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Multi-dimensional approach for evaluating land degradation in the Savanna belt of the White Volta Basin

By

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CERTIFICATION

I hereby declare that this work submitted as a thesis to the School of Research and Graduate Studies of the Kwame Nkrumah University of Science and Technology, Kumasi for the degree of Doctor of Philosophy in Climate Change and Land Use is the findings of my own investigation and does not contain material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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DEDICATION

I dedicate this piece of work to my parents (Mr. and Mrs. Baatuuwie) for their good intentions, initiatives and labour which has brought me to this far. Father, I will always remember the blessings invoked upon me before you passed to Glory.

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ABSTRACT

The White Volta Basin (WVB) is located within the Savanna Ecological Zone shared by Ghana, Burkina Faso and Togo. It is of national importance to the development of these countries through agriculture, urban water and hydro-electric supply, transportation, tourism and others. Despite its benefits and potentials, it is currently under threat due to land degradation (LD) driven by both anthropogenic and natural forces. A multidimensional approach was employed to assess the degradation at two spatial scales (i.e. Basin and sub-basin scales) and propose mitigation measures. Spatial data from remote sensing historical land cover (1990-2007); existing GIS database of soil erosion obtained from RUSLE was integrated to determine LD hotspots in the area at a basin scale. Sub-basin scale assessment was also done to complement the basin scale analysis to ensure information complementarities. Observable indicator system developed from literature and expert consultation was used in conjunction with FAO field protocol for mapping land degradation in the sub-basin. Additionally, data on socio-ecological determinants of land degradation and mitigation measures were also gathered through interviews and group discussions. The results indicated that land degradation is persistently occurring in the basin and can be effectively mapped using these indicators. Soil loss through erosion and negative land use/cover conversion (NLUCC) were common indicators identified and used to map land degradation at both basin and sub-basin's scales. About 82% of the basin is degraded due to negative land use/cover conversion or soil erosion. Of this, 33% of the basin's area is experiencing severe degradation. Degradation hotspots were found around areas where urbanization was on the increase. A cross-scale analysis of the different indicators at the two scales showed that, there exist matches and divergences between some indicators. The best indicator matches was between the net soil loss at the basin scale with that of soil erosion state at the sub-basin scale (92.6%) and erosion extent (92 %). There exists a great divergence between negative land use/cover conversions at the basin scale and erosion severity at the sub-basin scale with a divergent value of 87 %. Poor agricultural soil and rangeland management, deforestation as well as climate change were perceived to be the direct drivers of LD in the basin. Increased in human population, change in demand and consumption for food and fuel wood, poverty and inadequate labour were the main indirect drivers responsible for the degradation in the basin. Identified possible mitigation measures to combat the degradation in the basin include: controlled bush burning or no burning, minimum tillage and crop rotation. Others were stone bunds, organic manures and mineral fertilization. The study revealed that land degradation is occurring in the basin and can be mapped using both proxy and observable indicators. Thus, this will reduce the cost and time involved to assess land degradation at the sub-basin or field levels using traditional methods. It is therefore recommended that the appraisal of land degradation should embrace these three pillars (multi-scale, multi-indicators and actor-based) as proposed in this study for effective and accurate results as well as development of appropriate mitigation interventions.

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LIST OF ABBREVIATIONS

CERSGIS	Centre for Remote Sensing and Geographic Information Services
CIESIN	Center for International Earth Science Information Network
ETM+	Enhanced Thematic Mapper Plus
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
GIS	Geographic Information Systems
GLASOD	Global assessment of soil degradation
GEF	Global Environment Facility
GLCF	Global Land Cover Facility
GPS	Global Positioning System
HYSS	Hydrologically Similar Surfaces
IRIN	Integrated Regional Information Networks
IAC	InterAcademy Council
ICARDA	International Center for Agricultural Research in Dry Areas
IFPRI	International Food Policy Research Institute
IFAD	International Fund for Agricultural Development
ITTO	International Tropical Timber Organization
ITCZ	Inter-tropical Convergence Zone
IUCN	International Union for Conservation of Nature and Natural Resources
KNUST	Kwame Nkrumah University of Science and Technology
LADA	Land Degradation Assessment in Drylands
LD	Land degradation
LANSAT	Land Satellite
LUCID	Land Use Change Impacts and Dynamics

