Detecting and quantifying the extent of desertification and its impact in the semi-arid Sub-Saharan Africa: A case study of the Upper East Region, Ghana

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at George Mason University

By

Alex B. Owusu
Master of Science
Ohio University, 2005
Master of Arts
Ohio University, 2005
Master of Philosophy
University of Ghana, 2001
Bachelor of Arts
University of Ghana, 1997

Co-Directors:
Dr. Sheryl L. Beach, Associate Professor
Department of Geography and Geoinformation Science
Dr. Guido Cervone, Assistant Professor
Department of Geography and Geoinformation Science

Spring Semester 2009
George Mason University
Fairfax, VA
DEDICATION

This is dedicated to my wife Cecilia Owusu, who has supported me throughout this long journey.
ACKNOWLEDGEMENTS

My utmost appreciation goes to the Almighty God for bringing me this far. I would like to thank both of my advisors, Dr. Sheryl Beach and Dr. Guido Cervone, for their guidance and substantial contribution to this project. I thank my committee members, Dr. John Qu, Dr. Benedict Carton and Dr. Alexander Lotsch, for painstakingly reviewing my work with interesting and constructive suggestions. I thank my good friends, Dr. Bossman Asare and Daniel Amposah-Opoku, for spending sleepless nights reviewing this work.

I also would like to thank Dr. Allan Falconer for rescuing me at the time when there seemed to be no hope; without him, my world would have ended before I finished. I am equally grateful for Dr. Barry Haack and Dr. Wong for believing in me. I thank Dr. Liang You for his support and provoking thought that challenged my intellectual abilities; it was very inspiring and intuitive. Also, I am thankful to Dr. Alex B. Asiedu, my developing country mentor for his support.

Finally, I thank my wife Cecilia, my parents and my siblings for their spiritual and material support. I am equally grateful to my other family in Columbus, OH and my great friends Ama Akumanyi and Albert Adusei for their support.

This work is sponsored by Norman Borlaug, LEAP Grant, USAID, IFPRI and UC Davis. The work is also supported by GEOEYE Company through their image grant service.

However, I must emphasize, that I am solely responsible for any shortcomings, marginal or substantial, which may be found in this text.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>BACKGROUND</td>
<td>1</td>
</tr>
<tr>
<td>1.1</td>
<td>Global Concern for Desertification</td>
<td>1</td>
</tr>
<tr>
<td>1.2</td>
<td>Desertification: Sub-Sahara Africa’s Nightmare</td>
<td>6</td>
</tr>
<tr>
<td>1.3</td>
<td>Desertification: Emerging crisis in Ghana</td>
<td>11</td>
</tr>
<tr>
<td>1.4</td>
<td>Scientific Questions</td>
<td>15</td>
</tr>
<tr>
<td>1.5</td>
<td>Hypothesis</td>
<td>17</td>
</tr>
<tr>
<td>1.6</td>
<td>Scientific Goals</td>
<td>18</td>
</tr>
<tr>
<td>1.7</td>
<td>Research Objectives</td>
<td>19</td>
</tr>
<tr>
<td>1.8</td>
<td>Outline of Dissertation</td>
<td>19</td>
</tr>
<tr>
<td>1.9</td>
<td>Conclusion</td>
<td>21</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>UNDERSTANDING DESERTIFICATION: CAUSES AND EFFECTS</td>
<td>22</td>
</tr>
<tr>
<td>2.1</td>
<td>Desertification: Definitions and Concepts</td>
<td>22</td>
</tr>
<tr>
<td>2.2</td>
<td>Desertification: Measurement Problems</td>
<td>30</td>
</tr>
<tr>
<td>2.3</td>
<td>Desertification and Climate Coupling: West African Sudan-Sahel Region</td>
<td>35</td>
</tr>
<tr>
<td>2.4</td>
<td>Desertification as Human Phenomenon</td>
<td>42</td>
</tr>
<tr>
<td>2.5</td>
<td>Conclusion</td>
<td>56</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0</td>
<td>GEOSPATIAL APPROACH TO UNDERSTANDING DESERTIFICATION</td>
<td>59</td>
</tr>
<tr>
<td>3.1</td>
<td>Remote Sensing analysis of desertification as land use/land cover change</td>
<td>59</td>
</tr>
<tr>
<td>3.2</td>
<td>Remotely Sensed Normalize Vegetation Index (NDVI) Approach</td>
<td>65</td>
</tr>
<tr>
<td>3.3</td>
<td>Seeking Spatio-temporal multispatial approach for measuring desertification</td>
<td>77</td>
</tr>
<tr>
<td>3.3.1</td>
<td>Satellite Data</td>
<td>77</td>
</tr>
<tr>
<td>3.3.2</td>
<td>Climate Data</td>
<td>91</td>
</tr>
<tr>
<td>3.3.3</td>
<td>Socio-Economic Data</td>
<td>92</td>
</tr>
<tr>
<td>3.3.4</td>
<td>Direct Field Observation and location data with Geographic Position</td>
<td></td>
</tr>
</tbody>
</table>
LIST OF TABLES

Table 2.0: Monitored indicator of land recovery ................................................. 51
Table 2.1: Project Intervention for land recovery ............................................... 55
Table 2.2: Extent of Land recovery over the project period ............................... 55
Table 3.0: Range of spectral values for AVHRR channels ................................. 82
Table 3.1: Landsat Satellites, their Operational Periods, and Their Instruments .... 84
Table 3.2: Landsat 1-5 Instruments and Bands .................................................... 85
Table 3.3: Landsat 4-7 Instruments and Bands .................................................... 86
Table 3.4: Landsat Scenes, sensor and date of acquisition ............................... 87
Table 5.0: Correlations between Mean Annual Rainfall (Garu, UER) and Mean annual NDVI (UER) ................................................................. 178
Table 6.0: Characteristics of respondents (farmers) ......................................... 192
Table 6.1: Ghana’s Development Policy, strategy, instrument and role of Agriculture ................................................................. 213
Table 6.2: Perceived changes in life style in the UER since 1995 ....................... 226
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1.0: Global and Regional land area under the threat of desertification</td>
<td>3</td>
</tr>
<tr>
<td>Figure 1.1: Global Atlas of Desertification Risk</td>
<td>3</td>
</tr>
<tr>
<td>Figure 1.2: The severity of the impact of desertification on humans and life-supporting systems</td>
<td>4</td>
</tr>
<tr>
<td>Figure 1.3: Global sub-regional human drought fatalities</td>
<td>5</td>
</tr>
<tr>
<td>Figure 1.4: Map of Drylands and Desertification – Africa</td>
<td>8</td>
</tr>
<tr>
<td>Figure 1.5: World regional population in dryland areas under the risk of desertification as a percentage of regional population, with Africa having about 35% of its population in areas under the desertification risk</td>
<td>9</td>
</tr>
<tr>
<td>Figure 1.6: Per capita food production Index numbers 1961 =100</td>
<td>10</td>
</tr>
<tr>
<td>Figure 1.7: Total land area of Ghana by land use/land cover types (1992-1993)</td>
<td>11</td>
</tr>
<tr>
<td>Figure 1.8: Dryland and Dryland as a percentage of total land area of Ghana</td>
<td>12</td>
</tr>
<tr>
<td>Figure 1.9: Map of Ghana showing the UER</td>
<td>13</td>
</tr>
<tr>
<td>Figure 1.10: Map of the study area</td>
<td>15</td>
</tr>
<tr>
<td>Figure 2.0: Vector movement in vector space</td>
<td>34</td>
</tr>
<tr>
<td>Figure 2.1: Map of Sahel region and annual rainfall pattern (1901-1990)</td>
<td>36</td>
</tr>
<tr>
<td>Figure 2.2: Isohyets of Sahel region</td>
<td>36</td>
</tr>
<tr>
<td>Figure 2.3: Map showing the position of ITCZ in July-September 2007</td>
<td>38</td>
</tr>
<tr>
<td>Figure 2.4: Climates for Sahel West Africa</td>
<td>39</td>
</tr>
<tr>
<td>Figure 3.0: Example of AVHRR NDVI showing the greenness of African continent in 2001</td>
<td>65</td>
</tr>
</tbody>
</table>
Figure 3.1: LETM+ NDVI covering UER and Northern region of Ghana for October 27, 2001 ................................................................. 66

Figure 3.2: The absorption and reflectance of healthy and unhealthy vegetation in red and NIR bands .............................................................. 72

Figure 3.3: Multispatial NDVI analysis ................................................... 79

Figure 3.4: Steps for image processing ..................................................... 90

Figure 3.5: Locations where FGDs were held in the UER ........................... 94

Figure 4.0: Elevation Map of the UER, Ghana .............................................. 102

Figure 4.1: Drainage and topography of the UER ........................................ 104

Figure 4.2: The Mean Position of the ITCZ (10° W to 10° E longitude) .......... 108

Figure 4.3: The position of the African ITCZ June 2004 Dekad 3 .................. 109

Figure 4.4: The ITCZ position and sphere of influence observed between March 11 – 20, 2008 ................................................................. 109

Figure 4.5: Rainfall Distribution ............................................................... 111

Figure 4.6: Average Annual Rainfall for Garu and Manga-Bawku, UER (1983-2004) .114

Figure 4.7: Total Mean Monthly Rainfall for Garu (1983-2004) ...................... 116

Figure 4.8: Total Mean Monthly Rainfall for Manga-Bawku (1983-2004) ............ 116

Figure 4.9: Mean Monthly Temperature and Temperature Differences between Bawku and Garu, UER (1983-2004) ................................................. 118

Figure 4.10: Mean annual temperature trend for Garu and Bawku, UER .......... 119

Figure 4.11: Mean Monthly Relative Humidity and the differences between Garu and Manga-Bawku (1983-2004) ............................................ 120

Figure 4.12: Horsetail grasses use for thatching and local thatched house in the UER...122

Figure 4.13: Population concentration in the UER ....................................... 127
Figure 4.14: Total Population and Changing Density (1960-1998) ....................... 128
Figure 5.0: The Approximate size of the African continent .............................. 141
Figure 5.1: Biome types of the African continent ............................................. 143
Figure 5.2: Important environmental issues in Africa and number of countries under threat ................................................................. 146
Figure 5.3: Mean Monthly NDVI for Africa (1982-2007) ................................. 150
Figure 5.4: Mean Seasonal NDVI of Africa and the Sahel region (1982-2007) ........ 151
Figure 5.5: NDVI Map of Africa 2002 ................................................................. 152
Figure 5.6: The Mean Maximum Yearly NDVI for Africa (1982-2007) ............... 153
Figure 5.7: NDVI Sahel Africa 2001 ................................................................. 155
Figure 5.8: Mean Monthly (seasonal) NDVI for Sahel of Africa ....................... 156
Figure 5.9: Mean Maximum Annual NDVI for Sahel Region (1982-2007) .......... 157
Figure 5.10: Mean Annual Mean NDVI for Sahel (1982-2007) ......................... 158
Figure 5.11: Mean Spatial Pattern of Land Degradation ................................. 158
Figure 5.12: Normal yearly NDVI corresponding to normal rainfall of a normal year ............................................................. 160
Figure 5.13: GIMMS NDVIg Mean Composite NDVI -2001............................... 161
Figure 5.14: Mean NDVI for the UER 1982-2007 ............................................ 162
Figure 5.15: Annual NDVI trend for UER ....................................................... 163
Figure 5.16: Mean Spatial pattern of NDVI changes 1982-1990, 1990-1999, and 1999-2007 ................................................................. 165
Figure 5.17: Mean and Maximum spatial gains ............................................. 167
Figure 5.18: NDVI gainers and losers measure in percentages ....................... 168
Figure 5.19: Mean Spatial Pattern of Land cover change ............................. 168
Figure 5.20: LTM5 Mean NDVI for the months of October/November in the UER (1984-2002) ................................................................. 170

Figure 5.21: NDVI Changed Map of the UER (1999-2002) .........................171

Figure 5.22 Spatial pattern of change ......................................................172

Figure 5.23: GIMMS and LETM+ NDVI Spatial Degradation Comparison .......173

Figure 5.24: LETM+ and Google Earth Spatial Degradation Integrate .............174

Figure 5.25: Relationship between NDVI and Rainfall ...............................177

Figure 6.0: Spatial heterogeneity of the UER, captured by IKONOS 2 Satellite ...188

Figure 6.1: GIMMS NDVIg Pixel covering a land area of 8km with NDVI value of 0.34 ................................................................................. 189

Figure 6.2: Locations where participants for FGDs came from. These locations correspond to areas identified as most affected by desertification .......... 191

Figure 6.3: CCoLD modeling .................................................................... 196

Figure 6.4: Remnants of the original tall grass of the UER ..........................202

Figure 6.5: The succeeding vegetation (ecological succession), UER ............203

Figure 6.6: Severity of wildfire and rapidity of recovery after first rains ........206

Figure 6.7: Impact of early and late burning captured by IKONOS 2 Satellite ...219

Figure 6.8: Land Extensification in the UER ..............................................227

Figure 6.9: Land under cultivation of Maize increases while average yield per hectare decreases ............................................................ 228

Figure 6.10: Land under cultivation of rice increases while average yield per hectare decreases ..............................................................229

Figure 6.11: Land under cultivation of Groundnut increases while average yield per hectare decreases ......................................................230

Figure 6.12: Land under cultivation of Millet increases while average yield per
hectare decreases ……………………………………………………………………… 231

Figure 6.13: Land under cultivation of Guinea corn increases while average yield per hectare decreases ……………………………………………………………………… 232

Figure 6.14: Trend for mean yield per hectare for 7 major food crops produced in the UER ……………………………………………………………………… 233
ABSTRACT

DETECTING AND QUANTIFYING THE EXTENT OF DESERTIFICATION AND ITS IMPACT IN THE SEMI-ARID SUB-SAHARAN AFRICA: A CASE STUDY OF THE UPPER EAST REGION, GHANA.

Alex B. Owusu, Phd

George Mason University, 2009

Dissertation Co-Directors: Dr. Sheryl Beach & Dr. Guido Cervone

The semi-arid Sub-Saharan region of Africa is in a state of permanent instability at a variety of spatio-temporal momentum. Efforts at sustaining and managing this fragile but all-important ecosystem and its processes require collecting, storing and analyzing multispatial and temporal data that are accurate and continuously updated in terms of changes (degradation), types and magnitude of change. Remote sensing techniques based on multispectral satellite-acquired data (AVHRR, Landsat TM and ETM+) have demonstrated an immense potential as a means to detect, quantify, monitor and map these changes. However, much of what satellite sensors can detect and capture, especially in the form of vegetation index (NDVI), do not tell the entire story about land degradation. This research used multispectral remote sensing data from three sensors (AVHRR, Landsat TM, and ETM+ and IKONOS) to detect and quantify the spatio-temporal land degradation (desertification) to validate the local observation and perception of
desertification. The study also analyzes data on crop production in search of evidence proving or disproving degradation in the semi-arid sahel-sudan savannah transitional vegetation zone of the UER, Ghana.

Multispectral satellite-acquired NDVI, from AVHRR, Landsat TM & ETM+, show that vegetation greenness is on the ascendancy, although there are pockets (localized degradation) signs of severe land degradation; field evidence suggests that the increasing NDVI is caused by vegetation succession where locally adapted horsetail grasses have been displaced by environmentally efficient, short-lived, quick maturing and dense grasses due to excessive burning, rapid population growth and inappropriate development policies. Local people’s perceptions, supported by crop production data, suggest extensive land degradation. Other evidence includes food insecurity, diseases, rainfall variability and land extensification to marginal lands. Convergence of evidence suggests that desertification has advanced in the area more than previously thought and that more focused, community-based effort would be needed to combat desertification and restore the ecosystem’s integrity.
CHAPTER 1.0: BACKGROUND

1.1 Global Concern for Desertification

Several factors have combined to threaten, produce, alter and reproduce global vegetation cover. These include anthropogenic causes, natural events and the ecosystem dynamics. It is generally believed that the principal force altering and degrading global vegetation cover today is human use (anthropogenic factors)--agriculture and livestock raising, forest harvesting and management, and urban and suburban construction and development. There are also incidental impacts on vegetation cover from other human activities such as the damage done to forests and grasslands as a result of acid rain, caused from fossil fuel combustion and crops near cities damaged by tropospheric ozone resulting from automobile exhaust (Bottomley 1998; Singh 1984).

Bottomley (1998) has categorized contemporary global vegetation cover change (degradation) into two broad types, namely systemic and cumulative changes. Systemic change is classified to be operating ‘directly on the bio-chemical flows that sustain the biosphere and depending on its magnitude, can lead to global vegetation cover change, just as fossil fuel consumption increases the concentration of atmospheric carbon dioxide’. Systemic change is associated with the post-Industrial Revolution period and has, more importantly, grown over the past several years. Cumulative change, on the
other hand, is the most common type of anthropogenically-induced environmental change. This change is of local importance but assumes global magnitude if repeated over a long period. Examples of cumulative vegetation cover change include, but are not limited to, cropland, grasslands, wetlands, forests, and human settlements. Accordingly, some cumulative changes such as deforestation and desertification reached continental, or even global, proportions long before the 20th century (Bottomley 1998; Turner and Butzer 1992).

Desertification; often referred to as land degradation in arid, semi-arid and sub-humid regions (dryland regions) of the world; is considered a major cumulative land cover change that threatens the survival of global population (UNCED 1992; Reynolds & Stanfford Smith 2002, 2005). Desertification threatens 40% of the global land surface (Adger et al 2000; Wessels 2005; Veron et al 2006) and life-supporting system of approximately 2.5 billion humans (Reynolds et al 2007). According to the United Nations (UN), an estimated $45 billion (US) is spent on efforts to combat desertification annually (UNEP 2006).
Figure 1.0: Global and Regional land area under the threat of desertification

Figure 1.1 Global Atlas of Desertification Risk (UNEP 2006)
However, the causes and effects of desertification are complex and multifaceted, varying from local to regional and from one part of the world to another (Pickup 1998; Veron et al 2005; Prince 2002; Leemans and Kleidon 2002). The severity of desertification impact also varies on a spatio-temporal scale and is difficult to quantify. Yet, less-developed countries experience greater human misery than those with the resources to provide short and long-term relief to populations affected by desertification (Pickup 1998). The plate below shows the devastating nature of desertification on landscape and the biota.

Figure 1.2: The severity of the impact of desertification on humans and life-supporting systems (UNEP 2004)

Moreover, desertification problems have become inextricably intertwined with issues of food security, poverty and retarded development in poor countries, but in the developed
countries, the emphasis is on environmental degradation, inappropriate land use, loss of biodiversity and rural restructuring (Pickup 1998). Desertification problems have also been linked with the droughts and desiccation, which have affected some parts of the world, such as the Sahel region of Africa (Leemans and Kleidon 2002; Pickup 1998). Below is a graph showing global drought fatalities from 1980 to 2007 among four sub-regions of the world, with Africa being the worst affected sub-region.

![Graph showing global sub-regional human drought fatalities](image)

**Figure 1.3: Global sub-regional human drought fatalities**

The past 20 years have seen an increasing global effort to halt this global desertification menace and as of March 17, 2008, 193 countries have joined the global effort to combat the desertification menace by signing the United Nations Convention to Combat
Desertification (UNCCD), which Serbia was the last country to have signed on March 17, 2008 (UNCCD 2008).

1.2 Desertification: Sub-Sahara Africa’s Nightmare

The continent of Africa is said to be the origin of human race (UNEP 2008) and with one-fifth of the world’s total land area, Africa has 965 million people living there as of 2007 (UNEP 2008). Millions of years of human occupancy and resource extraction have had an untold stress on the land and its general environment, leading to unprecedented land degradation (desertification) and its associated human misery on the continent’s population.

The crisis of desertification on the continent of Africa has been narrated for centuries, dating back to the pre-colonial period (Davis 2004; 2005; Smith and Koala 2003). Spooner (1989) believes that desertification is a phenomenon that can be traced back to the medieval and Neolithic periods. Smith and Koala (2003) also argue that inappropriate traditional agricultural methods in the distant past were responsible for land degradation in the Negev and Northern Africa several centuries ago. In Morocco, for example, narratives of desertification crisis are said to have been frequently used to facilitate and justify leadership policy changes, as well as legal reforms, which gradually and systematically marginalized indigenous pastoralists (Davis 2004). Citing evidence from the official government literature which appeared after the United Nations Conference on Desertification (UNCOD) in 1977, Davis (2005) argues that overgrazing of Moroccan rangelands has been persistently cited as the main cause of rangeland degradation.
Similar stories have been told of the Machakos District of Kenya. Evidence of desertification is said to have been observed prior to 1900 and as far back as the 1930s; the Machakos Reserve acquired fame among conservationists, who saw misuse of land that led to deforestation, land degradation and soil erosion on large scale (Mortimore 2005; Maher 1937; Tiffen and Mortimore 1994). Several stories of desertification are narrated in many parts of the African continent and have become part of tribal mythology.

By the year 2001, it was estimated that desertification process was affecting about 46% of the African continent. The situation exacerbates, considering the fact that about 43% of the continent is hyper-arid, or extreme desert (Darko 1993). Interestingly, only 11% of the continental landmass is humid and can be excluded with certainty from the desertification processes. Of the 46% land surface considered under the desertification process, about 2.5 million km² is classified under low risk, 3.6 million km² under moderate risk, 4.6 million km² under high risk, and 2.9 million km² under very high risk. The regions with the highest predisposition to desertification are found along the margins of existing deserts and constitute about 5% of the continental landmass (Heiding 2001; Reich et al 2001). Below is the land degradation map of Africa, showing the extent of the desertification threat on the continent.
Desertification has had an untold hardship on the continent’s biological life and natural resources, with most of the land and water bodies currently being overexploited. The net effects are widespread poverty, malnutrition, hunger, starvation and wars across many parts of the continent. Conservative estimates state that nearly 400 million people (two-thirds of all Africans) live on two-thirds (1,287 million hectares) of the continent’s land area classified as arid, semi-arid or dry sub-humid area (threatened by desertification) (Darko 1998).
Figure 1.5: World regional population in dryland areas under the risk of desertification as a percentage of regional population, with Africa having about 35% of its population in areas under the desertification risk.

Others have estimated that about 22 million people (2.9% of the continent’s total population) live in desert margins with very high risk of desertification. Areas classified as low, moderate, and high desertification vulnerability have 14%, 16%, and 11% of the population respectively, and altogether, desertification is affecting about 485 million people on the African continent.

Currently, about 60 million more people will be forcibly moved from newly desertified areas of sub-Saharan Africa by the year 2020 if aggressive programs to stop the current...
trend are not pursued (Brasten 2004). Moreover, 25 countries face drastic food shortages due to extended drought, while 70% of the 485 million Africans threatened by desertification live on less than $2.00 a day (Jama et al 2003).

Figure 1.6: Per capita food production Index numbers 1961 = 100

It is against this background that Lloyd Timberlake, the author of the book *Africa in Crisis* summed it up as “Africa has taken too much from its land. It has overdrawn its environmental account” and the result for much of the continent has been “environmental bankruptcy” (Darkoh 1998). However, many environmental historians do not agree with Lloyd for saying that Africa has overdrawn its environmental account. In unambiguous terms, Songsore (1996) has stated,

“whereas the rich industrial north accounts for a mere 23 percent of the world’s people, its population earns 85 percent of the world’s income. The strains of this level of economic activity are felt in the loss of forests and species … it is therefore undeniable fact that the rich minority threatens the wider ecological integrity of humanity’s existence” (Songsore (1996, pp. 1 ).
Perhaps Lloyd’s statement may be a more precise reflection of the causes of the environmental crisis if he had stated that Africa has been forced to overdraw its environmental accounts and has since then left Africa in environmental bankruptcy.

1.3 Desertification: Emerging crisis in Ghana

Ghana is a West African country. It shares its northern border with Burkina Faso, eastern with the Republic of Togo, western with La Cote d'Ivoire and bordered on the south by the Gulf of Guinea. Latitudinally, Ghana lies between latitude 4° and 12° north of the equator. It also lies astride longitude 0° and 10 minutes east. Ghana has a total land area of 230,020 km², slightly smaller than the state of Oregon. The figure below (figure 1.5) shows the classification of Ghana’s total land area by ecosystem types.

![Figure 1.7: Total land area of Ghana by land use/land cover types (1992-1993)](image-url)
Of the 230,020 km² land area, almost 50% constitutes dryland area, which generally comes under the threat of desertification (land degradation).

![Dryland and Dryland as a percentage of total land area of Ghana](image)

**Figure 1.8:** Dryland and Dryland as a percentage of total land area of Ghana

Land degradation poses a serious threat to the natural resources, agriculture and the entire livelihood support system of the savanna regions, northern and southern Ghana, and more importantly, to the Sahel-sudan savannah transitional zone of the Upper East Region (UER) mainly due to the high resource demand on this fragile ecosystem and the large population base of the area (Yaro 2005; EPA 2006; EPA 2005; Agyarko 2000; Awudi 2005; Kwarteng 2002). The Ghana Vision 2020 (1996), Medium Term Agricultural Development Plan (MTADP) (1990) (Sanders et al 1995) and the third national report to the committee for the review of the UNCCD (2005) have identified desertification as the most serious environmental problem in Ghana and the UER in particular. The Environmental Protection Agency (EPA), in its National Action Plan (NAP 2005), has
directed attention to severe land degradation in the UER with a plan of action, which uses local stakeholders to address this desertification problem (EPA 2006). Below is the map of Ghana showing the location of the UER.

![Figure 1.9 Map of Ghana showing the UER](image)

The UER and its precise boundaries are outlined by figure 1.7 above. The UER is one of the latest ten regions of Ghana created in 1983. Latitudinally, it lies between 10°07’45” and 11°20’33” and in the case of longitude, it falls between 00°09’00”E and 00°27’33”W. Prior to its creation in 1983, it was administered as part of the Upper Region with its administrative capital in Bolgatanga and was later divided into the Upper East and Upper West Regions. The present UER shares common borders with the Republic of Togo in the East, Burkina Faso in the North, the Upper West, and the Northern regions in the West and South respectively. The region consists of former Bolgatanga and Bawku
Districts, and it is now subdivided into 8 districts, namely Bawku Municipal District, Bawku West District, Bolgatanga Municipal District, Bongo District, Kassena/Nankana District, Builsa District, Garu-Tempane District, and the Talensi-Nabdam District. It is, however, important to clarify that the numbers and boundaries of administrative districts of the UER have changed a number of times since its creation in 1983. A good example is the recent subdivision of Bawku East District into Bawku Central and Garu-Tempane districts and the division of Bolgatanga District into Bongo and Bolgatanga Municipal Districts. These subdivisions have implications on the study area’s boundary and its comparability to previous and future studies and maps; however, figure 1.8 below clearly defines the boundaries of the study area.

This study focuses on the UER of Ghana covering a land area of about 160x120km²; however, more emphasis would be placed on three main districts, consisting of former Bawku East, the present Bawku Municipal and Garu-Tempane Districts, Bawku West District, and eastern parts of former Bolgatanga District, which are the extreme north and eastern part of Ghana. These areas also constitute the worst affected districts in terms of desertification in Ghana (EPA 2005). Coincidentally, these three worse affected districts have the most productive agricultural lands and are the most populous of the eight districts in the UER (EPA 2005). Recent studies by International Food Policy and Research Institute (IFPRI 2007) and United States Agency for International Development (USAID 2006) have shown that the study area is a region of extreme poverty (9 out of 10 people are classified as very poor) and also a region of negative net migration due to land
degradation and erratic rainfall patterns (Daily Graphic 2007). Figure 1.8 shows the outline and relief of the districts of emphasis in the study area.

Figure 1.10: Map of the study area

1.4 Scientific Questions

The concern that the savanna region of Ghana and the UER are rapidly experiencing desertification has been officially expressed for decades now. For instance, Nsiah-Gyabaah (1994) quoted an official statement by the Chairman of the Provisional National Defence Council (PNDC), the then ruling military government of Ghana, in 1989 at an official dinner held in his honor during a state visit to Dar-es-Salaam in Tanzania, that “pest, drought and desertification had often devoured the hard work of African producers (Ghanaian farmers) and brought famine to large sections of the population” (Ghana High Commission 1989). The Ghana Vision 2020 document (1996), Medium Term
Agricultural Development Plan (MTADP) (1990) (Sanders et al 1995), and the third national report to the committee for the review of the UNCCD (2005) have identified desertification as the most serious environmental problem in Ghana and the UER in particular. Currently, desertification is said to be consuming the Sahel-sudan savannah transitional zone of the region at an alarming rate, thereby undermining livelihood supporting systems, as well as threatening food security of the area and forcing people to migrate (Nsiah-Gyabaah 1994; EPA 2005; Daily Graphic 2007; USAID 2006; IFPRI 2007).

Several attempts have been made with limited success and sometimes with worse results to control and combat the threat of desertification in this region. For example, Nsiah-Gyabaah (1994) has observed that the implementation of International Monetary Fund/World Bank Structural Adjustment Program/Economic Recovery Program (SAP/ERP), with its associated export promotion, currency devaluation, and withdrawal of agricultural subsidies with no due consideration to environmental impact, is one of the worst policies that have exacerbated land degradation (desertification) in Ghana. The Convention to Combat Desertification (CCD), on the other hand, outlined ten key principles, which in the view of the World Bank, holds great promise for combating desertification. The Ghana Government has, since the 1980s, drawn programs and action plans to combat desertification in this region. Currently, there is a plan of action, which addresses desertification through District Assemblies and local residents.
The Food and Agricultural Organization (FAO) attributes the limited success in combating desertification to the general uncertainty in the origins, extent, and gravity of the desertification process. However, FAO believes that technologies such as remote sensing and Geographic Information Systems (GIS) hold the key to combating desertification in the future. In view of the FAO’s concern, the questions to be answered in this study are stated thus:

- How much land degradation has actually taken place in the UER, Ghana?
- What are the main anthropogenic drivers of land degradation in the area?
- How does remote sensing technology improve understanding, spatial visualizing and communication on desertification?

There is an urgent need to answer these questions to provide accurate and up-to-date information about desertification as a precursor to any attempt to plan and combat desertification in the UER and Ghana. For this reason, the foremost priority of this study is to map the spatial extent of desertification, identify major anthropogenic drivers and impact of desertification on food security.

1.5 Hypothesis

The hypothesis to be tested in this study is stated thus: land degradation observed in the UER is more likely to be interannual and interdecadal land cover change than desertification. That is, a piece of land identified as degraded in one season is more likely
to experience regeneration in the next one or two seasons when environmental conditions might have improved, instead of remaining degraded for the study period.

1.6 Scientific Goals

The drive to combat desertification in the developed countries dwells on the fact that it degrades biophysical environment; in the developing countries, however, desertification is a matter of life and death. The life of rural people in these parts of the world is ultimately tied to the effective use of natural resources (Reynolds 2001). The fundamental goals of this dissertation include:

- to apply remote sensing and field observation to detect and quantify the extent of desertification.
- to communicate the spatio-temporal extent and severity of desertification in the UER of Ghana.
- to understand and identify, from local residents’ perspective, the key anthropogenic factors causing land degradation in the area.
- to bridge the knowledge gap for policy makers to monitor, plan and combat desertification as a prelude to improving agriculture and to achieving food security.
1.7 Research Objectives

The following specific research objectives were addressed in the study:

- Apply AVHRR NDVI / Landsat NDVI to map out land degradation that has occurred in the study area from 1982-2007
- To provide a broad picture of the temporal trend of land degradation, climate change, and food security in the UER.
- Analyze the major anthropogenic drivers of desertification at play in the study area through FGD.
- Recommend some policy interventions necessary for ameliorating and combating desertification and its impact in the region.

1.8 Outline of Dissertation

The dissertation consists of seven chapters. Chapter 1 introduces the topic of land degradation (desertification) from a global perspective and from sub-Sahara Africa. The chapter also reviews desertification in Ghana and specifically the study area as a precursor to the specific research questions and study objectives to be addressed. In chapter 2, we broadly discuss desertification. The chapter discusses various definitions and measurement problems, desertification in relation to climate, desertification as human factor, and the neo-Malthusian view of desertification. The chapter is concluded with specific success stories of recovery from land degradation in Africa. Chapter 3 focuses on remote sensing techniques for the analysis of desertification. Here, the chapter discusses some key remote
sensing algorithms for detecting and quantifying desertification and their drawbacks in relation to the method we are using. We discuss the multi-spatial and multi-level data approach for spatio-temporal analysis of desertification. Specifically, we discuss data and data sources, data processing, rationale for using this method, and associated problems and/or limitations.

In chapter 4, we discuss the nature of the study area in terms of topography, climate and vegetation. The chapter also discusses farming practices and land tenure systems of the study area. We apply multiscale and multitemporal NDVI trend analysis to quantify the spatio-temporal dynamics of desertification in the study area in chapter 5. The chapter also analyzes rainfall data and correlates that with NDVI in testing the study hypothesis.

Chapter 6 focuses on the analysis of field data collected during the focus group discussions with questionnaires. We examine the field data in search of concordance or divergence of evidence of desertification in the study area. We also examine major anthropogenic drivers of desertification in the study area and impact of desertification. We further discuss the effects of desertification on food security and poverty, as well as possible ways to address issues of food security in the area. Lastly, in chapter 7 we summarize the major findings and recommendations of this study. We conclude this report with future research questions arising from the research findings.
1.9 Conclusion

Desertification is a global problem, but developing countries of Sub-Sahara Africa is the worst affected. This is partly because most of the subregion’s populations have their lives tied to the natural environment. The destruction of the natural environment destroys the basic livelihood support systems of these people. Whereas rich nations of the West have the resources to provide relief for their population affected by desertification, poor nations of Sub-Sahara Africa have their affected population living on less than $1 a day, and cannot afford to provide shelter and clothing for them. It is against this background that over 99% of all desertification fatalities have occurred in Africa. Desertification is a real problem threatening the existence of real people, hence the need for more global effort to address desertification as a humanitarian crisis.
CHAPTER 2.0: UNDERSTANDING DESERTIFICATION: CAUSES AND EFFECTS

2.1 Desertification: Definitions and Concepts

Desertification, also referred to as dryland degradation, remains a controversial subject since its first scientific use in 1927. Lavauden is credited to having used the word desertification in a paper. Stated in French, Lavauden said ‘dans toute la zone … la desertification, si j’ose dire, Est purement artificielle. Elle est uniquement le fait de l’homme’ meaning ‘throughout the whole Sahara – I dare to say – desertification is fully artificial: uniquely man-made’ (Mainguet and Da Silva 1998). However, Aubreville (1949) (Dregne 1986; Hellden 1991; Thomas 1997; Lambin et al 2001; Geist and Lambin 2004) was the first person to use desertification in the scientific literature. The enormity of local and national studies focusing on the subject of desertification demonstrates not only its socio-ecological importance, but also the fact that some parts of the desertification puzzle remain unsolved (FAO 1999; Veron et al 2006; Geist and Lambin 2004).

Generally, the subject lacks an accurate and universally acceptable definition. This disallows scientists the opportunity to assess and measure it in its various forms. As pointed out before, the earliest attempt at defining desertification was given by Aubreville (1949) in his famous and ever-cited book Climats, Forets, et Desertification de l’Afrique Tropicale. Aubreville described desertification as the changing of productive
land into a desert as a result of ruination of land by man-induced soil erosion. Aubreville observed the ruination of land in the humid and sub-humid tropics where he worked. He concluded that tree cutting, indiscriminate use of fire, and exposing soil to erosion by water and wind through certain modes of cultivation were the principal causes of land degradation (Aubreville 1949, Dregne 1986). Similar definitions of desertification were found in the literature. For example, in 1984, UNEP limited the definition of desertification to ‘land degradation … resulting from diverse human impact” (Rasmussen et al 2001).

