WRI Accra report.
- d’Aquino, P., August, P., Balmann, A., Berger, T., Bousquet, F., Brondízio, E., & Warren, K. (2002). Agent-based models of land-use and land-cover change. In Proc. of an International Workshop (pp. 4-7).
- Daniel, L. Civco, James D. Hurd, Emily H. Wilson, Mingjun Song & Zhenkui Zhang (2002). A Comparison of Land Use and Land Cover Change Detection Methods. ASPRS-ACSM Annual Conference and FIG XXII Congress.
- Dawelbait, M. A., & Morari, F. (2011). LANDSAT, Spectral Mixture Analysis and Change Vector Analysis to Monitor Land Cover Degradation in a Savannah Region in Sudan (1987-1999-2008). Int. J. Water Resour. Arid Environ, 1, 366377.
- De Sherbinin, A. (2002). A guide to land-use and land-use cover change (LUCC). A collaborative effort of SEDAC and the IGBP/IHDP LUCC Project. Columbia University, New York.
- Dean, A. M., & Smith, G. M. (2003), An evaluation of per–parcel land cover mapping using maximum likelihood class probabilities, International Journal of Remote Sensing, 24 (14), pp. 2905-2920.
- Degu, A. M., F. Hossain, D. Niyogi, R. A. Pielke Sr., J. M. Shepherd, N. Voisin, & T. Chronis (2011). The influence of large dams on surrounding climate and precipitation patterns, Geophys. Res. Lett., L04405, doi: 10. 1029/2010GL04648.

- Duadze, S. E. K. (2004). Land use and land cover study of the savannah ecosystem in the Upper West Region (Ghana) using remote sensing. Ecology and development series No. 16.
- Eastman, J. R., Fulk M. (1993). Long sequence time series evaluation using standardized principal components. Photogrammetry. Eng. Remote Sens. 59(8):991–96
- El-Kawy, O. R. A., Rod, J. K., Ismail, H. A. & Suliman, A.S. (2010). Land use and land cover change detection in the Western Nile Delta of Egypt using remote sensing data. Applied. Geography. 31 (2011), 483–494.
- El-Raey, M., Sahraf El Din S.H., Kafagy, A.A. & Abo Zed, A.I. (1999). Remote sensing of beach erosion and accretion patterns along Damietta-port side shoreline, Egypt. International Journal of Remote Sensing, 20, pp. 1087–1106.
- FAO, (2000). The Ecocrop database. In: FAO (Editor), Rome, Italy.
- FAO, (2000). Two essays in climate change and agriculture. Rome: Food and agricultural organization.
- FAO, (2006). World Agriculture: Towards 2030/2050. Prospects for Food, Nutrition, Agriculture and Major Community Groups. Interim report. Global perspective studies unit. Rome
- Fisher, B., Anderson, S., Bryant, J., Margolese, R. G., Deutsch, M., Fisher, E. R. and Wolmark, N. (2002). Twenty-year follow-up of a randomized trial comparing total mastectomy, lumpectomy, and lumpectomy plus irradiation for the treatment of invasive breast cancer. New England Journal of Medicine, 347(16), 1233-1241.
- Fobil, J. N. and Attaquayefio D. K. (2003). Remediation of the environmental impacts of the Akosombo and Kpong dams. Volta Basin Research Project (VBRP).
- Food and Agricultural Organization of the United Nations (FAO). (1995). Planning for Sustainable Use of Land Resources. FAO Land and Water Bulletin 2. 472 pp. Rome: Food and Agricultural Organization of the United Nations.

- Food and Agriculture Organization (FAO). (2008) Climate and Climate Change in West Africa, 2008. http://www.fao.org/nr/clim/abst/clim_080502_en.htm. Accessed 12 May 2015.
- Geerts, S., Raes, D., Garcia, M., Del Castillo, C., & Buytaert, W. (2006). Agro-Climatic Suitability Mapping For Crop Production In The Bolivian Altiplano: A case study for quinoa. *Agricultural and forest meteorology*, 139(3), 399-412.
- Geker, J. (1999). The Effects of the Volta Dam on the People of the Lower Volta. The Sustainable Integrated Development of the Volta Basin in Ghana. VBRP, Legon, 119-121.
- Ghana Statistical Service, (2014). Ghana Living Standards Survey 6 (GLSS 6), Main report.
- Gleick, P. H. (2009). *The World's Water*. Island Press. ISBN, 10, 1-59726.
- Global Environment Facility (GEF)-United Nations Environment Programme (UNEP). (2002). Project Development Facility (PDF-B)
- Gonzales, C. A. (2009). Assessing the Land Cover and Land Use Change and Its Impact on Watershed Services in a Tropical Andean Watershed of Peru. A Master of Science thesis to the Department of Biological and Environmental Science, University of Jyvaskyla.
- Gordon, C. (1999). An overview of the fish and fisheries of the Volta basin. Gordon, C., & Amatekpor, J. A., (editors) *The Sustainable Integrated Development of the Volta Basin in Ghana Volta Basin Research Project*, Accra.
- Govindasamy, B, P., Duffy B. & Coquard J. (2003). High-resolution simulations of global climate, part 2: effects of increased greenhouse cases. *Climate Dynamics* 21: 391–404.
- Gregory, T. A., (2008). *Reoptimization of West African Dams to Restore Downstream Ecosystems & Livelihoods*.
- Grübler, A. & Nakićenović, N. (1994). International burden sharing in greenhouse gas reduction. International Institute for Applied Systems Analysis.