LUCC	Land Use/Cover Change
NSL	Let Soil Loss
MEA	Millennium Ecosystem Assessment
MLF	Ministry of Land and Forestry
MODIS	Moderate Resolution Imaging Spectroradiometer
NOAA	National Oceanic and Atmospheric Administration
NLUCC	Negative Land Use/Cover Conversion
NPP	Net primary productivity
NY	New York
NDVI	Normalized Difference Vegetative Index
OIs	Observational indicators
OECD	Organization for Economic Co-operation and Development
PLEC	People Land Management and Environmental Change
PIs	Proxy indicators
RII	Relative Importance Index
RUSLE	Revised Universal Soil Loss Equation
SADA	Savanna Accelerated Development Authority
SWAT	Soil and Water Assessment
SMART	Specific, Measurable, Achievable, Relevant, and Time-bound
SPSS	Statistical Package for the Social Sciences
SSA	Sub-Saharan Africa
SLM	Sustainable Land Management
SLM	Sustainable Land Management
SLaM	Sustainable Land Management for Mitigating Land Degradation
TM	Thematic Mapper
USA	United State of America

UN	United Nations
UNCED	United Nations Conference on Environment and Development
UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environmental Programme
USDA	United States Department of Agriculture
UTM	Universal Transverse Mercator
WASCAL	West African Science Service Centre on Climate Change and Adapted Land Use
WVB	White Volta Basin
WMO	World Meteorological Organization
WOCAT	World Overview of Conservation Approaches and Technologies

1.0 INTRODUCTION

1.1 Background

Land degradation (LD) is a global problem that has gained prominence in the 21st century due to the threat it poses to the environment in general. Land degradation with respect to dry lands is defined as "*the reduction or loss, in arid, semi-arid and dry sub-humid areas, of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns"* (UNCCD, 2012). The issue of land degradation will continue to be a global subject of importance due to the threat it poses on land resources, sustainable development and sustenance of vulnerable human societies (Stocking & Murnaghan, 2001; Millennium Ecosystem Assessment, 2005; Nkonya *et al.*, 2011; Lal *et al.*, 2012; UNCCD, 2012).

A large proportion of the world's population depends on land-based resources for their livelihoods and issues of land degradation are of serious concern to such people. It has been reported that more than 1.5 billion people are already living in geographical locations that are experiencing serious land degradation (Bai *et al.*, 2008; Nellemann *et al.*, 2009). The implication is that those depending on land-based livelihoods in such areas are seriously affected.

Land degradation has eaten up huge proportion of the land area in the world since the nineteenth century. Estimates by the Global Assessment of Land Degradation (GLASOD) in the early nineties (Oldeman *et al.*, 1991) indicates that about 15% of all global productive land has been degraded. Bai *et al.* (2008) reported an increase in the degraded global land area to 24%. A recent report by Lal *et al.* (2012) confirmed that about a quarter of the global land area has been degraded and a major consequence is an estimated 12% decline in global food production in the next 25 years (International Food Policy Research Institute- IFPRI, 2011).

In Africa, land degradation has long been recognized as a critical problem that is continuously worsening. It is estimated that two-thirds of Africa's productive land is affected by land degradation while nearly all the land area is prone to soil and environmental degradation (Vlek *et al*., 2008; TerrAfrica, 2009; FAO, 2011). These statistics do not exclude the White Volta basin (WVB) in West Africa which is a key resource to the development of the riparian countries (Ghana, Burkina Faso and Togo). This paints gloomy picture especially for the rural people who solely depend on land for their livelihood. As a global problem, the need to tackle it has been recognized by various international bodies such as the United Nations Convention to Combat Desertification, the Conventions on Biodiversity and Climatic Change, and the Millennium Development Goals (UNCED, 1992; UNEP, 2007).

Land degradation is however a complex phenomenon both in time and space making its quantification complicated. The incidence of land degradation is variable in its expression and is complexly interwoven as a result of physical, chemical and biological processes (Eswaran *et al.*, 2001; Bai *et al.*, 2008; Abu-Hammad & Tumeizi, 2010; UNCCD, 2012). This complex relationship poses a great challenge in its appraisal partly due to inadequate and effective methods to evaluate the degradation process holistically (Lu *et al.*, 2006; Le, 2012).