Expanding on Kassas’s concept of desertification from his study of desert expansion in Sudan, Kates, Johnson, and Dregne define desertification as the impoverishment of arid, semiarid, and some subhumid ecosystems by the combined impact of man's activities and drought. It is the process of change in these ecosystems that can be measured by reduced productivity of desirable plants, alterations in the biomass and the diversity of the micro and macro fauna and flora, accelerated soil deterioration, and increased hazards for human occupancy (Dregne 1977). In this definition, desertification does not refer only to totally devastated land where nothing grows. There are very few places where man and drought have totally destroyed the vegetative cover and caused virtually permanent land damage. Slight to severe, but not total, land degradation is much more common and much more significant in the vast majority of inhabited arid regions (Dregne 1977).
The most extensively-cited definition in the literature today came from UNCED. UNCED gave a definition of desertification, which was adopted by UNEP as: “land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities” (UNEP 1994). Emphasis placed on climatic variations in this definition, compared to the other two definitions above, is an indication of the disagreement that existed concerning different causative factors of dryland degradation (Hulme 1993). Even so, this authoritative definition by UNCED appears meaningless and lacks content without further defining what constitutes land degradation. In my view, however, desertification, for the purpose of monitoring and control, should be defined to include how it manifests itself for easy identification and management. According to Prince (2002), common manifestations of desertification, especially those that can be detected from remote sensing, are loss of biological productivity, soil erosion, lost of vegetation cover, land cover diversity change, as well as energy and water flux change. However, he adds that assessing desertification based on soil is a pathological activity and is counter-productive. Among all other manifestations, the most relevant one is surface vegetation change. Irrespective of how and what causes desertification, the initial observation that will prompt a second look will be progressive surface vegetation change. This proposition is also supported by Prince et al (1998) and Prince (2002), Veron et al (2005, 2006) and Reynolds et al (2007) and has become the current paradigm that researchers are looking into.
On its part, the UNCCD defines land degradation to include reduction of or loss of biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, range, pasture, forest, or woodlands arising from land uses or from processes resulting from human activities and habitation patterns (UNCCD 1992). Williams and Balling (1995), on the other hand, define land degradation as the reduction of biological productivity of dryland ecosystems, including rangeland pastures and rainfed and irrigated croplands. According to the authors, land degradation results from an acceleration of certain natural, physical, chemical, and hydrological processes, including erosion and deposition by wind and water, salt accumulation in soils, groundwater and surface runoff, as well as a reduction in the amount or diversity of natural vegetation, and a decline in the ability of soil to transmit and store water for plant growth. Even with what appears to be a clear definition of land degradation, the initial concern of these scientists is biological productivity, which would be seen as plant and vegetation cover changing over time, (here we are referring to negative change) such that even using NDVI, will manifest as reduction in NDVI. Nevertheless, it must be emphasized that scientists narrowly define land degradation to reflect their discipline and perhaps to generate interest in their studies. It is not uncommon to read geomorphological abstracts with land degradation focusing on erosional processes, while soil scientists focus on physical and chemical properties of the soil. Similarly, ecologists focus on productivity of natural vegetation, but botanists concern themselves with the changes in species’ composition and loss of biodiversity. By definition, what constitutes land degradation in the eyes of an ecologist or botanist would not be counted by the soil scientist and vice
versa (Rasmussen et al 2001). As environmental monitoring specialists, we would like to look at land degradation in terms of progressive degradation in vegetation cover; hence, land degradation process and desertification become synonymous and are used interchangeably. It must also be clarified that for progressive land degradation to be considered desertification, it should have been studied in a continuum, for no less than 15 years, by which period the threshold effects of inter-annual and inter-decadal climate fluctuations and desiccation would have been revived.

Another concept of interest to the definition of desertification and how it is studied is the concept of drylands, where they occur, the nature of drylands, and parts of drylands that can be included in desertification studies. Drylands refer to regions of water scarcity, which manifest in the form of poor primary production and nutrient cycling (Safriel et al, 2005). In dryland regions, precipitation is counterbalanced by loss of moisture through the combined effect of evaporation from surfaces and transpiration by plants, commonly referred to as evapotranspiration. Drylands are therefore measured by the difference between precipitation (moisture supply) and potential evapotranspiration (moisture loss), also known as the aridity index. Aridity index values lower than 1 indicate an annual moisture deficit (Safriel et al 2005). The World Atlas of desertification defines drylands as areas with Aridity Index (AI) of 0.65, that is, areas in which annual mean potential evapotranspiration is at least 1.5 greater than annual mean precipitation (Safriel et al 2005). According to Middleton and Thomas (1997), drylands are areas with an AI value of less than 0.65. Drylands differ by the degree of aridity, using AI (Precipitation –
potential evapotranspiration). In the World Atlas of desertification, UNEP has identified 4 subtypes of drylands with increasing degrees of aridity, namely dry subhumid, semiarid, arid, and hyper-arid. One, however, needs to point out that desertification does not occur in hyperarid regions because these regions are already existing deserts, which by definition, cannot be included in the desertification process.

In dryland regions, potential evapotranspiration exceeds precipitation and as such, are classified as regions of potential water deficit. This potential water deficit affects the ecosystem types and functionality, such as vegetation cover type, crop production, forage, drainage systems, animal life, and ability to meet human needs. It is equally common to classify dryland subtypes based on land use, a classification based on ecosystem types. Safriel et al (2005) classify drylands based on land use types as rangelands, croplands, and urban lands. Rangelands and croplands constitute about 90% of global dryland area and form the base of agropastoral livelihood (Safriel et al 2005). The latitudinal limit of global drylands extends between latitude 65° N and latitude 55° S, and they occur on all continents and encompass nearly half of the global landmass. The remaining land area is made up of polar, forest, and woodlands.

Other concepts relating to desertification are often confused with the desertification process itself. These are what Thomas (1997) describes as the 5Ds. These include Drought, Desiccation, Degradation, Desertification and Desertization. However, drylands degradation and desertification have already been explained above, and it therefore
becomes prudent to explain the remaining three concepts--drought, desiccation and desertization--and possibly show the relationship between the 5Ds. There is the need to distinguish between these terms, for they are closely linked and often confused for one another. Similarly, differentiating between them would not only enhance the meaning of desertification, but also its identification as a process that has a beginning and an ending. Distinguishing between these terminologies and/or processes is necessary because they have different causes and impacts and thus require different policy interventions for ameliorating and controlling their impacts.

Drought can be described as a behavioral pattern of an element of climate, rainfall over a period of no more than 3 years. Specifically we refer to drought over a period of one or two years with rainfall below average such that water scarcity becomes evident. Drought occurs naturally and lasts over a short-term (1±2 years) period when precipitation is significantly below normal recorded levels. Generally, ecosystems wither during periods of drought but recover rapidly after the rain returns (Darkoh 1998; Toulmin 1994; Agnew and Warren 1996). When expecting drought, there is the need for an early warning system coupled with a well-functioning rapid response system to deal with food and fodder shortage, emergency employment schemes, crop insurance, and programs for post-drought rehabilitation.

Secondly, we also talk about desiccation as a period of extended drought, lasting for a decade (Darkoh 1998). That is a period of well below-average rainfall which lasts for at
least one decade. It should be emphasized that drought and desiccation are differentiated by their temporal extent. In terms of their impact, one would agree that longevity of occurrence would determine the severity of impact, all things being equal; however, some droughts tend to be very severe. Desiccation, on the other hand, is measured in the longer-term (decadal order) deficits in rainfall which can seriously disrupt ecological and social patterns and require national and global responses. Recovery after desiccation is much slower, for trees may have died and vegetation may then take years to recover. Responses include management of population movements and the development of alternative livelihood systems (Agnew and Warren 1996). Desiccation preparedness would also involve measures to ensure adaptation in farming and livestock systems to withstand much drier and more variable rainfall.

In addition, dryland degradation is considered a persistent decrease in the biological potential of soils and vegetation due to human use and/or climate variability. Dryland degradation is synonymous to desertification and is therefore used interchangeably in this study. For a detailed description of land degradation and desertification, see above. Dryland degradation may be caused by either climate and/or human activities and requires interventions mainly in the areas of policy directed to regional and national levels. Some of the common areas of policy reform include land-tenure system, pricing policy for crop and livestock products and farm-level technological adaptation, education and other infrastructural support meant to ensure ecological recovery, stable incomes and

Desertization, on the other hand, is defined as the irreversible extension of desert land forms and landscapes to areas where they did not occur. Desertization can be considered the tail end of desertification. Whereas desertification is reversible, desertization is technically irreversible. Some analysts, including Thomas (1997), have argued that the irreversibility stems from cost, time and other resource constraints.

2.2 Desertification: Measurement Problems

Various researchers have attempted to measure desertification through a variety of approaches. In measuring desertification, one controversial issue has been the nature of the phenomenon. One school argues that it is a state. One the other hand, another school contends that it is a process. Others even maintain that reversibility, or lack thereof, must be the most crucial element for measuring desertification. While delineating phenomenon terms such as “state,” “process,” and “reversibility or irreversibility” is useful for measurement purposes; it also has implications for policymaking and management. Thus, in deciding on an approach to use for detecting and measuring desertification, one needs to consider a few questions.
First, is desertification a state or a process? If desertification is considered a state, then we can take a snapshot approach with a single satellite image to detect how it looks. This was the cardinal shortcoming of the first approach by Lamprey (1975) when he compared the southward boundary of the Saharan desert at two different time periods in southern Sudan. He used a vegetation map from 1958 and compared that with an aerial photograph of 1975 and field surveys to conclude that desertification advanced 90-100 km in 17 years. In reality, desertification is not static; it is a process and changes over time. In Sahel Africa, the presence of vegetative cover is also subjected to inter-annual and inter-decadal variations due to rainfall anomalies. This means that in periods of rainfall anomaly, vegetation declines and recovers sharply when rain returns. Plant seeds, especially in dryland areas, have the capacity to remain dormant for as long as 10 years during periods of drought and desiccation but are revived when conditions improve.

Using two dates to map desertification is an over-simplification of the problem because it says nothing about the vegetation status during intervening years. Moreover, it does not take into account interannual and interdecadal rainfall anomalies which can coincide with these two periods of analysis. It is against this background that Prince (2002) argued that desertification needs to be studied as a continuous process for no less than 15 years for any meaningful conclusion.

Secondly, is desertification reversible or irreversible? In this case, if we think desertification is irreversible; then desertification would be seen as desert-like conditions associated with bare surface and severe soil degradation, including gullies.
used the extent of soil degradation and the expert opinions of 250 people. They combined qualitative and quantitative variables of soil and vegetation and concluded that 70% of all drylands are affected by desertification. In reality, desertification has phases beginning with degradation of surface cover (vegetation) before reaching the soil (Collado et al 2002; Lu et al 2004). As identified earlier, the desertification process can be reversed, but when it gets to the soil, it is in the advanced stage. Desertification, therefore, has to be assessed in a continuum from the onset to the hyper state. Initially it is reversible and action must be taken before it reaches the irreversible state. It is against this background that GLASOD’s approach to analyzing and monitoring desertification was criticized as autopsy or postmortem by Veron et al (2006) and Prince (2002).

Next, we consider the Rain Use Efficiency (RUE) approach. Le Houerou (1984) suggests and applies it to the Sahel region of Africa, and Prince (2002) revisits it. What this approach sought to do was to approach desertification in terms of early warning by identifying early signs that can be detected before it reaches the autopsy state, that is, methodology based on early indicators. RUE is the ratio between annual above ground primary production (defined as the rate of aerial biomass accumulation by plants, ANPP) and annual precipitation (Prince et al 1998; Prince 2000, 2002; Veron et al 2006). The physical principle behind this approach is that desertification decreases the proportion of precipitation that is diverted to infiltration and transpiration largely due to increased runoff or evaporation. RUE adopts both statistical and remote sensing approach, including surface moisture detection and thermal to detect moisture and evaporation.
another sense, RUE is assessed in terms of NDVI and soil moisture. RUE is, however, criticized on the grounds that desertification does not always reduce ANPP. The Jornada Experimental Range at the Chihuahuan Desert of New Mexico shows that desertification did not substantially change ANPP (Hueneke et al 2002).

The last approach is based on red–NIR space Change Vector Analysis (CVA). Many studies have used CVA for land cover change characterization. CVA was one of the land cover change characterization approaches specifically designed for MODIS land cover product, before the launching of the MODIS Terra Satellite in 1999. The approach was tested in North Africa and South America, specifically in Egypt, Argentina, and Brazil. In Argentina and Brazil, researchers used the approach to study land cover change with Landsat 4 &5 data. For example, Lorena et al (2006) used the approach on Landsat TM4 data to map land cover/ land use dynamics in Peixoto, Acre State of Brazil. The approach is straightforward. It treats change as movement in vector space. A good example of CVA analysis is Red-NIR space change method. In this perspective, the algorithm uses the Red and Near Infrared (NIR) portions of the spectrum to classify land cover change in multitemporal images.

Red–NIR space change vector method is illustrated by the figure below.
Figure 2.0 above indicates vector movement in vector space between time 1 (T1) and time 2 (T2) in Red-NIR space. It also shows changing levels of brightness and greenness. Small circles show pixel location and the arrows indicate the direction of change.

This method is mathematically illustrated as:

$$A = \sqrt{(\Delta \rho_{Red})^2 + (\Delta \rho_{NIR})^2}.$$  \hspace{1cm} (3.1)

$$\theta = \begin{cases} 
\theta_0, & \text{if } \Delta \rho_{Red} \geq 0 \text{ and } \Delta \rho_{NIR} > 0; \\
90^\circ, & \text{if } \Delta \rho_{Red} < 0 \text{ and } \Delta \rho_{NIR} = 0; \\
180^\circ - \theta_0, & \text{if } \Delta \rho_{Red} > 0 \text{ and } \Delta \rho_{NIR} < 0; \\
180^\circ + \theta_0, & \text{if } \Delta \rho_{Red} < 0 \text{ and } \Delta \rho_{NIR} > 0; \\
270^\circ, & \text{if } \Delta \rho_{Red} < 0 \text{ and } \Delta \rho_{NIR} = 0; \\
360^\circ - \theta_0, & \text{if } \Delta \rho_{Red} = 0 \text{ and } \Delta \rho_{NIR} < 0; 
\end{cases}$$ \hspace{1cm} (3.2)

where

$$\theta_0 = \arctan \left| \frac{\Delta \rho_{Red}}{\Delta \rho_{NIR}} \right|;$$ \hspace{1cm} (3.3)

$$\Delta \rho_{Red} = \rho_{Red}^T_2 - \rho_{Red}^T_1;$$ \hspace{1cm} (3.4)

$$\Delta \rho_{NIR} = \rho_{NIR}^T_2 - \rho_{NIR}^T_1;$$ \hspace{1cm} (3.5)
If, for example, a pixel in T1 is vegetation and it is cleared for agriculture or urban development and becomes bare ground, then the change vector will move from low brightness and high greenness to high brightness and low greenness. This indicates a parallel movement on the red axis in the red–NIR space. When vegetation burns, both the greenness and brightness decrease and result in a parallel vector movement, but in an opposite direction to NIR axis in the plane. This method is suitable for determining the magnitude and direction of change. The method is, however, not suitable for showing trends in surface cover changes. It is also difficult to interpret, compared to LSMA, because the identification and interpretation of the direction and magnitude of vector movement in vector space is based on Look Out Table (LOT). This means that every analyst must know how to read the LOT in order to be able to use the method. Moreover, CVA requires in-depth knowledge and ground data of the study area in order to understand the change(s) that has (have) taken place in the landscape, hence the unsuitability of this technique for studying areas with little ground data.

2.3 Desertification and Climate Coupling: West African Sudan-Sahel Region

The West African Sahel is generally classified as the arid and semi-arid zone lying between the arid to hyper-arid Sahara Desert of the North and humid tropical guinea savanna to the South. Figure 2.2 is a map of total annual rainfall for Africa north of the equator, based on the twentieth century mean values from gridded rainfall dataset (New et al., 1999). The Sahel corresponds to the region of large rainfall gradients immediately south of the arid Sahara Desert, broadly denoted by the region in which annual rainfall is
less than 100 mm. The Sahel is generally defined as a region of varying latitudinal extent, lying astride several latitudes between 10º N and 20º N.

Figure 2.1: Map of Sahel region and annual rainfall pattern (1901-1990) (Nicholson et al 1998)

The Sahel has generally been defined as a region experiencing a certain range of annual rainfall, usually 200 or 300 mm in the north to 700 or 900 mm in the south (Nicholson, 1979, 2000). Longitudinal extent, the West African Sahel ranges from the East Coast of Nigeria to the coast of Senegal (15ºE -25º W), covering West African countries including the northern parts of Nigeria, Ghana and Cote d’Ivoire, Burkina Faso, Niger, Mali, Senegal, the Gambia, and the Mauritania.

Figure 2.2: Isohyets of Sahel region (Nicholson et al 1998)
Climatic variations can result in shifts in the isohyets in sub-Saharan North Africa of the order of hundreds of kilometers (Darkoh 1998). If definitions are based on rainfall amounts, then the Sahel must be seen as a mobile geographic entity (Darkoh 1998). In the West African Sahel zone, precipitation (rainfall and humidity) is the most important climatic control. The Sahel is characterized by steep latitudinal rainfall gradients, falling from 700 mm to 900 mm per year over some areas in the southern Sahel West Africa, but as low as 100 to 300 mm in the north, and, as with other semi-arid regions, characterized by high inter-annual rainfall variability. About 80-90% of the Sahelian rainfall occurs between July-September and is associated with the northward movement of the Inter-Tropical Convergence Zone (ITCZ) or the Inter Tropical Discontinuity (ITD).

source FEWS-NET/NOAA

Figure 2.3: Map showing the position of ITCZ in July-September 2007 (FEWS 2008)
The ITCZ is characterized by the low surface pressure cell which is embedded with a band of convergence produced by flow discontinuity where the trade wind systems of the North (North-East Trade Winds) and the South (South-West Monsoon Winds) meet. Over the Eastern Atlantic, the pressure cell coincides with a zone of maximum SST.

Relative humidity is highly variable depending on latitudinal location and the season of the year, with an average of 60% in the South to as low as 30% in the northern West African Sahel. The northward movement of the ITCZ in summer attracts moisture from the Gulf of Guinea in the South and Atlantic over continental North Africa in the form of the West African Monsoon. The most glaring characteristics of the Sahelian rainfall are its high variability and unreliability, which in the view of Zeng (2003) results from different influence from different ocean basins on inter-annual and inter-decadal time scales.

Temperature is uniformly high throughout the year with very high diurnal range due to the general absence of cloud cover. Day time temperatures are very high and nighttime temperatures are low. Below is the Temperature, Precipitation and Wind Speed graph of Dakar, the capital of Senegal, which depicts average climatic conditions of the northern West African Sahel region.
For the past 30 to 40 years, the Sahel region of West Africa has been characterized by devastating drought, which has negatively impacted the ecology, economy and the entire livelihood support systems of the region. According to Zeng (2003), the devastating nature of the recent western Sahelian drought is the impetus for the establishment of the UNCCDD.

A careful review of recently published literature points to two main hypotheses accounting for the recent drying conditions of West African Sahel. The first proposition
focuses on anthropogenic factors (Nicholson 2000) such as overgrazing and conversion of woodland to agriculture. The second proposition is large-scale atmospheric circulation changes triggered by multi-decadal variations in global sea surface temperature. According to the proponents of the anthropogenic forcing hypothesis, land degradation in western Sahel is mainly due to high population growth and poor land use practice, especially overgrazing and food production. Similarly, Chaney (1987) stipulates that land use and associated land cover degradation reduces surface roughness and variability, while exposing the surface to further degradation. These, in turn, tend to increase surface albedo and reduce moisture supply to the atmosphere. Pickup (1996) observes a similar positive feedback between surface and lower atmosphere in Australia. The net effect is reduction in precipitation and conditions suitable for vegetation growth (Zeng 2003). In their analysis of different scenarios of the feedback relationships between land surface and climate, Giannini et al (2003) conclude that although they believe the feedback mechanism, the extent to which such mechanism can constitute a leading cause of Africa’s climate variability has not been supported. This is because the change in land surface and vegetation cover was largely exaggerated. For example, recent application of remote sensing NDVI analysis of Sahara-Sahel expansion has concluded that the latitudinal border of the Sahara fluctuates in time and space in relation to rainfall variability (Tucker 1991; Hellden 1988). Others, including Biasutti and Giannini (2006), have articulated the possible impact of rising global temperatures due to gradual increase in anthropogenically induced greenhouse gases such as CO₂ and NO₂. This has the
tendency to ignite large scale climatic fluctuations, which may have played a significant role in rainfall deficit in the Sahelian region.

The second proposition emphasizes large-scale atmospheric circulation changes triggered by multi-decadal variations in global SST. Giannini et al (2003) used GCMs to compare different scenarios to analyze the impact of sea surface changes on the climate of West Africa. Xue and Fennessey (2002) have also analyzed the external forcing by ENSO and La Nina. Opinions are divided on the possible effects of ENSO and La Nina. However, Nicholson (2000) believes the occurrence of ENSO and La Nina in space and time (East Pacific and the month of December) seem too remote to have caused drought in the northern hemisphere summer (July-September). Nonetheless, Nicholson (2000) observes a positive correlation between the Sahel rainfall variability and SST changes over the northern and southern parts of the Atlantic Ocean. This proposition has also been supported by Xue and Fennessey (2002) and Hurrell and Hoerling (2005). Hurrell and Hoerling (2005) based their analysis on 60 simulations of global climate from five computer models. The results provided new evidence linking drought in southern Africa to the warming of the Indian Ocean. However, it contradicts earlier studies that also connected the Sahelian drought of northern Africa to the ENSO, La Nina, and the Indian Ocean. The new results clearly point out that the late 20th-century cooling of the North Atlantic Ocean is the key to explaining the Sahelian drought. They observed that a subsequent switch to North Atlantic warming is the main factor behind the Sahel's recent swing from drought to moist conditions and some recovery. When sea-surface
temperatures are warmer in the South Atlantic than in the North, it pulls the Sahelian monsoon cycle south. This is because the ITCZ does not reach its uppermost limit indicated by the apparent movement of the sun; hence, rainfall concentrates in the southern West Africa, which comes under the region of influence of the ITCZ (Hurrell and Hoerling 2003; Nicholson 2000). Hurrell (cited), however, points out that unlike the Indian Ocean warming the North Atlantic Ocean, cooling of the 20th century was natural and masked an expected greenhouse-gas warming effect. He notes that since 1990, the sea-surface temperature pattern has reversed, with rapid warming in the North Atlantic rather than in the South. The models suggest possible trend intensification in future decades. They projected that the Sahel monsoon will be some 20% to 30% wetter by 2049 compared to the 1950-99 average.

2.4 Desertification as Human Phenomenon

Desertification is a problem that affects hundreds of millions of people world-wide (Bransten 2004). Although the past 20 years have seen an increasing global effort to halt this problem, desertification keeps growing with the greatest impact in Africa and Asia. FAO argued that the limited success in curtailing the growing threat of desertification globally can be attributed mainly to the lack of understanding of the phenomenon, its origins, causes and extent of its impact (FAO 1995). Maestre et al (2005) identify two broad, mutually exclusive but unsatisfactory, causes of desertification, which they categorized into single factor causation and irreducible complexity.
The crux of the single factor causation is that desertification is a human-made phenomenon. The core idea is the overworking or breakdown of land due to excessive demand for resources and space by ever-increasing human population on limited land. In sum, desertification is caused primarily by a growing population on a fragile semiarid and arid ecosystem and/or by irrational and unwise land management practices by nomadic pastoralists, although questions are raised against the background that some semiarid regions’ not notable pastoral activities have also suffered land degradation. Others have also attributed desertification to multiple causative factors working locally with no distinctive pattern (Dregne 2002; Warren 2002; Maetre at al 2005). The debate goes unabated and there seems to be no end site to this controversy of desertification as human phenomenon versus climate driven.

Accordingly, Malagnou (2004) argues that “a combination of factors, including global warming, is to blame for the growing threat of desertification, but that the biggest culprit is man.” He continues, “climate change and change in rain patterns can induce desertification… but more often, it is created by man” (Malagnou (2004). Desertification is caused by overexploitation of the natural resources, whatever they are -- range [land] or forest or even soil fertility, which is overexploited.

Similarly, Darkoh (1998), Kelly and Hulme (1993) have observed that desertification is the outcome of resource management failure. In their view, desertification is an
anthropogenically-induced process caused by over-cultivation, overgrazing, deforestation, and poor irrigation practices, which results from increased human numbers and escalated demand, poverty, land shortage, civil strife or wars, and poorly conceived national policies (Darkoh 1993; UNEP 1992). They believe, however, that local causes of desertification may be worsened by external forcing such as excessive waste and global economy, trade policies and prices, debt burden, terms of trade, brain drain, and trade barriers, which force others to overexploit, over-cultivate, or over-utilize natural resources. Interestingly, the rhyming theme in this desertification debate is over-cultivation, over-utilization, over-exploitation, i.e. everything is over, however, the main issue that needs to be addressed is what causes everything to be over, such as over-cultivation, over-exploitation etc? Two main schools of thought with counter views on what causes everything to be over globally are discussed below.

• Malthusian and Pro-Malthusian view of land degradation

In 1798, Rev. Thomas Malthus is purported to have analyzed the relationship between population growth and environment (resource utilization). In his famous book (*Essay on the principle of population*), he is said to have postulated that where population has the tendency to grow exponentially, food production and environmental resources grow arithmetically and never keep pace with population; thus, if population is not checked artificially, nature will check further population growth through occurrences such as famine and other natural disasters. This Malthusian hypothesis is said to have been revisited in 1864 by George Perkins Marsh in his book *Man and Nature* (1864).
Malthusian disciples, such as Paul Ehrlich (1968) and The Club of Rome (1972), have revisited the Malthusian hypothesis and sounded warnings of human catastrophe if population growth goes unchecked. The rise of the desertification menace and its associated drought and human misery, especially hunger and wars in sub-Saharan Africa, has spawned a new crop of Malthusian disciples commonly referred to as Neo-Malthusianism. The current global population explosion and its associated intensification of human pressures on land (environment and natural resource) during the last 50 years or so have been cited in support of the Malthusian view of population-resource relationships, which negatively impact the natural system. Recent food shortages, climatic crisis, land degradation, and wars in developing countries, especially the African continent, have been used to vindicate the pro-Malthusian thesis. Accordingly, Neo-Malthusians see desertification as the direct result of exponential population growth on fixed natural resource (land), hence the extensive land degradation results from over-cultivation, over-utilization, over-grazing, over-exploitation, and many over. Therefore, desertification is seen by the Neo-Malthusians as the result of population exceeding global land carrying capacity.

- Critics of Malthusian and Pro-Malthusian with success stories from Africa

According to the critics of Malthusian and Neo-Malthusians, blaming land degradation on population numbers alone overstates the facts. As one expert puts it,

“from the point of view of a simple population head-count, China, India, Indonesia and Brazil might be regarded as jeopardizing the future of the earth’s resources. Yet, using a resource demand index, this risk is more fairly placed at
the door of the USA, Japan, Germany, the UK, Canada and Russia. In the case of
Indonesia, the USA exceeds its resource demand by a factor of 50. It is not
difficult to see where the population control effort should be applied. Sweden as a
country with a mere 8.6 million people exceeds the resource demand of
Bangladesh, a country of 116.4 million people, by some 15 times” (Chadwick
1994, pp 7).

Addressing issues of poverty, population growth and environmental degradation in
northern Ghana, including the UER, the study area, Songsore (1996) bluntly stated,
“Whereas the rich industrial north accounts for a mere 23 percent of the world’s people,
its population earn 85 percent of the world’s income. The strains of this level of
economic activity are felt in the loss of forests and species … it is therefore undeniable
that the rich minority threatens the wider ecological integrity of humanity’s existence.”
Perhaps Lloyd Timberlake’s statement that Africa has overdrawn its environmental
account resulting in environmental bankruptcy (page 9) may be better stated to reflect
causes of environmental crisis in Africa if we change it to read as follows: the world has
taken too much, demanded too much and given them too little, thereby overdrawn their
environmental accounts and caused Africa’s environmental bankruptcy. The Malthusian
critics are unanimous in their position that excessive consumption and waste are the main
drivers of the global environmental crisis. They believe that excessive consumption in the
developed world and unequal terms of trade in favor of the developed world (world
commodity pricing) has forced developing countries to mine their environment to meet
global demand and not just the number of people in those countries who consume less and generate less waste. It is against this background that the former Prime Minister of Malaysia, Dr Mahathir Mohammed, argued in 1992 during the World Conference on Environment and Development (Rio Conference 1992) that ceasing consumption in the developing world (by, say, killing all its population) would reduce the world’s pollution by only 10%, even though 85% of the world’s population lives in the developing world.

Recently, critics of Neo-Malthusianism proposition and environmental historians, such as McCann (1999), Acheampong (2002), and political historian Shillington (2005), have gathered evidence to counter the proposition that desertification is the direct result of overpopulation, proposed by Malthusians and Neo-Malthusians. Neo-Malthusian critics argue that the history of humankind is analogous to the history of the environment and natural resource degradation. Since the dawn of ‘man,’ he has utilized the environment as a means of survival. However, human pressure on land has been non-linear at an increasing trend with several interruptions. In areas and periods of intensive human activities, land and natural resources have recovered over time from human usage (English et al 1994; Barbier 2000; Tiffen et al 1994), allowing the recovery of some degraded natural ecosystems. This is perhaps an epitome of the spatial and temporal variability of land degradation from region to region and from period to period. Environmental historians, on the other hand, see environmental degradation in sub-Saharan Africa as being analogous to trans-Saharan trade and agricultural policies of European imperial powers that sought to increase agricultural production in the colonies.
to feed their population without investing in land and soil conservation and management practices. Kelvin Shillington, a British political historian, wrote about the environmental history of Ghana and noted that Ghana’s environmental history is directly linked to its political history, which determines what policies are implemented and the impact on the environment. The link between Ghana’s political history and environment has also been articulated by Nsiah-Gyabaah. Nsiah-Gyabaah (1994) argues that one of the worst times in Ghana’s environmental history was between 1984-2000 when the then PNDC military government implemented IMF/World Bank Structural Adjustment Programs (SAPs)/Economic Recovery Program (ERP) and the Program of Action to Mitigate the Social Cost of Adjustment (PAMSCAD). These programs sought to increase agricultural exports by encouraging farmers to farm more lands, but withdrew agricultural subsidies and also increased the cost of agricultural inputs, like chemical fertilizer. The policies had no environmental protection components and overlooked the possible negative environmental impacts. The net effect, according to Nsiah-Gyabaah (1994), is deforestation, soil exhaustion, extensive wild fire and bush burning, and desertification that have engulfed the entire dryland regions of Ghana. Nsiah-Gyabaah (1994), Reij and Steeds (2003), Mortimore (2005), Di Vecchia et al (2005) have demonstrated that given the right political policies, infrastructure, and adequate financial and human capital support, environmental problems like desertification can be reversed. Some case studies, especially from the African continent, challenging Neo-Malthusian proposition include the Central Plateau of Burkina Faso (1980–2002), the Machakos District in Kenya (1930–1990), and the Makueni District (Kenya). Others are the Maradi Department
(Niger), the Kano Region (Nigeria), the Diourbel Region (Senegal) (1960–2000), and the Integrated Rural Development Project in the Keita Valley, Niger (1960-2003) (Reij and Steeds 2003; Mortimore 2005; Di Vecchia et al 2005). Below are two case studies that challenge the neo-Malthusian proposition of land degradation being the direct result of rapid population growth.

Case Study 1: Machakos Experience

This is a well-known case study (success story) of improved long-term land degradation through effective resource management in the Machakos District of east-central Kenya. This was first published by English et al. (1994) and was carried by Tiffen et al (1994) and Barbier (2000). The Machakos District is inhabited by the Akamba tribe, who has lived there for centuries. As far back as the 1930s, the Machakos lands (semiarid lands) were classified as suffering from acute land degradation, which put doubt on the region’s ability to support both its human and livestock population. This situation persisted through the 1970s to the extent that the region was seen as suffering ‘Malthusian-syndrome,’ that is mass poverty, land abandonment and large out-migrations, widespread deforestation, and chronic fuelwood shortages.

However, recent studies have observed that the Malthusian syndrome does not exist in the Machakos region, although it was predicted 30 years ago. According to Barbier (2000), some recent studies have compared agricultural development and land
management in the Machakos region over the past 50 years and concluded that the region’s population is now five times larger than it was 50 years ago.

The value of agricultural output per capita, in real terms, is 3 times more than what it was in the 1930s (English et al., 1994; Barbier 2000). There was also substantial improvement in almost all major indicators of resource management and economic development.

The Machakos success is attributed mainly to innovation, particularly in farming systems, crops and the adoption of improved land management techniques (Barbier 2000). The Machakos experience is a case of rapid population growth leading to positive social-economic change and, more importantly, positive environmental effects. Observers believe that sound land management practices have resulted in improved agricultural productivity and higher per capita incomes. Rapid population growth in the region has increased land under cultivation, expanding about four or five fold compared to 1930 levels, it is mainly because about one-third of the population has settled in areas that were previously infested with tsetse flies (English et al., 1994).
Table 2.0: Monitored indicator of land recovery

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Conditions seen by Bernard (1978)</th>
<th>Conditions seen by English et al 1994</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil depletion and erosion</td>
<td>Soil depletion and erosion are still major problems</td>
<td>No evidence that soil fertility is declining, this appears to be under control and not causing any significant loss of productive capacity</td>
</tr>
<tr>
<td>Declining crop yields</td>
<td>Lack of data</td>
<td>No evidence</td>
</tr>
<tr>
<td>Use of ‘marginal’ lands</td>
<td>Pressure exerted on marginal lands can further promote deteriorating conditions</td>
<td>No evidence that farming systems in these areas are leading to long term degradation</td>
</tr>
<tr>
<td>Changing crop emphases</td>
<td>Switching to crops tolerant of poor soils</td>
<td>Not borne out, e.g. continued preference for maize rather than sorghum, and shift to horticultural crops</td>
</tr>
<tr>
<td>Reduction of fallow</td>
<td>As the cycle of cultivation and fallow is reduced under increased pressure, soils experience nutrient impoverishment</td>
<td>Reduction has occurred but has been replaced by new, more productive indigenous systems</td>
</tr>
<tr>
<td>Food shortages and malnutrition</td>
<td>Movement of people into marginal lands has adversely affected diets</td>
<td>Occur in exceptional years, but malnutrition not severe, except in socially deprived families, even in the dry 1970s</td>
</tr>
<tr>
<td>Landlessness, land disputes etc.</td>
<td>Not sufficiently examined</td>
<td>No evidence one way or the other</td>
</tr>
<tr>
<td>Rural indebtedness</td>
<td>Not sufficiently examined</td>
<td>No evidence one way or the other</td>
</tr>
<tr>
<td>Underemployment and unemployment</td>
<td>Lack of ‘jobs’, but labor still a significant constraint for agriculture</td>
<td>Become a felt problem in some areas</td>
</tr>
<tr>
<td>Out-migration</td>
<td>Continues at a substantial rate: in the hill country half the young men are off to Nairobi and Mombassa</td>
<td>Appears to have declined as the sex ratio has moved closer to unity and there is no evidence of significant movement out of the district by sexes</td>
</tr>
</tbody>
</table>
Some of the changes that were made include the replacement of traditional bush-fallow rotation and livestock herding systems with improved farming systems, which are market-oriented. This change was also in part due to unavailability of bush, scrub and general grazing lands (communal grazing lands), which is a common feature in most subsistence farming communities in Sub-Saharan Africa. Above is table 2.0, showing major indicators studied and how much they have changed from the 1930s to 1994.

It is also argued that the introduction of the market-oriented farming system stabilized food production to the level required for basic subsistence, which increased per capita value of agricultural production and diverted other resources to production of cash crops such as coffee, cotton, fruit, and horticulture. Moreover, Machakos is also said to have invested in improved land management practices and adopted a wider crop selection, which are also quick maturing and fodder crops.

Other departments of technological improvements include ox-drawn ploughs, intensive livestock rearing, and monocropping, which facilitated planting, harvesting, and weed control. Likewise, farming techniques like contour ploughing, terracing, animal manuring and land preparation before early rains, good ways of controlling soil erosion, and of increasing yield were adopted. (English et al., 1994; Barbier 2000).

Case Study II: KEITA experience, Niger

The Keita Valley is a well-known region representing a borderline for the Sahara desert, which allows the development of a multiethnic community composed by peasants
coming from southern regions and nomads from the North (Di Vecchia et al 2005; Reij and Steeds 2003). The region had a total population of 65,000 in 1962, but increased its population to 230,000 inhabitants by 2003. The valley is found in the central part of the Republic of Niger. It covers an area of approximately 4,860 km², which is mainly comprised of a plateau with rocky slopes and valleys. The valley forms a watershed, which has been subjected to strong winds and water erosion due to soudano-Sahelian climate conditions experienced in the area. Characteristically, the region has a short rainy season extending from June to September. The annual mean rainfall ranges between 400 and 500 mm, characterized by intra-annual, inter-annual, and inter-decal variability.

Recorded data shows that mean annual rainfall fell between 1960 and 1990, particularly the peak rainfall month of August. It was also observed in 1962 that the plateau slope was entirely covered by forest vegetation; however, in 1972, strong signs of forest degradation appeared and by 1984 this forest had completely disappeared (Di Vecchia et al 2005). Over a decade (1973 – 1984), the period of extreme dryness witnessed a line of demarcation between two environmental and socio-economic systems with very different characteristics, a period of irrecoverable damages to the ecosystem to the extent that people refer to as the breaking point. Consequently, crop production dropped to its lowest point, while herds became decimated. By 1984, it was feared that the region could soon become a region of negative net migration mainly due to the inability of the environment to sustain meaningful livelihood (Di Vecchia et al 2005).
In 1982, the Ader Doutchi Maggia Rural Development Project (PDR-ADM), which became known as Keita Project, was launched as an Italian Initiative for the Sahel to promote food security. The project became operational in 1984 and went through three phases, which ended in 2003. The main objective was to increase food security over a very large area, while combating desertification through the reduction of soil erosion and reforestation.