- Gu, G., & Adler, R. F. (2003). Seasonal rainfall variability within the West African Monsoon system. *CLIVAR Exchanges*, 8, 11-15.
- Guide, E. U. S. (2008). ENVI on-line software user's manual. ITT Visual Information Solutions.
- Gumma, K. M., Prasad, T. S., & Bubacar, B. (2010). Delineating shallow ground water irrigated areas in the Atankwidi Watershed (Northern Ghana, Burkina Faso) using Quickbird 0.61-2.44 meter data. *African Journal of Environmental Science and Technology*, 4(7), 455-464.
- Gyasi, E. A. (1999). The Sustainable Integrated Development of the Volta Basin in Ghana Volta Basin Research Project, Accra.
- Gyasi, E. A., Karikari, O., Kranjac-Berisavljevic, G., & Vordzogbe, V. V. (2006). Study of Climate Change Vulnerability and Adaptation Assessment Relative to Land Management in Ghana. University of Ghana, Legon, Accra, 1-91.
- Hansing, O. & Wittich, K. P. (1995). Area averaged vegetation cover fraction estimated from satellite data. *Int. J. Biometeor.*, 38
- Hathout, S. (2002). The use of GIS for monitoring and predicting urban growth in East and West St Paul, Winnipeg, Manitoba, Canada. *J. Environ. Manage.* 66, 229–238.
- Heilig, G. K. (1994). Neglected dimensions of global land-use change: reflections and data. *Population and Development Review*, 831-859.
- Hijmans, R.J., Guarino, L., Cruz, M. & Rojas, E. (2001). Computer tools for spatial analysis of plant genetic resources data: DIVA-GIS. *Plant Genetic Resources Newsletter*, 127: 15-19.
- Hijmans, R. J., Guarino L., Jarvis A., O'Brien R., Mathur P., Bussink C., Cruz M., Barrantes I. & Rojas E. (2005). DIVA-GIS – Version 5.2 – Manual. Available at <http://www.diva-gis.org/Materials.htm>.
- Hoffhine, E., (2000). Forest Change Detection, Harvest and Cover Type Distinction Using Multiple Dates of Landsat Thematic Mapper. M.S.-degree Thesis, University of Maine, Orono.

<https://mofafoodsecurity.wordpress.com/food-security-situation-in-ghana/>: date accessed 11th July 2015.

Huette, A. R., W. J. D. Van Leeuwen, G. Hua, J. Qi & A. Chehbouni, (1992). Normalization of multidirectional red and NIR reflectance's with the SAVI. *Remote Sensing of Environment*, 41: 143-154.

Hurd, J.D., D.L. Civco, C. LaBash, & P. August. (1992). Coastal wetland mapping and change detection in the northeast United States. in Proc. 1992 ASPRS/ACSM/RT'92 Convention, Washington, D.C. 1:130-139.

Hurd, J.D., E.H. Wilson, S. Lammey & D.L. Civco. (2001). Characterization of Forest Fragmentation and Urban Sprawl using Time Sequential Landsat Imagery. Proc. 2001 ASPRS Annual Convention, St. Louis, MO.

Hussain, I. (2005). Pro-poor Intervention Strategies in Irrigated Agriculture in Asia. Poverty in Irrigated Agriculture: Issues, Lessons, Options and Guidelines (Bangladesh, China, India, Indonesia, Pakistan and Vietnam). Project Final Synthesis Report. IWMI, Colombo.

IPCC. (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC.

IPCC. (2007). Climate Change: Impacts Adaptation and Vulnerability. Contribution of working group II to the Fourth Assessment Report of the IPCC.

Iqbal, M. F., & Khan, I. A. (2014). Spatiotemporal land use land cover change analysis and erosion risk mapping of Azad Jammu and Kashmir, Pakistan. *The Egyptian Journal of Remote Sensing and Space Science*, 17(2), 209-229.

Iqbal, M. F., Khan, M. R. & Malik, A.H. (2013). Land use change detection in the limestone exploitation area of Margalla Hills National Park (MHNP), Islamabad, Pakistan using Geo-spatial techniques. *J. Himalayan Earth Sci.* 46 (1), 89–98.

IWMI (International Water Management Institute). (2013). "Water Policy Briefs." [Available Online]: <http://www.iwmi.cgiar.org/publications/briefs/water-policy-briefs>.

- Jung, G. and Kunstmann, H. (2007). High-resolution regional climate modelling for the Volta region of West Africa.
- Klepeis, P., Turner B. L. (2001). Integrated land history and global change science: the example of the Southern Yucat'an Peninsular Region Project. *Land Use Policy* 18(1):27–39
- Koku, J. E., (2002). Environment, Livelihood and Natural Resource Management In The Lower Volta Basin Of Ghana.
- Lachaud, J. P., (1998). Modelling the determinants of poverty and the labor market in Africa: the case of Burkina Faso. Working Papers CED 32. Bordeaux: Bordeaux University
- Lambin, E. F. and Geist H. J. (2006) *Land-Use and Land-Cover Change, Local Processes and Global Impacts*, Springer 2006
- Lambin, E. F., Baulies X, Bockstael N, Fischer G, Krug T, Leemans R, Moran EF, Rindfuss RR, Sato Y, Skole D, Turner B. L, Vogel C, Nunes C & Augè J. I (1999) *Land-use and land-cover change implementation strategy*. Stockholm, Sweden: IGBP Report No. 48
- Lambin, E. F. & Geist H. J. (2002) Global land-use and cover change: What have we learned so far? *Global Change Newsletter* 46, p. 27-30.
- Lambin, E. F., Geist H. J. & Lepers E. (2003) Dynamics of land-use and land-cover change in tropical regions. *Annual review of environment and resources* 28, p 205
- Lambin E. F., Turner BL, Geist HJ, Agbola SB, Angelsen A, Bruce JW, Coomes OT, Dirzo R, Fischer G, Folke C, George PS, Homewood K, Imbernon J, Leemans R, Li X, Moran EF, Mortimore M, Rama krishnan PS, Richards JF, Skanes H, Steffen W, Stone GD, Svedin U, Veldkamp TA, Vogel C & Xu J (2001) The causes of land-use and land-cover change: moving beyond the myths. *Global Environmental Change* 11, p. 261-269.
- Lambin, E. F. (1997). Modelling and monitoring land-cover change processes in tropical regions. *Progress in physical geography*, 21(3), 375-393.