Another major challenge hampering effective monitoring and assessment of land degradation is the fragmentation of current knowledge in structure, procedure as well as criteria and indicators. This impedes the flow of knowledge between land degradation monitors at the local, national, regional and international levels making the results of such studies inapplicable to provide their needed benefits (Stringer & Reed, 2007; Bauer & Stringer, 2009; Reed *et al.*, 2011). For instance assessments of land degradation at international scales focus mainly on expert opinions to quickly assess degradation at a global coverage with minimum cost (Oldeman *et al.*, 1991; UNEP, 1997). Unfortunately, such assessments are biased and hardly incorporate information from the local scale (van Lynden & Kuhlmann, 2002). Information at the local scale however is inevitably essential for the design of technological interventions.

Local scale approaches of land degradation assessment are mostly empirical measurements using indicators. This approach is weak in terms of data representativeness (Pickup, 1989) and limited in spatial and temporal resolution in providing information on long-term basis. It is also labour intensive, time consuming and expensive especially for large areas (Loughran, 1989; Hill *et al.*, 1995) and in some cases impossible in inaccessible areas.

With the advancement of technology in the fields of modeling, remote sensing and Geographic Information Systems (GIS) (Maitima *et al.*, 2004), it is possible to rapidly map out areas that are experiencing degradation in an effective manner. These techniques offer the opportunity to map and evaluate land degradation at different temporal and spatial scales at a faster rate at a lower cost (Sanchez *et al.*, 2009). An example of such approach is the Global Assessment of Land Degradation and Improvement (Bai *et al.*, 2008) and Le *et al*. (2012) in West Africa that identified ‘hot spots' of land degradation and 'bright spots' of land improvement. Despite the benefits of these techniques, they have often been criticized, especially for insufficient calibration and validation. This calls for approaches that will overcome these methodological flaws and provide accurate results from land degradation assessment especially in WVB for policy and decision making.

Within the WVB, efforts have been made to tackle land degradation but these efforts did not stand the test of time and scale. Land degradation mitigation technologies/measures such as Sustainable Land Management for Mitigating Land Degradation (SLaM), People Land Management and Environmental Change (PLEC) in northern Ghana and many others were recommended and promoted. However, they did not meet expectations partly due to divergence between the perspectives of the scientists, technology developers, local experts and the views of land users who are expected to implement the findings and recommendations (Stocking & Murnaghan, 2001). Thus, the failure to recognize all the actors in the appraisal and development of the intervention towards fighting land degradation and sustainable land management was a critical weakness.

This study therefore seeks to address the above methodological gaps for land degradation assessment in the WVB which is experiencing serious land degradation. The aim of the study was to design a systematic framework that takes into consideration the spatio-temporal variations and socio-ecological complexity in evaluating land degradation at two (Basin and sub-basin) levels. This is because; land degradation intrinsically entails interaction among natural, economic and socio-political processes that behave differently at different scales. Hence, an indicator of a process has its optimal reflective value at a particular level (Verburg *et al.*, 2004; Stein *et al.*, 2001) and will be evaded if not systematically planned to include its reflective level.

1.2 Problem Statement and Justification

The WVB is a major socio-economic resource for the riparian countries, especially Ghana and Burkina Faso. The basin is the main source of hydropower which fuel industrial and major economic development in these countries. Also, the WVB supports rain fed agriculture and irrigation facilities that improve food security and the livelihoods of many rural people in these countries and beyond. Agriculture remains the main economic activity as well as source of employment and income for most of the population in these countries. According to a report by UNEP-GEF Volta Project (2010) about 80% of the labour force in Burkina Faso is employed in crop production and/or livestock. The picture is not different in Ghana. Agriculture still accounts for nearly one third of Ghana's GDP and it is even more dominant in the White Volta Basin, with more than 50% of employees engaged in this sector (UNEP-GEF Volta Project, 2013). The sustainability of livelihood activities of the inhabitants in the area is under serious threat due to land degradation.