The project subdivided the area into units, which were named Elementary Territorial Units, focusing on the following activities (also summarized in the table below):

- reclamation of the plateau and the abandoned land in the valleys for agricultural and pastoral purposes
- reforestation of the slopes, of the stream Koris banks and dunes
- creation of wind breaks and forest areas
- control of the water flow in the Koris by banks consolidation and small dams

The project also integrated social and economic development projects, including building schools, medical centers, wells and roads, and providing technical assistance and financial support for the creation of new economic activities. Some studies that have evaluated the Keita project and its impact include PEICRE 1996, CeSIA, IBIMET-CNR 2002, Viterbo 2005 and Land Cover classification, expressed by the LCCS standards of FAO-Africover. Today, the Keita Valley has become a success story being told across the globe.
Table 2.1: Project Intervention for land recovery

<table>
<thead>
<tr>
<th>Interventions until 2003</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reclamation and improvement of agricultural and pasture lands, reforestation and dune fixation</td>
<td>34,483 ha</td>
</tr>
<tr>
<td>Trees planted</td>
<td>18,000,000 ha</td>
</tr>
<tr>
<td>Road construction</td>
<td>313 km</td>
</tr>
<tr>
<td>Drilled wells</td>
<td>5</td>
</tr>
<tr>
<td>Excavated wells</td>
<td>708</td>
</tr>
<tr>
<td>Rural buildings</td>
<td>$28,000 m^2$</td>
</tr>
<tr>
<td>Small dams</td>
<td>40</td>
</tr>
<tr>
<td>Dams</td>
<td>2</td>
</tr>
<tr>
<td>Weirs</td>
<td>251</td>
</tr>
</tbody>
</table>

Some of the successes the project has recorded are summarized in the table 2.3 below:

Table 2.2: Extent of Land recovery over the project period

<table>
<thead>
<tr>
<th>Type of land cover (hectares)</th>
<th>2002</th>
<th>1984</th>
<th>Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woodlands</td>
<td>45,542</td>
<td>10,876</td>
<td>319%</td>
</tr>
<tr>
<td>Shrub lands</td>
<td>67,422</td>
<td>95,950</td>
<td>-30%</td>
</tr>
<tr>
<td>Grasslands</td>
<td>17,417</td>
<td>60,277</td>
<td>-71%</td>
</tr>
<tr>
<td>Rainfed croplands</td>
<td>150,730</td>
<td>84,102</td>
<td>79%</td>
</tr>
<tr>
<td>Irrigated croplands</td>
<td>1,006</td>
<td>968</td>
<td>4%</td>
</tr>
<tr>
<td>Bare</td>
<td>124,196</td>
<td>144,998</td>
<td>-14%</td>
</tr>
<tr>
<td>Dunes</td>
<td>21,847</td>
<td>32,441</td>
<td>-33%</td>
</tr>
</tbody>
</table>

Interestingly, the Keita project has transformed much degraded grassland to woodland within a period of 20 years. From 1984 to 2002, woodland increased by 319%, while cropland increased by 79%. Grassland decreased by 71%, while bare surface and dunes decreased by 14% and 33% respectively.
According to Reij and Steeds (2003), over a period of 15 years, 1984-1999, a total investments of $63 million, plus 12 million food rations valued at about $12 million, were made in the Keita valley. This resulted in a restoration of the productive capacity of about 20,000 ha of strongly degraded land, 9,300 ha for cropping and the remaining land area for sylvo-pastoral use. Similarly, 17 million trees were planted between 1982 and 1999 and about 1,300 ha of sand dunes were fixed. In addition, 1,400 km of stream banks were stabilized, 40 small dams were built, as well as two major dams and hundreds of small, low dams, and more than 300 km of rural roads were constructed. Others include the construction of wells, schools, and health clinics and training of over 100,000 people in soil and water conservation techniques. Moreover, about 148 women’s groups with more than 10,000 members’ savings and credit associations were formed to promote savings and investment. Conservative estimates project that more than $6 million per year was generated from the project, of which 42 % came from livestock, 25 % from vegetables, 22 % from cereals, and 11 % from wood.

2.5 Conclusion

Given that the lives of millions of people are potentially threatened by desertification and its ripples effect, it is surprising that for so many years there is no consensus on what it is. This has hampered the development of common methodology for assessing its status on global, regional and local scales. Since 1975, conflicting and sometimes contradictory definitions have been used and has created different assessment methodologies and estimates (Veron et al 2006). Common misconceptions emanating from the
misunderstanding, misuse and sometimes conflicting methodologies include reversibility and irreversibility, static vs. dynamic nature of desertification and above all what proximate indicators can be adequately used to detect and measure desertification.

Recent success stories including Keita experience of Niger, Makachos experience of Kenya, Boserupian experience of Nigerian and many others have shown that given the right investment and approach, desertification is reversible. We also learnt that local people are much concerned and are willing to go extra miles to tackle desertification problem, however, lack of infrastructure and financial resources constitute a major hindrance to local effort to combat desertification threat.

From Keita and Makachos success story case studies, there is little doubt that population growth and land conservation can be made bedfellows, contrary to what is suggested by Malthusian and Neo-Malthusian activists; however, making them bedfellows comes at a price---including investments in infrastructure, investment in land and people. Perhaps what is vivid on the African continent and, for that matter, Africa south of the Sahara, is inadequate infrastructure, lack of investment in land and people to help them cope with pressure on land.

While we do not dispute the fact that population numbers can lead to land degradation due to the demand for space, food and other natural resources, far beyond the recharge (renewable) rate of these natural resources, we also argue that over-emphasizing the
desertification problem on population numbers alone leaves the main drivers unaddressed, as observed from the above success stories. In sub-Saharan Africa, regions with high rates of land degradation usually have sparse population, e.g. Mali, Niger and Burkina Faso; they are equally poor with low infrastructural development, have extreme ecological conditions and above all are exporters of primary products, which are under priced in the global market, hence the unequal terms of trade. In this case, we argue that serious attempts at addressing the desertification crisis in sub-Saharan Africa should address issues of poverty; underdeveloped infrastructure; human capital development, and global resource drain through under pricing and unequal terms of trade.
3.1 Remote sensing analysis of desertification as land use/land cover change

Land use/land cover and its dynamics is regarded as one of the most important controls of the biospheric dynamics (Mass 1999; Schneider et al 2003). It affects both energy and material flows in the ecosystem, which has tremendous impact on the ecosystem stability and functionality. It is against this backdrop that the study of land cover/land use change continually attracts many researchers and also remains a subject of worthy investigation. However, land cover/land use change has eluded scientists without a single methodology for investigation or predicting the likely change in the future. This is perhaps due to the varying state and dynamics of land cover/land use and also the varying rates of change. A survey of available scientific literature reveals that different researchers have developed and applied different methodologies to detect and monitor land use/land cover change (Lu et al 2004; Singh 1989). The main objective of this section is to review some of the common methodologies specifically developed and applied to land use and land cover change associated with desertification and dryland regions in general and identify their shortcomings in order to proceed with our approach to overcome these shortcomings.

Land cover/land use change detection has been defined as a process of identifying differences in the state of the land surface by observing it at different times (Singh 1989;
Lu et al (2004). The ultimate objective for performing change detection, according to Green et al (1994), is to ascertain differences in multi-temporal images of land cover caused by variables of interest by controlling differences in the image caused by variables not of interest to the study. Land use/land cover change detection involves three main processes: 1) land cover and land use image processing and classification. This includes geometric rectification, image registration, radiometric and atmospheric correction, and topographic correction of the study area. Interestingly, topographic, geometric, and radiometric correction for Advanced Very High Resolution Radiometer (AVHRR) images are performed at the source; 2) selection and implementation of suitable land use/land cover change detection and; 3) accuracy assessment of the change detection results (Lu et al 2004; Schneider et al 2003). According to Lu et al (2004), accuracy of change detection approach hinges on nine (9) factors, including the precise geometric registration of multi-temporal images, calibration and/or normalization of multi-temporal images, availability of quality ground truth data for accuracy assessment, the nature and complexity of the landscape, change detection algorithm employed, knowledge and familiarity of the study area, time and cost restriction, and the skills of the analyst. Moreover, a good and effective change detection approach should answer questions relating to area and rate of change, spatial distribution of change type, change trajectories of cover-types, and accurate assessment of change detection results.

Lu et al (2004) cautioned that before land cover change detection is performed, one must satisfy certain conditions. These include precise registration of multi-temporal images,
precise radiometric and atmospheric calibration, similar phonological state between multi-
temporal images, and selection of the same spatial and spectral resolution images.

A wide range of change detection algorithms have been developed and applied over the years. Singh (1989) and Coppin & Bauer (1996) summarize eleven broad, different categories of change detection algorithms that were found in the literature by 1995. Out of the eleven algorithms, the first seven, as listed below, were said to be the most frequently used, while the remaining four were in an experimental state as of 1995. These categories of algorithms include:

1. Mono-temporal change delineation.
2. Delta or post classification comparisons.
4. Composite analysis.
5. Image differencing.
7. Change vector analysis.
8. Image regression.
10. Background subtraction.
11. Image ratioing.

Some common change detection algorithms used specifically for the study of desertification are reviewed below.
Supervised and unsupervised classifications are two methods commonly used for land cover/land use change analysis. Most researchers use the approach in comparison with other approaches in terms of capability to map out the phenomenon of interest. However, the approach is believed to not be very suitable for a highly diverse environment. A careful search of published remote sensing literature shows that the most commonly used supervised and unsupervised classification algorithms are the spectral angle mapper and Isodata, respectively. In the following pages, we summarize some published land use/land cover change studies using Isodata and Spectral Angle Mapper (SMA), unsupervised and supervised classification methods respectively.

Yang et al (2007) applied unsupervised classification’s ISODATA to analyze land use/land cover change in Chandlers Ford in the UK, a place not well known for desertification, but noted for rapid land cover change. For this research, the researchers used a multi-spectral IKONOS image. They also compared ISODATA results with another algorithm, Genetic Algorithms (GA). The classification success was measured using producer's accuracy or completeness and end-user’s accuracy or correctness. Producer’s accuracy is the number of pixels that are correctly assigned to a certain class divided by the total number of pixels of that class in the reference data. Similarly, user's accuracy or correctness is the number of pixels correctly assigned to a certain class divided by the total number of pixels automatically assigned to that class. In all, GA proved to be a better classifier than ISODATA. GA gave four land cover change classes, while unsupervised ISODATA gave three complete classes. Comparing figures from GA
and ISODATA, the population size increased; the overall accuracy also increased from 49.1% to 69.8% and four instead of only three classes were found. The same effects were evident from user’s accuracy: the overall accuracy increased from 54.4% to 71.1% and again GA, as compared to ISODATA, detected four classes.

The effectiveness of these techniques was evaluated using examples of IKONOS satellite image data. Based on independent ground truth, an overall accuracy of 71.1% was reached with GA as compared to 65.1% when using the ISODATA algorithm (ID).

Shrestha et al (2005), on the other hand, used linear spectral unmixing with spectral angle mapper in a study of desertification. The study used imaging spectrometer data to detect and map desert-like surface features. Absorption feature parameters in the spectral region between 0.4 and 2.5 μm wavelengths were analyzed and correlated with soil properties, such as soil color, soil salinity, gypsum content, and so on. The study applied linear unmixing and supervised classification’s spectral angle matching techniques to assess their suitability in mapping surface features for land degradation. The study showed that linear unmixing provided more realistic results for mapping “desert-like” surface features than the spectral angle matching technique.

Collado et al (2002) and Lu et al (2004) have articulated beautifully the effectiveness of Linear Spectral Mixture Analysis (LSMA) in mapping and quantifying desertification, based on their experience in South America. The LSMA model is physical-based change detection approach, which analyzes multi-temporal images and classifies them into
fractional pixels and/or image of land cover classes. Fractional images or pixels of cover classes for different periods can be compared to ascertain changes that have occurred between the periods’ understudy. For example, we can analyze desertification by applying this method to quantify the extent of spatio-temporal change in the study area between time one (t1) and time two (t2). Moreover, it gives you an idea as to the type of change and the direction where the change is more rapid.

In another study, Chikhaoui et al (2005) characterized the state of land degradation in a small Mediterranean watershed using Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data and ground-based spectroradiometric measurements. The visible bands near-infrared and six shortwave infrared (SIR) bands of the ASTER sensor were calibrated using ground measurements of the spectral reflectance. Field measurements were carried out in the Saboun experimental basin located in the Marl Soil Region of the Moroccan Western Rif. The study leads to the development and evaluation of a new spectral approach to express land degradation. This index is called Land Degradation Index (LDI), based on the concept of the soil line derived from spectroradiometric ground measurements. In this study, they compare LDI and the Spectral Angle Mapper (SAM) approaches to assess and map land degradation. Results show that LDI provides more accurate results for mapping land degradation (Kappa = 0.79) when compared to the SAM method (Kappa = 0.61). Validation and evaluation of the results were based on the thematic maps derived from the ground data (organic matter, clay, silt and sand) by kriging.
3.2 Remotely Sensed Normalize Vegetation Index (NDVI) Approach

NDVI refers to the ratio of the amount of energy reflectance in the near infrared (NIR) and the red (RED) portions of the electromagnetic spectrum (EMS), (0.72–1.10 and 0.58–0.68 mm), respectively. Using AVHRR sensors, NDVI is calculated as:

\[
\text{NDVI} = \frac{\text{Ch}2 - \text{Ch}1}{\text{Ch}2 + \text{Ch}1}
\]

AVHRR Channel 1 (Ch1) is the visible red and Channel 2 (Ch2) is the NIR.

Figure 3.0: Example of AVHRR NDVI showing the greenness of the African continent in 2001
On the other hand, if one decides to use Landsat Thematic Mapper (LTM) data and/or Landsat Enhanced Thematic Mapper Plus (LETM+), NDVI would be calculated as:

$$\text{NDVI} = \frac{4-3}{4+3}$$  \hspace{1cm} (2)

where 4 and 3 are bands 4 and 3, respectively. An example of LTM NDVI is shown below.

![LETM+ NDVI](image)

**Figure 3.1:** LTM+ NDVI covering the UER and Northern region of Ghana for October 27, 2001

Theoretically, NDVI values range from $-1.0$ to $+1.0$. NDVI in the positive value range indicate green or vegetated surfaces (reflectance in NIR>RED) and higher positive values indicate increases or greener vegetation. This is mainly because healthy green vegetation reflectance peaks in the NIR region, mainly due to leaf mesophyll structure and lowest in the red region of the EMS, largely due to chlorophyll absorption (Kremer and Running...
1993). Negative values of NDVI usually indicate non-vegetated surfaces like water, ice, and snow. There are several studies relating NDVI to vegetation biophysical variables such as leaf area, canopy coverage, productivity, chlorophyll density and vegetation phenological changes (Goward et al. 1985; Justice et al. 1985; Tucker et al. 1985; Townshend and Justice 1988; Spanner et al. 1990; Yoder and Waring 1994; Peters and Eve 1995; Prince et al. 1995), and these are more reasons why NDVI, in spite of some shortcomings, remains valid for studying vegetation change.

Many studies have utilized NDVI capabilities to study desertification due to the ability of NDVI to determine the presence or absence of vegetative cover and inter-annual and seasonal variability in vegetative cover in the arid and semi-arid regions of the world. NDVI has proven to be useful in the study of seasonal and inter-annual behavior of different vegetation types in arid and semi-arid regions (Geerken and Ilaiwi 2004). Malo and Nicholson (1990) observed that phenology of six vegetation types in Western Sahel of Africa measured by NDVI is affected by soil moisture availability; however, it was useful in studying vegetation dynamics. Peters and Eve (1995) and Peters et al. (1997) distinguished shrub, grass, and mixed shrub and grass vegetation of deficient canopy coverage in the Chihuahua Desert, southern New Mexico. Similarly, Weiss et al (2004) used NDVI to examine 11 years (1990–2000) of seasonal and inter-annual vegetation variability in semi-arid central New Mexico, USA. They examined six different vegetation communities, including the Great Plains/desert grassland, the Chihuahuan Desert, the pinon-juniper woodland, the juniper savanna, the Colorado Plateau shrub-
steppe, and the Colorado Plateau grassland (Moore 1989–2001). Schmidt and Karnieli (2000) studied the Negev Desert in Israel and found that over a period of 2 years, NDVI peak values coincided with field observations of annual and perennial vegetation response to rainfall. Nicholson et al (1998) used AVHRR NDVI from 1980 to 1995 to study the southward expansion of the Sahara Desert and found that the edge of the Sahara fluctuates with rainfall, rather than a steady march. The southern boundary of the Sahara advanced southward and then retreated at least three times, resulting in a movement of about 300km over several years. They concluded that there is no progressive southward march of the Sahara desert over the West African subregion.

Tucker et al (1991) and Tucker and Nicholson (1999) used AVHRR NDVI 1980-1990 and 1980-1997 to study the purported southward expansion of the Sahara desert. The studies concluded that while the southward margins of the desert, demarcated by the 200mm rainfall isoline, have fluctuated markedly, there has been virtually no net increase in the desert's area from 1980 to 1997. The two studies suggest that the Sahel region, south of the Sahara, has actually become greener during the time period 1981-1990 and 1980-1987.

However, using NDVI for the study of desertification is saddled with some uncertainties that are worth mentioning. Prominent among them are uncertainties relating to atmospheric variations, sensor calibration, and sensor degradation over time (James and Kullari 1994; Townshend 1997). Also, surface heterogeneity complicates interpretation
of NDVI in the study of desertification. Arid and semi-arid regions are characterized by high heterogeneity and sparse vegetation, which increase the level of uncertainty in interpreting NDVI values due to low registration of NDVI values. Also, low and scattered vegetation canopy in arid and semi-arid regions make NDVI prone to issues of mixed pixels and background noise which results from incomplete coverage, soil, and soil moisture effect (Weiss et al 2004, Kremer and Running 1993, Peters and Eve 1995). Huete (1988) demonstrated that NDVI is prone to background scattering and soil darkening, which become exacerbated in dryland regions due to sparse distribution of vegetation.

A modified version and perhaps more recent application of NDVI to the study of desertification is Rain Use Efficiency (RUE). RUE was first proposed by Le Houerou in 1984 and applied in the Sahel region of Africa in the 1990s by Justice et al (1991), but its rigorous application was delayed until recently when Prince (2002) used the method to study desertification in the Sudan-Sahel savanna region of north western Africa, mainly due to unavailability of long-term accumulated data required for its effective application (Prince et al 1998; 2008; Prince 2002). RUE is said to be the measure of Annual Net Primary Production (ANPP) and annual rainfall expressed as dry plant material produced over 1 ha in 1 yr mm$^{-1}$ of rainfall (Hein and Ridder 2006). Net Primary Production (NPP) is derived from NDVI, which is calculated as the amount of reflectance in the near infrared (NIR) and the red (RED) bands of the EMS. The interpretation of RUE indicates that in a given area, decline in RUE over space and time indicates ecosystem degradation.
(Varnamkhasti et al. 1995; Snyman 1998; Hein and Ridder 2006). Decrease in RUE is interpreted as a reduction in the capacity of the vegetation to transform water and/or nutrients to biomass. This may involve processes such as a loss of vegetative cover, decreased availability of plant nutrients, and compaction of topsoil which accelerates run-off (Snyman & Fouche 1991; Hein and Ridder 2006).

RUE is, however, criticized on the grounds that desertification does not always reduce ANPP. A study of the Jornada Experimental Range at the Chihuahuan Desert of New Mexico shows that desertification did not change ANPP (Huenneke et al 2002), where grasses were displaced by desert scrub. Other studies, supported by our own recent fieldwork in the Sudano-Sahelian grassland regions of West Africa indicate substantial intra- and inter-annual variations in species composition, species cover and density, and productivity (Breman & de Wit 1983; Le Houérou 1989, Breman & de Ridder 1991; He´rault & Hiernaux 2003; Hein and Rider 2006), which creates substantial variations in RUE from year to year, even at a single location irrespective of any degradation process. The inter-annual variations in species’ composition, cover, density, and productivity in the Sudano-Sahel region is determined by annual rainfall, both duration and intensity, and more importantly by the frequency and intensity of burning in that particular location. The number of years a particular piece of land or location remains without burning, the higher the species’ diversity and species’ density from year to year and hence RUE. Also, vegetation recovering from burn scars in spring tends to have higher NDVI, which form the basis of RUE, than senescent vegetation, which complicates RUE.
Despite the criticism leveled against the use of NDVI for the study of desertification, it still remains the most widely used and perhaps the most relevant indicator of the desertification process than other Vegetation Indices (VIs), given that the phenomenon of desertification, by definition and indicators, is progressive negative surface vegetation change. Using NDVI, we are able to focus on process indicators and avoid assessing desertification after the fact, nor with just expert opinions. NDVI as process indicators also serve as earlier warnings and can be detected from a remote sensing perspective, a perspective commonly shared by pundits like Prince et al (1998), Prince (2002), Veron et al (2005, 2006), and Reynolds et al (2007). We also use NDVI to avoid confusion with rock and soil reflectance, and above all, to avoid under and over estimation of vegetation presence and health, an essential indicator of desertification. We can demonstrate this point by comparing the general VI with NDVI in the analysis below.

The spectral signature is defined as the characteristic set of reflectance by a target over the electromagnetic spectrum. Different targets reflect different amounts of energy at different wavelengths. A multispectral satellite sensor is designed to sense Earth targets at multiple bands designed to distinguish different types of ground cover such as vegetation, water, rocks, etc. In studying vegetation, healthy vegetation looks different from harvested land, and both are different from open water (Campbell 2008). VIs are used to measure vegetation health, based on inclined vegetation reflectance in red and NIR bands called the red edge.

The general formula for VI is:
VI = NIR – Red  \hspace{1cm} (3)

Figure 3.2: The absorption and reflectance of healthy and unhealthy vegetation in red and NIR bands (Simmon 2009)

Using the example from figure 3.1, the VI measure of healthy and unhealthy green vegetation would be calculated as follows:

Healthy Vegetation: 0.50-0.08 = 0.42 \hspace{1cm} (3a)

Unhealthy Vegetation: 0.40 – 0.30 = 0.10 \hspace{1cm} (3b)

VI values range from –1.0 to +1.0. VI in the positive value range indicates green or vegetated surfaces (reflectance in NIR>RED) and higher positive values indicate increases in green vegetation.
According to Campbell (2008), there is one major problem with using VI to measure vegetation. He stated that two identical patches of vegetation could have different VI values if one were in bright sunshine and another under a hazy sky. The bright pixels would have larger values, NIR and red, and therefore a larger absolute difference between the band reflectance values. As a result, a more preferred version of the VI, the NDVI, is normally used. The NDVI is preferred because it helps to compensate for this major problem, simple VI explained above, by focusing on the difference in proportion to total illumination. It does this by using the ratio of the difference to the sum (Campbell 2008).

The formula for calculating NDVI is shown in equation (1) above. We can demonstrate the potency of NDVI using the same figures used for VI in equation (3a) and (3b) by substituting the reflectance figure in NDVI equation (1) above.

\[
\text{Healthy Vegetation: } \frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72 \quad (1a)
\]
\[
\text{Unhealthy Vegetation: } \frac{(0.40 - 0.30)}{(0.40 + 0.30)} = 0.14 \quad (1b)
\]

There are many variations of VI and they follow these same principles, but healthy vegetation shows higher values in NDVI as shown by equation (1a) than VI in (3a) and (3b) (Campbell 2008). Similar reflectance characteristics are exhibited by bare soil and rock in their reflectance levels in NIR and red bands; however, on bare soil and rocks, NDVI values are near zero. Clouds, water, and snow, on the other hand, exhibit
reflectance behavior opposite of vegetation in NIR and red bands; hence NDVI shows negative values in their presence.

Generally, cloud cover constitutes a major problem for remote sensing by obscuring the vegetation below and this affects NDVI calculation. In an effort to circumvent problems caused by cloud cover, NDVI is typically calculated using multiple composite images of the same area, with the hope that at least one image will be cloud-free. For example, the GIMMS NDVIg used for this study was 15 consecutive days of AVHRR data composite to make the NDVI product. This means that for each pixel of each band, the highest of the 15 values is used and the lower remaining is thrown out. Generally, the highest value data area is either cloud-free or represents the least cloudy day. Cloud interference in GIMMS NDVIg used for this study could be possible only if the study area was covered continuously for all 15 days.

The need for a process-indicator based approach for assessing desertification is paramount to the drive to combat desertification in sub-Saharan Africa. However, previous approaches have focused on end-product indicators such as soil degradation (GLASOD). What is missing is that desertification is not necessarily a product, rather a process that has a beginning and an end; hence, the product-based approach leaves much of the quintessential problem of desertification, diminishes the propensity to unravel the mystery of desertification, and above all the likelihood of recovery. We present policy makers and practitioners half the truth about desertification, as we ignore the gist of the
desertification problem, origins, and processes. By doing so, policymakers and analysts are left with few policy options to address the issue of desertification. It is in line with these that we focus on vegetation change trends, as depicted by NDVI, to detect and quantify desertification. By using vegetation change trends, we offer policymakers the option to identify and plan their options before desertification reaches insurmountable levels.

Secondly, the indicator-based approach helps to develop pre-emptive approaches rather than reactive approaches. Frontliners have feedback on areas that need more attention and approaches that need to be continued or discontinued by revisiting the indicator that propelled the initial action. This is because we can identify areas of recovery against areas of continual degradation. Another interesting aspect of focusing on NDVI for detecting desertification is the ability to monitor and/or observe in a continuum to avoid the trap of inter-annual/intra-annual and inter-decadal cover changes associated with drought, desiccation, and rainfall anomalies commonly found in the Sahel Africa (Nicholson 1995; 2002).

A remarkable character of NDVI in the African region and Sahel subregion is the extent of fluctuations linked to the inter-annual and inter-decadal fluctuations associated with drought and desiccation. As defined in chapter two, drought refers to a period of one to three years of below normal rainfall as established by the local climate. Desiccation, on the other hand, is a period of below normal rainfall, usually lasting 3-10 years.
Expectedly, vegetation withers within this period; however, when conditions revive, vegetation recovers sharply. This means that drought and desiccation can be observed with NDVI trends depicting peaks and troughs of either 3 years or up to 10 year intervals. However, when NDVI trends decline or fall below a certain level (usually set by the base year) continuously or consistently for over 10 years, then we have a process indicator that suggests desertification in action. This framework is also linked to the causative agent of the desertification. Since no drought or desiccation lasts for more than 10 years, if the land degradation trend depicted by NDVI persists for more than 10 years, we talk of desertification. We also have a cause to reason that there may be two possible causative agents--either climate change or human-induced land degradation. It is against this background that desertification was defined by UNEP (1994) as land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climatic variations and human activities.

Interestingly, a change in local climate takes place over a longer period and in an imperceptible manner, such that vegetation undergoes adaptation. Climatologists talk about the climate of land area only after the elements of climate have been studied for a long time, usually no less than 35 years, which is well over the required period to recognize desertification. This means desertification occurs far ahead of climate change, which feeds into the argument of whether land degradation (desertification) causes climate change or climate change causes land degradation. However, Chaney (1987) postulated about how land use and associated land cover degradation reduces surface roughness and
variability, thereby exposing the surface to further degradation. These, he said, tend to increase surface albedo and reduce moisture supply to the atmosphere. Pickup (1996) supports Chaney’s argument with his observation of positive feedback between surface and lower atmosphere, as he observed in Australia. They conclude that the net effect of this feedback between degraded surface and lower atmosphere is reduction in precipitation and other conditions suitable for vegetation growth (Zeng 2003). This explains why land degradation in Sahel West Africa is attributed to anthropogenic forcing, mainly due to high population growth and poor land use practice, especially overgrazing and food production, which degrades the land surface, and the degradation feeds back into climate modification. Again, various studies of climate change do not talk about climate change even in a 50 year interval. Moreover, the current trend of climate change that has dominated global discussions is attributed to human activities. It therefore suffices to attribute current desertification trends globally to human activities and not climate change, although climate change cannot be wholly exonerated.

3.3 Seeking Spatio-temporal multispatial approach for measuring desertification

3.3.1 Satellite Data

NASA Earth Science Missions (ESM), such as Moderate Resolution Imaging Spectroradiometer (MODIS), National Oceanic and Aeronautical Agency’s (NOAA) AVHRR, and Landsat Missions, have provided enormous amounts of data at different spatial, spectral, and temporal resolutions that the current data analysis tools have not kept pace with in processing the data to meet the specific end-users’ needs. It is,
therefore, pertinent that more novel and problem-specific techniques are developed to meet the current need of available data and end-user needs. In chapter one, we discussed the specificity of desertification phenomenon and more particularly in the Sahel savannah belt of Sub-Sahara Africa, with its rainfall irregularities, which makes the region unique and as such requires a unique approach and perhaps, in the words of Nsiah-Gyabaah (1994), requires multiple datasets for its study. It is against this background that this study analyzes NDVI from two different sources--AVHRR GIMMS NDVIg data (1982-2007), 8km spatial resolution, and Landsat TM5 and ETM+ NDVI (1984-2007), 30m spatial resolution--to analyze the phenological changes (trends) in land degradation over a period of 26 years (1982-2007). The approach seeks to observe changes in NDVI over space and time in order to conclude (confirm or deny) local observations of vegetation dynamics in the study area. In this analysis, we are interested in annual mean maximum NDVI and annual mean of mean NDVI over the 26 years, annual changes in NDVI in relation to rainfall regimes of the area, and pixel level NDVI regimes over the study period. The pixel level NDVI focuses on pixels that have either decreased (degraded) or increased (gained vegetation) NDVI values over the study period of 26 years (1982-2007). The spatio-temporal approach of this study is summarized by the figure below:
1. GIMMS NDVIg dataset:

The Global Inventory Modeling and Mapping Studies (GIMMS) data is recorded by AVHRR sensors on 5 satellites: NOAA-7, NOAA-9, NOAA-11, NOAA-14 and NOAA-16. GIMMS data has a spatial resolution of 8 km and a temporal resolution of 15-day maximum NDVI composite. The satellite series NOAA 7, 9, 11, 14 and 16 were used for the International Satellite Land-Surface Climatology Project (ISLSCP) Initiative II NDVI record. The AVHRR satellite series flew in sun-synchronous polar orbits with a nominal overpass 1:30 or 2:30 pm local daytime at launch. However, it has been observed that the overpass times drift by approximately 1-2 minutes per month and reach as high as 4 1/2
hours within the time of recording the data used for this study. This creates variations in illumination and view angles over time. The sensors have a 55 degree swath width, which enables daily view of each pixel on the Earth’s surface but at different illumination angles in its 9-day repeat cycle. Maximum NDVI value data composition tends to select pixels which are acquired at near-nadir mode with minimum atmospheric effects; however, illumination and atmospheric effects remain.

Global Inventory Modeling and Mapping Studies (GIMMS) Normalized Difference Vegetation Index (NDVI) datasets used for this study have been generated to provide a nearly 26 year (1982-2007) satellite recording of changes in terrestrial vegetation (Tucker et al 2005). In spite of numerous shortcomings of NDVI in studying desertification discussed above, GIMMS NDV1g also called GIMMS NDVI used in this study was chosen for several reasons explained below. The GIMMS NDV1g dataset from 1982-2007 was prepared with various shortcomings of NDVI in mind. For instance, the dataset has new features including reduction in NDVI variations occurring from sensor calibration, view geometry, volcanic aerosols, and other effects not related to actual phenological changes of interest to this study (GIMMS NDV1g documentation 2004). Specific cases include the NOAA-9 (sensor) descending node data from September 1994 to January 1995, which was known to have been affected by volcanic stratospheric aerosol, and was corrected from the affected datasets, 1982-1984 and 1991-1994. Also, NDVI was improved using Empirical Mode Decomposition/reconstruction (EMD) to minimize effects of orbital drift (Pinzol et al 2004; 2002). The GIMMS NDV1g was
originally produced as global NDVI to provide inputs for computing the time series of biophysical parameters contained in the International Satellite Land Surface Climatology Project (ISLSCP) Initiative II collection (Tucker et al. 2005). However, GIMMS NDVI has been used and/or tested for climate and biogeochemical modeling to calculate photosynthesis, the exchange of CO₂ between the atmosphere and the land surface, land-surface evapotranspiration and the absorption and release of energy by the land surface (Hall et al. 2006; Hu et al. 2008; Karlsen et al. 2005; Tucker et al. 2005; Pinzol et al. 2004; 2002).

The GIMMS NDVI data is of course resolution on a global scale with a spatial resolution of 8km. However, the decision to use AVHRR GIMMS data, in addition to its relevance and also the fact that some of the identified shortcomings have been addressed, is based on long term data availability and accessibility, which is necessary for the study of desertification (Prince et al. 1998; Veron et al. 2006). Also, AVHRR NDVI data is useful for analyzing changes in vegetation cover over a long period. Again, GIMMS NDVI becomes useful to this study for the fact that detailed observation and analysis of identified degraded pixels can be verified and validated with Lansat TM5 and ETM+ data of 30m resolution. Furthermore, several studies attest to the fact that GIMMS NDVI performs far better, in terms of vegetation monitoring, than AVHRR pathfinder data (Tucker et al. 2005; Hall et al. 2006; Hu et al. 2008; Karlsen et al. 2005).
The AVHRR flown on NOAA-14 and previously on NOAA-7, NOAA-9, and NOAA-11, has 5-channel instruments, which scan continuously at a ground resolution of 1 km. The 1 km data has been re-sampled and averaged to nominal 8 km resolution GIMMS NDVI data. AVHRR Global Area Coverage (GAC) at 8 km resolution is available at no cost. AVHRR sensors acquire data in 5 spectral bands: band1-the visible, band2-the near infrared and the remaining three bands (bands 3, 4, and 5) in the thermal region. The GIMMS NDVI data does not make use of the three thermal bands. The spectral ranges of the five AVHRR channels are contained in Table 3.0 below.

Table 3.0: Range of spectral values for AVHRR channels

<table>
<thead>
<tr>
<th>AVHRR Ch. Number</th>
<th>Range (micrometers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.58 - 0.68</td>
</tr>
<tr>
<td>2</td>
<td>0.725 – 1.0</td>
</tr>
<tr>
<td>3</td>
<td>3.55 - 3.93</td>
</tr>
<tr>
<td>4</td>
<td>10.30 – 11.30</td>
</tr>
<tr>
<td>5</td>
<td>11.50 – 12.50</td>
</tr>
</tbody>
</table>

The spectral bands commonly used for vegetation monitoring are the Channel 1 visible band (0.58 to 0.68 micrometers) and Channel 2 in the near infrared band (0.725 to 1.0 micrometers). The spectral response curves for these channels are said to be similar to those of bands 5 and 7 on the Landsat satellite (Tucker et al 2005). The mathematical combinations of Channel 1 and 2 data are found to be sensitive to the presence of green
vegetation and are, therefore, called vegetation indices. This is mainly due to the
differential reflectance of vegetation in these wave bands. The differences in Ch2 and
Ch1 data values, computed as Ch2-Ch1, is an indicator of the degree to which the IFOV
being sensed includes green vegetation.

The vegetation index of interest to this study is the Normalized Difference Vegetation
Index (NDVI). The NDVI is defined by the equation (1) above.

The NDVI is mostly preferred for global vegetation monitoring mainly due to partially
compensating for changing illumination conditions, surface slope, and viewing aspects
(AVHRR online documentation 09/04/08). Clouds, water, and snow have larger
reflectance in the visible band than in the near infrared band, so for these features, NDVI
is negative. Rock and bare soil have similar reflectance in these two bands and result in
vegetation indices near zero. In scenes with vegetation, the NDVI ranges from 0.1 to 0.6;
higher values are associated with greater density and greenness of the plant canopy.

(2) We supplemented the GIMMS NDVI data with seven LTM5 and LETM+ data. The
Landsat mission was first launched on July 23, 1972. The first Landsat satellite carried on
board two instruments that look at the Earth's surface--the Return Beam Vidicon (RBV)
and the Multi-Spectral Scanner System (MSS). The original satellite was called the Earth
Resources Technology Satellite (ERTS-1) and later became Landsat-1, followed by
Landsats-2, -3, -4, -5, and -7. Landsat-6 failed at launch.
The RBV and MSS were flown on all the first three Landsat satellites. Landsat 4 and 5 had MSS and the Thematic Mapper (TM). Landsat-6 was equipped with the Enhanced Thematic Mapper (ETM) and Landsat-7 carried the Enhanced Thematic Mapper-plus (ETM+). The operating dates of Landsat satellites and instruments they carried on board are listed in Table 3.1 below.

Table 3.1: Landsat Satellites, their Operational Periods, and Their Instruments

<table>
<thead>
<tr>
<th>Spacecraft</th>
<th>Launched</th>
<th>Out of Service</th>
<th>Instruments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat-2</td>
<td>January 22, 1975</td>
<td>February 25, 1982</td>
<td>RBV, MSS</td>
</tr>
<tr>
<td>Landsat-3</td>
<td>March 5, 1978</td>
<td>March 31, 1983</td>
<td>RBV, MSS</td>
</tr>
<tr>
<td>Landsat-4</td>
<td>July 16, 1982</td>
<td>June 15, 2001</td>
<td>MSS, TM</td>
</tr>
<tr>
<td>Landsat-5</td>
<td>March 1, 1984</td>
<td>Operational</td>
<td>MSS, TM</td>
</tr>
<tr>
<td>Landsat-6</td>
<td>October 5, 1993</td>
<td>October 5, 1993</td>
<td>ETM</td>
</tr>
<tr>
<td>Landsat-7</td>
<td>April 15, 1999</td>
<td>Operational</td>
<td>ETM+</td>
</tr>
</tbody>
</table>

The TM instrument on board Landsat 4 and 5 and the ETM+ on Landsat-7 view the Earth’s surface with 7 spectral bands. The bands 1, 2, 3, 4, 5, and 7 are sensitive to light from the sun reflected by Earth surface targets. Each band focuses on different parts of the reflected portions of the electromagnetic spectrum. The parts of the electromagnetic spectrum (EMS) are defined by the wave length of the light waves. Band 1 of the TM and ETM+ instruments records in the wave length range of 0.45- 0.52 microns (μm) (the blue
portion of the spectrum). Also, bands 2 and 3 of the TM and ETM+ instruments record reflected green and red light, respectively. TM and ETM+ bands 4, 5, and 7 record reflected light in the infrared portions of the spectrum, specifically near infrared (NIR, band 4) and short wave infrared (SWIR, bands 5 and 7). Unlike the other bands, band 6 of the TM and ETM+ instruments record heat energy emitted by the Earth's surface in the thermal band of the EMS. In addition to the reflected and thermal bands, the ETM+ instrument of Landsat-7 has an eighth band, the panchromatic band. ETM+ band 8 is sensitive to reflected light energy across a broad range of wavelengths that includes blue, green, red, and near infrared. Unlike the other bands, band 8 of the ETM+ has a spatial resolution of 14.25 meters, instead of the 28.5 meters of bands 1, 2, 3, 4, 5, and 7. The sensitivities of Landsat instruments (RBV, MSS, TM, and ETM+) and bands are listed in Tables 3.2 and 3.3 below.