- Lane, A., & Jarvis, A. (2007). Changes in climate will modify the geography of crop suitability: agricultural biodiversity can help with adaptation. *SAT eJournal*, 4 (1), 1-12.
- Laux, P., Kunstmann, H. & Bárdossy, A. (2007). Predicting the regional onset of the rainy season in West Africa. *International Journal of Climatology*. doi:10.1002/joc.1542.
- Leemans, R., Lambin E. F, McCalla A., Nelson J., Pingali P. & Watson B. (2003). Drivers of change in ecosystems and their services. In *Ecosystems and Human Well-Being: A Framework for Assessment*, ed. H Mooney, A Cropper, W Reid. Washington, DC: Island.
- Lemoalle, J. and Devaraj de Condappa. (2010) Farming systems and food production in the Volta Basin, *Water International*, 35:5, 655-680, DOI: 10.1080/02508060.2010.510793
- Lemoalle, J. (2007). Global trends in the Volta basin. *BFP Volta Reports Series*.
- Lillesand, T. M. & Kiefer R. W. (1994). *Remote sensing and image interpretation*. John Wiley and Sons.
- Liu, X. H., Skidmore, A. K., & Osten, V. H. (2002), Integration of classification methods for improvement of land-cover map accuracy, *ISPRS Journal of Photogrammetry & Remote Sensing*, 56, pp 257-268.
- Lo, C. P., and Watson, L. J. (1998). The influence of geographic sampling methods on vegetation map accuracy evaluation in a swampy environment. *Photogrammetric Engineering and Remote Sensing*, 64(12), 1189-1200.
- Lobell, D. B., Burke, M. B., Tebaldi, C., Mastrandrea, M. D., Falcon, W. P., & Naylor, R. L. (2008). Prioritizing climate change adaptation needs for food security in 2030. *Science*, 319(5863), 607-610.
- Loveland, T. R., Zhu Z., Ohlen D. O., Brown J. F., Reed B. C. & Yang L. M. (1999). An analysis of the IGBP global land-cover characterization process.

- Lunetta, R.L., Johnson, D.M., Lyon, J.G. & Crotwell, J. (2004). Impacts of imagery temporal frequency on land-cover change detection monitoring. *Remote Sensing Environment*. 89(4), 444-454.
- Lunetta, R.L., Knight, F.K, Ediriwickrema, J., Lyon, J.G., & Worthy, L.D. (2006). Landcover change detection using multi-temporal MODIS NDVI data. *Remote Sensing of Environment*, 105, 142-154.
- Mallapattu, P. K., Reddy J. R & Sreenivasula. (2013). Analysis of Land Use/Land Cover Changes Using Remote Sensing Data and GIS at an Urban Area, Tirupati, India. *The Scientific World Journal*, vol. 2013, Article ID 268623. doi:10.1155/2013/268623
- Manakos, I., Scheneider T. & Ammer U. (2000). A Comparison between the ISODATA and the eCognition Classification Methods on Basis of Field Data. *IAPRS*, 33(Supp. B7): 133-139.
- Martin, N., & Van De Giesen. N. (2005). Spatial distribution of groundwater production and development potential in the Volta River Basin of Ghana and Burkina Faso. *Water International* 30.2 (2005): 239-249
- Masiyandima, M. & Giordano, M. (2007). Sub-Saharan Africa: Opportunistic exploitation In: the agricultural groundwater revolution: opportunities and threats to development.
- McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J., & White, K. S, (2001). *Climate change 2001: Impacts, Adaptation and Vulnerability*. Cambridge: Cambridge University Press.
- Mei, X. & Qing, R., (1999). Change detection based on remote sensing information model and its applications on coastal line of Yellow River Delta. *Earth Observation Centre, NASDA, China*
- Ministry of Environment and Science (MES). (2002). National biodiversity strategy for Ghana. CBD. <http://www.cbd.int/doc/world/gh/gh-nbsap-01-en.pdf>
- Ministry of Food and Agriculture (MOFA). (2011). *Agriculture in Ghana, facts and figures*. Statistics, research and information directorate.

- Ministry of Food and Agriculture. (2015). North Tongu District Background. <http://www.mofa.gov.gh/site> date accessed, 12/05/15
- Mona, A. A., Dawelbait, & Francesco, M. (2011). LANDSAT, Spectral Mixture Analysis and Change Vector Analysis to Monitor Land Cover Degradation in a Savannah Region in Sudan (1987-1999-2008) *International Journal of Water Resources and Arid Environments* 1(5): 366-377
- Mortimore, M. (1998). *Roots in the African dust: sustaining the Sub-Saharan drylands.* Cambridge University Press.
- Muttitanon W., & Tripathi N.K. (2005). "Land use/ land cover changes in the coastal zone of Ban Don Bay, Thailand using Landsat 5 TM data", *International Journal of Remote Sensing*, Vol. 26, No. 11, 2311-2323. Taylor and Francis. (ISSN: 1366-5901, Impact Factor 1.182).
- Natural Heritage Institute (NHI). (2007). *Opportunities for Environmentally Hydropower Dam Re-optimization In The West African Power Pool Network of ECOWAS.*
- Nunes, C. & Auge J. I. (1999). *Land-use and Land-cover Implementation Strategy* (Stockholm: IGBP)
- Nyamekye, C. (2010). *Classification of time series of NDVI for Assessment of land cover change in Ghana using Noaa/A VHRR data* (Doctoral dissertation, Department of Geomatic Engineering, Kwame Nkrumah University of Science and Technology).
- Ofori, E. A. (2011). *Sustainable Irrigation Development in the White Volta sub-Basin: UNESCO-IHE PhD Thesis.* CRC Press.
- Okine, C. B. & Nyarko, J. A. (2008). *Volta Basin Residents Train in Tree Management.*
- Opoku-Ankomah, Y., & Cordrey, I. (1994). Atlantic sea surface temperatures and rainfall variability in Ghana. *Journal of Climate*, 7, 551-558.
- Osman-Elasha, B. (2010). *Mapping of Climate Change Threats and Human Development Impacts in the Arab Region.* United Nations Development