Table 3.2: Landsat 1-5 Instruments and Bands

<table>
<thead>
<tr>
<th>Channel</th>
<th>RBV Spectrum</th>
<th>RBV Pixel Size</th>
<th>MSS Spectrum</th>
<th>MSS-Pixel Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.48-.57 μm green</td>
<td>79 meters, 1.5 acres</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>2</td>
<td>.58-.68 μm red</td>
<td>79 meters, 1.5 acres</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>3</td>
<td>.69-.83 μm IR</td>
<td>79 meters, 1.5 acres</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>4</td>
<td>N/A</td>
<td>N/A</td>
<td>0.5-.6 μm green</td>
<td>79 meters, 1.5 acres</td>
</tr>
<tr>
<td>5</td>
<td>N/A</td>
<td>N/A</td>
<td>0.6-.7 μm red</td>
<td>79 meters, 1.5 acres</td>
</tr>
<tr>
<td>6</td>
<td>N/A</td>
<td>N/A</td>
<td>0.7-.8 μm IR</td>
<td>79 meters, 1.5 acres</td>
</tr>
<tr>
<td>7</td>
<td>N/A</td>
<td>N/A</td>
<td>0.8-1.1 μm IR</td>
<td>79 meters, 1.5 acres</td>
</tr>
</tbody>
</table>
Table 3.3: Landsat 4-7 Instruments and Bands

<table>
<thead>
<tr>
<th>Band</th>
<th>TM Spectrum</th>
<th>TM Pixel Size</th>
<th>ETM+ Spectrum</th>
<th>ETM+ Pixel Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.45-0.52 µm blue</td>
<td>28.5 meters, 0.2 acres</td>
<td>0.45-0.52 µm blue</td>
<td>28.5 meters, 0.2 acres</td>
</tr>
<tr>
<td>2</td>
<td>0.52-0.6 µm green</td>
<td>28.5 meters, 0.2 acres</td>
<td>0.53-0.61 µm green</td>
<td>28.5 meters, 0.2 acres</td>
</tr>
<tr>
<td>3</td>
<td>0.63-0.69 µm red</td>
<td>28.5 meters, 0.2 acres</td>
<td>0.63-0.69 µm red</td>
<td>28.5 meters, 0.2 acres</td>
</tr>
<tr>
<td>4</td>
<td>0.76-0.9 µm NIR</td>
<td>28.5 meters, 0.2 acres</td>
<td>0.75-0.9 µm NIR</td>
<td>28.5 meters, 0.2 acres</td>
</tr>
<tr>
<td>5</td>
<td>1.55-1.75 µm SWIR</td>
<td>28.5 meters, 0.2 acres</td>
<td>1.55-1.75 µm SWIR</td>
<td>28.5 meters, 0.2 acres</td>
</tr>
<tr>
<td>6</td>
<td>10.4-12.5 µm TIR</td>
<td>120 meters, 3.6 acres</td>
<td>10.4-12.5 µm TIR</td>
<td>57 meters, 0.9 acres</td>
</tr>
<tr>
<td>7</td>
<td>2.08-2.35 µm SWIR</td>
<td>28.5 meters, 0.2 acres</td>
<td>2.1-2.35 µm SWIR</td>
<td>28.5 meters, 0.2 acres</td>
</tr>
<tr>
<td>8</td>
<td>N/A</td>
<td>N/A</td>
<td>0.52-0.9 µm panchromatic</td>
<td>14.25 meters, 0.05 acres</td>
</tr>
</tbody>
</table>

Here, IR = infrared; NIR = near infrared; SWIR = short wavelength infrared; TIR = thermal infrared (long wavelength); and µm = micron or micrometer.

This study used seven Landsat TM5 and ETM+ images (1982-2007) cloud free (0% cloud cover) surface reflectance data with a spatial resolution of 30m. The decision to use seven TM5 and ETM+ scenes is based on data availability at the right conditions and the fact that the greater part of, if not all of, the study area falls within one Landsat scene path 194 and row 053. The selection of the 7 scenes was done carefully to avoid phenological changes in vegetation caused by seasonal variations. We therefore selected 7 scenes listed below from the month of October/November.
Table 3.4: Landsat Scenes, sensor and date of acquisition

<table>
<thead>
<tr>
<th>Date</th>
<th>Sensor</th>
<th>Month of Acquisition</th>
</tr>
</thead>
<tbody>
<tr>
<td>20_10_1984</td>
<td>TM5</td>
<td>October</td>
</tr>
<tr>
<td>21_11_1984</td>
<td>TM5</td>
<td>November</td>
</tr>
<tr>
<td>18_11_1986</td>
<td>TM5</td>
<td>November</td>
</tr>
<tr>
<td>30_11_1990</td>
<td>TM5</td>
<td>November</td>
</tr>
<tr>
<td>7_11-1999</td>
<td>TM5</td>
<td>November</td>
</tr>
<tr>
<td>09_11_2000</td>
<td>ETM+</td>
<td>November</td>
</tr>
<tr>
<td>27_10_2001</td>
<td>TM5</td>
<td>October</td>
</tr>
<tr>
<td>30_10_2002</td>
<td>ETM+</td>
<td>October</td>
</tr>
</tbody>
</table>

In addition, data has been selected to take care of intra-seasonal phenological variations related to local seasonal variability due to rainfall, agricultural harvest, and bush burning. The month of October/November was selected because it is the period just after the raining season and before the onset of the dry season. It is also a period before local bush burning for hunting, grazing, fire festival, and agricultural purposes. Furthermore, October/November marks the end of agricultural harvesting in the UER. By selecting data from the month of October/November and near anniversary dates, phenological variations would be normalized (Lunetta et al 2002; Lu et al 2004; Coppin et al 1996).

The high spatial resolution of Landsat TM5 and ETM+ data make them suitable for this study, since it can capture almost all major local variation in land degradation (Collado et
Various studies have attested to the spatial variability in degradation and causative agents, which have also been the basis of criticism for some earlier attempts at quantifying and analyzing desertification globally (Veron et al 2006). Local variations and causes are very important not only to this study, but also for any attempt to combat desertification locally. The Landsat TM5/ETM+ data is also useful for validation of AVHRR data.

Landsat images used in this study were purchased from the United States Geological Service (USGS) Center for Earth Resources Observation and Science (EROS) data center at Sioux Falls, South Dakota, with the financial support from the Borlaug-LEAP Grant administered by the Leadership Enhancement in Agriculture Program (LEAP); University of California Davis (UC Davis); and the International Food Policy and Research Institute, Washington, D.C.

The data was radiometrically and geometrically corrected at the source and the digital numbers were converted to radiance and to reflectance. This reduced processing time and cost and ensured timely completion of the study. However, further normalization was performed to correct for atmospheric effect and transform the data to surface reflectance using the FLAASH image normalization package in the ENVI 4.4 software. Image processing steps followed in this study are listed below:

i. The seven Landsat scenes were co-registered using image to image registration package in the ENVI 4.4 software.
ii. Image subsetting – Landsat image is 185x185 km; meanwhile, the study area is approximately 160x120, so we therefore need to subset the image to the region of interest (study area). For the purpose of subsetting, the images were projected to the same projection as the shapefile of the study area (UTM zone 30) with Datum NAD W84. The images were overlaid with the study area boundary shapefile in ENVI 4.4 software. The images were subsetted to cover the study area.

iii. NDVI processing: ENVI 4.4 software was used to process NDVI through Idl band math functionality. Band math is a mathematical approach that performs mathematical operations on an image based on selected mathematical operations.

NDVI is the Normalized Difference Vegetation Index, an index ascribed to Rouse et al. (1973), although the concept of a normalized difference index is said to have been first introduced by Kriegler et al. (1969) (Ray 1994). NDVI has the advantage of varying between -1 and 1, with 1 indicating the maximum and -1 the minimum.

NDVI was calculated as:

\[
\text{IDL NDVI} = \frac{\text{float(b1)} - \text{float(b2)}}{\text{float(b1)} + \text{float(b2)}}
\]

Where b1 represents Landsat band 4 (NIR) and b2 represents band 3 (Red) and float converts the image from byte to a floating number.

iv. Image inspection and further validation with GPS location data taken from the field during the field survey (December 07-February 08).

v. Generation of NDVI values for the degraded pixels of the AVHRR data.
Plotting of GIMMS NDVI degraded pixel values into a line graph over the study period.

Figure 3.4: Steps for image processing

Essentially, using 2 different sensor images of different spatial resolutions allowed two levels of analysis from coarse to medium spatial resolution. The two levels of analysis can also be understood as pixel level analysis (8km), which equates 266 landsat pixels. The study performed trend analysis on annual mean NDVI levels using GIMMS NDVI and compared that to the NDVI generated from seven single scene images of Landsat TM5 and
ETM+. We further validated the observations from GIMMS NDVI and Landsat TM5/ETM+ scenes with GPS location data for places known to have degraded, precisely towns.

3.3.2 Climate Data

Pickup (1996) and Chaney (1987) have articulated the positive feedback relationship between lower atmosphere and land degradation. Nicholson (2000), Zeng (2003), Xue and Fennessey (2002) have also identified the extent to which inter-annual and inter-decadal rainfall determines the vegetation pattern in the Sahel region of West Africa. It is against this background that climatic factors, particularly rainfall and relative humidity, became very vital to the analysis of greenness, and for that matter, desertification in the UER. The study utilized climate data collected by the Ghana Meteorological Services Department. The available data obtained included rainfall data (1984-2006), Relative Humidity data (1984-2006), and temperature data (1984-2006). The climate data is crucial for understanding the natural variability of climate in the study area and it is necessary for showing the cycle of climate in relation to land degradation within the same period.

Climatic factors, especially rainfall and humidity and their variations, have a direct relationship with soil moisture and vegetation greenness, including agriculture and food security (Pickup 1986). Rainfall was correlated with NDVI data to show the direction and magnitude of deviation from normal. This relationship between NDVI and precipitation
also help in analyzing causes of land degradation within a particular period, especially in reference to climate variability and anthropogenic causes. Climatic data for the study was secondary data collected by the Statistical Service of Ghana (SSG), the District and Regional Office of Ghana Meteorological Service at Bolgatanga. Climate data was available for 2 weather stations in the region, including Garu and Manga-Bawku, UER.

3.3.3 Socio-Economic Data

Three main types of socio-economic data were used in this study. These include the following:

1. Local perceptions of the natural environment and its changes over the past 40 years. These were collected through a focus group discussion with a questionnaire.
2. The other two socio-economic data were secondary data consisting of crop production and population data from 1983-2004. The details of the data are explained below.

1. Data from Focus Group Discussions (FGD) with questionnaire

This is primary data collected from the field through FGDs with questionnaires. The data includes the perceptions and observations of local people on desertification, changes in climatic factors, anthropogenic causes (land use practices and cultural practices), and the interplay of climate and desertification on agriculture (productivity changes) and the subsequent impact on population, especially migration. This data was collected by administering 60 questionnaires to some focus groups of local residents in six
communities in the study area and some 20 questionnaires administered to regional administration employees whose work relates directly to land degradation and vegetation in general. These include the Regional Director of Environmental Protection Agency (EPA), the Regional Director of MoFA in charge of crops, six district directors of MoFA, four agricultural extension officers, and the Regional Director of the Ghana Meteorological Services Department, Bolgatanga.

The focus group selection was based on the snowballing method. Snowball sampling is described as an approach for effectively locating information-rich informants (Patton 1990). The approach starts with a few potential respondents who recommend other respondents with the characteristics that the research is looking for. In this study, we started by contacting the district MoFA officer who recommended potential respondents with the characteristics identified in this study and those respondents also recommended other information rich respondents who met the predefined criteria. Snowball sampling is not a stand-alone tool; it is a tool for selecting participants with knowledge about specific problems and it is always aided by other tools, such as interviews or surveys to extract the information needed. Having identified participants with the skills and knowledge or characteristics required, we invited them to participate in focus group discussions with questionnaires. The questions were written in the English language but were translated into their local language (Guruni) and with the help of four research assistants hired from each community visited. The specific communities where the FGDs were held were
identified from the preprocessing of Landsat TM5 images as areas seriously affected by land degradation. Below is a map showing locations where FGDs were held in the UER.

![Map showing locations where FGDs were held in the UER](image)

Figure 3.5: Locations where FGDs were held in the UER

Each recommended person selected for the study met the following criteria: a farmer, a resident in the areas for at least 15 years, and at least 20 years of age. Also, the person(s) was/were willing to participate without coercion and/or fear or influenced by and/or anticipated any sort of reward. In all, 60 questionnaires were administered in the Gruuni language to sixty local residents (farmers) who met at six locations including Bolgatanga, Zualugu, Zebila, Bawku, Bugri, and Garu. In each of the six locations, a focus group of
10 people was organized. Each focus group member was given one set of the questionnaire, which was completed with the help of the field research assistants.

Questions in the questionnaire were both pre-coded and open-ended, and they relate to local knowledge of land degradation (desertification), drivers and dates of occurrence where possible, patterns of rainfall, agricultural practices, population trends, including migration, food production (food security), and policy implementation.

2. The second group of socio-economic data includes crop production, land under cultivation and yield. This data was secondary data collected and compiled by MoFA, an official governmental agency responsible for agriculture in Ghana and in the regional office of the UER, Bolgataga. They include seven main crops cultivated in the region, yield per hectare, total annual production, and total land area under cultivation. Conspicuously missing was data on land management, such as investment on conservation and fertilization, irrigation facilities, and crop improvement.

3. The third socio-economic data includes population data for the region and the districts.

This includes population characteristics such as age and sex distribution, growth rate, and labor force. However, there was no data on migration and cost of agricultural labor, even though migration and labor costs constitute a very important piece of information to this study.
3.3.4 Direct Field Observation and location data with GPS

Direct observation method of data collection is a primary data collection method referred to by sociologists and anthropologists as a participatory approach, but to remote sensing scientists, it is either a reconnaissance survey when performed before image processing or ground truthing after image processing. However, they normally aimed at collecting first-hand information about the phenomenon under study. In some cases, it involves validation and sampling of Earth surface targets. Perhaps the point of divergence between the remote sensing scientist and anthropologist is that in the anthropological studies, the subject of study is a human being, and for that matter, the researcher lives and behaves like the subject. In the case of remote sensing, the subject is mostly the ecology or natural environment; hence the research observes how the subject looks, map locations, and other physical attributes.

In this study, the direct observation method was used to collect data for two main purposes: first, to get first-hand information about the nature and type of degradation in the area; secondly, for image processing about the nature and type of land degradation and also to map and capture live pictures for data validation purposes. This data collection involves a field trip with GPS and a camera to map areas identified as degraded for the preprocessing (reconnaissance image survey) of the satellite image and also map the location of some permanent feature that might not have changed very much, especially those that are highly visible on the landscape.
3.4 Methodological weaknesses, problems, and limitations of the study
a) Lack of continuous and long-term Landsat data:

The study originally proposed to use Landsat TM5 data for the month of November, covering the period of 1984-2007. Unfortunately, there were only six Landsat TM5 data found in the Landsat TM5 archives. Of the six available scenes, two were captured in November 1984; another two were in November 1990; one in November 1986 and one in November 2000, meaning only four scenes from 1984-2000 would be valid for the study. To make up for the satellite data shortfall, we added three Landsat ETM+ images from November 1999, 2001, and 2002. Moreover, the Landsat scenes of our study area (path 194; row 53) did not cover the entire study area, even after it was corrected to the terrain, mainly due to the alignment of the swath. We made an effort to mosaic multiple scenes, but due to the descending node direction of the satellite movement, scenes from the adjacent (path 195; row 53) and upper swath (path 194; row 52) did not correspond to the dates that we had data from the main scene (path 194; row 53). Data acquisition date differences and inconsistencies in cloud cover and others, therefore, precluded the possibility of mosaic scenes for complete coverage of the study area. However, a greater part of the area falls within the selected scenes. We did not find the excluded area large enough to have an impact on the results.

We also felt the need for more continuous and long-term data. We therefore obtained AVHRR GIMMS NDVIg data. This is AVHRR time series data processed into global NDVI. Although it reduced processing time and also has greater accuracy, since accuracy
issues had already been corrected, it allowed less manipulation, since it was already an NDVI product. Also, the GIMMS NDVIg data was coarse in spatial resolution and as such, more generalized than we planned for. Due to the inherent weakness of the GIMMS data caused by the spatial resolution, we felt the need to process the few Landsat TM5 and ETM+ data available to validate the trend that was observed in the GIMMS NDVI. Another problem was lack of ground data prior to 2007, when we visited the study area to serve as the basis for assessing the extent of degradation and also for validating the accuracy of the NDVI analysis and local perception of land degradation. This means we have no land cover data to justify any conclusion of land cover change. We, however, validated the accuracy of our analysis using GPS position measurements taken from towns and villages visited during the fieldwork. We also loaded the map to Google Earth for validation purposes.

b) Socio-economic and cultural data used for this study was partly collected through focus group discussions with questionnaires from January 6, 2008 to February 8, 2008. This period was the dry season, which made most roads and places accessible. However, the dry and hazy harmattan weather conditions made life extremely difficult for the research during the fieldwork. Also, the dry season was off-farm season and post-harvest period, as such, most places were bare, giving the impression that land degradation has reached the extreme; however, local residents mentioned the return of the green just at the onset of the rains. We also did not have the opportunity to observe farming activities during the fieldwork. Some experts, including Nsiah-Gyabaah (1994), have underscored
the potency of land degradation study focusing on continuous monitoring of the microenvironment over a long period of time for detecting and quantifying environmental change. However, time and financial constraints precluded long term ecological change observation and monitoring and limited the fieldwork to about 45 days.

The collection of field data was also saddled with the problem of accessibility and lack of willingness to divulge information by the study respondents. Our field visit coincided with land use and ownership conflict between two ethnic groups in the Bawku and Garu-Tempane areas, which created tense conditions and an atmosphere of suspicion about strangers, with the view that information given would be used by the other ethnic group or government agencies against the informant or his/her ethnic group. To reinstall confidence and an atmosphere of willingness to divulge information, we hired research assistants from each community visited. We therefore hired twelve research assistants instead of the two originally planned for. Fortunately, this change did not increase cost, although extra training time was required.

The accuracy of secondary data used for this study cannot be certified. Nsiah-Gyabaah (1994) has outlined problems associated with data collection in northern Ghana by government departments. He noted that human error, data communication and storage procedure, and the caliber of personnel used in data collection in northern Ghana often affects the accuracy and consistency of data. Also, information gathered from the MoFA office (Bawku West District) indicates that some local residents tend to understate
livestock numbers for the fear of information being used for taxation purposes. Although we cannot prove the accuracy of these assertions, we caution that secondary data used in this study were collected for different purposes and by different organizations and personnel, and as such, could affect data accuracy and therefore be used with care.

3.5 Conclusion

In spite of the advances made in the desertification detection and quantification methodological development, effective assessment of the accuracy of these methodologies are hampered by two main issues, including the lacking of a reference situation and the complexity of desertification nexus. Assessing desertification would have been easier and more understandable if there was a reference situation for comparison of how things were or should have been in comparison with how they are now. The general absence of data on how things were detracts from conclusions on how things are today. Secondly desertification nexus are complex and multiplicatively intertwined with physio-ecological, climatic, socio-economic, and political factors such that it becomes impossible to separate the head from the tail. For these reasons, scientists like Nsiah-Gyabaah (1994) and Hueting (1980) have vehemently called for holistic, a multi-disciplinary analytical approach that integrates physio-ecological, economic, and socio-anthropological data for effectively unraveling the complexities of desertification and its nexus. Thus, the method used in this study incorporates data from multiple sources, including satellite data, other physio-ecological data, social, and economic data in search of convergence and divergence of evidence for innovation in problem identification and development of appropriate interventions for combating desertification.
4.1 The UER: Physical Environment

4.1.1 Topography and Geology

The topography of the UER can be described as gentle, undulating land with an altitude of between 110-200 meters above sea level and slopes ranging from 1% to 5% (Dietz and Millar 1999). There are occasional outcrops of inselbergs and uplands that slope around 10%. The highest points in the region are found in the eastern portions of the region, within the Garu-Tempane district, which has peaks rising up to 430 meters above sea level (MoFA 2006). There are also isolated peaks found in the Bawku West District (central portions of figure 4.1 below), such as the Boya-Kpalsako hills and Zongoyiri. The lowest portions of the study area are areas found within the valleys of the White and Red Volta Rivers.

The study area forms part of the Volta River Basin and specifically the part of the basin which forms the confluence of three major rivers, the White and Red Volta Rivers (from Burkina Faso) and the Sissili River (also from Burkina Faso). The geology consists of igneous and sedimentary rocks. The rocks are mainly intrusive granite outcrops that have resisted erosion over the years and Voltaian sandstone with similar characteristics as the granite. Below is the digital elevation map showing the relief of the study area.
4.1.2 Soil Characteristics:

The soil of the region can be better understood through the geology, drainage, and climate of the area. There are few, but localized studies outlining the soil characteristics of the region. This is partly because of the political subdivisions of the region into districts and also because of the drainage system that divides the region into three main drainage basins. As observed by MoFA report (2006), the topography of the region has been modified and shaped by the drainage system of the area. It is, therefore, not surprising that the soils of the region are fragmented into several subtypes and variously described by local studies. Atta-Quayson (1995) describes the soils of the eastern parts of the region as groundwater
laterites which are poorly drained and loam in nature. The western parts of the study area, covering the Balgatanga and Bongo districts, consist of soils mainly dominated by savanna ochrosols, which are well-drained, porous, and loam. MoFA (Bawku West) (2005) describes the soil of the central portions of the study area (Bawku West District) as predominantly Tanchera and Kolingu associations. This soil is developed over granites and sandstones with the topsoil varying in texture from coarse sandy-loams to clay with varying amounts of gravel (MoFA Bawku West 2005; Dietz and Millar 1999).

The Tanchera associations are soil with loose, porous, coarse texture and easily cultivated. They are also easily eroded with poor nutrient content and are generally acidic. They have organic matter levels averaging 0.5% in the topsoil, but fall drastically in the subsoil. Whereas nitrogen content of this soil is negligible, phosphorus content hovers around 50ppm. These soil associations have low moisture retention due to sandy texture and high draining nature of the soil (MoFA Bawku West 2005). The second soil association in this part of the study area is the Kolingu soils. Kolingu soils have gravelly topsoils, low moisture retention capacity, and high percolation through the gravelly topsoil to the semi-permeable decomposing clayey subsoil, which forces the percolating water to flow laterally down-slope to valley bottoms (MoFA Bawku West (2005). The nature of this soil association makes it more susceptible to drought and perennial water shortages.

Other soil associations identified in the study area include the Mogo Constitution and Nangodi association, mainly found in the northern potions of the study area, around the
Ghana-Burkina Faso border. These soils generally have less accumulation of organic materials in the topsoil, a characteristic attributed to high soil temperature, rapid organic matter decomposition, frequent burning of vegetation cover, and post harvest reduction of soil organic matter content.

4.1.3 Drainage

![Map of UER drainage and topography](image)

Figure 4.1: Drainage and topography of the UER

UER is drained by three main streams and their tributaries. These include the White Volta in the East, the Red Volta in the central portions of the region and the Sissili River in the West (Regional Coordinating Unit, 2003). The volume of water in these rivers is directly
related to inter- and intra-annual seasonal rainfall regimes of the area. These streams can be classified as permanent and have their annual regime peaks in August-September, which coincide with the rainfall peak for the year. From January to April (the dry season), the volume of water in these streams reduces to the minimum due to low recharge and the drying up of many perennial tributaries and ephemeral streams that form the source of recharge through springs and runoff from rainfall (Regional Coordinating Unit 2003; MoFA 2005).

All three streams take their sources from Burkina Faso and flow southward to the UER. Upon leaving the UER, they join together as the White Volta and flow southward to the Volta Lake. There are also a large number of ephemeral streams that flow from the Sahelian zone to join these permanent streams to form the catchment area of these streams. However, there are no major tributaries, permanent stream tributaries, to these streams except numerous short, wet seasonal streams springing from the surrounding hills and rock outcrops. The courses of these numerous streams are not well-defined as they wander over granite and Birimian rocks. Most of these intermittent streams dry out completely during the dry season (December – March), leaving bare alluvium plain, but they then rise to a sizable stream during the rainy season (April – November). Floods, sheet, and gully erosions are common features along riverbanks and intensively farmed areas of the region (MoFA, Bawku West 2005; Regional Coordinating Unit 2003; Dietz and Millar 1999).
4.1.4 Climate

The climate of the UER would be better understood if discussed in the broader context of the climate of Ghana. In one sense, it would help us to understand the unique nature of this region in relation to other parts of Ghana, and in the other sense, it becomes relevant in the context of climate change and the inter-annual and/or inter-decadal climate variability associated with the West African subregion as a whole.

Ghana is located between latitude 4° 44’27”N and latitude 11° 10’04”N and longitudes 000° 23’ 05” and 003°15’47” East and West, respectively. The climate of Ghana can be certainly described as the tropical, equatorial type; however, it varies between the northern and southern parts of the country and also between the savanna and forest regions. The climate of Ghana is better explained in terms of the annual excursion of the low pressure cell called the Inter Tropical Convergence Zone (ITCZ), also known as the Inter Tropical Discontinuity (ITD). The ITCZ location is determined by the apparent movement of the sun within the tropics and as such the oscillating air mass systems of the African continent.

As the sun moves North and South of the Equator during its annual excursion cycle, the land and water beneath warms. The warm air and water vapor rise, creating a vacuum, i.e. low-pressure belt. This low pressure cell is characterized by calm and ascending winds,
which creates a pressure gradient to attract the moist-rich southwesterly trade winds and the dry northeasterly winds to the zone. The ITCZ then forms the boundary and converging point of the trade winds on the subcontinent. This zone, which forms along the equator, was originally called the doldrums but now more common names include the Inter Tropical Convergence Zone (ITCZ), the Inter Tropical Discontinuity (ITD), and the Inter Tropical Front (ITF). This zone is important for African climate because the rising air and water vapor caused by the warmth of the sun leads to cloud formation and rainfall.

Below is ITZC position tracking graph, which forms a wave-shaped pattern, stretching from 10° East to 10° West across the African subcontinent. The y-axis of figure 4.2 tracks the latitudinal position of the ITCZ from the equator (latitude 0°) and latitude 25° N. The x-axis, on the other hand, tracks the monthly dekadal position of the ITCZ from March to November each year.
Figure 4.2: The Mean Position of the ITCZ (10° W to 10° E longitude) (2007)

Although the line tracker above tracks the normal ITCZ positions between latitude 10° and 24° North and longitude 10°E and 10°W, the annual atmospheric conditions can speed up or delay the progress of the line, so its location is not exactly the same from year to year. Figure 4.3 below also shows the actual position of the ITCZ in June 2004, which differs from the mean ITCZ position in June.
Figure 4.3: The position of the African ITCZ June 2004 Dekad 3 (NOAA 2006)

Figure 4.4: The ITCZ position and sphere of influence observed between March 11 – 20, 2008 (NOAA 2008)
Figure 4.4 above shows the northern and southern edges of the ITCZ in relation to the northern and southern normal positions. The ITCZ position variability introduces the inter-annual climate variability in the West African subregion.

Between March 21st and September 21st, the sun is in the northern hemisphere, which concentrates heat in the northern hemisphere. The ITCZ then moves gradually North of the equator, which puts the West African sub-region under the coverage of southwesterly winds; this then brings rainfall to West Africa. Conversely, the sun moves gradually to the southern hemisphere after September 1st and the ITCZ also follows gradually, and the West African sub-region comes under the northeast trade winds (Harmattan winds) which brings dry conditions in the subregion from November to March. Because Harmattan winds blow from the Saharan desert, it is dry and dusty, which causes hazy conditions and drought in the subregion (Dietz and Millar 1999).

4.1.4.1 Rainfall

Climatic condition differences between various parts of Ghana are primarily caused by the changing positions of the ITCZ and its variance, which in turn determines which air mass (southwesterly winds also known as the monsoon winds and the northeasterly winds also called the harmattan winds) affects different parts of the country at different times of the year and hence rainfall pattern differences between the northern and southern parts of the country.
Southern Ghana has a bimodal rainfall pattern, which runs from March through July and from September to November. The peak of the major rainy season occurs in June/July, followed by a minor dry season in August and the minor rain season from September to November. December to March is essentially a dry season when the country comes under the harmattan winds. Mean annual rainfall of southern Ghana ranges from 1500mm inland to 2200mm in the south-western corner along the coast where the highest mean annual rainfall is recorded. However, the eastern coastal areas of Ghana, including the Accra plains, experience the lowest rainfall records in the entire country. There is a system of rainfall anomaly along the eastern coastal areas which is explained in terms of the alignment of the coast line which forces the monsoon winds to blow parallel to the coast, causing rainfall offshore and the general absence of highlands to cause orographic uplift of monsoon winds to cause rainfall along the coast. Below is the isohyets map showing the rainfall pattern of Ghana.

Figure 4.5: Mean Annual Rainfall Distribution – Ghana (FAO Online data 2007)
Northern parts of the country, on the other hand, have a monomodal rainfall pattern. Northern Ghana experiences a squall between January and April, followed by occasional rains until August and September when the rainfall reaches its peak, but then starts experiencing a dry season starting in late November. Rainfall ranges from 830 to 1200 mm a year.

4.1.4:2 Relative Humidity (RH)

RH measures the amount of water (moisture) in the air relative to the amount of water (moisture) the air can hold at its saturation point of the temperature at which the measurement was taken. The mean RH of Ghana ranges between 50% and 80% North and South, respectively. The low RH of the North is mainly attributed to the drying effect of the harmattan winds and the high temperature associated with the region (Ghana Meteorological Services 2006).

4.1.4:3 Temperature

Temperature describes the degree of hotness or coldness of air. Average temperatures of Ghana range between 21° and 32°C (70–90°F), depending on whether you are in the South or North, respectively. The harmattan blowing over the Sahara Desert as dry and dusty desert wind blows from the Northeast from December to March. This tends to absorb moisture and lower humidity. They also cause very hot day temperatures and cool
nighttime temperatures in northern Ghana between December and March, but start affecting southern Ghana in January. Most areas in Ghana have their highest temperatures around February/March and lowest in August. The diurnal temperature range is relatively small in the South but greater in the North, especially in January, mainly due to the effects of the harmattan winds. No temperature lower than 10°C (50°F) has ever been recorded in Ghana.

4.1.5 Climatic Conditions of the UER

4.1.5:1 Rainfall

The UER is in the northern part of Ghana. It is located between latitude 10°30’ N and 11° 10’04” N. The latitudinal location of the UER puts it in a unique position in relation to the ITCZ and, for that matter, the nature of the climatic conditions experienced in the region. The climate of the region is described by Keay (1939) as Sudan Savannah type. Within the constraints set by available data, we analyze climate data, specifically rainfall, temperature and RH from two weather stations: Manga-Bawku, located on latitude 11°05’ and Garu, which is located southeast of Manga-Bawku on latitude 10°58’. The latitudinal location difference also introduces slight variations in climatic data recorded. Generally, the UER has a monomodal rainy season that starts in April and ends in November. The monthly rainfall increases gradually from April and reaches the maximum in July-September and begins to decrease gradually from late October to November. There is a prolonging dry season beginning at the end of November and
lasting until the beginning of April, when the region comes under the influence of the ITCZ. The mean annual rainfall ranges from 900mm to 1150mm, a character of rainfall irregularities typically found in the region (figure 4.6). The rainfall pattern and the climate of the region is controlled by two oscillating air masses--the southwesterly winds that blow from the Gulf of Guinea (April-November) bring rainfall to the region, whereas the northeasterly winds (harmattan) blowing from the Sahara, reaching their maximum in January, bring dryness and dust into the region. Below is the rainfall graph of data recorded from two meteorological stations in the UER from 1983-2004: Manga-Bawku, at an elevation of about 751 ft above sea level and Garu, also at an elevation of 748 ft above sea level.

![Rainfall Graph](image)

Figure 4.6: Average Annual Rainfall for Garu and Manga-Bawku, UER (1983-2004)
Figure 4.6 shows the irregular nature of rainfall in the UER and Manga-Bawku in particular. From the data almost every year with good rainfall in Manga-Bawku is followed by a year with low rainfall, and this affects local agriculture negatively. Manga-Bawku generally records less rainfall than Garu, with the exception of 1999 and 2003, when mean annual rainfall was highest in Manga-Bawku. Over the 21-year period, 1983 had the least rainfall in Manga-Bawku, with an annual mean rainfall total well below 500mm. Conversely, the lowest rainfall record for Garu over the 21 years was in 1986, with a mean of almost 650mm of rainfall. The general pattern of rainfall records between Manga-Bawku and Garu conforms to the general pattern of rainfall in the Sahelian West Africa, a feature observed by Darkoh et al (1998) in Niger when they analyzed rainfall variability latitudinally. UER records an average of 7-9 months of rainfall annually; however, local residents interviewed for this study claim to have observed a reduction in the rainfall period. As far as they can recall, rainfall starts in April and ends in November; however, in recent years, the rains start in late May and ends in November, reducing the rainy months to 7-8 months a year on the average. This reduction in rainfall has affected agricultural planting and the harvesting period. Additionally, local residents have observed spatial discontinuity of rainfall over the last 20 years. Also, 2 out of every 3 people interviewed described the pattern of rainfall as sporadic, i.e. temporally irregular and spatially discontinuous. For these reasons, some communities in the region begin crop planting and harvesting earlier than others, although it used to be uniform throughout the region.
Figure 4.7: Total Mean Monthly Rainfall for Garu (1983-2004)

Figure 4.8: Total Mean Monthly Rainfall for Manga-Bawku (1983-2004)
Whereas local people have strongly emphasized the point that rainfall has delayed in recent years, rainfall data records from Garu and Manga-Bawku from 1983-2004 give no convincing evidence of late rains. The rainfall data presented in figure 4.7 and 4.8 are monthly averages and not daily averages; this makes it difficult to determine how early or how late the rain comes. The local observation of late rain could be a matter of days, instead of monthly data being analyzed here. It would be more conclusive to have daily rainfall figures in order to generalize about rainfall patterns in the UER. Meanwhile, we conclude that monthly rainfall data did not show any changes in the starting months of rainfall over the past 22 years from 1983-2004.

4.1.5:2 Temperature

Relatively, the UER experiences high temperatures year-round, which causes high moisture losses off the soil through evapotranspiration. The mean monthly temperature declines slowly from the highs of about 34.6 in the middle of the dry season to lows of about 26.8 in August, the rainy season. Figure 4.9 shows the mean monthly temperature records from Manga-Bawku and Garu and the differences in temperature between the two locations from 1983 to 2004. The temperature graph is wavelike in shape. It rises gradually from January to reach the peak in April, then declines gradually to the minimum in August and rises a little in October-November and declines in December-January.
Mean annual temperature recorded in both Manga-Bawku and Garu show that the temperature is gradually increasing in the region. The highest temperature recorded in Bawku was 29.7°C in 1998 and the lowest was 28.53°C in 1988 during the study period, signifying a difference of about 4% temperature range. Whereas temperature is warming in both Bawku and Garu, the latter seems to have warmed up faster in recent years to have caught up with Bawku, even though Bawku is known to be a warmer location than the latter. Figure 4.10 shows that the temperature of Garu has warmed faster than Bawku.
The decline in temperature between May and October is mainly due to the onset of the rainfall. On the other hand, the dry, dusty harmattan winds that blow over the region between December and February tend to bring cold conditions to the region and also absorb and reflect more solar radiation during that period, hence the decline in temperature. Comparatively, Garu is colder than Manga-Bawku, primarily due to its southward location of latitudes 10°58’ N and 11°05’N, respectively. The temperature difference between the two locations reaches its peak in May with a temperature difference of about 0.6° Celcius and its lowest in December; however, Garu gets warmer
than Manga-Bawku in November with a temperature difference of 0.3° Celsius (C) in favor of Garu.

4.1.5:3 Relative Humidity

Relative Humidity in the Upper East is generally high in the rainy season (May-September) and low in the dry harmattan season (December – March). Relative Humidity can be as high as 80-90% in the rainy season, but drops to as low as 26% during the dry season (MoFA 2005). Mean monthly RH records from Garu and Manga-Bawku (1983-2004) are shown in figure 4.8.

Figure 4.11 Mean Monthly Relative Humidity and the differences between Garu and Manga-Bawku (1983-2004)
4.2 Current Vegetation

The UER lies within the sub-Sahel vegetation transitional zone occupied by Sudan and Guinea savanna. The vegetation includes widely spaced, short deciduous trees and ground flora of a continuous cover of grasses of different heights (MoFA 2005). The present vegetation is believed to have undergone drastic transformation from the original grass species that occupied the region. According to MoFA (2005), very little of the species in the area are in their original state. The current vegetation consists of degraded tree savanna dominated by fire-resistant species due to persistent annual wildfire plaguing the area. In upland areas that have experienced less disturbances from farming and wildfire burning, the common species found include Butyrosspermum parkii (known locally as shea tree), Adansonia digitata (baobab tree), dawadawa, silk cotton, thorn, ebony trees, and various species of the Acacia tree. Remnants of close forests are also found along the alluvial plains of the Red and White Volta rivers. The close forest vegetated areas are dominated by different species of Anogeissus leiocarpus, Acacia polyacantha, Anadira inermis, Diospyros mespiliformis, and Khaya senegalensis (MoFA 2005). There are some pockets of natural vegetation along the banks of the Red and White Volta Rivers in areas infested with Onchocerciasis (river blindness) and Trypanosomiasis (sleeping sickness) diseases. These diseases preclude human habitation and livestock bleeding in those areas and as such the vegetation remains natural or as climatic climax.
There are also protected forest areas developed as community woodlots and the common tree species in these community woodlots include teak, acacia, neem, mango, and cashew trees. The grass cover and shrubs, especially horsetail grasses, are said to have reduced greatly, leaving some places bare. This reduction in vegetative cover in the area is mainly attributed to perennial bush burning and removal of long grasses for thatching (roofing) of local homes. As a result, local people travel to other regions including Upper West and Northern regions to purchase long grasses for thatching (MoFA 2005). Some local residents’ interviewed during our focus group discussions recounted their experience of local vegetation change to as far back as the 1960s where most areas in the region have close vegetation cover with trees. They also recounted how the savanna grassland was dominated by tall elephant (horsetail) grasses commonly used for thatching and supporting local craftsmanship.

Figure 4.12: Horsetail grasses use for thatching and a local thatched house in the UER
The local craft was the off-season employment for locals during the dry season when there are no regular farming activities. The horsetail grasses are used for baskets, hats, and shopping baskets mostly sold at the historic Bolgatanga and Bawku markets, which were very popular in the West African subregion during the 17th century and even up to the 1980s. Bolgatanga, the capital of the UER, is located on the trans-saharan trade route where many traders from the Mediterranean regions of Europe and North Africa and other West African countries attended periodic markets in search of smocks, baskets, and leather goods. Narratives from the focus group discussion show that the region has been experiencing ecological succession where the tall elephant grasses are being replaced by short, less rich grasses that are not suitable for thatching and basketry. As such, local residents travel to Northern and Brong Ahafo regions (south of UER) to purchase or cut elephant grasses for thatching and basketry. This has affected off-season employment and also the cost of roofing local thatch houses. Most residents have resorted to aluminum sheeting, which is neither conducive to local weather nor affordable to these poverty-stricken local residents.

The vegetation change, according to informants, can be attributed to certain local cultural practices including the annual bush burning for hunting and farming purposes, incidental burning resulting from incomplete cigarette pieces dropped after smoking in the dry season, burning resulting from charcoal burning, and burning for the purpose of controlling venomous snakes and other reptiles. The use of fire for farming and hunting purposes was ranked the number one reason why people use fire in the UER. The
research sought to find out spatial disparity in the use of fire. In the Garu-Tempane district, all respondents agreed to have used fire for land clearing on a yearly basis. In the Bawku West District, 95% of respondents said they use fire on a yearly basis in their farms, but in the Bawku Municipal area, 20% of respondents said they have never used fire for clearing land; 60% use or observe fire in their community at least every five years. The frequency of fire usage accounts for the nature of present vegetation in the region, which MoFA (2005) describes as fire resistant plants that are well-adapted to local conditions. Other causes of vegetation degradation identified by MoFA officials in the region include the cutting of young trees for firewood and building materials, including elephant grasses for thatching.

4.3 History and People of the UER

Historically, the majority of the people of present day northern Ghana, comprising of Mossi, Mamprusi, Dagomba, and Gonja, were said to have come from the same parent stock and migrated to the area from Zamfara (Hausa banza bokwoi). According to Adu-Boahene (1968), they first settled in Mali and under the leadership of Tohajiye, also known as the ‘Red Hunter,’ they moved to Gambaga or the Nalerigu area where they formed the Mamprusi Kingdom. From Gambaga, the group was subdivided and some members of the ruling class moved to form the Mossi Kingdom of Yatenga; the Gonja moved south to form the Gonja state and Dagomba in the present day northern region of Ghana. Part of the ruling class who settled in the present day UER trace their ancestry to
Na Gbewaa, the powerful king of the Mossi Traditional Area. In the late 17th century and early 18th century, the area was part of the powerful Mossi States, which include the Dagomba in the South and the Mamprusi in the North. Although the region was influenced by the Asante Empire, it never became part of Asante. It is said that the Asantes formed a strategic alliance with the Mossi States for the purpose of controlling the Trans-Saharan Trade route, which passed through Bawku and Bolgatanga in the UER. Due to the political stability of the region, it became a refuge camp for people who escaped slave raiding by Samori and Babaturi in the 18th Century. Others’ historical accounts also talk about the nature of land fertility and drainage systems, which attracted many farming settlers. Nomads also migrated southward from Burkina Faso and Mali to the area during the dry season for grazing of the cattle and migrated North to avoid black fries during the rain season, hence the extreme population of the area. During the colonial period, the UER was referred to as the North Mamprusi.

Today, the UER covers a total land area of about 8,842 km², approximately 3.7% of the total land area of Ghana. It had a total population of roughly 1.15 million people in 1998, living in 911 communities with an annual growth rate of about 2.2%. The average population density of the UER is 125 people/km² in urban areas and 100 people/km² in rural areas, compared to Ghana’s average population density of 63/km². There are some studies showing that the population density of the Bawku municipal area is about 240 persons per kilometer (IFAD 2006). However, the UER is largely rural with 87.1% in 1984 and currently 84.3% of the region classified as rural (IFAD 2006). The population
was estimated to be growing at an annual rate of 2.6% in 1960, 3.0% in 1970, 3.0% in 1984, 2.2% in 1998, and currently 1.1% (Regional Coordinating Council 2008). Below is figure 4.13 showing the total population and density trends from 1960 to 1998. Figure 4.13 below shows that the total population of the UER rose from 415,000 in 1960 to 773,000 in 1984, representing an increase of about 86% in 24 years and then rose again from 773,000 in 1984 to about 1,015,000 in 1998, which is also an increase of 34% but decreased by about 0.93% per annum over the past 10 years to the current total population of 920,089. Although the annual growth rate seems to have slowed down, the population density per square kilometer is getting higher and higher, increasing from 47 to 61 people /km² over 10 years (1960-1970) and to 87 in 1984 and 114 /km², and that is a source of worry to many analysts as it exerts excessive pressure per km of land, hence land degradation. Figure 4.12 is a population distribution and density map of the UER. The map shows that the highest concentration of people is found in the north-eastern corner of the region centered around Bawku in the Bawku Municipal area and in the central portions of the region around Bolgatanga, the regional and Bolgatanga municipal area. There are two corridors of sparse population of North-South alignment. The first corridor is the Zebila-Zongairi, through Binaba, all in the Bawku West district. The second corridor is the western corridor, which covers the western half of the region, extending south from Kayoro and Paga through Sandema, Doningo to Wias in the south-west.
The population impact may be a major problem for more years to come, considering the fact that 47% of the total population is under 15 years, and women of childbearing ages, 15-49, constitute 24.9% of the region’s total population in 2000, as compared to 23% in 1984 (GSS 2001). The age and sex structure of the region’s population shows that there are more females than males. However, the sex structure varies by age. The proportion of male population aged 0-19 years is 56.3%, compared to females 49.0%. Between ages 20 and 64 years, females constitute 45.1%, which is higher than males at 36.8%, and the population 65 years and above have 6.8% of males compared to 5.9% of females. Among females within the reproductive age group of 15-49 years, there is an overall excess of 13.0% more females than males, and this means that the region’s population has the
momentum to grow over the next couple of years (GSS 2001). The propensity for the region’s population to grow further becomes more interesting if one factors in the fact that most people use family labor in their farms; they tend to favor more children. Additionally, religious affiliation is likely to increase the population of the region, considering the fact that 46.4% and 22.6% of the region’s population professes traditional and Islamic religions, respectively, and only 28.3% are Christians (Regional Coordinating Council 2008). In Ghana, people in Islamic and traditional religions tend to have more children compared to Christians.

Figure 4.14: Total Population and Changing Density (1960-2008)
The region is inhabited by seven major ethnic groups, including Mole Dagbon people (74.5%), Grusi (8.5%), Mande-Busanga (6.2%), and Gurma (3.2%). In addition to these 7 major ethnic groups, there are several minor ones such the Bimoba who constitute 2.8% of the region’s population, the Busanga 5.9%, the Kusasi, and the Mamprusis. Others include the Dargarte, the Dagombas, and the Vagala people. The population who are Ghanaians by birth or parenthood make up 92.5%, those by naturalization constitute 5.3%, and the remaining 2.2% are non-Ghanaians, mainly settlers from neighboring West African countries. Major languages spoken in the region include Gurune, Kusal, Kasem, Buili, and Bisa (Ghana Health Services 2008).

The UER is believed to be the least urbanized region in Ghana, with about 15.7% of its population living in urban centers and the remaining 84.3% living in rural areas. Urban centers in Ghana, by definition, have a population of 10,000 or more. Two districts in the UER, the Bolgatanga Municipal area and the Bawku Municipal, have the levels of urbanization comparable to most urbanized regions of Ghana. The Builsa, Bongo, and Garu-Tempane Districts are the least urbanized. The region had only seven urban centers in 1999. The largest urban population concentration is in the Bawku Municipal, about 43.7%, followed by 34.1% in Bolgatanga, 16.5% in Kassena-Nankana, and 5.6% in Bawku West (Dietz and Millar 1999).

One of the most important population characteristics that impacts economic development and natural resources is population redistribution. Population redistribution is generally
determined by migration; however, in spatio-political analysis, government policy such as regional demarcations and redistricting becomes a vital factor. By analyzing population distribution by districts in the UER, it is highly impossible to ignore recent government policy to redistrict the region into 9, instead of 6, districts. For example, former Bawku East had about 43.7% of its population in urban centers, with the new demarcation; Bawku Municipal is expected to be about 80% urban, while the Bolgatanga Municipal Area is close to 100% urban, up 65.9% since the redistricting in 2007.

Although policies such as regional and district demarcations are important, their impacts are more political than spatial. Conversely, migration plays an important role in relocating people spatially and, as such, is vital for ecological analysis and planning purposes. The current population distribution of the UER may have been affected in one way or another by migration. Unfortunately, lack of up-to-date vital statistics precludes any serious migration analysis in the region and has limited this analysis to more description of migration patterns. This notwithstanding, the recent population census of Ghana acquired some limited information on residents in terms of place of birth and migration status. Our field study also gathered some information on migration trends, which are presented below.

The census data was collected to compare locality of birth with locality of enumeration. In the analysis, it was observed that the data contained statistics on return migrants, that is, some people who were born in the locality of enumeration but may have returned after
years of migration. The difficulty in data classification is whether return migrants are classified as immigrants or not. The general trend of migration in the UER is that some people are born in the region; migrate to other regions for such purposes as education, work, marriage, and culture. However, upon retirement, or say divorce, or better still on seasonal basis, they return home. Such people, return migrants, on the basis of comparing migration with place of birth cannot be said to have never migrated because he or she was counted at the birthplace. Most analysts believe comparing locality of birth with locality of enumeration is only a crude measure of migration and gives little information. The enumeration statistics shows that in all districts of the UER, the population enumerated in their locality of birth falls between 86.7% in Bolgatanga and 93.6% in Bawku West. This means that the UER has 6 to 13% migrants.

Migration patterns observed in the UER show that the Bolgatanga Municipal Area, the regional capital, receives the highest proportion of Ghanaian migrants, about 37.2%. The second most popular destination is the Bawku Municipal Area, which attracts about 23.9% of the region’s migrant population. The rest include Kassena-Nankana (16.0%), Bongo (10.3%), Builsa (6.5%), and Bawku West (6.1%). It is important to note that 90% of all migrants to the region are Ghanaian-born, with the exception of the Bongo District. The district with the least foreign migrants is Builsa. Kassena-Nankana, Bongo, Bolgatanga, and Bawku Municipal Areas have significant foreign immigrants, mainly because these districts share common borders with neighboring West African countries such as Burkina Faso and Togo, which facilitates easy border crossing and trading.
The Northern and Upper West are the neighboring regions in the South and West, respectively. However, the adjacency of the two regions has no significant attraction on migrants into the region. Available data shows that 69.4% of migrants to the region come from southern Ghana. The Ashanti region accounts for the bulk of migration to the UER contributing 32.6%, while the two neighboring Northern and Upper West regions combine to constitute 22.7%. Most migrants from the Ashanti, Northern and Upper West regions mostly settle in three main districts: the Bawku Municipal, Bolgatanga Municipal, and the Kassena-Nankana district. Migrants’ preference for the Bolgatanga Municipal Area is because the district contains the regional capital where white-collar jobs are found. It is also a nodal town where wholesale and retail trade activities are concentrated. Legal and illegal small-scale gold mining, “galamsey” activities, have also attracted migrants into the district. Bawku, on the other hand, is an ancient trading town and also serves as the main entry point to Ghana from northern Togo and southern Burkina Faso. Bawku’s strategic location facilitates trade across the Ghana border into both Togo and Burkina Faso. The Bawku Municipal Area is also noted for onion production, which many southerners buy and sell in the southern parts of the country. In the case of Kassena-Nankana, the district attracts migrants due to constellation of several institutions of higher learning found in the area. These include world-renowned Health Research Centre, University of Development Studies, and the flourishing irrigation project at Tono, which attracts migrants with the requisite technical expertise (Dietz and Millar 1999).
4.4 Economic characteristics

Farming is the main occupation in the region. The sectoral contributions to the regional economy in order of magnitude are agriculture and related work (65.9%), production and transport equipment (14.5%), sales (9.5%), services (3.9%), and professional, technical, and related work (3.8%) (Regional Coordinating Council 2005). The regional economy classified in terms of occupational structure consists of agriculture (66.4%), mainly small-scale holder farmers who farm an average size of 3 hectares, employing 2 out of every 3 people. Generally, the region lacks a formal sector. About 1.7% of the region’s labor force is engaged in administrative, managerial, clerical, and related works. The gender division of labor is also an important phenomenon in the regional economy. There is twice as much female representation in sales as opposed to males. The proportion of females in sales work is 13.3% and males is 5.8%. Agriculture is male-dominated work, with males constituting 71.8% of agricultural labor compared to 61.2% of females (Regional Coordinating Council 2005).

The undue rurality of the UER coupled with over-reliance on rain-fed, low technology and subsistence agriculture largely accounts for the extreme poverty of the region. According to the International Food Policy and Research Institute (IFPRI) (2007), 9 out of every 10 people in the region live on less than a dollar a day (IFPRI-Ghana 2007). In terms of both incidence and depth of poverty, the UER is said to be among the poorest, if not the poorest, of the country. IFAD (2006) observed that while the average poverty
decreased in most parts of Ghana, in the 70s and 80s, the UER saw an increase in poverty.

4.5 Farming Systems and Agricultural Practices

Farming, particularly crop farming, is the main activity in the UER. The 1984 and 2000 censuses show that 80% and 82%, respectively, of the population of the region consider farming as their primary source of livelihood, and the remaining 20% and 18%, respectively, consider farming a very important secondary activity (Dietz and Millar 1999). The difficult agro-ecological conditions of the area make farming an odious and risky activity; however, farmers tend to be adaptive, focused on survival and risk minimization by cultivating multiple plots, mixed crops, quick maturing crops, and disease resistant crops (Dietz and Millar 1999). Among 60 farmers interviewed for this study, the minimum number of farm plots cultivated per person is 2 and the maximum is 5, with an average plot size of 3-5 hectares. Among reasons cited for multiple plots cultivation are unavailability of large plots, risk of crop failure and pests, low soil fertility, and rainfall pattern. Crops cultivated are local climate adapted, due to unreliable rainfall and frequent drought. Farmers use low and simple, but locally adapted technologies such as locally produced hoes, cutlasses, and sickles. There are few wealthy and large-scale farmers using oxen-driven ploughs, bullock ploughs, donkeys, tractors, and other community pool farming implements.
The common feature of the farming systems of the area include the tendency and orientation towards subsistent and low cash income farming, including compound farming and market gardening in urban areas of Bawku Municipal and Bolgatanga Municipal areas. There are also few large scale and capital intensive farming systems in the area, including irrigated farming in Pawlugu. Mixed farming of crops and livestock is also a common feature of farming in the UER. On the average, every farmer has 34 livestock, according to our field study. However, the reliability of this figure is questionable, and according to some district MoFA officials interviewed for this study, farmers hardly disclose the exact number livestock they have due to the fear that the statistics would be used for taxation purposes.

Most farmers adopt continuous cropping systems where a piece of land is cultivated yearly due to high population and land scarcity. However, there is a sizable proposition of farmers practicing farm rotation systems with a fallow period of 2-3 years. Recounting their experience in the area, some farmers said that 10-20 years ago, one could abandon a piece of land for 7-10 years before returning to that same piece of land for farming. Nowadays land has become scarce, and so they farm the same piece continuously, which has affected the fertility and crop production.

Ofori-Sarpong (1998) talked about the low level use of external farming inputs, such as chemical fertilizers, insecticides, and pesticides. For this study, 75% of farmers interviewed said they use fire to clear the agricultural residue after harvesting and also
clear land for cultivation in order to return the burnt ash into the soil to refertilize the land. Others use household refuse for composting to refertilize the land, while some use animal droppings, including cattle dung as fertilizers. There are some local farmers using chemical fertilizers, weedicides, pesticides, and insecticides; however, there are no records on them, mainly because they are used on a small scale. Also, these agricultural inputs are sold in the open market by petty traders, while both subsistent and large scale farmers purchase and apply them on their farm at their own discretion with no records. 

Farm labor is mostly provided by members of the household. The household, by definition, is a group of persons living together as one unit and sharing farming and housekeeping arrangements (Dietz and Millar 1999). There is occasional non-household labor provided by a married first son who does not live there and shares housekeeping arrangements, but sees providing that occasional farm labor as a responsibility to the extended family. There is also one type of farm labor known locally as ‘noboa.’ In this concept, some members of the community agree to provide farm labor in turn. There is also the hired day labor provided by the youth, in which a person is hired to provide farm labor on a daily basis, usually 4-5 hours a day, and get paid by the standard daily wage rate set in the community.

Agreeably, the greater part of agricultural labor in the UER is provided by family labor consisting of father, mother, and children, with the average family size of 7 children among respondents of this research. Men in the family are mostly responsible for tilling the land, but women are involved in almost every aspect of the farming practices,
including marketing of farm produce. However, the sustainability of family labor has recently come under question. In this study, 80% of respondents have at least two members in the family that have migrated to other parts of Ghana, usually to the cocoa farming regions of the Ashanti, Brong Ahafo, and Western regions of Ghana. Others migrate to big cities like Tamale, Kumasi, and Accra in order of popularity in terms of migration destination among respondents. What is fascinating is the fact that migrants who go to cities tend to remit during farming season to their parents to help them hire paid day work labor, while those migrating to cocoa growing areas return home to help their parents during land clearing and planting. Typically, migrants who go to cocoa growing areas return home yearly and more frequently than urban migrants. These notwithstanding, 32% of our respondents said migration has affected their farming practice and have therefore responded by reducing the number of plots farmed annually. Similarly, 36% of the respondents have resorted to hiring labor to maintain their farms, while the remaining 32% said they have not been affected by migration either because the migrating family members remit to assist hiring or return during land preparation and planting to assist. The future of family labor in relation to agricultural development in the UER appears unsustainable and appears threatened by migration.

4.6 The land tenure practices of the UER

Land ownership and access to land is vested in the community and one’s position in the community by customs and the constitutional law of Ghana. However, land
administration is by and large done according to customary laws and practices. In metropolitan areas like the Bawku Municipal area and the Bolgatanga Municipal Area, the department of town and country planning plays an important role, though in consonance with customary laws. Traditionally, land is held in trust for the natives of the land by the Tindana; the Tindana is the spiritual and traditional leader who grants user rights to individual families in the community, which means every family has a portion or portions of the land that the Tindana has awarded them user rights. Tindana occupies a position, which according to Ofori-Sarpong (1998) is of significance in religious, political, and land matters within the area of his authority. He performs adjudication and arbitration on issues involving community and individuals. The Tindana of a given area is a system of heritage through the patrilineal descent of the original family to have settled the area. It is passed on from father to the male heir, usually the first son.

4.7 Conclusion

Throughout history, availability of water and fertile soils has been the main resource for development of human civilization and urbanization. Civilization is said to have started from the banks of Tigris and Euphrates. The bio-physical conditions of the UER, including availability of water and relatively fertile soils, have been the main reason for the emergence of strong and powerful Mossi-Dagomba states that provided safe heavens for people escaping slave raiding during the 16th and 17th century slave raiding and nation wars. These powerful nation states created population and market centers that have existed till today. The ever growing populations on limited land and years of modern day
neglect, unequal economic development, and exploitative policies have contributed to the land degradation, poverty, and civil unrest plaguing the UER today.

UER is now becoming the Sahara desert of Ghana, with traditional horsetail grasses replaced by low, dense, quick maturing but highly flammable and less quality grasses. The region is regarded as the worst affected region by the desertification menace. Some efforts are being made, with support from multinational organizations like Friends of the Earth, IFAD, and DENIDA, the results have not been too encouraging. The future of addressing land degradation in the UER hinges on a carefully crafted integrated approach that addresses the issues of population, agricultural development, poverty, and ecological nexuses using a community participation approach involving the Tindana’s Association, local residents, and all other stakeholders.
CHAPTER 5.0: MULTI-SPATIAL AND MULTI-TEMPORAL APPROACH FOR DETECTING AND QUANTIFYING DESERTIFICATION IN THE UER

5.1 Africa Biome

With a total land area of 30,330,000 sq km (approximately 11,699,000 sq mi), including its satellite islands, Africa is the second largest continent in the world. The size of the African continent is often overlooked and underestimated. Interestingly the continent is said to be larger than the combined size of China (9.6 million km²), the USA (9.4 million km²), Western Europe (4.9 million km²), India (3.2 million km²), Argentina (2.8 million km²), and the three Scandinavian countries and British Isles (The Times Atllass 2009). Figure 5.0 shows the African continent and its shape and size in relation to other countries as described by The Times Atllass.

The continent has roughly 22% of the world's total land area and about 20% of its population. It stretches 8050km (4970 mi) from its northernmost point, Ra's al Abya in Tunisia across the equator to Cape Agulhas in South Africa, the southernmost end. At the widest point, the continent measures 7560km (about 4700mi) from the tip of Cape Vert in Senegal, in the West, to Raas Xaafuun (Ras Hafun) in Somalia, in the East. In terms of elevation, the continent peaks at Mt Kilimanjaro, an approximate height of 5895m (19,
340ft) above sea level in Tanzania and measures 153m (502ft) below sea level at the lowest point in Lake 'Asal in Djibouti. Africa has a regular coastline characterized by few indentations.

Figure 5.0: The Approximate size of the African continent (The Times Atlas)

The continent is commonly divided along the lines of biome types, and the common divisions include biomes dominated by desert, such as the Sahara Desert, the Namib
Desert, and the Kalahari Desert. The Sahara Desert is said to be the world's largest desert. It cuts a swath through the northern half of the continent from the west coast to the east coast. The Namib and Kalahari Deserts are found in the southern part of the continent, precisely in Namibia and South Africa. Desert regions on the African continent are shown in red on the biome map of Africa, shown by figure 5.1. It covers the entire Sahara, stretching from the northwestern coast of Africa from the coast of Mauritania and Morocco through Libya, Tunisia, and Egypt across the Red Sea to the Arabian Peninsula. Offshoot of the Sahara desert is also found along the horn of Africa, precisely in Eritrea and Ethiopia.
The Namib and Kalahari Deserts are shown in red color along the west coasts of Namibia and the Republic of South Africa.

Mountain vegetation zone occurs around high mountain areas of Cameroon, Angola, Eastern Africa, and parts of Ethiopia. They are found in areas with average annual rainfall only slightly below 1250mm per annum. Mountain vegetation zones are covered
by shrubs, which gives way to oil palms, hardwood trees, and primitive conifers towards lower elevations. On the biome map of Africa, mountain vegetation is commonly found around the Ethiopian highlands of Ethiopia, Mt. Cameroon in Cameroon, the mid-slopes of Mount Kilimanjaro in Tanzania, Mt. Kenya and Aberdare in Kenya.

The forest belt occurs south of the Savanna belt, north and south of the equator. The forest biome of Africa is divided into three subtypes of decreasing richness and diversity mainly due to rainfall variations. These subtypes include the tropical rain forest; tropical, moist, deciduous forest; and the tropical dry forest. The tropical dry forest and tropical, moist, deciduous forest form a transitional zone from the Savanna to the tropical rainforest. The tropical rainforest subtype occurs where the average annual rainfall is 1270 mm and above. It has a dense surface cover of shrubs, ferns, and mosses, above which tower evergreens, oil palms, and numerous species of tropical hardwood trees. The tropical rain forest, which forms part of the world’s 34 biodiversity hotspots with extremely high concentration of endemic species and a high risk of habitat loss, is found in the Congo basin parts of Central Africa and the coast of West Africa (Holmgren and Poorter 2007; Mittermeier et al. 2004).

The West African portions of the forest belt extend eastwards along the coast from the coast of Senegal and stop at Togo where it shares a border with the Dahomey Gap, a woodland savanna in Togo and Benin, which extends from the north to the Gulf of Guinea (White 1983). The gap separates the West African forest from the rest of the
African rain forests in East and Central Africa. About 22% of the 2800 vascular plant species of the Upper Guinean forests are restricted to this region (Jongkind 2004). Understanding the distribution patterns of endemic forest species provides important insights into the underlying processes explaining deforestation, land degradation, and desertification.

The largest biome of the continent is the African Savanna. In the northern end of the savanna, it borders the Sahara Desert, stretches south to the forest belt of West Africa and is found between the Congo forest of Central Africa and the deserts of Southern Africa, the Namib and Kalahari Deserts. The African savanna is also divided into three subtypes of decreasing richness, mainly due to annual total rainfall and rainfall distribution. The savanna woodland zone, with a relatively higher annual rainfall of 890 to 1400 mm, covers vast areas with a continuous layer of grass cover and fire-resistant shrubs interspersed with deciduous and leguminous fire-resistant trees. Generally, the threat of desertification in this zone is low. The second savanna subtype is the savanna grassland zone, which experiences an annual rainfall of between 500 and 890 mm per annum. The subzone is covered by low grasses, shrubs, and scattered trees and experiences medium levels of desertification threats. The final savanna subtype is the thornbush zone, which forms typical steppe vegetation, with an annual rainfall ranging between 300 and 510 mm. The subzone usually has a thinner grass covering and more scattered succulent or semi-succulent trees, such as cacti and Baobab, and are the most threatened zone by desertification. Below is figure 5.3 showing the top 8 environmental problems of the
African continent and the number of countries threatened by these environmental problems. The y-axis of figure 5.2 shows various environmental problems and the x-axis shows the number of countries under threat.

Figure 5.2: Important environmental issues in Africa and number of countries under threat

The figure separates soil erosion and desertification mainly because desertification occurs in arid, semi-arid, and dry subhumid areas only, while soil erosion occur in all biomes,
including forest belts, deserts, humid, dry-subhumid, arid, and semi-arid regions. In general, the African Savanna is the biome worst affected by desertification, which currently threatens 18 countries excluding existing deserted areas (UNEP 2005). Desertification does not occur in existing desert regions, hence the exclusion of already deserted countries, such as Libya and other Sahara Desert countries.

Within the savanna zone is the Sahel region of Africa, a region that has become a global laboratory for experimentation in an effort to expand the frontiers of knowledge on climate change and land degradation. This is mainly due to the region’s known environmental calamity, which has created a humanitarian crisis and thousands of ecological refugees, primarily due to long periods of drought, food shortages, and desertification. According to UNEP, the drought in the Sahelian region began in 1968 and has since led to the deaths of between 100,000 and 250,000 people, while disrupting millions of lives and families and the total collapse of the agricultural bases of five countries (UNEP 2005).

From 1977-1985, several publications emerged in the scientific and peer-review journals, sounding the alarm of emerging human catastrophe in the Sahel due to desertification. However, in the late 1980s and early 1990s, a reversing trend was seen with most publications announcing the miracle of the greening of the Sahel. Many of these studies used a satellite-based vegetation index, which indicates that greenness, measured in terms of NDVI, is increasing in the Sahel region of Africa. Some of these studies include Diouf
and Lambin (2001) in Senegal, Rasmussen et al (2001) in Burkina Faso, and Tucker et al (1991), Nicholson et al (1998), and Prince (1998) in the Sahel region of West Africa. The general conclusion based on NDVI analysis was that desertification was either decreasing or was a phenomenon of greenness variability linked to inter-intra-annual and inter-decadal variability in rainfall. NDVI time-series shows a wave-like trend of rise and fall coinciding with inter- and intra-annual and inter-decadal rainfall irregularities. Practically, vegetations wither during drought years or years of below average rainfall and recover when rainfall returns to normalcy. Whereas we do not doubt the findings of these studies, we think that computing NDVI over such a vast landscape tends to over-generalize the degree of greenness and can potentially give false impressions about the extent of desertification in the region.

Secondly, causes of desertification identified in the Sahel region, such as human overexploitation, overgrazing, overcultivation, and the overcutting of trees, operate on a local scale and therefore become difficult to analyze over such a large region as Sahel. Also, the Sahel region stretches across countries with different agricultural practices and policies, with different environmental policies and institutions implementing them. Furthermore, data availability, data currency, and accuracy from different countries across the Sahelian region makes it difficult to analyze desertification and its dynamics over the entire Sahelian region. In this part of the study, we analyze satellite-based NDVI trends from 1982-2007 over the African region, the Sahel region, and the UER, Ghana to
compare multi-spatial NDVI dynamics portrayed by the NDVI trend in an effort to understand desertification dynamics spatio-temporally.

5.2.1 NDVI as desertification indicator on the African Continent

Vegetation greeness measured in terms of NDVI on the African continent has a linear relationship with the seasonal changes of the year. Greater parts of the African continent, particularly sub-Sahara Africa which stretches from the southern borders of the Sahara Desert to the northern borders of South Africa and Namibia due to its tropical location and near constant temperature, have their seasons generally determined by rainfall. As such, there are two main seasons, the rainy season and the dry season. During the rain season (northern summer), when the sun is in the northern hemisphere, the ITCZ moves north of the equator to create a low pressure belt, which brings the African monsoon winds to the northern parts of the continent. This is the period from March 21st to September 23rd, hence NDVI increases in the northern parts of the continent from March to September to show a northern summer, the rainy season (see figure 5.4 below). Conversely, the sun apparently relocates to the southern half of the continent from October to February, which relocates the ITCZ to the southern half of the continent to attract moisture-loaded winds to create a rainy season in this part of the continent. For this reason, seasonal NDVI from the African continent shows two peaks, March-September for the northern summer, also the rain season in the North, and October-February for the southern summer, which is also the rain season in the South as shown on
Figure 5.3 below. On figure 5.3, the y-axis indicates mean monthly NDVI values from 1982 to 2007 and the x-axis indicates months of the year, from January to December.
Figure 5.4: Mean Seasonal NDVI of Africa and the Sahel region (1982-2007)

Figure 5.4 shows that the mean monthly NDVI (1982-2007) for southern Africa peaks around 0.46 in March as compared to the northern Sahel NDVI, which peaks around 0.44 in June, given a decrease of a percentage point. Figure 5.4 compares NDVI for the Sahel region, which lies in the northern part of Africa with NDVI for the entire African continent. The Sahel NDVI rises gradually from April, reaches its maximum in August/September, then dips a little in October before finally declining in November/December. On the other hand, the African NDVI shows a gradual rise from December to peak in February, which is a depiction of a southern summer, which then falls in March and rises again in April to October/November to coincide and depict the
northern summer. The seasonal NDVI differences between northern and southern Africa are shown on the NDVI map, figure 5.5 below. The mean monthly NDVI for the African region also shows greenness disparity between the northern and southern halves of the African continent.

Figure 5.5: NDVI Map of Africa 2002
Figure 5.6 below shows the mean maximum annual NDVI trend for Africa between 1982 and 2007.

naturally and lasts over a short-term (1±2 years) when precipitation is significantly below normal recorded levels. It is also referred to as the inter-annual rainfall variability, a common phenomenon on the African continent. Generally, ecosystems wither during periods of drought to conserve available water, as a means of survival, hence the absence of green leaves, which is indicated by decreased NDVI, but vegetation recovers rapidly after the rain returns, hence increased NDVI trend. The 8-year period from 1997-2005 of NDVI trend shows continuously low NDVI trend, suggesting a period of desiccation. Darkoh (1998) describes desiccation as a period of extended drought lasting up to a decade. Usually, we talk of desiccation when drought extends between three and ten years, as in the case of the period spanning 1997-2005.

It is, however, important to caution that on a continent as large as Africa, desiccation may be a sub-regional or some stochastic local phenomena but can have impact (regional and sub-regional effect) on the general NDVI trend of the entire continent. The NDVI trend from 1982-2007 from the African continent shows no evidence of desertification. Desertification manifests itself in the form of progressive reduction of NDVI over a period of no less than 15 years. Also, NDVI can be rising and falling at the same time, yet be below the general average of the period under investigation, which is evidence of desertification. However, there is also no strong evidence to negate the fact that desertification can be taking place in some parts of the continent. The NDVI analysis of the African continent includes regions of tropical rainforest and desert land where desertification is practically impossible.
The general conclusion from observing NDVI trend on the African continent is that NDVI shows the expected inter-annual and inter-decadal variations from 1982-1997, followed by 8 years of decline, signifying desiccation from 1997-2005. However, there is evidence of recovery since 2005 from the observed desiccation from 2005-2007. Whereas we can not conclude desertification for the entire African continent, we can isolate some regions within the dry sub-humid, arid, and semi-arid regions where desertification is possible. In the next paragraph, we will take a critical look at the Sahel region to determine if there are possible signs of desertification from 1982-2007.

5.2.2 NDVI and desertification in the Sahel Africa

In refocusing our discussions on desertification, we analyze NDVI of the Sahel region of Africa, where the likelihood of land degradation is higher. In order to be consistent with other earlier studies, we define Sahel, similar to Tucker et al (1991), as the region between latitude 10° N and 25° N and longitude 16° W and 39° E.

Figure 5.7: NDVI Sahel Africa 2001
Characteristically, the Sahel region falls within the arid, semi-arid, and the dry subhumid regions north of the equator where desertification normally occurs. In the southern parts of the Sahel region (around latitude 10° N), annual rainfall is as high as 1100mm. However, in the extreme North, the annual rainfall can be as low as 300mm. Rainfall duration ranges from 5 months in the South to as low as 3 months in a year in the North. It is also characterized by torrential rains and flash flooding.

The NDVI of the Sahel region is no different from the rest of the continent; it coincides with the rainy season that peaks in September. The NDVI rises from May to September and declines sharply in October, until it reaches the minimum in March. The seasonal trend of NDVI for the Sahel region computed over a period of 26 years (1982-2007) is shown on figure 5.8 below.

![Figure 5.8: Mean Monthly (seasonal) NDVI for Sahel of Africa](image-url)
This shows that the Sahel region has a single rainfall maximum (monomodal rainy season), which lasts for a few (about 5) months, from April/May to September/October and a long dry season from October/November to March/April, depending on the latitudinal location.

The mean maximum NDVI for the Sahel region shows unique and interesting characteristics worth analyzing. Studies conducted in the region over the 1980s and early 1990s sang the praises of Sahel greening; however, the same NDVI studied from 1982-2007 shows that the Sahel greening was subjected to temporary irregularities. The period 1982-1990 saw NDVI rising and falling, portraying (responding to) the inter-annual rainfall irregularities of the region, though generally on the rising side.
Figure 5.10: Mean Annual Mean NDVI for Sahel (1982-2007)

Figure 5.11: Mean Spatial Pattern of Land Degradation
However, the period 1990-1994 saw 4 years of continuous decline in NDVI below average, showing a decrease of about 5.4%, which signifies a period of desiccation. 1995-2001 saw NDVI recovering above average, with the highest mean maximum annual NDVI in 1997 and the highest annual mean NDVI in 2001. This is followed by another five years of falling NDVI below the period average 2002-2006. Generally, NDVI in the Sahel region has been on the positive side, showing an average increase of 2.66% over the 26-year period from 1982-2007, with 1982 as the base year.

5.2.3 Temporal variability of NDVI for Desertification in the UER

By definition, the UER forms part of the Sahel region, located between latitude 10.40 N and 11.5 N and longitude 1.36 W and 0.09 E. It falls within the dry sub-humid portions of the Sahel with an annual rainfall of about 1100 mm. The normal trend of NDVI in the UER shows a gradual rise from April, peaks in September and declines gradually from late October and reaches its minimum in February. Below is figure 5.12 showing the normal NDVI trend in the UER. This is similar to the normal trend of NDVI in the Sahel West Africa above.
However, in abnormal years, which would simply be interpreted as drought years where the annual mean rainfall falls below average, the NDVI trend would look different, corresponding to the timing of the rain in the locality of interest.