Programme, Regional Bureau for Arab States. Arab Human Development Report; Research Paper Series.

- Ostrom, E. (1990). *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge, UK: Cambridge Univ. Press. 280 pp.
- Owusu, K. (2009). Changing rainfall climatology of West Africa: Implications for rain-fed agriculture in Ghana and water sharing in the Volta Basin.
- Ozesmi, S. L & Bauer, M. (2002), *Satellite Remote Sensing of Wetlands, Wetlands Ecology and Management*, 10, pp 381-402.
- Pal, M. & Mather, P. M. (2003). An assessment of the effectiveness of decision tree methods for land cover classification. *Remote Sensing of Environment*, 86, pp.554–565.
- Parker, D. C., Manson, S. M., Janssen, M. A., Hoffmann, M. J. & Deadman, P. (2003). Multi-agent system models for the simulation of land-use and land-cover change: a review. *Ann. Assoc. Am. Geogr.* 93(2):314–37
- Parthasarathy, U., Jayarajan, K., Johny, A. K., & Parthasarathy, V. A. (2008). Identification of suitable areas and effect of climate change on ginger-a GIS study.
- Parthasarathy, U., Nandakishore, O. P., Jayarajan, K., Saji, K. V., & Nirmal, K. (2014). Prediction of Crop Suitability of Certain Indian Spices–A GIS Approach.
- Peter, D. T., Michael, L. L. (2003). Measuring praise and criticism: inference of semantic orientation from association. *ACM Trans. Inf. Syst.* 21, 315–346.
- Petit, C. (2001). Quantifying processes of land-cover by remote sensing, resettlement and rapid land-cover change in south-eastern Zimbabwe *Remote Sensing* 22(17): 3435-3456
- Plantier, T. M., Loureiro, P., Marque, M. C. (2006). Spectral analyses and classification of ikonos images for forest cover characterisation. *Proceedings of the 2nd Workshop of the EARSeL SIG on Land Use and Land Cover, Center for Remote Sensing of Land Surfaces, Bonn*, 28-30.

- Porter, J. R., Jamieson, P. D., & Grace, P. R. (2007). Wheat Production Systems and Global Climate Change. In *Terrestrial Ecosystems in a Changing World* (pp. 195-209). Springer Berlin Heidelberg.
- Prakasam, C. (2010). Land use and land cover change detection through remote sensing approach: A case study of Kodaikanal taluk, Tamil nadu, *International Journal of Geomatics and Geosciences* 1(2): 32-44
- Purevdor, T. S., Tateishi, R., Ishiyama, T. & Honda, Y (1998). Relationship between percent vegetation cover and vegetation indices. *International journal of remote sensing*, 1998, 19 (18), 3519-3535.
- Rai, P. K., Gupta, S., Mishra, A., & Onagh, M. (2011). Multi-seasonal Irs-1c Liss III Satellite Data for Change Detection Analysis and Accuracy Assessment: A Case Study. *Journal of GIS Trends*, 2 (1), 13-19.
- Ramirez, J., & Bueno-Cabrera, A. (2009). Working with climate data and niche modeling I. Creation of bioclimatic variables. *International Center for Tropical Agriculture (CIAT)*, Cali, Colombia, 1-6.
- Ramirez-Villegas, J., Jarvis, A., & Läderach, P. (2013). Empirical approaches for assessing impacts of climate change on agriculture: the EcoCrop model and a case study with grain sorghum. *Agricultural and Forest Meteorology*, 170, 67-78.
- Reilly, J., Baethgen, W., Chege, F. E., Geijn, V. D. S., Erda, L., Iglesias, A., & Howden, M. (1996). Agriculture in a changing climate: impacts and adaptation. In: RT Watson, MC Zinyowera & RH Moss (eds.), *Climate change 1995; impacts, adaptations and mitigation of climate change: scientific-technical analyses*. Cambridge (UK), Cambridge Univ. Press, 1996, pp. 427-467.
- Richards, J. A. (1995). *Remote sensing digital image analysis. An introduction*. Second revised and enlarged edition. Springer. Verlag. Berlin.
- Rodgers, C., van de Giesen, N., Laube, W., Vlek, P. L. G., & Youkhana, E. (2007). The GLOWA Volta Project: A framework for water resources decision-making and scientific capacity building in a transnational West African Basin. *Water Resources Management*, 21(1), 295–313. doi:10.1007/s11269-006-9054-y

- Rosegrant, M. W., Paisner, M. S., Meijer, S. & Witcover, J. (2001). *Global Food Projections to 2020: Emerging Trends and Alternative Futures*. Washington D.C.: International Food Research Institute.
- Rosenzweig, C., Parry, M.L., Fischer, G. & Frohberg, K. (1993). *Climate change and world food supply*. Oxford: Environmental Change Unit, University of Oxford, UK.
- Sagoe, R. (2006). *Climate change and root crop production in Ghana*. Crop Research Institute: Kumasi, Ghana (2006):2-37
- Saxena, K. R. (2005). *Dams: Incidents and accidents*, A. A. Balkema, Leiden, Netherlands.
- Schindler, J., & Ghana, U. E. (2009). *Ecology and Development Series No. 68*, 2009.
- Schultz, B. (2002). Role of dams in irrigation, drainage and flood control. *International Journal of water resources development*, 18(1), 147-162
- Sivakumar, M. V. K., & Hatfield, J. L. (1990). Spatial variability of rainfall at an experimental station in Niger, West Africa. *Theoretical and Applied Climatology*, 42(1), 33-39.
- Stemmler, J. & Su, Z., (1993). In Su, Z. 2000. Remote sensing of land use and vegetation for mesoscale hydrological studies. *Int. j. remote sensing*, 2000, vol. 21, no. 2, 213-233.t
- Sunnar, F. & Musaogilu, N. (1998). An analysis of changes in multi-date data set: A case study in the Ikitelli area, Instabul, Turkey. *International journal of remote sensing*, 19 (2), 225-235.
- Tansey, K. T. & Millington, A. C. (2006). *Land use/land cover change detection in Metropolitan Lagos (Nigeria): 1984-2000*. ASPRS 2006 Annual Conference Reno, Nevada, May 1-5
- Tayyebi, A., Delavar, M. R., Saeedi, S., Amini, J., & Alinia, H. (2008). Monitoring land use change by multi-temporal Landsat remote sensing imagery. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 37(B7), 1037-42.

- Terrasson, I., Fisher, M. J., Andah, W., & Lemoalle, J. (2009). Yields and water productivity of rain-fed grain crops in the Volta Basin, West Africa. *Water International*, 34(1), 104-118.
- Thornton, P.K., Jones, P.G., Ericksen, P.J. & Challinor, A.J. (2011). Agriculture and 905 food systems in sub-Saharan Africa in a 4°C+ world. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, (1934): 117-136.
- Titriku, P. K. (1999). Agriculture in the Volta basin: Problems and prospects. Gordon, C., & Amatekpor, J.A., (editors) *The Sustainable Integrated Development of the Volta Basin in Ghana Volta Basin Research Project*, Accra.
- Torahi, A. A. & Suresh, C. R. (2011). Land Cover Classification and Forest Change Analysis, Using Satellite Imagery - A Case Study in Dehdez Area of Zagros Mountain in Iran *Journal of Geographic Information System*, 2011, 3, 1-11 doi:10.436/jgis.2011.31001
- Travis, R. (2006). Drought and its effect on vegetation, comparison of Landsat NDVI for drought and non-drought years related to land use land cover classifications.
- Tucker, C.J. (1979). Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment*, 8: 127-150.
- Tufuor, K. (2012) *Ghana Forestry Report – draft Towards ECOWAS Forest Convergence Plan*.
- Tuinhof, A.; Foster, S.; van Steenbergen, F.; Talbi, A. & Wishart, M. (2011). Appropriate groundwater management policy for sub-Saharan Africa in face of demographic pressure and climatic vulnerability. *Strategic Overview series Number 5*. Washington, DC, USA: World Bank.
- Turner, B. L. II, Clark C., Kates R. W., Richards J. F., Mathews J. T., & Meyer W. B. (eds.) (1990). *The Earth as Transformed by Human Action: Global and Regional Changes in the Biosphere over the past 300 years*. Cambridge: Cambridge University Press.

- Turner, B. L. II, Skole D., Sanderson S., Fischer G., Fresco L., & Leemans R. (1995). Land-Use and Land-Cover Change; Science/Research plan. IGBP (International Geosphere/Biosphere Programme).
- Tutu, B. D. (2008). Assessing The Effects of Land-use/cover change on ecosystem services in Ejisu-Juaben District, Ghana: The case study of carbon sequestration. Enschede, ITC.
- UNEP-GEF Volta Project. (2010). Volta Basin Transboundary Diagnostic Analysis: National Report Ghana. UNEP/GEF/Volta/NR GHANA 1/2010
- UNFCCC (2013). Climate Change. Impacts, Vulnerabilities and Adaptation in Developing Countries. Bonn: United Nations Framework Convention on Climate Change.
- United Nations Environment Programme (UNEP) Project Development Facility (2002). Volta River Basin Preliminary Trans boundary Diagnostic Analysis. Final report.
- UN-Water. (2009). Climate Change Adaptation is Mainly About Water. Key message prepared for the 15th session of the Conference of the Parties to the United Nations Framework Convention on Climate Change. New York, UN-Water. Available from <http://www.unwater.org/downloads/>
- UN-Water. (2011). Water and Climate Dialogue. Adapting to Climate Change: Why We Need Broader and 'Out-of-the-Box' Approaches.
- USGS, http://www.landsat.usgs.gov/panchromatic_image_sharpening_php, date accessed; 14/05/15.
- Ustin, S.L., P.J. Zarco-Tejada S. Jacquemoud & G. P. Asner. (2004). Remote sensing of environment: state of science and new directions. In: S.L. Ustin (ed.): Remote Sensing for Natural Resources Management and Environmental Monitoring, pp: 679-728.
- Van de Giesen, N., Liebe, J., & Jung, G. (2010). Adapting to climate change in the Volta Basin, West Africa. Current science, 98 (8), 1033-1037.