Twenty-six years mean NDVI, composed of a 15-day average composite from 1982 to 2007 and plotted to time-series NDVI for the UER is presented below. Figure 5.13 below is the mean NDVI map for 2001, covering the UER.
The NDVI, showing surface greenness of the UER, indicates that greenness in the region has increased steadily, after starting lows of what appears to be drought years of 1982, 1983, and 1984. Generally, the NDVI trend shows that the mean NDVI is increasingly steadily from 1982-2007. It also shows the regular cycle of NDVI fluctuations linked to rainfall anomalies associated with the study area. From the period 1982 to 2007, vegetation greenness measured in terms of mean NDVI rose steadily from an annual mean of about 0.37 in 1982 (the base year) to about 0.45 in 2007, the end year. This indicates a positive NDVI change of about 21.6% over a period of 26 years. On average, the NDVI has increased by about 6.7% from 1982-2007.
As expected, the NDVI of the UER also shows a similar rise and fall trend as in the Sahel region NDVI, of which the UER forms a part. However, there are some important differences between the NDVI of the UER and the Sahel. First, NDVI has increased by a higher percentage point in the UER with an average of 6.7%, against the Sahel average of 2.6% over the 26-year study period.

Figure 5.14: Mean NDVI for the UER 1982-2007
Secondly, whereas the Sahel NDVI shows signs of desiccation from 1990-1994 and 2002-2006, the UER NDVI does not show any sign of desiccation or drought, suggesting that there are no signs of climate anomalies in the UER in those same years, with the exception of the starting years 1982-1984, which of course form the base years for comparison.
The NDVI trend of the UER confirms the general observations of previous studies that the Sahel region is getting greener and greener. What we cannot say is whether desertification had taken place prior to 1982, the base year for this study, in order to conclude that there is recovery. As far as we can ascertain from the NDVI observations (1982-2007), there are no indications of desertification; rather, there is a significant increase of surface greenness, averaging about 6.7%, a percentage point well above the Sahel region average of 2.6% and Africa average which saw a decrease of about -0.04%.

5.2.4 Spatial variability of NDVI for Desertification in the UER

Having extensively looked at the temporal dynamics of NDVI, this section looks at the spatial dynamics of NDVI in the UER. The focus of this section is to analyze how NDVI has changed over the surface over time. We analyze the pattern of NDVI changes by comparing three spatio-temporal ranges, expanding from 1982-1990, 1990-1999, and 1999-2007. Figure 5.16 shows a spatial pattern of NDVI changes.
Figure 5.16: Mean Spatial pattern of NDVI changes 1982-1990, 1990-1999, and 1999-2007

Figure 5.16 is the mean of mean changes for the designated periods. The figure is a depiction of losers and gainers, i.e. pixels that lost surface greenness and those that saw an increase in surface greenness over the reference period. From 1982 to 1990, an average of 41 pixels of 8km² which converts to 328 km² (37.4%) lost greenness measured in terms of NDVI in the UER. Conversely, land area of approximately 2064 km² (62.6% of land surface) gained or showed increase in surface greenness. The period 1990 to 1999 saw 102 pixels (816 km²) losing its surface greenness, while 197 pixels of 8km² (1576 km²) gained greenness. However, more land area lost surface greenness from 1990-1999.
than the period 1982-1990. Areas that lost vegetation are concentrated around the south-central portions of the study area. Compared to 1982-1990 and 1990-1999, the period 1999 to 2007 lost less vegetation. An average of 19 pixels (8 km²) equals 152 km² of lost vegetation, while 280 pixels, equivalent to 2240 km², gained vegetation.

Figure 5.16 shows which period had the highest gains and loses. Whereas 1999-2007 had the lowest number of pixels losing greenness, the period 1982-1990 had the highest gain in greenness; the period 1990-1999 had both the highest number of pixels losing greenness, and at the same time, the minimum gains in vegetation greenness.

Figure 5.17: Mean and Maximum spatial gains

The maximum gain for 1990-1999 was almost 48% of the maximum NDVI for 1987 and 2007, and the maximum gain for 1999-2007 is greater than the yearly mean NDVI recorded over the 26-year period. In general, surface greenness increased from 1982 to 2007, indicated by the positive mean gains for 1982-1990; 1990-1999; and 1999-2007, confirming the observation from the temporal NDVI trend that surface greenness, as depicted by the NDVI, shows greening of the UER from 1982-2007.
Figure 5.18: NDVI gainers and losers measured in percentages

Figure 5.19: Mean Spatial Pattern of Land cover change
The spatial pattern of gainers and losers show that more pixels in the eastern and central portions of the study area gained vegetation, while south western portions of the study area lost more vegetation from 1999-2007. The maximum NDVI gain per pixel is about 62.9%, while the maximum loss per pixel is -0.6%. The gains and losses per pixel, computed into percentages, are shown in figure 5.18 above. The overall mean gains and losses show that land degradation is not uniform in the UER, nor does it occur at the same rate. It is against this background that we conclude that land degradation is a function of land use, more likely the frequency and intensity than climate, although climate cannot be wholly exonerated.

5.3 NDVI for Desertification Analysis Using LTM5 for the UER

The accuracy of GIMMS’ NDVIg for monitoring surface greenness has been validated from several studies, including Tucker et al (2005), Hall et al (2006), Hu et al (2008), and Karlsen et al (2005). However, this study was interested in the differences in NDVI trend of medium and coarse resolution satellites. We therefore gathered LTM5 and ETM+ data with spatial resolution of 30m, compared to 8km by GIMMS NDVI. Within the limits set by available LTM5 data, we analyzed the NDVI trend from seven LTM5 and LETM+ scenes, specifically scenes captured in the months of October/November, in order to avoid phenological changes due to seasonal changes in NDVI. The results are summarized below.
LTM NDVI shows that the UER is generally sparsely vegetated with a few clusters of heavily vegetated areas and several exposed areas. Green vegetated areas are mostly found along river banks forming corridors. Some studies, including Dietz and Millar (1999) and the Regional Coordinating Council (2005), have indicated that areas along river banks are infested with black flies and onchocerciasis (river blindness) and therefore not favored for human usage. Also, the ever-greenness of vegetation along river banks makes it difficult to burn, compared to other areas that dry out completely and therefore become susceptible to annual burning. Below is the NDVI map of the UER from LTM5. Statistics computed from LTM5 and LTM+ images show that the average vegetation of the areas rose by about 103.4% between October 20, 1984 and October 30, 2002, using October 20, 1984 as the baseline, while on the average, NDVI increased by about 29.7%.

Figure 5.20: LTM5 Mean NDVI for the months of October/November in the UER (1984-2002)
Although temporal analysis of Landsat NDVI indicates rising trends, spatial analysis shows widespread pockets of degradation in the area. Change detection performed of LTM images of 1999 and 2002 show that degradation occurred between the two time periods in the eastern and central portions of the study area. It also shows urban expansion in the Balgatanga, Navorongo, and Paga areas. Below is a spatial change map of 1999-2002. The map shows areas of greening, indicated on the map by green, areas of no change between the two time periods indicated by white color, and areas of degradation indicated by brown color.
Although LTM NDVI equally shows greening, it shows more degradation of the area than the GIMMS NDVI. This difference in the spatial pattern of degradation raises the question of analytical scale. It therefore becomes pertinent for remote sensing NDVI based study of desertification to answer the question of scale, both temporal and spatial. Temporal analysis in highly variable areas such as the UER and Sahel region in general must be considered very important in drawing conclusions. Vegetation in this part of the earth is highly contingent on rainfall pattern. In the UER residential neighborhoods of urban centers turn into green fields during the rainy and agricultural growing seasons as most people convert their backyards into full fledged farms. However, backyards turn
into grazing and burnt fields during the post-harvest periods, hence the timing of data acquisition becomes very important and make the difference between green fields and degraded land. Furthermore, comparison between LTM NDVI, and AVHRR GIMMS NDVI underscores the need for high spatial resolution data for analyzing desertification in the UER. It is observed from the field study conducted, that the principal driver of land degradation in the UER is the use of fire for farming and other agricultural purposes. However, the average farm size in the region is 3-5 hectares, which coverts to 0.03 to 0.05 km\(^2\) whereas the AVHRR GIMMS data used is 8 km\(^2\); it is therefore not surprising that much of the degraded areas tends to be absorbed and averaged out in the broader picture to show much greener areas. On the other hand, finer resolution LTM and LETM+ data, 0.03km, which is about the average farm size in the UER, is able to depict pockets and clusters of degraded lands much better as shown on the figure below.

Figure 5.23: GIMMS and LETM+ NDVI Spatial Degradation Comparison
Figure 5.24: LTM+ and Google Earth Spatial Degradation Integrate
Some of the common reasons for land degradation include land extensification to marginal lands such as areas previously infested with black flies, which causes river blindness. Some MoFA officials interviewed in this study spoke of the recent eradication of black flies from some river valleys, making those areas suitable to cultivation and grazing. Increasing agricultural activities and urbanization have also played an important role in land degradation in the UER.

5.4 Desertification or Interannual Rainfall Variability

When Lampray (1975) published his study of desertification in Southern Sudan, it came under criticism for failing to understand the African Sahel environment. The study compared the vegetation map of 1958 with 1975 aerial photographs of the study area and further conducted field surveys to conclude that desertification advanced 90-100 km in 17 years. Lampray was criticized for taking a snapshot view of vegetation and desertification by looking at the nature and state of vegetation cover in 1958 and, comparing it to that of 1975, a static view of vegetation and desertification. The thesis of the criticism was that vegetation and desertification are not static. Vegetation changes from season to season and year to year. Similarly, desertification is a process and changes over time. In a region like Sahel Africa, the existence and state of vegetative cover is also subjected to inter-annual and inter-decadal variations due to rainfall pattern changes. It is, therefore, insufficient to use two dates to map desertification without knowing what happened in between those intervening years. Critics concluded that observed changes in the
vegetation boundaries may be due to inter-annual and inter-decadal rainfall variations and not desertification. In order to avoid this trap in this study of desertification in the UER, we hypothesized that the observed land degradation in the UER by local people could simply be land degradation arising from inter-annual and inter-decadal rainfall variability. Alternatively, land degradation in the area is real desertification arising from human activities. The hypothesis was analyzed in two ways, based on the understanding that climate irregularities, specifically rainfall, can affect land degradation in two ways: intra-annual and inter-annual/inter-decadal.

First, intra-annual rainfall variability refers to a rainfall pattern in one year, and here, the interest of this study is how vegetation greenness, measured in terms of NDVI, changes with the season within a year. The normal pattern of rainfall in the UER, as copiously described in different sections of this study, shows that the rainfall starts in April/May and ends in October/November, whereas the dry season begins in November/December and ends in March/April. In this portion of the study, we looked at the mean monthly rainfall over 26 years (1982-2007) and correlated that with the mean monthly NDVI over the same period. Figure 5.21 below shows the relationship between the mean monthly NDVI and the mean monthly rainfall in the UER (1982-2007).
The GIMMS NDVIg used for this study is a 15-day composite, giving every month two points to indicate the first and second 15 days of the month denoted by 1 and 2 respectively; however, the rainfall data is the average for the month. Figure 5.23 shows a strong linear relationship between the mean monthly NDVI and the mean monthly rainfall in the UER. NDVI rises from March, reaching the maximum in September when rainfall also attains its maximum. The monthly NDVI fluctuations are largely determined by monthly rainfall experience in the area. Desertification is a phenomenon that stretches in a continuum over years, as such, seasonal variations in NDVI do not say much about
Therefore, we should not confuse seasonality of NDVI with annual changes that can portray desertification. This is not to say seasonality of NDVI is not relevant; it is useful for monitoring vegetation health, and its cumulative effect translates into annual averages, which are useful for desertification studies.

Secondly, the study tested the correlation between the mean annual NDVI and the mean annual rainfall for Garu, UER. The null hypothesis tested in this study was stated thus: land degradation observed in the UER is more likely to be inter-annual and inter-decadal land cover change than desertification. The null hypothesis was to be rejected at a significant level of 0.05 of correlation and the results from the hypothesis testing are shown on table 5.0 below.

Table 5.0: Correlations between Mean Annual Rainfall (Garu, UER) and Mean annual NDVI (UER)

<table>
<thead>
<tr>
<th></th>
<th>Mean NDVI</th>
<th>Mean Rainfall Garu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean NDVI</td>
<td>Pearson Correlation</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>26.000</td>
</tr>
<tr>
<td>Mean Rainfall</td>
<td>Pearson Correlation</td>
<td>.492*</td>
</tr>
<tr>
<td>Garu</td>
<td>Sig. (2-tailed)</td>
<td>.017</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>23</td>
</tr>
</tbody>
</table>

* Correlation is significant at the 0.05 level (2-tailed).
The statistical testing is a two-tail test of correlation between the NDVI (X) variable and the rainfall at Garu (Y) variable. NDVI has 26 observations, while rainfall has 23 observations.

The Pearson Correlation tests the strength and direction of a linear relationship between the X and Y variables. In this study, the mean annual NDVI is the X variable and the mean annual rainfall measured at Garu is the Y variable. According to Cohen (1988), a correlation coefficient ranges between +1 and -1. A correlation coefficient of +1 indicates a perfect correlation, positive and negative respectively, +0.3 indicates a medium correlation and a correlation around +0.5 indicates a strong correlation. The Pearson Correlation coefficient for this study is 0.492, signifying a high correlation between the mean annual NDVI and the mean annual rainfall in the UER. Also, for the correlation to be significant enough to merit accepting or rejecting the hypothesis, the 2-tailed test significant level must be 0.05 or less. For this observation, the Pearson Correlation is 0.492, indicating a positive linear relationship. The level of significance at the 2-tailed level of significance test is 0.017, indicating that 98.3% of the time, NDVI in the UER is predicted by the mean annual rainfall at Garu. At a confidence level of 98.3%, the correlation is significant enough to merit the acceptance of the null hypothesis that the land degradation observed in the UER is a phenomenon linked to the inter-annual and inter-decadal land cover change, rather than desertification caused by annual rainfall variability in the area.
We conclude from the correlation analysis that the local perception of desertification is not supported by GIMMS NDVIg from 1982 to 2007. The GIMMS NDVIg data shows that fluctuations in vegetation greenness (measured by NDVI) are largely linked to inter-annual and inter-decadal rainfall variability, characteristics uniquely attributed to the Sahel region of Africa. The characteristics of rainfall were confirmed by local residents interviewed for this study. Describing the pattern of rainfall in the area, participants of this study stated that they have observed changes in rainfall pattern of the area, with rains starting late, that tended to be irregular and torrential. Similarly, NDVI data from the study area shows that every good rainy year in the region is followed by a slightly lower rainfall year, thereby making rainfall highly unreliable and unpredictable, which in turn dictates the NDVI regime observed in the study area, even though the NDVI is generally increasing.

5.5 Conclusion

“To date, although a great deal of data on land resources are available, it has not been possible to get a clear picture of the status of desertification at regional or national levels” (UNCCD 2000 in Veron et al 2006 pp. 1). This study provides a clearer picture of the status of desertification in the UER, taking inspirations from other studies including Lamprey (1975) and Prince et al (1998). Given that desertification is a matter of life and death to many residents of the UER and dryland regions of Africa, whose survival are tied to dryland vitality, it is imperative that scientists build consensus and collaborate to
provide accurate information and credible methodology for its assessment. Since the Stebbing’s pioneering work on desertification in 1935, several other works, providing different estimates using different methodologies have surfaced and have been critiqued in the literature. Notwithstanding the unfavorable reviews by some scholars in the field, these works have shaped and improved the direction of the discourse and contributed to the methodological development over the years. Two prominent studies that have received much attention and reviews in the literature and have also contributed tremendously to the current debate on desertification are by Lamprey (1975) in southern Sudan and by Prince et al (1998) in the Sahel region of Africa. These studies vary both in time and space, hinging on different perceptions which directed the methodological approach and conclusions, their points of divergence and convergence have proven to be the strength of many current desertification studies including this one.

Lamprey’s study was an attempt to quantify the rate of advancement of the Sahara desert by comparing the location of the southern margins of the Sahara desert at two different times; that is the 1958 margins according to a vegetation map produced by Harrison and Jackson in 1958; and the 1975 margins according to aerial and terrestrial surveys conducted by Lamprey (1975). He concluded that there was 90–100 km displacement of the margins of the Sahara desert in 17 years, meaning desert edges were encroaching at the rate of 5.5km per year. Although Lamprey’s approximation was criticized, it represented the then-ruling paradigm of desertification, which was regarded as an extension of existing deserts. This paradigm was said to be based on observations of
foresters like Stebbing (1935) and Aubreville (1949). Aubreville wrote that, these are real deserts that are being born today, under our eyes, in the regions where the annual rainfall is from 700 to 1500 mm (Aubreville 1949). From their perspective, desertification was regarded as human creation. It was seen as an irreversible state of land characterized by sand dunes, scarce open thorny vegetation (Veron et al 2006). One major flaw of this paradigm, and for that matter Lamprey’s conclusion, was that his approach ignored the fundamental role of climate variability. Later scholars, including Hellden (1991) and Tucker et al (1991), using field work and satellite remote sensing datasets, have shown that desert boundaries are very dynamic and fluctuate year after year in direct relationship with annual and perennial rainfall regimes. They have argued that desertification is a dynamic process which can be reversed over time.

Taking cues from criticisms against Lamprey (1975) and the overall call for practical, objective methodology based on indicators, Prince et al (1998) assessed the desertification status of the Sahel region by means of the rain use efficiency (RUE) and concluded that evidence from rain-use efficiencies does not indicate extensive Sahelian desertification. RUE was calculated as the ratio between annual above-ground primary production (the rate of aerial biomass accumulation by plants, ANPP) and annual precipitation. The main assumption of RUE, according to Veron et al (2006 pp.6), was that “different plant traits, favored by natural selection, and community structure (e.g. soil cover, plant biomass), account for the spatial variation in soils or climate leading to a convergence in the limiting resource use efficiency and that the departures from the
average RUE would, thus, constitute the result of human management”. Although the application of RUE in Australia (Holm et al 2003), South Africa (O’Connor et al 2001), and Senegal (Diouf and Lambin 2001) have yielded similar results, Hein and de Ridder (2006) have stated in their recent publication that incorrect understanding of the relationship between RUE and rainfall has led to a misinterpretation of the satellite record of desertification in the African Sahel. Also the Jornada Experimental Range at the Chihuahuan desert of New Mexico, USA has shown that desertification may not necessarily imply a reduction in ANPP, suggesting that RUE is a poor indicator.

On the basis of these studies and their numerous critics, this study was framed to advance knowledge on contentious issues such as static vs. dynamic, reversibility vs. irreversibility, spatial and temporal scales and more importantly the need for long term study. Some critical observations in going forward with this study was that Lamprey followed the then-prevailing static view, while Prince et al (1998) might have used only 9 years of data, although other scientist including Prince (2002), Nsiah-Gyabaah (1994), Veron et al (2006) have underscored the importance of long-term ecological data in desertification studies. Analysis of NDVI from GIMMS data shows that the NDVI from the Sahel region 1982-1990 projected a strong rising trend, however, the periods after 1990; more especially the period from 2001 to 2006 shows a disturbing declining trend. This reinforces the call for long–term analysis in order to make a very conclusive argument, which is one of the contributions of this dissertation.
Whereas long–term and continuous analysis is important, we also find that spatial patterns of degradation may contradict temporal patterns. The spatial pattern of degradation shows moderate to severe localized degradation areas of Senegal, southern Sudan, Niger, and Mali (see figure 5.11). We therefore concluded that although the general surfaces appearance is important, localized degradation tends to be overlooked, and this raises question of scale. Prince et al (2007) stated that one major problem with RUE is the difficulty of computing RUE over the entire Sahel region. Comparing AVHRR GIMMS NDVI of 8km resolution with LETM+ NDVI of 30m resolution, we observed widespread pockets of degradation in the LTM+ NDVI of the UER which were not captured in the GIMMS NDVI, hence spatial resolution of data changes land degradation dynamics observed in the analysis.

This dissertation concluded that Lamprey (1975) made a very important contribution to methodological development, however, he fell short in terms of viewing desertification as static and irreversible. Prince et al (1998) responded to the need for practical, objective methodology based on indicators, however, their study did not have long-term data and also did not account for localized land degradation, which creates localized impact on communities, regions, and countries. Future studies should therefore look into temporal and spatial scale differentials in impacts of desertification.
CHAPTER 6.0: LOCAL PERCEPTIONS AND OBSERVATIONS OF THE PROCESS OF DESERTIFICATION IN THE UER

6.1 Concern for satellite data and local perception of desertification

VIs, particularly the NDVI, have been used to monitor desertification through vegetation stress levels over time. Desertification phenomenon affects vegetation in several ways, including vegetation abundance, vegetation health, vegetation cover and/or canopy structure, vegetation diversity and growth. Negative trends in any of the above listed vegetation characteristics manifests in a reduction in NDVI values. Conversely, positive changes in NDVI values indicate healthy vegetation and recovery from stress arising from factors including desertification. Many studies using satellite data indicate that greenness is increasing in the Sahel region of Africa. In chapter five, we studied the NDVI trend from 1982-2007 of the UER. Invariably, the time series of GIMMS NDVI shows that greenness in the region is rising sturdily, re-enforcing the findings of other studies conducted in Africa and Sahel. By contrast LTM5 NDVI shows that, although there is a general trend of rising NDVI, there are localized degradations in the region. The findings from these numerous satellite data-based studies have credibility and have also gained worldwide acceptance, mainly due to the fact that satellites have wider spatial coverage than what the individual human eye can see. Also, that is what the data says and the data was captured with little human interference; hence, possibilities of errors are very minimal.
In this study, we sought to compare what satellite data shows about desertification trends in the study area with local observations, including what local people can remember or say about desertification in the area, since they settled in the area, and more importantly, since 1982. We further supported local perceptions with field observations from the visit to the study area and pictures we took during the field study. We are interested in convergence and divergence of evidence of desertification between satellite data and local observations. Some of the reasons why we did this study include the fact that satellite data dates back to 1972 only, but the people have lived in the area since the 12th century. Also, the idea that the area is experiencing desertification dates back to the late 1950s; and so convergence of what the people can recall, compared to what the satellites have observed, would be a more credible scientific work and would be considered valuable information on desertification in the study area.

Additionally, we pursue this research because satellite data, NDVI, usually gives a generalized view of vegetation in terms of greenness of the surface captured in the picture element (pixel) of a satellite. Consider the fact that the GIMMS’ NDVIg from AVHRR used for this study has a pixel size of 8km and the LTM5 has a pixel size of 30m resolution; we have a reason to argue that the pixel value of NDVI may vary between GIMMS NDVI and LTM5 NDVI and may not be a true reflection of vegetation on the ground. This is because one pixel includes multiple endmembers averaged over 8km of land area of different proportions, and it is computed into one digital number by multispectral AVHRR sensors. Similarly, LTM5 averages multiply endmembers of 30m
land surface into one digital number, showing greenness of the area. Comparing GIMMS’ NDVIg 8km pixel to the LTM5 30m pixel, one digital number of GIMMS’ NDVI would be represented by 266 pixels, meaning 266 different digital numbers represent 266 different pixels of 30m each. The phenomenon being described is shown by figure 6.1 and 6.2 below. Similarly, if we compare the GIMMS’ NDVIg and TM5 with the IKONOS 2 image of a 4m pixel, we get different pictures of vegetation on the ground. Within a land area of 8km, GIMMS’ NDVIg gives 1 digital number, whereas TM5 gives 266 digital numbers. IKONOS 2, on the other hand, gives 2000 pixels represented by 2000 digital numbers. Figure 6.1 shows three impressions of 8 km land area captured with an IKONOS 2 sensor at a spatial resolution of 4m, about 2000 pixels. The left upper corner image shows an unclassified IKONOS 2 image combining bands 2,4, and 1, for red, green, and blue, respectively. The upper right corner image, on the other hand, shows an IKONOS 2 NDVI, using band combinations of band4 and band3 for near infrared (NIR) and Red, respectively. Similarly, the lower left image is a classified image of the same IKONOS 2 image scene, classified into 10 different land cover types, ranging from healthy green vegetation, shown by green, burn scars by red, bare surface by magenta, and fallow farm lands by yellow. Other cover types identified in the classified IKONOS 2 scene are shown in figure 6.1; the lower left includes coral for open farmlands, sea green for towns and paved surfaces, blue for lower grass, and purple for water bodies, which are mostly contaminated. The last IKONOS 2 scene is shown on figure 6.1; the lower right is a false color image which gives different tones of reddish to vegetation of different levels of greenness. Essentially, figure 6.1 shows the spatial heterogeneity of the
study area and different ways that we can look at the same scene. However, when applying the concept of NDVI using GIMMS’ NDVIg of 8km spatial resolution, all green covers would be aggregated and averaged into one value, representing the abundance of greenness, which also describes the current state of vegetation. NDVI values range between -1 and 1, with -1 representing a non-vegetating (nongreen vegetation) surface, while 1 represents a completely covered surface with healthy green vegetation. Declining vegetations or non-healthy green vegetation covers move the number towards 0. This means that if a pixel has a NDVI value of 0.3, then the 8km land area has a low level cover of healthy green vegetation.

Figure 6.0: Spatial heterogeneity of the UER, captured by the IKONOS 2 Satellite
Unfortunately, multispectral sensor systems do not allow effective disaggregating of pixels to components, as do hyperspectral sensor systems. This has serious implications for studying vegetation and desertification, particularly in the Sahel West Africa and the UER, where land surface is heterogeneous due to the nature of landholding systems. Field data gathered for this study indicate that average farm size of a farmer in the Upper East Region is 3 hectares, which converts to 0.03 km²; this also means that 1 AVHRR GIMMS NDVIg pixel of 8km² is equivalent to 800 hectares, representing approximately 267 farm lands in the Upper East Region. This makes it extremely difficult for satellite data of such a low spatial resolution to differentiate between degraded farmlands, fallow lands, grasslands, and protected forests on a single farm plot.

Another concern stems from a study of desertification in the Chihuahua desert, New Mexico. In this study, Huenneke et al (2002) observed the possibility of desertification
without a substantial decrease in NDVI. Similarly, other literature on the dynamics of Sahelian grasslands reveals substantial inter-annual variations in vegetation species’ composition, species’ cover and productivity mainly due to rainfall variations and frequency of fire (Breman & Cisse’ 1977; Penning de Vries & Djite’ye 1982; Breman & de Wit 1983; Le Houe’rou 1989, Breman & de Ridder 1991; He’rault & Hiernaux 2003), which affects NDVI in many different ways. Without disputing the potency of NDVI for desertification studies, we felt the need and scientific value of listening to the people who live with the problem (desertification) and also obtaining physical evidence for meaningful conclusions.

6.2 Local Perception of Desertification in the UER

The extent to which the narratives on land degradation, field observations, and literature of the nature of vegetation cover in the UER can be validated from satellite images becomes very important in arguing whether desertification is taking place in the study area or not. The study, therefore, focused on a well-informed audience with valuable information about land degradation in the study area. The field study was conducted from December 27, 2007 to February 9, 2008. Criteria for selection and qualification for inclusion in this study has been explained in chapter 3. In all, 60 local residents participated in this study. The spatial distribution of participants is shown in figure 6.2 below.
Participants came from 4 districts in the UER. These include Bawku West, the Bawku Municipal Area, Garu-Tempane, and the Bolgatanga Municipal Area. Each participant responded to the same set of questions read to him or her in his/her local language. The set of questions included both pre-coded and open-ended questions and open spaces where respondents could openly comment on related issues that were not addressed in the questionnaire.

Characteristically, the respondents to the study included 25% females and 75% males. The maximum age was 83 years, minimum age 25 years, and average age of 50.7 years. On the average, every farmer participating in the study had 4 different farm plots and an
average livestock of 34 herds, made up of cattle, sheep, and goats. The characteristics of respondents are summarized in table 6.0 below.

<table>
<thead>
<tr>
<th>Respondents</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total No. Respondents (farmers)</td>
<td>60</td>
</tr>
<tr>
<td>Maximum Age</td>
<td>83</td>
</tr>
<tr>
<td>Minimum Age</td>
<td>25</td>
</tr>
<tr>
<td>Average Age</td>
<td>50.7</td>
</tr>
<tr>
<td>Average Household Size</td>
<td>14.3</td>
</tr>
<tr>
<td>Average number migrated</td>
<td>4</td>
</tr>
<tr>
<td>Sex ratio (F:M)</td>
<td>1:4</td>
</tr>
<tr>
<td>Average number of farm plots</td>
<td>4</td>
</tr>
<tr>
<td>Average farm size (hectares)</td>
<td>3</td>
</tr>
<tr>
<td>Livestock per household</td>
<td>34</td>
</tr>
</tbody>
</table>

We analyzed the responses of these local residents (respondents) to the questionnaires administered during fieldwork between December 27, 2007 and February 9, 2008. The responses to questions and narrations given by participants were summarized and combined with other secondary information about land degradation in the UER into a model of land degradation referred to in this study as Continuous Cycle of Land Degradation (CCoLD). The model (framework) developed from this analysis describes the genesis of land degradation, the ease (rate) of progression, and the degree of difficulty
of reversing the degradation with time and agent (causal factors). CCoLD can be viewed in three axes: degradation momentum on the left, degradation factors or processes (causative factors) in the middle, and difficulty of recovery on the right axis. The CCoLD can be analyzed in stages, either based on the rate of degradation, the rate of recovery, and/or the state of vegetation cover. When the CCoLD is analyzed based on the rate of degradation, which is the left axis, it can be categorized into three stages: the very slow degradation stage, rapid degradation stage, and slow degradation stage. These stages are indicated on the CCoLD by the thickness of the degradation line. On the other hand, the CCoLD can be categorized into four stages based on the degree of recovery difficulty, indicated by the right axis. The four stages of recovery rate include rapid, high, medium, and slow recovery stages. Finally, we can analyze the CCoLD based on the state of the land cover. Under the state of the vegetation cover, we can identify about 5 stages beginning with climax savanna woodland, followed by stage two--the pro-climax vegetation. Stage three is the open savanna with mixed economic trees and other trees, followed by stage four, which is mainly an open savanna with economic trees and seasonal grasses and crops. Usually, trees constitute less than 10% on the vegetation cover at the fourth stage of the CCoLD. The last stage is the open land stage, in which the land surface has much reduced vegetation with widely scattered trees and environmentally efficient crop varieties.

The CCoLD, as described below, explains the land degradation process in the UER, which according to the respondents, dates back to the past 30 or more years as they have
observed, recollected, and have narrated. It is also important to state that, based on what
the local people say, desertification in the UER began before the genesis of multispectral
satellite remote sensing data collection about earth surface changes.

The CCoLD sees some parts of land degradation and recovery as natural cycles that occur
with little or no human impact. This portion of the CCoLD is the natural ecosystem
functioning and the natural ecosystem maintenance cycle. This natural ecosystem
perturbation is a unique, but important, character of African Savanna ecology. In the
natural cycle portion of the CCoLD, natural and prescribed (deliberate) fire becomes the
most important factor, although human population undoubtedly has a role to play. In this
perspective, fire was seen as a tool for the savanna ecosystems’ maintenance. In the
absence of fire, the savanna biome tends to be dominated by woody species. Fire may
occur naturally through lightning or anthropologically as a deliberate way for protecting
the savanna against this woody invasion (Sarmiento 1984; Kadomura 1989). Rangeland
management practices include prescribed burning, which reduces the effects of
devastating fires (Hough 1993) and regenerates palatable grass for grazing livestock. This
practice is not limited to savanna ecology, but is also in forest ecology to reduce wildfires
(de Ronde et al 1990). This raises questions about the role of fire in the origins of the
savanna (e.g. Aubréville 1949; Innes 1971; Kadomura 1989), the nature of savanna
vegetation, whether African savanna is a natural vegetation or climatic climax vegetation,
and what is a disturbance in fire ecology and when the savanna ecosystem is in
equilibrium. The vegetation at this stage fluctuates between climax and pro-climax. The
CCoLD model indicates that there is a continuous natural cycle where periodically the land gets disturbed by fire and grazing; however, due to the low frequency of fire, controlled human population, and livestock, vegetation recovers easily from disturbance. Perhaps this can be dated back to the period from the 1930s to 1960s, in which the UER had a total population of approximately 400,000 and a population density of about 40 people per km². Around this time in history, traditional agricultural practice was the bush fallow system, a system of farming in which farmers rotate between a number of farmlands (farming plots).

A farmer farms (cultivates) on one plot for about two years and harvests his or her produce within the two-year period and abandons that piece of land for 7-10 years while farming on other plots and then returns to the same plot after the 7-10 years (fallow period). During this period, the plot of land lies fallow and regains fertility naturally and becomes a pro-climax savannah. Land fertility is restored and vegetation is recovered, while all other ecological functioning of the area restores to normalcy.
Figure 6.3: CCoLD modeling
The likelihood of rapid recovery from disturbances becomes hampered if further disturbances occur to aggravate the situation. Here, the major challenge is population growth. Increased population creates demand for land and exploitation of other environmental resources. In most agricultural communities, the clearing of land for agricultural purposes increases, while the fallow period reduces and exacerbates land degradation. This pressure creates a new land cover, an open savanna, through intensified farming, grazing, and burning. At this stage, the rate of degradation is rapid, while the rate of recovery reduces. In the case of the UER, this stage of the CCoLD was reached in the 1960s when the population was increasing gradually and people still had 5-7 farm plots. Agriculture is still subsistence such that they can afford to practice the bush fallowing system type of agricultural practice. Others practice the mixed farming system with the animal population increasing. The minimum fallow period was four/five years, which allowed the land to recover naturally from disturbance, but at a slower rate.

In the third stage of the CCoLD, consistent efforts are required to reverse land degradation; however, due to increasing human and livestock populations and the demand for housing and vegetation removal, land degradation increases. The demand for housing, using vegetation for thatching the houses, household energy supply, bush burning, and increasing agriculture activity, compounds land degradation and thus degrades faster. Land cover changes from open savanna to park savanna. This stage of the CCoLD was passed in the UER region between the 1970s and 1980s, with the introduction of commercial agriculture through government agricultural development.
policies such as Operation Feed Yourself (OFY) (1974/75) and Operation Feed Your Industries (OFYI) (1975/1976), as well as a structural adjustment in the early 1980s. Finally, land degradation increases under severe population pressure, agricultural extensification to fragile ecosystems and marginal lands. Surface exposure to sand baking and burning decomposes soil nutrients; wind and water erosion blows and washes away the top soils, leaving impoverished land, which supports mainly environmentally efficient crops. Basically, trees are found along river courses and reserves, including community forestry. This is the period of the 1990s and 2000s. Although subsistence agriculture persists, most farmers have the intention to sell, although their agricultural output is low due to soil exhaustion, low agricultural inputs, and climate fluctuation.

Generally, CCoLD also suggests that the part of land degradation process resulting from anthropogenic impact begins with population growth (increasing population density) and the use of uncontrolled fire, which gets exacerbated by increasing cultivation and vegetation removal (trees and grasses) and is further aggravated by more intensified cultivation. Further tree removal and exposure leads to spread of diseases and degradation continuously; hence, we can describe the situation as Continuous Cycle of Land Degradation (CCoLD). CCoLD indicates that land degradation may be a linear progression if there is no intervention to address the underlying causes. This linear progression will manifest in negative vegetation change in surface greenness, which can be analyzed in terms of decrease in NDVI. Over the last 30 or more years, the UER has been experiencing land degradation resulting from population growth, uncontrolled fire,
farming, and land cover removal, including cutting for firewood and thatching houses and grazing of livestock.

With increasing population pressure, the number of farm plots per person decreases. This, in turn, decreases the fallow period, hence there is not enough time for natural land recovery. Population growth also increases frequency of fires, grazing, and resource extraction, thereby exerting extra pressure on land and diminishing the possibility of land recovery from disturbances. The UER’s population grew from 415,000 in 1960 to 773,000 in 1982, representing an increase of 86% in 24 years, which increased the average population density from 45 people per km$^2$ to 71 people per km$^2$, and to 115 people per km$^2$ in 1998. With population pressure, bush fallow systems become unsustainable and therefore force a change in farming practices from the bush fallow system to continuous cropping. Today, the UER faces land scarcity such that a piece of land for housing has its backyard for crop cultivation (compound farming) and livestock raising, an agricultural system commonly practiced in Bolgatanga, Navorongo, and Bawku municipal areas and the final consequence has been outward migration and hence the current population of 920,089, compared to 1,015,000 in 1998.