- Villordon, A., Njuguna, W., Gichuki, S., Ndolo, P., Kulembeka, H., Jeremiah, S. C. & Mwanga, R. O. (2006). Using GIS-based tools and distribution modeling to determine sweet potato germplasm exploration and documentation priorities in sub-Saharan Africa. *HortScience*, 41(6), 1377-1381.
- Vitousek, P.M. (1992). Global environmental change: An introduction. *Ann. Rev. Ecological Evolution System*. 23, 1–14.
- Weldeab, S., Lea, D. W., Schneider, R. R., & Andersen, N. (2007). 155,000 years of West African monsoon and ocean thermal evolution. *Science*, 316, 1303 – 1307
- Williams, K. A. (2005). An overview of the US National Plant Germplasm System's exploration program. *HortScience*, 40(2), 297-301.
- Woldemichael, A. T., Hossain, F., Pielke, R., & Beltrán-Przekurat, A. (2012). Understanding the impact of dam-triggered land use/land cover change on the modification of extreme precipitation. *Water Resources Research*, 48(9).
- Wong, R. K., Fung, T., Leung, K. S & Leung, Y. (1997). The Compression of a Sequence of Satellite Images Based on Change Detection. *International journal of remote sensing*, 18 (11), 2427-2436.
- Woodwell, G. M., Hobbie J. E, Houghton R. A, Melillo J. M. & Moore B. (1983). Global deforestation: contribution to atmospheric carbon dioxide. *Science* 222: 1081–86
- World Water Assessment Programme (WWAP), (2011). *Water and Climate Dialogue - Adapting to Climate Change: Why We Need Broader and 'Out-of-the-Box' Approaches*
- WWAP (World Water Assessment Programme). (2009). *World Water Development Report 3: Water in a Changing World*. Paris/ London, UNESCO/Earthscan
- Xiao, J., Shen, Y., Ge, J., Tateishi, R., Tang, C., Liang, Y., & Huang, Z. (2006). Evaluating urban expansion and land use change in Shijiazhuang, China, by using GIS and remote sensing. *Landscape and Urban Planning*, 75, 69–80.
- Yates, D. N., & Strzepek, K. M. (1998). An assessment of integrated climate change impacts on the agricultural economy of Egypt. *Climatic Change*, 38(3), 261-287.

- Yeboah, F. K. (1999). Mitigative Actions Taken by the VRA on Dam Affected
- Yumbya, J., De Vaate, M. B., Kiambi, D., Kebebew, F., & Rao, K. P. C. (2014). Geographic Information Systems for assessment of climate change effects on teff in Ethiopia. *African Crop Science Journal*, 22, 847-858.
- Yusuf, K. O., and Salami, A. W. (2009). Influence of Jebba Hydropower Dam on statistical distribution of hydro-meteorological variables in Niger River Basin, Nigeria. In 1st Annual Civil Engineering Conference, University of Ilorin, Nigeria (Vol. 26, pp. 32-40).
- Zhou, J. & Civco D.L. (1998). A wavelet transform method to merge Landsat TM and SPOT Panchromatic Data. *International Journal of Remote Sensing* 19(4):743-757.
- Zubair, A. O. (2006). Change Detection in Land Use and Land Cover Using Remote Sensing Data and GIS. A project submitted to the department of geography, University of Ibadan in partial fulfilment for the award of Master of Science (MSc) Degree in Geographical Information Systems.

APPENDICES

APPENDIX 1: SOCIO-ECONOMIC SURVEY QUESTIONNAIRE

The data collected for this survey is for academic purposes only and shall be kept strictly confidential as your identity shall also not be required. The purpose of this survey is to improve our understanding of the drivers of land use change and the influence of rainfall variability on the livelihoods of farmers.

Kindly Tick (✓) where appropriate and provide answers to open-ended questions.

Interview Date..... District.....

Community

SECTION A: ACKGROUND INFORMATION

1. Farmer's Gender: Male Female
2. Age: 18-25[] 26-35[] 36-45[] 45 and above[].....
3. Marital Status: Single [] Married [] Divorced []
4. Years of residence of respondent in the community
0-5 [] 5 -10 [] 10-15 [] 15-30[] >30[]
5. Highest educational level: No Formal Education[] Primary[] Middle(JHS)[]
Secondary(SHS) [] Tertiary []
6. Household size?
7. What types of crops do you cultivate on your farm?
.....

SECTION B: AGRICULTURE LAND USE AND DRIVERS OF LAND USE CHANGE

8. Do you have knowledge on land use changes?
 Yes No
9. If yes what is your general observation on land use change? (*please tick appropriate*)

1	Increasing farm lands and decreasing vegetation	
2	Decreasing farmlands and increasing infrastructure	
3	Increasing infrastructure and decreasing vegetation	
4	Decreasing vegetation and increasing bare lands	
5	Decrease in size of wetlands and marshy areas and increasing infrastructure	

6.

Other.....

.....

10. What kind of land tenure system do you have?

i) Owned[] ii) Leased[] iii) Communal land[] iv) Other.....

11. If owned how?

i) Inherited[] ii) Bought[] iii) given by government[] iv)

Other.....

12. In what year did you acquire the farming field?

13. What was on your farm (field) when you acquired it?

i) Forest[] ii) Grazing land[] iii) Bush[] iv) Woodlot[] v) Crops[]

vi) Other

14. How large is your farm?

15. How long have you been farming?

i) <5yrs[] ii) 5-10yrs[] iii) 10-20yrs[] iv) 20-30yrs[] v) >30yrs[]

16. Have you fallowed (rested) this field before?

i) Yes[] ii) No[]

17. If yes

why?.....

.

18. Do you plant trees to replace trees that have been taken down?

i) Yes[] ii) No[]

19. Why?

.....

.

20. What common tree species do you use for fuel wood?

.....

21. Would you seek to acquire land in a different area of this district ?

i) Yes[] ii) No[]

22. What will you use this land parcel for?

.....