The use and occurrence of fires in the UER is not well documented. Yet, some studies have shown that continuous biomass burnings have important implications for atmospheric chemistry and soil nutrient balance through the process known as pyrodenitrification (Goldammer 1990; Levine 1991, 1996; Crutzen & Andreae, 1990).
Fire ecosystems such as the sudano-Sahel regions of West Africa, and the UER to be specific, are characterized by low soil fertility and a landscape of sparse vegetation cover. Fire has modified the eco-community composition, hydrological processes at the soil surface, soil structure, and rates of soil erosion (Sillans 1958; Vogl 1974; Guerra et al. 1998). In the Sahel savanna regions, other impacts of fire documented in the literature include the prevention of the replacement of the herbaceous strata by woody biomass and to enhance, in the short term, the production of some graminaceous plants (Menaut 1993). The longer term impact of fire may induce changes in vegetation cover through their impact on soil nutrients (Crutzen & Andreae 1990). Moreover, farmers burn the vegetation to maintain the herbaceous vegetation for grazing, which further degrades vegetation. At this stage, the biophysical environment appears to be more open savanna, interspersed with farmlands and some economic trees such as the shear butter trees, and other trees used for burning charcoal. Some common impacts include declining food production signifying declining soil fertility, intermittent rainfall, also indicating a tilt in the ecological balance, ecosystem instability, and above all, increasing food prices. The difficulty of land recovery from degradation increases and therefore requires a systematic plan including land use change. There is also the need for some land investments including land preparation, the use of artificial fertilizers, which help to regenerate fertility, and ultimately vegetation recovery. Land degradation in the UER had passed the third stage based on evidence and other documentations concerning land degradation in the region. The third stage of the CCoLD must have been reached in the 1970s and early 1980s. By the mid 1990s, the UER had reached the stage of park savanna with trees
covering about 10% or less. The trees consist mainly of economic trees such as shea butter, mango trees, etc.

The UER is moving to the last stage of the CCoLD where the area is characterized by decreased vegetation cover, decreased soil fertility and increased soil erosion, ecological succession (vegetation take over) by environmentally efficient crops, and grasses which are of less quality and utility to the people. At this stage, even though desertification has taken place, it is very difficult to detect from multispectral satellite remote and NDVI in particular. This is due to the fact that the new vegetation is low, has a broad surface, and is quick maturing, although it dies out quickly. Today, the vegetation in the UER is short grass compared to the tall elephant grass, which required limited soil nutrients and responded to rainfall quickly. They have hairy-like seeds that disperse and germinate quickly and produce a dense surface of green cover a few days after the first rain and stay green, but die out quickly as soon as the rainy season ends. They are equally flammable and burn quickly. Below are figures 6.4 and 6.5 showing the vegetation takeover (ecological succession) in the UER discussed above.
Figure 6.4: Remnants of the original tall grass of the UER
Figure 6.5: The succeeding vegetation (ecological succession), UER
Figure 6.6: Severity of wildfire and rapidity of recovery after the first rain
Whereas local residents interviewed for this study attribute desertification to factors such as rampant and uncontrolled fire, researchers like Nsia-Gyabaa (1994) and Benneh (1996) have linked the desertification of the UER to failed government development policies and programs. According to Benneh (1996), environment and resource management are two sides of the same coin required for development and so environmental degradation can be seen as a failure to manage development on a sustainable basis. He argued that severe land degradation was observed in the northern savanna region of Ghana, including the study area in the 1940s, which led to the early introduction of land planning and soil erosion measures in areas focusing on the agricultural use of land, water, and grazing resources (Benneh 1996; Nsiah-Gyabaah 1994). The government’s department responsible for planning and executing these conservation measures include the Departments of Agriculture and Forestry working in conjunction with the local people. Subsequently, the Land Planning and Soil Erosion Ordinance was passed in 1953, and amended in 1957, which created permanent committees of the areas designated for effective planning and control of land degradation (Benneh 1985). In the early 1970s, there was growing concern about increasing land degradation, aridity, and desertification in the Upper regions, including the UER; the government responded to the growing concern by commissioning the Council for Scientific and Industrial Research (CSIR) in 1974 to conduct research on the impact of drought on agriculture and rural development in the Upper regions. One could easily see the impact that governmental policy could have on land degradation and recovery. Relating the CCoLD to government development policies, especially agricultural policies
in Ghana, it is not far fetched that the UER reached the third phase (human-induced land degradation phase) of the cycle in the early 1970s. The impact of land degradation was felt in drought and decreasing food production (Girdner et al 1980).

As far back as 1971, Ghana observed declining food production in its food growing areas of the UER, Upper West, and Northern regions resulting in increasing food prices and demand for pay increases and other civil unrest. At that time, the government and stakeholders blamed farmers’ use of the same technology as their grandfathers and poor rainfall leading to poor soil conditions and poor food crop production (Girdner et al 1980). Contrary to officials blaming climatic conditions and obsolete agricultural technology, Girdner et al (1980) have argued that the official explanation circumvents the historical foundation of the problem and as such the solution to the problem of agricultural development in Ghana. In their view, the crux of the problem is the neglect of food production and lack of policies to improve food crop production in favor of agricultural policy inherited from British colonial administration after independence. British colonial administration in Ghana focused agricultural policy on the production of foods and raw materials to feed and supply the metropolitan areas of the colonial power (Girdner et al 1980). They therefore pursued a policy that encouraged Ghanaian farmers to produce crops with the greatest export potential and profitability. Some of these crops include palm oil and cocoa to the neglect of locally consumed staples and as such did nothing to protect or stop land degradation in those areas of the UER, Northern and Upper West regions.
Girdner et al (1980) believe that Ghanaian peasant farmers’ eagerness to supply the increasing demand for these crops in metropolitan UK spared the influx and the concomitant hegemony of colonial settlers to established plantations to grow these crops in Ghana, as compared to other British colonies in Africa, such as Kenya and Zimbabwe. The Ghanaian peasant farmers’ willingness to cultivate and supply these European crops were in part due to the substantial cash paid to cocoa and palm oil producers in the middle parts of the country. Ghanaian farmers did not revolt against this agricultural policy also because large-scale land alienation and harsh labor codes were not experienced in Ghana, as they were in some other British African colonies. However, there was an over reliance on export crops, which guaranteed regular and secured income to the farmer.

Post-independent Ghana maintained this same agricultural policy that relies on export crops, hence the continuity of a mono-crop economy developed originally to satisfy the overseas demand to the neglect of local demand. While export commodities such as cocoa are an important component and measure of the health of Ghana’s economy, it also meant neglect of local food production. This is clearly shown by government policy of guaranteed income to cocoa and coffee producers annually, while local food production continues to decline to such an extent that Ghana spent $180 million to import food and raw materials in 1970 (Girdner et al 1980). Just after toppling the civilian government in 1972, the military government, The National Redemption Council (NRC), headed by Lieutenant Colonel Ignatius Kutu Acheampong, that took over the administration of the
country in 1972, sought to modernize agriculture as a precursor to economic development through a program that became known as OFY. This program sought to achieve food security, self-reliance, and food independence and made huge investments in land revitalization including irrigation dams, supply of organic fertilizers, mechanization of agriculture, and other agricultural implements. Similarly, the government attempted to control pest and fire outbreaks. Interestingly, by 1975, OFY achieved such a high success that it is on record that 1974-1975 was the year that Ghana imported the fewest grains into the country. Perhaps the key to the short-lived success chalked by OFY was agricultural credit, which helped farmers, particularly in the UER, Upper West, and the Northern regions to invest in land conservation and rehabilitation practices. However, OFY was short-lived because of lack of demand, dwindled agricultural credit, storage facilities, and other economic infrastructure such as lack of spare parts and transportation; corruption, and above all weather failure. In a desperate attempt to save the situation, the government initiated a new program to attract some farmers to the production of raw materials by launching OFYI in 1976. Farmers responded, hoping that there would be agricultural credit and a guaranteed market for industrial crops instead of producing food crops with no market or storage facilities. Most farmers converted their land to production of industrial crops, and prominent among them in the UER was cotton. By the close of harvest in 1977, it became apparently clear that OFYI was a failure due to poor soil and rainfall failure. Also, food production fell short of local demand due to farmers shifting to production of cash crops and the general absence of agricultural credit coupled with the breakdown of irrigations dams.
The 1977-78 drought, coupled with acute shortages of food and essential commodities, compelled farmers in the area to mine their land with many resorting to unhealthy farming practices. Anthropologically-induced land degradation therefore entered the third phase on the CCOLD. It is also important to emphasize the continual population growth, which doubled the pressure on land. By this period, the population of the UER had increased to approximately 773000, an increase of 86% from 1960, and the population density reached 71 people per km². In 1983, Ghana applied to the United Nations (UN) General Assembly for UN Sudano-Sahelian (UNSO) assistance to combat drought and desertification, which was granted in 1984 by UNSO (UN General Assembly Resolution 39/68, December 1983) (Nsia-Gyabaah 1994).

According to Nsiah-Gyabaah (1994), an important watershed in the history of land degradation in northern Ghana, including the UER, is the introduction of ERP in 1983. Following the food shortages of the late 1970s and subsequent economic hardships, the Ghanaian military led by Ft. Lt. Jerry John Rawlings intervened and overthrew the governing military government in 1979, handed over power to civilian administration in 1980, and returned to overthrow the civilian government in late 1981. In 1983, the then military government introduced a new International Monetary Fund (IMF) and the World Bank ERP, which in the view of Nsiah-Gyabaah (1994), served as a catalyst for land degradation in Ghana.
The ERP was launched under the guidelines of the World Bank and the IMF. According to a country study by the Library of Congress (LC) (LC online bookstore), the overriding purpose of Ghana’s ERP was to reduce the country’s debts and to improve its trading position in the global economy. Whereas we are not sure of the real purpose of the ERP, some skeptics believe the World Bank and IMF ERP meant to force Ghana to concentrate on exporting more so that they could pay back their debt. If this is true, one should expect such a program to have negative repercussions on the local economy, especially on products for local consumption such as local staple food. Some of the interesting provisions of the ERP program included an export promotion drive, the removal of agricultural subsidies, and a guaranteed market for exportable crops, to mention a few.

The ERP was criticized for ignoring the plight of those farmers not involved in the export sector. The country’s agricultural resources were overwhelmingly geared towards cocoa rehabilitation and other export sectors, and not toward food production. According to the LC country report (La Verle, Online bookstore 12/20/08), farmers generally suffered as the percentage of the total country’s budget devoted to agriculture fell from 10% in 1983 to 4.2% in 1986 and to 3.5% in 1988. The report further stated that though cocoa contributed less to Ghana’s GDP compared to food crops, cocoa received 9% of Ghana’s capital expenditures in the late 1980s. It also received about 67% of Ghana’s recurrent agricultural expenditures because of its export value. Similar observations were made from the implementation of ERP in Latin America and other African countries that the ERP and its structural adjustment programs accelerated economic and environmental problems instead of solving them. In Ghana, the adjustment program led to inappropriate
economic development, environmental degradation, and mass rural poverty. It also created a rift between population and resource exploitation, which subsequently accelerated land degradation. Over 100,000 civil and public servants lost their jobs, while about one million Ghanaians were expelled from Nigeria and most of these people sought refuge in farming. Agriculture offers job avenues to the highest proportion of the economically active population, mainly as farmers, farm laborers, and other workers in agricultural related activities.

As part of the effort to reduce the negative impacts of ERP on agriculture and land degradation, the Agricultural Services Rehabilitation Project (ASRP) was implemented (1987-90), followed by the Medium Term Agricultural Development Program (MTADP) (1991-2000). The MTADP emerged as a main policy document for the Ghana government to be implemented by MoFA throughout the 1990s. Within the MTADP framework merged various programs and projects (with funding from the World Bank) for improving the agricultural sector. Some of these programs and projects included the Agricultural Diversification Project (ADP) (1991-99), the National Agricultural Research Project (NARP) (1991-99), the National Agricultural Extension Project (NAEP) (1992-2000), the Agricultural Sector Adjustment Credit (ASAC) (1992-99), the National Livestock Services Project (NLSP) (1993-99), the Agricultural Sector Investment Project (ASIP) (1994-2000), and the Fisheries Capacity Building Project (FCBP) (1995 to present). Others include the Accelerated Agricultural Development Strategy (AAGDS) of 1996 to enhance agricultural growth. A sub-strategy under AAGDS meant to facilitate
rapid transformation of the agricultural sector is the Agricultural Services Sub-sector Investment Project (AgSSIP), which commenced in 2002. Building on AgSSIP, MoFA prepared the Food and Agriculture Sector Development Policy (FASDEP) document (2002) and some commodity specific programs under the President’s Special Initiatives (PSIs), both of which were adopted as the national agricultural sector approach to managing agricultural development and provided a broad framework for agricultural development in Ghana. The impact of these programs in relation to the environment, food security, poverty, and the agricultural sector’s ability to absorb shed labor from urban nonagricultural employment (buffer) are listed on the table below:

Other related national policies and programs in the 1990s that have impacted agriculture either directly or indirectly are the National Feeder Roads Project (NFRP), the Coastal Wetlands Management Project, the Environmental Resource Management Project (MRMP), the Financial Sector Adjustment Program (FINSAP), the Village Infrastructure Project (VIP), the Program of Actions to Mitigate the Social Cost of Adjustment (PAMSCAD), and minimum wage increments.

Mixed growth was recorded in the agricultural sector. A very low agricultural growth was recorded in 1990 and 1992. The annual average rate of agricultural growth was 1.97% during the 1990s, compared to 3.57% growth during the 1980s. It is estimated that the general agricultural growth declined during the 1990s.
Table 6.1: Ghana’s Development Policy, strategy, instrument and role of agriculture

<table>
<thead>
<tr>
<th>Policies/ Instruments/ Strategies</th>
<th>Roles of Agriculture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Environment</td>
</tr>
<tr>
<td>Market Liberalization</td>
<td>+/-</td>
</tr>
<tr>
<td>- Price Deregulation</td>
<td>+</td>
</tr>
<tr>
<td>- Subsidy Removal</td>
<td>--</td>
</tr>
<tr>
<td>- Input Supply Privatization (e.g. fertilizer, agro-chemicals)</td>
<td>-</td>
</tr>
<tr>
<td>Internal Marketing of Cocoa</td>
<td>--</td>
</tr>
<tr>
<td>- Guaranteed Price</td>
<td>-</td>
</tr>
<tr>
<td>- More Private Agencies</td>
<td>-</td>
</tr>
<tr>
<td>Medium Term Agricultural Development Program (MTADP)</td>
<td>+</td>
</tr>
<tr>
<td>Agricultural Diversification Project (ADP)</td>
<td>-</td>
</tr>
<tr>
<td>National Agricultural Research Project (NARP)</td>
<td>+</td>
</tr>
<tr>
<td>National Agricultural Extension Program (NAEP)</td>
<td>+</td>
</tr>
<tr>
<td>Agricultural Sector Investment Project (ASIP)</td>
<td>+/-</td>
</tr>
<tr>
<td>Financial Sector Adjustment Program (FINSAP)</td>
<td>+/-</td>
</tr>
<tr>
<td>Village Infrastructure Project (VIP)</td>
<td>+/-</td>
</tr>
<tr>
<td>Environmental Resource Management Project (MRMP)</td>
<td>+</td>
</tr>
<tr>
<td>Program of Actions to Mitigate the Social Cost of Adjustment (PAMSCAD)</td>
<td>+</td>
</tr>
<tr>
<td>Accelerated Agricultural Development Strategy (AAGDS)</td>
<td>-</td>
</tr>
<tr>
<td>Agricultural Services Sub-sector Investment Program (AgSSIP)</td>
<td>+</td>
</tr>
<tr>
<td>Food &amp; Agriculture Sector Development Policy (FASDEP)</td>
<td>+</td>
</tr>
<tr>
<td>National Feeder Roads Project (NFRP)</td>
<td>-</td>
</tr>
<tr>
<td>Minimum Wage Increases</td>
<td>+</td>
</tr>
</tbody>
</table>

(+ ) means positive effect; ( - ) means negative effect. Source: Asuming-Brempong (2003)
Agriculture's contribution to the country’s aggregate output growth averaged 12.78% per annum during the 1990s, and -27.8% and -7.1% in 1990 and 1992, respectively (Asuming-Brempong 2003), with the negative share of the aggregate growth originating from the fall in agricultural real output in 1990 and 1992.

During the period (1983-2001) that the ERP and its associated subprograms were implemented, Ghana’s agricultural sector was saddled with numerous problems, which went a long way to increasing land degradation in the country. First, the financial sector liberalization and monetary policies implemented during the period resulted in very high agricultural lending rates at an average rate of over 45% per annum and a crowding out of agriculture in formal domestic credit allocation, resulting in a fall in the agricultural sector’s share of credit during the period (Asuming-Brempong 2003). Financial institutions have tended to divert credit from the sector to invest in treasury bills, which are high-interest yielding assets. Lack of agricultural credit prevented any real effort to invest in land improvement and new agricultural technologies. In addition, little efforts were made to reduce agricultural risk. Agriculture in Ghana even until today remains largely rainfed and subject to the vagaries of weather, thereby making agriculture a more risky business. Agricultural risk is even higher in the UER where rainfall, particularly the amount, frequency, timing, and distribution tends to be very uncertain, while access to irrigation facilities has been inadequate. Banks were therefore hesitant to take higher risks and therefore limited agricultural credit.
Also, the ERP and other policies include foreign exchange market liberalization and the flexible exchange rate regimes, coupled with trade liberalization, which increased the importation of goods and excessive increased demand for foreign exchange. These led to astronomical depreciation of the local currency (the Cedi). In Ghana, most of the agricultural inputs are imported but with a depreciating local currency, the prices of these inputs increased significantly, depriving farmers, especially food crop producing farmers, the capacity to invest in land and other productivity-increasing technologies. The high prices precipitated cost-price squeeze in which farmers responded by cutting down the utilization of these technologies, which resulted in fallen agricultural productivity. Farmers’ production and incomes fell, and farmers could not feed their families, much less invest in land. Food crop producing farmers resorted to survival-first approach, while the country spent millions of dollars on food imports to meet the ever-increasing demand. The demand for improved agricultural technologies (including fertilizer and other agro-chemicals) declined, thus precipitating low agricultural productivity (Asuming-Brempong 2003). The privatization of the sale and distribution of agrochemicals, coupled with inadequate knowledge of the handling of such chemicals, also led to use, misuse, and improper handling of chemicals including banned environmentally unfriendly chemicals with dire environmental consequences.

Generally, the incentive to produce food crops declined. Producers of commodities such as rice, cotton, tomatoes, and livestock, the main commodities from the UER, were out-competed from the Ghanaian market by cheap foreign imports through trade
liberalization, the main reason why, though most regions of Ghana have halved poverty, the UER remains extremely poor.

The export promotion associated with government policies also increased incentives for the exportation of timber, which sparked uncontrolled timber harvesting throughout Ghana and further aggravated land degradation in the country. It is estimated that the rate of destruction of unreserved forest in Ghana between 1983-2001 was 25,000 hectares every year, using methods that are not environmentally friendly and regarded as unsustainable for forest resources harvesting.

Another impact of ERP on land degradation was urban sprawl and intensity of construction activities in towns and villages. The government embarked on massive construction and infrastructural projects, which created an incentive for the construction sub-sector. The result was an increased demand for sand and stone and other building materials. The demand and the rate of the exploitation of sand and quarrying activities increased significantly, causing land degradation in many parts of Ghana, including Bawku and Bolgatanga in the UER.

Privatization and availability of mineral prospecting chemicals increased the incentive for the exploitation of minerals, such as gold, in the country. Illegal and legal small-scale gold mining operations, known in Ghana as “galamesey,” became profitable. The intensity and number of small-scale surface mining operators and large-scale mining
activities increased during the period. The output of mining and quarrying increased significantly. However, mining has adverse environmental consequences, especially when the operators have limited skills and resources for reclamation and also for handling the chemicals involved. Moreover, licenses to mine were issued without requiring remediation of the environmental impact. Some of the common impacts found in the UER include exposed topsoil with its attendant erosion and loss of fertile soil, deep trenches, and emission of toxic gases like arsenic trioxide and sulfur dioxide, water pollution, and a decline in land productivity.

Synergies of human activities and government policies have clearly created an ecological footprint in the UER that needs to be taken seriously. Where government policies have created the framework and impetus to degrade the land, local people, through their lifestyle, have nailed the coffin by directly degrading the land. However, all is not lost, knowing where we were, how we came, and where we are today is equally captivating and provides an incentive for return. Some of the controversial issues in the desertification debate include the question of reversibility and irreversibility. Luckily, we learned success stories of land recovery from degradation from the African continent. These success stories include the Boserupian experience from northern Nigeria, the Machakos experience from Kenya, the Keita and Tivu experience from Niger, and many heartbreaking stories of recovery from land degradation. What is more reassuring about the prospects of abating and combating desertification in the UER is the rich environmental knowledge displayed by participants of this study. Many of the
participants could set the record straight about the origins of desertification, and the stages and signs they have observed today. Some of the common signs noted by participants include increasing dust storms, the silting of riverbanks, ecological succession, erratic but often torrential rains, the drying of surface and streams, etc. Also, many of the participants thought the desertification problem is reversible. However, 80% of the respondents expected the government to take the lead in solving the desertification problem in the region. Similarly, respondents were unanimous (100%) about the devastating nature of fire and the role it plays in the desertification process, although 4 out of every 5 participants depended on fire for clearing the land. They underscored the role of burnt ash in refertilizing as the primary purpose. Others used fire for hunting and clearing the old growth to ensure new and palatable grass for feeding their livestock. Many local residents believed that fire was an integral part of the ecology and so burning is a normal process and becomes very difficult to eschew in the short-term. We want to argue here that other studies have equally underscored the role of fire in African savanna ecology and that absence of fire becomes an ecological disturbance, which invariably leads to succession (Sarmiento 1984; Kadomura 1989). Whereas we do not dispute the findings of such research, we have problems with the type and timing of burning in the UER. During the field study for this research, we observed two burned areas adjacent to each other (see map below).
Figure 6.7: Impact of early and late burning captured by the IKONOS 2 Satellite

One was burned approximately around November/December and the other around late December/January. We observed that the area burned in January was widespread and
completely burnt with no leftovers. However, the area burned in November/December had several portions left over. The leftover vegetation served as windbreaks during January/February, the dry season when there are no farming activities. From late December to February, the UER comes under the north-east trade winds (harmattan), which are dry and dusty, carrying no moisture. Harmattan winds tend to dry the surface and carry significant amounts of dust from the open field. When an area experiences burning in late December-February, during and after the arrival of harmattan winds, it tends to burn out completely and bake the soil. Winds blow away the burnt ashes that are supposed to fertilize the soil. Also, burning in late December-February tends to spread uncontrollably to neighboring areas causing extensive damage. Conversely, when burning is done in November, the area is at least not completely dry and therefore tends to leave leftover vegetation. Again, the area experiences some rainfall in late November and early December before the arrival of the harmattan winds. This rainfall dissolves and returns the burnt ash to the soil before the harmattan winds arrive to carry the ash away.

The situation being described here can be categorized into early and late burning. We therefore see early burning as a lesser evil compared to late burning. We further argue that the culture of uncontrolled burning is unsustainable; hence we recommend a government takeover of burning, if it is done at all, and must be done early before the onset of harmattan winds. Preferably, the prohibition of burning is ideal, yet it can also lead to catastrophic and astronomical losses when it occurs accidentally. It may also lead to ecological succession not favored by local people. Ideally, the government should engage and initiate dialogue with local people about combating desertification and ensure
local participation in the planning and implementation of programs and policies to combat desertification. This participation will create awareness, empower local people and create a sense of ownership in which local people will understand that combating desertification is in their best interest and the best survival strategy for them and generations unborn.

6.3 The nature of changes in agricultural production in the UER vis-à-vis Desertification

At the conference on the environment held in Stockholm, Sweden in 1972, the then Prime Minister of India, Indira Gandhi, said “poverty is the greatest polluter.” She therefore called for global action against poverty as a prelude to solving problems of environmental degradation. In the same token, the World Bank argued in its World Development Report (WDR) in 2008 that, “If agricultural growth has such unique abilities to reduce poverty, then why hasn’t it been more consistently realized across developing countries?” (World Bank 2007 226). The report observed that poverty dropped in China, India, Vietnam, and other countries when they experienced a major surge in agricultural growth comparable to the industrial take-offs and rising incomes that created Japanese and Korean economic revolutions. The report further argued that, in spite of the great potential of agriculture to spurt economic development, it has been used too little to generate growth in many developing economies such as those of Sub-Saharan Africa (World Bank 2007). Conversely, Gyasi (1996) has argued that agriculture has traditionally formed the main economic activity in Sub-Saharan Africa countries. Agriculture is seen as the main
employer of Sub-Sahara Africa’s burgeoning population, the generator of the bulk of the sub-region’s income, including foreign exchange earnings and the most important land-use factor (Gyasi 1996). Taking Ghana for example, agriculture employs about 60% of its entire labor force, contributes 50% of the gross domestic product and 60% of export earnings, and above all occupies 57% of the total land area (Ministry of Agriculture 1991). Agriculture’s contribution to the regional economy becomes more stunning when narrowed down to the UER. It employs 80% of the labor force, generates about 90% of household incomes, and covers about 65% of the land area. Since Ghana’s independence in 1957, agriculture has been identified and focused on as a springboard to economic development. Almost every development policy in Ghana since independence has had agricultural development as the top agenda with the ultimate aim of spurting economic development through agricultural income and savings for industrial development. All said and done, environmental degradation would be solved by alleviating poverty because “poverty is the greatest polluter,” said Gandhi in 1972, and poverty is alleviated through agricultural growth (World Bank 2007). Since Ghana’s development effort has focused on agricultural growth, and achieving a growth rate of about 5% p.a. for the past 7 years, one would expect that environmental degradation would be declining, since by implication, environmental degradation is negatively correlated to agricultural growth, when we combine statements by Gandhi in 1972 and the WDR in 2008. This section reviews agricultural growth in relation to land degradation in the UER by examining agricultural production and yield in relation to changes in agriculture as a major land use factor.
Gyasi (1996) has categorized agricultural land use practices in Ghana, and in the UER, into three major systems. These include the pure livestock, the cropping systems, and the mixed farming system. Comparatively, the cropping system is the most important in the UER. It includes two subsystems: small-scale indigenous methods (smallholder farming system), such as the traditional shifting cultivation and its modification into land rotation or bush fallow system, and the large-scale mechanized farming system. The smallholder peasant farming system is the dominant farming system in the UER. Over 80% of farmers in the UER are peasant farmers. These peasants usually employ intercropping and a mosaic layout system, which is less capitalized, has low artificial external inputs, and is more nature-based, labor intensive, and family operated (Gyasi 1996). The WDR, 2008 states that the agricultural growth-for-development approach has been less favorable and achieved minimal success in developing countries, particularly Sub-Saharan Africa (SSA) for six reasons, including (1) incomplete and uneven reforms of the international trade regime, especially in the Organization for Economic Co-operation and Development (OECD); (2) reduced, but continuing policy biases against agriculture in many developing countries; (3) underinvestment and poor investment of public resources in agriculture and donors turning their backs on agriculture too early; (4) incomplete institutional development (especially for smallholders) following descaling of the state in agriculture; (5) lags in the release and adoption of new waves of technological innovations; and (6) the depletion of natural resources and rising climate change, undermining productivity gains. However, in the case of Ghana, and the UER in particular, the cardinal failure of agricultural growth for development can be categorized
into three. These include lack of adequate consideration for smallholder peasant farmers, particularly food crop producers, who form the bulk of farmers in the country. The net effect is lack of access to agricultural credit, use of simple but inefficient technology, over-cultivation of arable agricultural lands, low income for peasant farmers, food shortages, high food prices, and hunger. A report by the Ghanaian Times (January 24, 2009), indicated that officials estimate that Ghana’s local production of rice fell as low as 30%, while the remaining 70% was imported at the cost of $500 million in 2007, compared to $100 million in 2000.

The second reason for the failure of the agricultural growth-for-development approach is the gross neglect of the biophysical environment that sustains agriculture in the area. As it is a major land-use factor in the UER, agriculture exerts a modifying influence on the natural environment, through vegetation burning and removal. This, in turn, creates a feedback effect in the lower atmosphere to cause dry surfaces, excessive evapotranspiration, warming, and climate change. All of these have ripple effects on the ecology and nutrient cycle, ecological balance and regeneration, food security, and human health. Other effects include irregular rainfall pattern, flooding, silting of riverbanks, and low soil moisture. Recent statistics released from the MoFA (UER) indicate that food crops’ production has declined sharply over the last four years. For example, maize production decreased from 60,835 metric tons in 2004 to 40,104 metric tons in 2007. Millet also decreased from 54,630 metric tons in 2003 to 43,760 metric tons
in 2007. Other food crops whose production decreased include sorghum from 127,820 metric tons in 2004 to 68,453 metric tons in 2007 (MoFA 2008).

The third reason for the failure of the agricultural growth-for-development approach in Ghana and the UER is inadequate and obsolete infrastructure. Given the difficult environmental conditions, including the biophysical conditions of climate variability and poor soils, it is evident that any serious effort towards agricultural growth should also provide irrigation facilities, improve transportation infrastructure, invest in soil fertility amelioration, and erosion controls. Other infrastructure missing from the agricultural development agenda in the UER is preservation, marketing and storage facilities, education, and health infrastructure.

Failure to address these three major problems has led to severe land degradation, irregular rainfall regime, and drought, decreasing yield per hectare in the phase of extensification of land use, food insecurity and hunger, poverty, and civil strife. In a project report, the International Fund for Agricultural Development (IFAD) (2006) noted that poorly maintained feeder roads and lack of transportation services hamper farmers’ access to the market in the UER. In the same study, IFAD asked 104 farmers to identify major changes in the living conditions since 1995; 31.7% of respondents said they are hungrier now than prior to 1995. Similarly, 10.7% identified lower crop yield and poor soil fertility as changing their living conditions. Other factors identified in the study include more education for children (25%), better health care (20.2%), and widespread livestock
disease (8.7%). Crops and livestock combine to constitute 19.3%, while a third of the respondents are concerned about adequate food. Data from the IFAD study in 2006 is shown in table 6.2 below.

Table 6.2: Perceived changes in lifestyle in the UER since 1995
Source: IFAD 2006

<table>
<thead>
<tr>
<th>Life-changes</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>More hunger</td>
<td>31.7</td>
</tr>
<tr>
<td>More education for children</td>
<td>25</td>
</tr>
<tr>
<td>Better health-care</td>
<td>20.2</td>
</tr>
<tr>
<td>Lower crop yields/poor soil fertility</td>
<td>10.6</td>
</tr>
<tr>
<td>Widespread livestock disease</td>
<td>8.7</td>
</tr>
<tr>
<td><strong>Total number of people interviewed =</strong></td>
<td><strong>104</strong></td>
</tr>
</tbody>
</table>

Also, the Ghana Living Standards Survey indicates that the percentage of the UER population living in poverty is 88%, while IFPRI estimated that 9 out of every 10 people in the region lives on less than $1 a day (IFPRI 2008). This extreme level of poverty, according to IFAD, manifests in stunted growth rate for children under five years of age, a rate higher than the national average (31.7% against 25%). The UER also has a very high infant mortality rate, 33 per every 1000 live births. The UER leads the country in environmental degradation, deforestation, and loss of soil cover, broadly as a result of extremely high population densities not accompanied by agricultural intensification,
rather land use extensification, which consumes more land and degrades the environment (IFAD 2006). The above facts and figures underscore the impact of land degradation on the life supporting system (natural environment) of the population in the UER and hence the extreme poverty endemic in the region. Below are statistics compiled by MoFA, UER on land under agriculture, agricultural yield, and types of crop cultivated from 1987 to 2007.

Figure 6.8: Land Extensification in the UER

Figure 6.8 shows that the total land area under cultivation has increased for every crop since 1987, with groundnut having the highest increase among all crops. With an initial land area of about 47,322 hectares in 1987, groundnut cultivation increased to about
111,860 hectares of land in 2006, given an overall average land area of about 85,742 per annum, which represents an increase of roughly 136% from 1987. Similarly, guinea corn also shows a dramatic increase in land area under cultivation. Land area under cultivation of guinea corn increased from an initial land area of 66,544 hectares in 1987 to 111,678 hectares in 2006.

Figure 6.9: Land under cultivation of Maize increases while the average yield per hectare decreases
Figure 6.10: Land under cultivation of rice increases while the average yield per hectare decreases.
Figure 6.11: Land under cultivation of Groundnut increases while the average yield per hectare decreases.
Figure 6.12: Land under cultivation of Millet increases while the average yield per hectare decreases
Figure 6.13: Land under cultivation of Guinea corn increases while the average yield per hectare decreases
Figure 6.14: Trend for mean yield per hectare for 7 major food crops produced in the UER

Whereas land under cultivation has increased for about 100% for almost every crop, yield per hectare has decreased for almost every crop over the same time period. Figure 6.10 shows that rice, which saw land under cultivation increasing from 7,000 hectares to 44,397 hectares, also saw yield per hectare increasing from about 1.06 tons per hectare from 1987 to as high as 2.6 tons in 1998, but declined sharply to about 1.6 metric tons per hectare in 2006, as do other crops.
In a study, Dietz and Millar (1999) have observed that the ultimate aim of farmers is survival, ensuring that they have enough harvest for the year to feed their family before thinking about selling for money. This is because agriculture in the UER is risky and the main sources of risk include frequent drought, disease outbreaks, flood (all indicators of desertification), post-harvest losses, and price fluctuations. In analyzing coping mechanisms of farmers in the UER, in the phase of decreasing yield per hectare, Dietz and Millar (1999) have contended that farmers tended to spread their risk in order to maintain almost the same harvest and income annually to ensure survival. Coping mechanisms adopted by farmers to spread risk include cultivating multiple farm plots, mixed cropping, and mixed farming. Others have resorted to the diversification of crops. This explains why non-traditional crops like cowpea and soya beans have emerged in the area since 2001. It is therefore not surprising that respondents to this study who are all farmers identified the impact of desertification in the area to include reduced soil fertility, changing climatic conditions, drought, diseases, and other health issues. What we observe from crop production in the UER is decreasing yield per hectare arising for multiple factors including decreasing soil fertility, and periodic drought, although there is no significant evidence of drought from our data and other ecological factors. Since 1995, IFAD, in conjunction with the Ghana Government and a consortium of multinational organizations, initiated a program to help farmers deal with land degradation and soil fertility, as part of Ghana’s poverty alleviation and plans to control advancing desertification in the region. The program involves agricultural credit, improving existing and constructing new irrigation dams and boreholes, composting for soil refertilization,
and farmer education. However, not all farmers have access to these resources and it also might take some time to realize the full impact.

6.4 Conclusion

In conclusion, we might not be able to conclude that the decreasing crop yield per hectare and increasing food insecurity and poverty in the UER are solely caused by land degradation, however, characteristics of agriculture, particularly crop production and the ecological factors that affect crop production such as sporadic rainfall, decreasing soil fertility, and diseases are all footprints of desertification and are positively related to desertification. Similar characteristics have also been observed from other parts of Africa undergoing severe desertification, such as Niger (Keita experience), Kenya (Machakos Experience), and Northern Nigeria (Boserupian experience). It is therefore not surprising that local people say desertification is getting worse. This local observation is not entirely disproved by satellite data. Whereas the general observation from temporal NDVI analysis suggest greening of the region, the spatial pattern of degradation shows that land degradation in the area is more localized than general. This is revealed by the changed detection performed between 1999 and the year 2002. Field study and other literature attributed localized degradation mainly to land use practices and the recent eradication of black flies that cause onchocerciasis from the affected areas, which has made it possible for agricultural land use extensification to previously onchocerciasis-infested areas. Other
factors include urban sprawl in areas around Bolgatanga, Bawku, Navorongo, and Paga areas.

It should be however emphasized that local people have knowledge and, although memory fades with time, consistency of the evidence from 3 to 5 people speaking on the same topic at different places and times make for powerful evidence of that knowledge. This is the basic for judging romanticization of facts from the truth. We conclude from this study that desertification is a major problem in the UER and therefore something needs to be done to combat it.
CHAPTER 7.0: SYNTHESIS, IMPLICATIONS FOR POLICY, AND RECOMMENDATIONS

7.1 Synthesis of Research

The earth is the home of humankind, but living on the earth has been a struggle to improve the well-being of humankind. In this struggle, the environment has provided materials and at the same time frustrated the effort (Songsore 1998). This re-enforces the caveat of sustainable development as a guiding principle to human behavior. The core of sustainable development is the connection between human aspiration and the ecological integrity, which when neglected, has devastating consequences. Although this inextricably intertwined relationship between human aspirations and the ecology has been known since antiquity, it has been grossly overlooked such that the ecological degradation has continued to an insurmountable stage; the consequences have not only been frustrating, but also ravaging to humankind. Conservatively, it is estimated that the life supporting system of approximately 2.5 billion people is affected by desertification globally, while 50% of global arable land has been affected with North America and Spain, having the largest land area, and the continent of Africa having the highest human casualties (Dregne 1986; Veron et al 2006; Kwarteng 2002). At the launching of World Desertification Day 2007 in Prague, it was stated that 8,000 to 10,000 km² of arable land is converted to deserts every single year; in Central Asia alone, sand dunes continue to
advance 100km north of Beijing, the Chinese capital, and 60 million people will be forced to move from newly desertified areas of Sub-Sahara Africa by the year 2020 (Bransten 2004). Accordingly, the UN spends an estimated $45 billion (US) on efforts to combat desertification annually.

This expenditure notwithstanding, the causes and effects of desertification are complex and multifaceted, varying from local to regional and from one part of the world to another (Pickup 1998; Veron et al 2005; Prince 2002; Leemans and Kleidon 2002), leaving desertification still a mystery, even though scientific work to unravel the mystery started in the 1930s. The severity of the desertification impact also varies on a spatio-temporal scale and is difficult to quantify (measure). What is certain about desertification is that less-developed countries, especially those in Sub-Saharan Africa experience greater human misery than those with the resources to provide short and long-term relief to the affected and threatened populations (Pickup 1998). Today, desertification is regarded as Sub-Saharan Africa’s nightmare and regarded as the greatest environmental problem of 18 countries in the subregion (UNEP 1995). Unfortunately, it has not been possible to clearly map out the spatio-temporal extent of desertification, either on national or regional levels in Sub-Saharan Africa, even though some data exists (UNCCD 2000).

The foremost concern of this study was to employ an indicator-based approach, specifically NDVI, to detect and quantify the spatio-temporal extent of desertification and its impact in the UER, Ghana, to push the frontiers of the discourse to find a more
proactive way to monitor and control desertification in the semi-arid Sub-Saharan Africa, with the belief that the findings can be replicated in other parts of the world. The study was guided by the fact that there are two inter-generational positions about desertification on the Sub-Saharan African sub-region. These two opposing generational views include the pre-1990 views that saw desertification as an emerging crisis of the sub-region and the post-1990 scholars who sang the praises for greening Sub-Saharan Africa, using evidence from satellite images. The study was equally mindful of methodological weaknesses observed in previous studies, mainly linked to inter-decadal and inter-annual rainfall fluctuations characterizing the sub-region. The study also considered other methodological and conceptual weaknesses of others previous studies; including the reversibility or irreversibility of desertification, the definition of desertification, and the issue of whether desertification is a process or a state. With these cautions in mind, the study utilizes NDVI from 1982-2007, a period of 26 years, to analyze desertification in Sub-Sahara Africa, using UER as a case study. We used NDVI because it is a process indicator, and for a period of 26 years to underscore the need for desertification to be studied in a continuum, which invariably avoids the traps of reversibility vs. irreversibility, inter-annual and inter-decadal irregularities, and state vs. process arguments.

Given the differences between two generations of scholars who looked at the same problem at two different times and with different methods, it makes scientific sense and interest to combine methods and data that encompass the two generational approaches for
convergence of evidence. The study utilizes satellite data, in conjunction with local residents’ observations, field observations, and other secondary data including climate and food production from the study area for this study.

The study finds that the UER is a well-settled, lowland area with an average height of 200m above sea level. The geology consists of igneous and sedimentary rocks. The rocks are mainly intrusive granite outcrops that have resisted erosion over the years and Voltaian sandstone with similar characteristics as granite. The soils of the region are shaped by the geology, drainage, and climate of the area. The eastern parts of the region are characterized by groundwater lateratic soils, which are poorly drained and loam in nature. The western part, on the other hand, is covered by soils mainly dominated by savanna ochrosols, which are well-drained, porous, and loam but easily tilled. The central portions of the study area are predominantly Tanchera and Kolingu soil associations. These soils are developed over granite and sandstone with the topsoil varying in texture from coarse, sandy-loams to clay with varying amounts of gravel (MoFA Bawku West 2005; Dietz and Millar 1999). The UER is drained by three main streams and their tributaries. These include the White Volta in the East, the Red Volta in the central portions of the region, and the Sissili River in the West, but these streams join together as the White Volta upon leaving the region and flow southward.

The climate of the study area is tropical continental with an annual rainfall average of 1100mm and temperature of 30°C; the rainy season is between May and October and the
dry season from November to March. February is the warmest month, while August is the coldest. Local observations were that the rainy period (duration) is getting shorter and more erratic, thereby affecting farming activities. Traditionally, rainfall begins in April and ends in November, but local people have observed the rain season starting in May and going to November. The rainfall data used for this study was monthly averages, which did not show any significant shift in rainfall pattern. Rather, they show an increase in average annual rainfall for Manga-Bawku since 1989, but that does not negate local observations in any way. We therefore conclude that data does not support the local view, but it is likely that the purported delay in rainfall is a matter of days or weeks, rather than months, but a few days or weeks delay in rainfall do not necessarily constitute a major climatic shift. Moreover, the erratic nature of rainfall makes it difficult to conclude on such a minimal shift. Kwarteng (2002) wrote that a 30-year study of rainfall data for the area (1960-1990) shows a 20% reduction in rainfall and 30-40% reduction in surface run-off. On the other hand, a recent study of the Sahel region by Hurrell and Hoerling (2005) shows that the rainfall pattern of the region has improved since 1990. This latest finding is consistent with our observation that the rainfall trend shows an overall increase in average annual rainfall since 1989 in Manga-Bawku. This observed increase in rainfall over Sahel, according to Hurrell and Hoerling (2005), is caused by SST warming over the Atlantic Ocean since 1990. They projected that the region will be 20-30% wetter by 2049 compared to the 1950-99 average.
The extent to which rainfall relates to vegetation health cannot be understated and manifested in the study of desertification in Sub-Saharan Africa. The extent of correlation between rainfall and NDVI was tested in this study and it shows a Pearson Correlation coefficient of 0.017. This correlation is significant at two-tail test, suggesting that 98.3% of the time, vegetation greenness, indicating vegetation health, growth, diversity, density, and cover type responds to rainfall. All things being equal, desertification negatively impacts vegetation health, growth, diversity, density, cover type, and abundance, which manifest in negative changes in NDVI over space and time. It is against this background that NDVI is used as a desertification process indicator in a continuum. Continual decline in NDVI can be set in motion by rainfall irregularities and a decrease in soil nutrients commonly associated with drought, desiccation, and/or desertification. The difference among the three is a matter of longevity, ranging from 1-3 years, 3-10 years, and over 15 years for drought, desiccation, and desertification, respectively. Using NDVI for mapping, desertification is a search for continual decrease/decline in NDVI lasting for a minimum of 15 years.

Analysis of NDVI data over the continent of Africa shows that the mean monthly NDVI (1982-2007) for southern Africa peaks around 0.46 in March as compared to the northern NDVI, which peaks around 0.44 in June, given a difference of a percentage point, suggesting greener vegetation in the southern half of Africa rather than the northern half. The mean annual NDVI from 1982-2007 shows a general trend of rise and fall every two to three years. The NDVI declined from 1982 to 1983 and rose from 1984 to 1986 and
declined again. Generally, there are 4 peaks occurring from 1984-1986, 1989-1991, 1996-1997, and 2004-2007. Periods of low NDVI observed in the 26-year NDVI trend analysis include 1982-1983, 1988, 1994, and the largest stretch of an 8 year period from 1997-2005. The rise and fall of the NDVI trend from 1982-1997 suggest regular drought on the African continent. The general conclusion is that NDVI is increasing on the African continent, yet this does not nullify the possibility of desertification in some parts of the continent, since desertification occurs in arid, semi-arid, and dry sub-humid regions. It was therefore important to focus on regions where there were high possibilities of desertification, such as the Sahel region of Africa.

Annually, the NDVI from the Sahel region rises from May, reaches the peak in September, and declines sharply in October until it reaches the minimum in March. This annual NDVI trend coincides with the rainfall cycle of the Sahel region. The mean annual NDVI analysis from 1982-2007 shows that the Sahel is greening, but is subjected to spatial and temporal irregularities. The period 1982-1990 saw NDVI rising and falling, portraying the inter-annual rainfall irregularities of the region, though on the rising side generally. However, the period 1990-1994 saw 4 years of continuous decline in NDVI below average, showing a decrease of about 5.4%, which signifies a period of desiccation. The period of 1995-2001 saw NDVI recovering above average with the highest mean maximum annual NDVI in 1997 and the highest mean annual mean NDVI in 2001. This is followed by another five years of falling NDVI below the period average 2002-2006. Generally, NDVI in the Sahel region has been on the positive side, showing a
net average increase of 2.66% over the 26-year period from 1982-2007, with 1982 as the base year. However, the Sahel NDVI data does not suggest the miracle of green landscape as suggested by others studies. We therefore caution that land degradation has not ended in the Sahel yet and must, therefore, be treated with utmost care.

The normal trend of NDVI of the UER shows a gradual rise from April, peaks in September, and declines gradually from late October, and reaches the minimum in February. The mean annual NDVI, showing surface greenness of the UER, indicates that greenness in the region has increased steadily, after starting lows of what appears to be drought years of 1982, 1983, and 1984. Generally, the NDVI trend shows that mean NDVI increased sturdily from 1982-2007. It also shows a regular cycle of NDVI fluctuations linked to rainfall anomalies associated with the study area. From the period 1982 to 2007, the NDVI rose steadily from an annual mean NDVI value of about 0.37 in 1982 (the base year) to about 0.45 in 2007, the end year. This indicates a positive NDVI change of about 21.6% over a period of 26 years. On the average, the NDVI has increased by about 6.7% from 1982-2007. Spatially, NDVI for the UER from 1982 to 1990 shows an average of 328 km² (37.4%) lost greenness measured in terms of NDVI in the UER. Conversely, land area of approximately 2064 km² (62.6% of land surface) gained or showed an increase in surface greenness. The period 1990 to 1999 saw 816 km² losing its surface greenness, while 1576km² gained greenness. However, more land area lost surface greenness from 1990-1999 than the period 1982-1990. Compared to 1982-1990 and 1990-1999, the period 1999 to 2007 lost less vegetation. An average of
152 km\(^2\) lost vegetation while 2240 km\(^2\) gained vegetation greenness. The maximum mean gain for 1990-1999 was almost 48\% of the maximum NDVI for year 1987 and 2007, and the maximum mean gain for 1999-2007 is greater than the yearly mean NDVI recorded over the 26-year period. In general, surface greenness increased from 1982 to 2007, indicated by the positive mean gains for 1982-1990; 1990-1999; and 1999-2007, confirming the observation from the temporal NDVI trend that surface greenness, as depicted by NDVI, shows greening of the UER from 1982-2007.

LTM5 and LETM+ NDVI used for validation also show that the UER is generally sparsely vegetated with a few clusters of heavily vegetated areas and several exposed areas. Green vegetated areas are mostly found along riverbanks forming corridors. These findings confirm findings from a study by Dietz and Millar (1999) and the Regional Coordinating Council (2005) that indicated areas along riverbanks are infested with black flies and onchocercisis (river blindness), and therefore deprived human usage. Also, the ever-greenness of the vegetation along riverbanks make it difficult to burn, compared to other upland areas that dry out completely to cause vegetation dryness and therefore become susceptible to annual burning. Spatio-temporal NDVI statistics computed from LTM5 and LETM+ data show that the average maximum green vegetation of the areas rose by about 103.4\% between October 20, 1984 and October 30, 2002, using October 20, 1984 as the base year, while on the average NDVI increased by about 29.7\%. This increase notwithstanding, there are localized areas of degradation that are of major concern. We therefore conclude from the NDVI analysis that these pocket areas of land
degradation, which are not vivid in the high resolution GIMMS NDVI, but appear in the high resolution LTM5 NDVI is a function of data resolution (scale). What we observed is a general trend of greening with pockets of localized degradation on the Sahel and the UER.

One of the inherent weaknesses of desertification studies and conclusions is the lack of reference data for comparison with conclusions. Satellite data collection, that we use now, dates back to 1972. However, the origins of desertification on the African continent, the Sahel region, and the UER go as far back as the 1930s and beyond, yet we have no reference data prior to 1970. It therefore circumscribes generalizations about the origins and directions of desertification. The current generation of people living in the UER have experienced vicissitudes of vegetation in the area, which when combined with satellite observations, is much more telling than any of them individually. The study sought convergence of evidence between local residents’ views of desertification and that of satellite observation. Local residents’ views were solicited through focus group discussions with a questionnaire, in which a participant had a questionnaire with a set of questions, which were read to him or her in his/her local language (Guruni), and the response was transcribed by a research assistant for the study. In all, 60 local residents participated in the study with participants selected through a snowballing method, with the help of district MoFA Officials with jurisdiction over the districts.
The field data collected was analyzed and built into a model called CCoLD. This model explains land degradation trends, stages, difficulty of recovery, and causative agents. The model points out that land degradation in the UER was stated prior to the 1960s. However, the process has been accelerated by demographic changes in the region that saw the population tripling over 38 years. Increasing population, coupled with demand for resources and space, has led to land use practices that emphasize land extensification, rampant and uncontrolled use of fire, indiscriminate cutting of vegetation, and low to no investments in land improvement. Whereas individuals are to be blamed for taking the direct action to degrade the land, government policy is regarded as setting the framework for land degradation by pursuing development policies and programs that directly and indirectly degrade the land. In addition to direct human causes of degradation, it is believed that livestock have, in no small way, contributed to land degradation in the UER. Although the UER cannot be said to be an important livestock region, compared to other Sahelian countries like Mali, Senegal, and Burkina Faso, data collected from the field indicates that the average household has 34 livestock. We, however, dispute the figure, knowing that farmers in the area usually understate their livestock numbers to avoid taxation.

Today, the UER is degraded to the extent that there is less than 10% tree cover, mostly riverine vegetation found in riverbanks and around water bodies. These consist of economic trees, drought and fire resistant trees such as the shea tree, Mango, Baobab, acacia, and cacti. Other common types of vegetation found in the area today include
environmentally efficient short grasses that have replaced the traditional horsetail tall grasses found in the area and the scattered remnants of the horsetail grasses. Essentially, local residents’ descriptions of the vegetation change show an ecological succession where low quality, but ecologically efficient, grasses have replaced high quality, soil, and climate demanding horsetail grasses. Additionally, local residents talk about reduction in crop yield, frequent dust storms, erratic and irregular rainfall, and occasional flash flooding, silting of river banks, soil erosion, diseases, and shortening of the rainy season as some of the common signs of desertification found in the area. They therefore concluded that desertification is worsening and that there is the need for urgent action to ameliorate and eventually combat it.

The study finds an interesting, but consistent, dichotomy between local observations supported with evidence from the field and NDVI trends analyses also consistent with some recent studies in the Sahel region of West Africa. Whereas the local people believe that desertification is on the ascendancy, the NDVI indicates a path to decline. However, there are some consistencies between NDVI and local observation. NDVI shows that vegetation is very low in some areas, indicated by a mean Landsat NDVI of 0.24 and this is consistent with the local view of low vegetation and declining vegetation cover. NDVI shows that some areas have lost vegetation over the study period, which is equally consistent with the local view of population pressure and land degradation in populous areas around the Bawku, Bolgatanga, and Paga areas. Three reasons may account for points of divergence between NDVI and local observation. First, the observed greenness
may have been accounted for by the spatial spread of environmentally efficient grasses
that have a wider surface spread than the tall, slim horsetail grasses, previously
occupying the area. Also, there are studies showing how NDVI increases dramatically
with spring vegetation, especially areas recovering from burn scars, compared to the fall
senescent vegetation. This can introduce some distortions into the true state of vegetation

The second reason is the spatial and temporal resolution of the GIMMS NDVI data used
for the study. The GIMMS data has 8km resolution while the average farm size is
0.03km. The averaging of multiple endmembers into one digital number obscures the fine
details of space and, as such, any degraded area less than 8x8 km is obscured. This is
proven by the LTM5 NDVI that shows several pockets of land area degraded across the
study area. Furthermore the presence of green vegetation, especially in urban areas of
UER is highly variable with agricultural season. During planting, many people use their
backyard for cultivation of cereals but turn the same backyard to grazing grounds after
harvest. It is therefore not surprising that images acquired during the post-harvest season
would show most urban and peri-urban areas as more degraded than previously thought.
We therefore caution that satellite data acquired for the study of land degradation in the
UER must be selected with care.

The third reason accounting for the difference in observation by NDVI and local
residents may be linked to the extensive cultivation in the area. Annual land under
cultivation increases, giving the land surface a greener appearance by those quick maturing and environmentally efficient crops. However, the yield keeps decreasing, a good sign of soil exhaustion, which is purported to have been observed in Ethiopia in the 1970s. Analysts observed the first of its kind in Ethiopia in the mid 1970s, where crops grew greener but did not produce a good yield. This situation is an indication of how efficient crops can be environmentally, in utilizing available meager nutrients and moisture, but do not produce yield in response to land degradation and exhaustion. We therefore concluded that greenness, per se, does not debunk the existence of desertification, and that scientists may be cautious using NDVI for desertification as it does not tell the entire story. Also, the study agrees that desertification is real in the area, even if there are signs of greening and that a more recovery-focused approach, including investment in land recovery and infrastructure, is needed to generate a land recovery success story. Humankind, in meeting their aspirations in the UER, relegated the ecology to the background, various governments, in their drive to achieve accelerated economic development, failed to realize the need to preserve ecological integrity and the negative repercussions that neglecting ecological integrity can have on economic development. The net effect is a region of burgeoning population, living on less than $1 per day, living with damaging effects of desertification helplessly. The final question is: is it too late?
7.2 Policy Implications

Given the complex and sometimes obscure nexus between the fragile ecology, the burgeoning population, and the bleak economic situation of Sub-Saharan Africa, and the Sahel region in particular, one can understand the urgent need for policies and actions that comprehensively address rural poverty and the rapid depletion of natural resources and promote sustainable development. The quintessential question is, given that there is increasing poverty in the midst of abundance, an emaciated and dying population, and limited financial resources and infrastructural problems, how does a country achieve both economic growth and reduced environmental degradation at the same time? Balancing these competing ends has been the cardinal failure of development policies implemented in Ghana. For example, the primary objective of Ghana’s ERP was the improvement of economic performance by revitalizing agriculture, forestry, mining, and the manufacturing industry. Although positive economic growth of about 4.5% was recorded, it was estimated that the environmental cost of achieving that economic growth was as high as 41.7 billion cedis, approximately 4% of the gross domestic product (GDP), an equivalent of US$128.3 million in 1988 alone (Anane 2000). Ghana, like many sub-Saharan African countries, sees economic development and environmental conservation as antithesis. Recent success stories from the African continent have shown that economic development and environmental conservation can be bedfellows, given that the right and appropriate policies and programs tailored to achieve the two are implemented.
The preamble to Ghana’s Environmental Action Plan (EAP 1989) states, “attempts over the years to address environmental problems in Ghana have been ad-hoc and largely cosmetic, or at best sector-oriented and therefore limited in scope.” It continues, “it has become evident that the body of existing legislation on various aspects of the environment is inadequate, and many provisions have no bearing on present-day realities as well as the aspirations of the people in the country. There is clearly the need for a new direction and trust in the national development efforts to ensure that plans aimed at improving the standard and quality of life take due cognizance of environmental considerations” (EPC 1989 20).

In taking cognizance of environmental needs in development programs, we can learn from recent success stories, such as the Machakos and Keita experience of Kenya and Niger, respectively. Machakos’ and Keita’s experiences show that the answer to the question of achieving both economic growth and reduced environmental degradation hinges on addressing two central issues:

1. The compatibility of sustainable resource management with rapid population growth; and

2. The possibility of turning around a degradational cycle towards conservation.

The experience from the Machakos district of Kenya and the Keita district of Niger explains the need for appropriate market-oriented policies and adequate infrastructure in enhancing the efficient use of natural resources, in the midst of a burgeoning population. Some of the market-based policies include the reorientation of agriculture from
subsistence to production for market, agricultural credit, the creation of a market for produce and supporting marketing infrastructure. Some of the supporting infrastructure needed in Ghana, and the UER in particular, include adequate and accessible all weather roads, storage facilities, irrigation facilities to make agriculture a year-round activity rather than seasonal, agricultural machinery and supporting social services such as schools, medical centers, and information dissemination services. The two success stories from Kenya and Niger debunk the conventional assumption that an increased population must necessarily lead to land degradation. On condition that the right approach and policies are not adopted, population growth and economic development need not result in land degradation.

In our view, the policy failure in addressing Ghana’s environmental problems is attributable to three main factors:

Lack of data. Interestingly, Ghana does not have up-to-date data on the state of the environment. It is, therefore, not surprising that environmental issues are not included—even if they do, they are on an ad-hoc basis- in a national development plan, which reflects the available data. In an interview with an official from Ghana’s EPA, the governmental department responsible for programs relating to desertification, he argued that Ghana is technically not experiencing desertification. This statement puts Ghana in a state of denial and, as such, relegates the need for appropriate measures to address the desertification menace to the background. Data compiled by GLASOD and UNEP in 1990 estimated that Ghana has moderate desertification, on the scale of slight, moderate,
severe, and very severe (Veron et al 2006; Nsiah-Gyabaah 1994). Ghana, therefore, got to the stage of desertification where moderate to severe sheet and rill erosion were evident in the 1990s. In reality, desertification becomes far advanced when slow signs like soil erosion become visible; it is against this background that Prince (2002) calls the assessment of desertification based on soil erosion a pathological activity, meaning assessment after the fact. By observing sheet and rill erosion, Ghana’s desertification level has actually gone beyond level 3 of the CCoLD, on a 1-5 point scale. Local residents interviewed for this study outlined signs of desertification in the area, which are part of the signs identified by UNCCD as slow signs of desertification, which become evident only when desertification is in the advanced stage. This explains why there is the need for current data on the state of the environment in order to focus on proactive, rather than reactive, approaches.

The second factor for the failure to address environmental degradation is the multiplicity of disjointed and fragmented institutions and laws geared towards environmental protection. This creates a situation in which institutions tend to work against each other, instead of working together, while institutional arrangements work at cross purposes. For instance, it has been estimated that there were as many as 22 governmental agencies and bodies responsible for conserving the environment with different, but sometimes conflicting and duplicating, mandates in Ghana in 1996 (Benneh 1996). People have talked about an incident in the late 1980s and early 1990s where an export promotion council and ministry of lands and forestry were encouraging and issuing licenses for
logging for export in the midst of depleting forests, while the EPA was seriously campaigning against logging. There is, therefore, the need for harmonization of purpose, coordination of efforts, and creation of a coherent body of laws that meet the realities of today and not yesterday.

The final reason for dismal success in environmental conservation efforts in Ghana is lack of human-centered policies and approaches. For instance, the structural adjustment policy, which was part of Ghana’s ERP, was criticized as adjustment without a human face. This is because the program sought to increase agricultural production while increasing the cost of farming inputs and removing agricultural subsidies. It also aimed to reduce poverty by laying people off from their jobs and promoting agricultural production by issuing import licenses for importation of cheap foreign food stuffs to out-compete locally produced high cost food stuffs. Moreover, in the phase of land degradation and climate change, local farmers adapted some coping mechanisms for short-term relief; however, government programs and policies would rather work against local adaptation by imposing expert knowledge and encouraging export-oriented crops, which worked to the detriment of local food production. There is the need for people and local conditions, friendly policies and programs, which incorporate local knowledge and grassroots participation in conception and implementation.

Government policy needs to create a sense of ownership and empowerment for local people to deal with land degradation. Given that land ownership and jurisdiction is in the
hands of Tindana, the local leader, a community-based approach to land conservation in which governmental agencies and personnel work with Tindanas seems plausible. Again, fire has been the most consistently identified culprit of land degradation in the UER. In view of the widespread and frequency of fire in the region, wildfire policy, this looks at burn or no burn; and if burn, the timing of burning and, more importantly, prescribed and controlled burning, becomes necessary. In Sub-Saharan Africa, adaptation has been an integral part of society. In many places, societal resiliency has been driven by continuous adaptation. It is, therefore, myopic to ignore societal adaptations and survival mechanisms in the face of ecological change, and should therefore be taken seriously in policy design and implementation.

7.3 Recommendations

- We want to recommend, as a matter of urgency, the establishment of a state of the environment and geospatial database that will continuously map out and collect a spatio-temporal environmental and land use data to help monitor environmental trends in Ghana. This will help in continuous assessment, planning, and incremental management of the environment.

- We also recommend coordination and harmonization of all programs involving the Ghana government, nonprofit organizations, and local people within the national environmental action plan, geared towards re-afforestation and recovery
of degraded lands and urban green where more trees and grasses are planted to be part of the urban landscape of the area.

- Also, it is important that any effort at addressing land degradation in the area include programs to address food security, agricultural development, and residential land uses in an integrated manner to ensure that programs do not compete or become isolated in order to not work against each other.

- Since land degradation in the UER is found more around population centers, and along roads and rivers, it is important to address the issue right from population centers around the Bawku, Bolgatanga, and Paga-Navorongo areas.

- The need for a national wildfire policy is long over due. There is, therefore, the need for wildfire/bush burning policies and programs that ensure prescribed burning for certain areas within certain times of the year, beyond which, burning must be strictly prohibited.

7.4 Summary

This study of detecting and quantifying desertification and its impact was conducted not just because it makes economic and ecological sense, but really because it borders on the lives of millions of people, who are remote to power sources and as such have a distant
voice, are resource poor, and above all need help. Motivated by these syndromes, the study has accomplished four main goals, which include the following:

- Using a vegetation change trend measured by satellite data from AVHRR, LTM5 and LETM+, and IKONOS2, the study has mapped and quantified the spatio-temporal extent of land degradation in the UER over a period of 26 years. The continuity of AVHRR data, validated by selected LTM5 and LETM+ scenes, has created a longitudinal profile of vegetation in the UER. This avoids the trap of land degradation resulting from inter-annual and inter-decadal vegetation variability linked to rainfall regimes of the study area. In addition, using NDVI, the approach focused on process indicator measured in a continuum, instead of what Stocking (2001) called the sterile approach, which focuses on soil. The study concluded that future studies should take cognizance of scale, both spatial and temporal. Moreover localization of degradation tends to be obscured and that most remote sensing studies run the risk of generalizing trends to the neglect of certain areas or local specifics, which creates differential impacts.

- The study has also measured the spatial extent of land degradation and highlighted the severity of the desertification problem in the UER. It is hopeful that policy makers, stakeholders, and civil society support groups, including multinational organizations and other nongovernmental organizations, would better understand the plight of desertification victims and assist in both short and long term efforts to ameliorate and eventually combat the desertification menace.
• One important accomplishment of this study is the voice given to the voiceless victims of desertification. Hitherto, who hears the voices of these folks? Scientists for far too long have focused solely on remote sensing technology and its fancy visualization of increasing NDVI over the Sahel. However, the greater part of the desertification story is not told by the current state or the art. What this study has uniquely done is given the desertification victims a voice by telling scientists, policy makers, and other stakeholders their version of the story, which until now, is not told by remote-sensing technology and other methodologies. Perhaps this will be an eye-opener for remote sensing scientists to learn and to listen to the people.

• In addition to telling the world what is not known about the UER, the study has also made some policy recommendations that are problem-solving and community specific, which holds the potential to address desertification and food security issues in the area.

• Finally, it is our ardent belief that what has been accomplished in this study could be replicated in other parts of the world and help solve this global crisis and make life meaningful to about 2.5 billion people under the threat of desertification globally.

Future study:

1. The extent to which land degradation is caused by agriculture is evident in this study; however, we are not sure what have been the actual farming practices that have the greatest impact. We recommend that future studies should look at different farming practices and their contribution to, or impact on, land degradation.
2. Also, we found that adaptation has been a key to success in many communities; however, we are not sure of how local adaptations and coping mechanisms help in either solving or worsening land degradation. There is, therefore, the need for detailed study on land degradation and adaptations in the UER. We also recommend regional dialogue on rural adaptations against land degradation and climate change in Africa.

3. To be effective and efficient in combating land degradation, certain spatial decision concepts are relevant. Originally, this study sought to include a decision support system as part of the study; however, lack of data, time, and financial resources did not allow that to materialize. We therefore recommend future work on a decision support system that integrates land capability data, land use, population, grazing, and vegetation and elevation data to evaluate and predict future directions and at risk areas for planning purposes.
<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AI</td>
<td>Aridity Index</td>
</tr>
<tr>
<td>ANPP</td>
<td>Annual Net Primary Product</td>
</tr>
<tr>
<td>ASTER</td>
<td>Advanced Spaceborne Thermal Emission and Reflection Radiometer</td>
</tr>
<tr>
<td>AVHRR</td>
<td>Advanced Very High Resolution Radiometer</td>
</tr>
<tr>
<td>CCD</td>
<td>Convention to Combat Desertification</td>
</tr>
<tr>
<td>CCoLD</td>
<td>Continuous Cycle of Land Degradation</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon Dioxide</td>
</tr>
<tr>
<td>CSIR</td>
<td>Council for Scientific and Industrial Research</td>
</tr>
<tr>
<td>CVA</td>
<td>Change Vector Analysis</td>
</tr>
<tr>
<td>EAP</td>
<td>Environmental Action Plan</td>
</tr>
<tr>
<td>ENSO</td>
<td>El Niño-Southern Oscillation</td>
</tr>
<tr>
<td>EPA</td>
<td>Environmental Protection Agency</td>
</tr>
<tr>
<td>ERP</td>
<td>Economic Recovery Program</td>
</tr>
<tr>
<td>FAO</td>
<td>Food and Agricultural Organization</td>
</tr>
<tr>
<td>GA</td>
<td>Genetic Algorithms</td>
</tr>
<tr>
<td>GCMs</td>
<td>Global Circulation Models</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information Systems</td>
</tr>
<tr>
<td>GLASOD</td>
<td>Global Assessment of Human Induced Soil Degradation</td>
</tr>
<tr>
<td>GPS</td>
<td>Geographic Position System</td>
</tr>
<tr>
<td>IFAD</td>
<td>International Fund for Agricultural Development</td>
</tr>
<tr>
<td>IFPRI</td>
<td>International Food Policy and Research Institute</td>
</tr>
<tr>
<td>IMF</td>
<td>International Monetary Fund</td>
</tr>
<tr>
<td>ITCZ</td>
<td>Inter-Tropical Convergence Zone</td>
</tr>
<tr>
<td>ITD</td>
<td>Inter Tropical Discontinuity</td>
</tr>
<tr>
<td>LC</td>
<td>Library of Congress</td>
</tr>
<tr>
<td>LETM+</td>
<td>Landsat Enhanced Thematic Mapper Plus</td>
</tr>
<tr>
<td>LOT</td>
<td>Look Out Table</td>
</tr>
<tr>
<td>LSMA</td>
<td>Linear Spectral Mixture Analysis</td>
</tr>
<tr>
<td>LTM</td>
<td>Landsat Thematic Mapper</td>
</tr>
<tr>
<td>LTM5</td>
<td>Landsat-5 Thematic Mapper</td>
</tr>
<tr>
<td>MODIS</td>
<td>Moderate-resolution Imaging Spectroradiometer</td>
</tr>
<tr>
<td>MoFA</td>
<td>Ministry of Food and Agriculture</td>
</tr>
<tr>
<td>MTADP</td>
<td>Medium Term Agricultural Development Program</td>
</tr>
<tr>
<td>NAP</td>
<td>National Action Plan</td>
</tr>
<tr>
<td>NDVI</td>
<td>Normalize Vegetation Index</td>
</tr>
<tr>
<td>NIR</td>
<td>Near Infrared</td>
</tr>
<tr>
<td>NO₂</td>
<td>Nitrogen Dioxide</td>
</tr>
<tr>
<td>NRC</td>
<td>National Redemption Council</td>
</tr>
<tr>
<td>OECD</td>
<td>Organization for Economic Co-operation and Development</td>
</tr>
<tr>
<td>Acronym</td>
<td>Full Form</td>
</tr>
<tr>
<td>-----------</td>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td>OFY</td>
<td>Operation Feed Yourself</td>
</tr>
<tr>
<td>OFYI</td>
<td>Operation Feed Your Industries</td>
</tr>
<tr>
<td>PAMSCAD</td>
<td>Program of Action to Mitigate the Social Cost of Adjustment</td>
</tr>
<tr>
<td>PDR-ADM</td>
<td>Ader Doutchi Maggia Rural Development Project</td>
</tr>
<tr>
<td>PNDC</td>
<td>Provisional National Defence Council</td>
</tr>
<tr>
<td>RUE</td>
<td>Rain Use Efficiency</td>
</tr>
<tr>
<td>SAPs</td>
<td>Structural Adjustment Programs</td>
</tr>
<tr>
<td>SST</td>
<td>Sea Surface Temperature</td>
</tr>
<tr>
<td>UER</td>
<td>Upper East Region</td>
</tr>
<tr>
<td>UN</td>
<td>United Nations</td>
</tr>
<tr>
<td>UNCCD</td>
<td>United Nations Convention to Combat Desertification</td>
</tr>
<tr>
<td>UNCCDD</td>
<td>United Nations Convention on Combating Desertification and Drought</td>
</tr>
<tr>
<td>UNCED</td>
<td>United Nations Conference on Environment and Development</td>
</tr>
<tr>
<td>UNCOD</td>
<td>United Nations Conference on Desertification</td>
</tr>
<tr>
<td>UNEP</td>
<td>United Nations Environmental Program</td>
</tr>
<tr>
<td>US</td>
<td>United States</td>
</tr>
<tr>
<td>USA</td>
<td>United States of America</td>
</tr>
<tr>
<td>USAID</td>
<td>United States Agency for International Development</td>
</tr>
<tr>
<td>UK</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>WDR</td>
<td>World Development Report</td>
</tr>
</tbody>
</table>
APPENDIX 2

Desertification analysis questionnaire (Upper East Region, Ghana): Please explain the reason and how this information shall be used and confidentiality of it using attached script

Name of Interviewer ……………………………………………………………………….
Questionnaire Number: …………………………… Date …………/……./200……………
Region: Upper East Region (UER) District: ………………………………………………

Village/Town Name: ……………………………………………………………………..

Respondent Information:

Sex:  Male ………… Female ……… Number of years of resident in the district ………
Age …………………. Farming Practice……………………………………………………
Number of Livestock …………………………… Number of farms ……………………
How many members are in the household ……………………………………………
How many have migrated …………………. How often do they come back home ……. 
Type of migration: Seasonal ……………………… Permanent …………..
Rural-Urban ……… Rural-Rural ………… Region of Destination ……………………..

Agriculture

Does this migration affect farm size or farming practice? (y) (n) Please explain ………
What is your average farm size …………………and how many farm plots ………
How often do you farm on the same piece of land and why ………………………………
How often do you burn your land ……………………………………………………..
Have you noticed any change in your land’s productivity …………………………
Explain what you think might contribute to that ………………………………………
Where do you graze your livestock ……………………………………………………………
How often do you graze on that piece of land …………………………………………………
Do you have any reason for grazing at any specific place? Explain
………………………………………………………………………………………………………………

Environmental
Have you noticed any change in the rainfall pattern, Please explain .........................
………………………………………………………………………………………………………………

Please describe the rainfall pattern as you can remember for the years of living here
………………………………………………………………………………………………………………
Do you see any change in the vegetation pattern? ..........................................................

Describe the vegetation pattern as far back as you can remember ..............................
………………………………………………………………………………………………………………

How often do you experience bush fire in your area  a) every year (b) every two years (c) 
>5 years (d) more than once a year (e) only during fire festival

Why do people burn (a) Hunting (b) clear land for farming (c) grazing (d) fire festival
(e.) Any other(s) …………………………………………………………………………………

Rank the above reasons in order of importance
1.
2.
3.
4.
5.
6.

Do you think the area is experiencing vegetation change (Desertification)
………………………………………………………………………………………………………………

What environmental problems are you facing in your area .................................

Do you see land degradation as a problem .........................................................
Explain how? ............................................................................................... 

What are your people doing about environmental degradation
………………………………………………………………………………………………………………

Do you expect any help ..............................................................
From where ........................................................................
Type of help expected .................................................................
How do you think land degradation (desertification) can be stopped or prevented
........................................................................................................

What do you know about desertification ...........................................
Do you think it is problem in your community and why ................................
Can you recall the time when you first observed desertification in your area ..........
REFERENCES


Adu-Boahen, A., (1968). Topics in West African history. Western Printing Services, Bristol, UK


Chadwick, M.J., (1994). "Visions of a Sustainable World: Ethical Evaluations or Political


269


http://earthtrends.wri.org


Environmental Protection Agency (Ghana), (2003). National Report to the committee for the review of the United Nations Convention to Combat Desertification. EPA, Accra Ghana


Environmental Protection Agency (Ghana), (2002). National action programme to combat drought and desertification. Accra: EPA.


Hueting, R., (1980). New scarcity and economic growth: More welfare through less productivity? Amsterdam, Holland


projects drought in southern Africa, rain in Sahel. National Center for Atmospheric Research; press release 24-may-2005


Dunlaagberuk, East Mamprusi District, Northern Region of Ghana. University of Development Studies, Tamale Ghana


Lambin E.F., et al. (2001). The causes of land-use and land-cover change: Moving beyond the myths. Global Environmental Change 11: 261–269.


A change vector analysis technique for monitor land use/land cover in SW Brazilian Amazon: Acre State. National Institute for Space Research- INPE, Brazil.


MoFA, (2006). Regional Agricultural Review; MoFA, Bolgatanga


in Serengeti National Park, Tanzania. Regional Remote Sensing Facility, Nairobi Kenya


Stebbing, E.P., (1935). The encroaching Sahara: the threat to the West African colonies,


Web References:


Daily Graphic (2007)


Ghana Districts: www.ghanadistricts.com

Ghana Information (12/02/08)

Ghana Medical Services (2008-12-06)


Upper East Region  http://www.africanaonline.com/africa.htm

CURRICULUM VITAE

Alex B. Owusu graduated from Simms High School, Fawoade, Kumasi – Ghana in 1990. He received his Bachelor of Arts degree in Geography and Resource Development from University of Ghana, Legon - Ghana in 1997. In the year 2000, he received Master of Philosophy degree in Geography and Resource Management, also from University of Ghana. After serving in the position of the Executive Director of Computerland Ghana Ltd for two and half years, Alex relocated to Athens, Ohio –USA, where he enrolled to receive a dual Master’s degree in Environmental Policy and Planning (Ms) and International Affairs (MA) in the year 2005.

In January 2006, Alex enrolled to the Department of Earth Systems and Geoinformation Sciences, now the Department of Geography and Geoinformation Science to pursue his PhD in Earth Systems and Geoinformation Science.