23. What will you consider as the major drivers of land use change?

(Please tick \checkmark for each)

	Strongly agree	Agree	Strongly disagree	Disagree	Don't know
Population					
Rainfall variability					
Poor Soil condition					
Socio economic (job, food)					

Other:

.....

KNOWLEDGE ON CLIMATE CHANGE AND VARIABILITY

24. Have you ever heard of climate change or are you aware of it?

- i) Yes [] ii) No []

25. Please tick the number that you feel best represents your knowledge of climate variability and change?

- i) No knowledge [] ii) Minimal knowledge [] iii) Some knowledge [] iv) Extensive knowledge [] v) Expert knowledge []

26. Have you ever received any professional advice (e.g. from agricultural officers) regarding the effect of a changing rainfall patterns on crop yield? i) Yes [] ii) No []

27. If yes, what was that advice?

.....
.....
.....

28. Have you noticed any changes in the climate (temperature and rainfall) over the years?

- i) Yes [] ii) No []

29. What pattern do you experience in temperature now compared to some years ago?

- i). Increasing ii). Decreasing iii). Fluctuating iv). No change v). No Observation

30. What pattern of rainfall do you experience now compared to some years ago?

- i) Increasing [] ii) Decreasing [] iii) Fluctuating [] iv) No change []
v) No Observation []

31. Has the length of dry spells during the rainy season increased?

- i) Yes [] ii) No [] iii) can't tell []

32. When (month) does the rain begin?

33. In what month do you start planting?

34. Has there been a change in the month of planting during the rainy season?

1. Yes 2. No

35. If yes

Why?.....

..

36. Has there been a change in the length of rainy season over the years?

1. Yes 2. No 3. can't tell

37. If yes what is the nature of change?

1. Increasing 2. Decreasing 3. Fluctuating 4. No change 5. No Observation

Impact of Change in rainfall and temperature

38. Has there been a change in your crop yield?

Yes[] No[] Don't Know[]

39. How do you compare your crop yield situation with the past 10 years?

1) Increasing [] 2) same [] 3) declining [] 4. Other

.....

40. How is your crop yield situation affecting your affecting your standard of living?

.....

.....

41. What do you think are the causes of these changes in your crop yield?

- i) Less rain[] ii). high temperature[] iii). low soil fertility[] iv). i-iii []
v). Other

42. What can you say about these statements: Rainfall and temperature have (*please tick*)

- [1] reduced my crop yield {T} {F} {N/A}
[2] increased my crop yield {T} {F} {N/A}
[3] not changed my crop yield {T} {F} {N/A}
[4] affected my soil negatively {T} {F} {N/A}
[5] affected my soil positively {T} {F} {N/A}

ADAPTATION STRATEGIES

43. Have you made any changes to your farming practices because you have noticed changes in temperature and rainfall?

- i) Yes[] ii) No[]

44. If yes, what adjustments have you made to suit these changes and variability?

- i).....
ii).....
iii).....

45. Do you receive information on weather forecast or early warning to enable your household to respond to extreme climatic conditions in a timely fashion?

- i) Yes[] ii) No[]

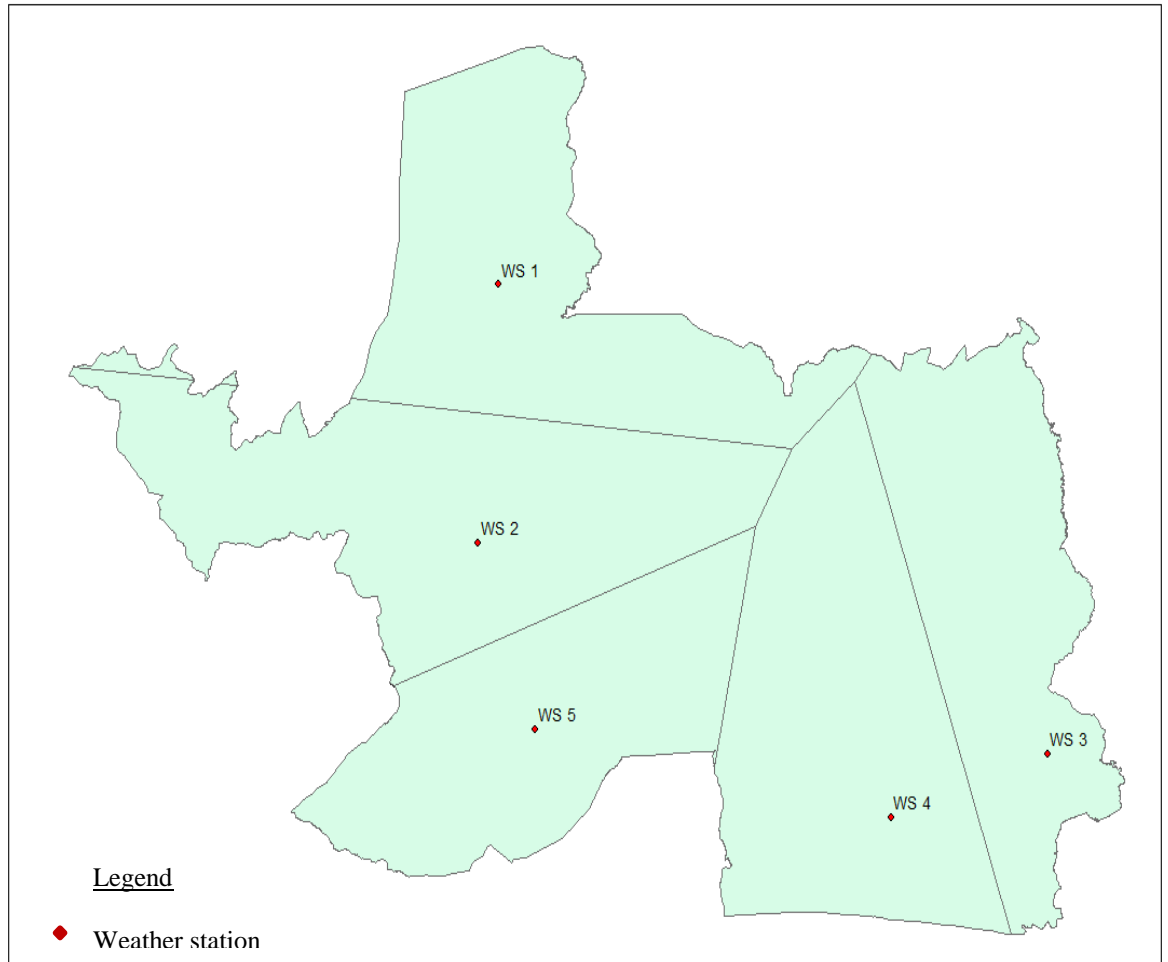
Thank You.

**APPENDIX 2: AVERAGE CLIMATE DATA VALUES FOR THE LOWER
VOLTA BASIN**

Years	Avg. Temperature (°C)	Avg. Annual Rainfall (mm)
1960	32.9	972.6
1961	33.2	1134.8
1962	33.1	1258.0
1963	30.6	1272.8
1964	32.7	1073.7
1965	34.9	1100.8
1966	31.8	1001.4
1967	31.9	847.0
1968	32.5	1250.4
1969	29.2	797.3
1970	29.4	867.1
1971	33.2	858.5
1972	32.8	715.1
1973	33.4	937.9
1974	33.4	841.6
1975	33.1	730.7
1976	32.2	787.9
1977	30.0	657.2
1978	30.6	758.5
1979	28.3	764.2
1980	33.5	864.5
1981	33.8	996.9
1982	32.8	946.2
1983	32.6	633.3
1984	32.1	878.5
1985	32.9	865.3
1986	32.6	671.5
1987	32.2	896.5
1988	32.0	791.3
1989	32.2	806.9
1990	32.2	687.8
1991	33.2	832.6
1992	33.4	634.8
1993	33.5	979.1
1994	33.7	803.5
1995	33.6	847.1
1996	33.3	1008.3
1997	33.3	866.9
1998	33.6	666.6
1999	32.8	904.2
2000	33.0	726.9
2001	32.9	876.2
2002	33.6	841.6

2003	33.4	763.3
2004	33.2	791.4
2005	33.4	716.0
2006	33.5	960.4
2007	33.4	1015.0
2008	33.4	1124.9
2009	33.5	878.6
2010	33.8	878.8
2011	33.2	818.2
2012	33.4	663.4
2013	32.4	794.1

APPENDIX 3: THIESSEN POLYGON ALGORITHM MAP SHOWING WEATHER STATIONS



Source: Author's Construct

APPENDIX 4: REGRESSION RESULTS FOR CAUSALITY RELATIONSHIP BETWEEN LAND USE CHANGE AND DRIVERS OF LAND USE CHANGE (POPULATION, RAINFALL VARIABILITY, SOIL CONDITION AND SOCIO-ECONOMIC CONDITION)

Variable	Beta	Std. Error	t-value	p-value
(Constant)	1.705	0.12	14.08	0.00
Population	-0.120	0.34	-3.530	0.001**
Rainfall variability	0.136	0.069	1.967	0.051*
Poor soil condition	0.056	0.037	1.508	0.133
Socio-economic(Job, food)	-0.154	0.071	-2.164	0.032**

Adj. R-Square=0.794

R=0.912

F-statistics= 21.549

Note:* significant at $p < 0.1$; ** significant at $p < 0.05$

**APPENDIX 5: CROP YIELD DATA VALUES FOR STUDY DISTRICTS AND
CORRELATION TABLES**

ADA EAST DISTRICT

Years	ha (cassava)	Cassava yield (MT)	Yield/ha	ha (maize)	Maize yield (MT)	Yield/ha
2005	2350	18800	8	1188	150.4	0.8
2006	2900	20010	6.9	1213	170.4	0.8
2007	2942	20594	7	1286	228.8	0.8
2008	3485	24395	7	1380	304	0.8
2009	3526	25387.2	7.2	1388	310.4	0.8
2010	2600	18200	7	1390	312	0.8
2011	2603	18221	7	1425	340	0.8
2012	2650	13250	5	1450	180	0.4
2013	2915	20405	7	1374	336.6	0.9

	ha (cassava)	cassava
ha (cassava)	1	
cassava	0.8209	1

	ha (maize)	Maize
ha (maize)	1	
Maize	0.6535	1

LOWER MANYA KROBO DISTRICT

Years	ha (cassava)	Cassava yield (MT)	Yield/ha	ha (maize)	Maize yield (MT)	Yield/ha
2005	12520	159004	12.7	13602	23123.4	1.7
2006	9190	117632	12.8	8990	14384	1.6
2007	9194	117683.2	12.8	9840	16728	1.7
2008	9198	131531.4	14.3	9812	18642.8	1.9
2009	10001	156015.6	15.6	10640	19152	1.8
2010	10998	186966	17.0	11102	21093.8	1.9
2011	10770	215400	20.0	13650	28665	2.1
2012	10850	217000	20.0	13751	28877.1	2.1
2013	4350	87000	20.0	6045	12694.5	2.1

	ha (cassava)	cassava
ha (cassava)	1	
cassava	0.63204	1

	ha (maize)	maize
ha (maize)	1	
maize	0.9647	1