Currently, high population within the WVB coupled with the direct impacts of climate change is putting pressure on the basins natural resources. Increasing demographic pressure has resulted in the over-exploitation and misuse of land resources. In the current circumstances of climate change, any natural resource with such a value is likely to attract a lot of pressure and suffer degradation in one form or the other if not managed properly. In the case of the WVB, the bane of its sustainability and functioning is land degradation as mentioned earlier. However, the issue with land degradation in general is complex in space and in time which makes it difficult to effectively detect on timely basis both at large scale and at small scale. Its timely detection is critical because it is difficult to reverse land degradation at an advanced stage and when it is usually beyond the capacity of the local people to manage.

A multi-dimensional approach which encompasses multi-scale, multi-indicators and actor-based framework is required in evaluating the complex system such as land degradation especially within the WVB. The multi-scale of the framework focused on evaluating land degradation at different spatial and temporal scales within the WVB (Basin and sub-basin scales). Degradation occurs over many spatial scales at varied magnitude with time. It varies from site of impact to whole fields and catchments (Stocking & Murnaghan, 2001) therefore exhibiting complex interactions with time. Different regions may also be experiencing considerably varied drivers of land degradation; differing from biophysical, socioeconomic to political factors (Lu *et al.*, 2006; Stocking & Murnaghan, 2001) which need to be taken into account during land degradation assessment.

The multi-indicators component of the framework involved the use of more than one indicator for land degradation assessment. This was necessary because, the use of a single indicator often gives singular expression of land degradation or its impact and is most often susceptible to errors, misinterpretation and chance (Stocking & Murnaghan, 2001). Combination of indicators however permits a more robust comparison of different types of measure to obtain a better and complete understanding of the degradation in a particular area (Stocking & Murnaghan, 2001). The actor-base of the framework includes seeking the viewpoint of land degradation from different experts and stakeholders of the land.

1.2.1 Aim and Research Objectives

The aim of the research was to evaluate land degradation at different scales across the White Volta Basin and propose mitigation measures to reverse the degradation. The following specific objectives were set to answer the research questions raised:

1. To develop an indicator system for detecting different stages of land degradation in the White Volta basin,
2. To map land degradation hotspots in the White Volta Basin,
3. To identify matches and divergences between basin and sub-basin scale indicators for measuring LD,
4. To identify socio-ecological causes of land degradation in the basin,
5. To derive measures for mitigating land degradation and land restoration in the White Volta Basin.

1.2.2 Research Questions

The study contributed both theoretical and practical knowledge to the understanding of land degradation in the White Volta Basin. The questions raised below were as a result of significant gaps in the literature relating to land degradation assessment in the White Volta Basin. The research questions were:

1. What criteria and indicators best detect the different stages of land degradation in the White Volta basin?
2. Where are the land degradation hotspots in the White Volta Basin?
3. What indicator (s) best measure LD at the different scales?
4. What are the social and ecological causes of land degradation in the basin?
5. What mitigation measures are available that can be explored to combat land degradation in the basin?

1.3 General Research Approach

The research began with an in-depth review and analysis of the relevant literature on land degradation. It involved the conceptualization of a spectrum of the successive stages of land degradation, criteria and indication of assessment. Standard methods for data collection and analysis were also identified during the literature review.

A reconnaissance survey was carried out to provide a better understanding of the characteristic of the study area. A participatory maping of degraded areas was done with local experts and communities/farmers. Socio-economic survey was conducted to identify and rank key causes of land degradation in the study area. Field measurement of biophysical indicators of land degradation was also carried out at the local scale. Remote sensing and GIS methods were employed to assess the trend of land use/cover change as a proxy of land degradation in the study area. These techniques were also used to further analyse and evaluate land degradation in the study area. Based on the outcome of the land degradation, management measures that will reverse or mitigate land degradation and restore land ecosystem services are proposed.

2.0 LITERATURE REVIEW

2.1 Definitions and Key Concepts

There are several definitions of land degradation which can sometimes be mystifying. According to UN/FAO (1997), land degradation generally denotes the temporary or permanent reduction in the productive capacity of the land. Others however defined land degradation as, the collective decline of the productive potential of the land, including its major functions and services, farming systems and values as an economic resource (Rosister, 2001; MEA, 2005; Ezeaku & Davidson, 2008; McDonagh & Bunning, 2009; Nachtergaele *et al*., 2010). The United Nations Convention to Combat Desertification (UNCCD, 2012) however has a unique definition of land degradation which pertains to dry lands. It defines land degradation as:

> "A reduction or loss, in arid and semi-arid and dry sub-humid areas, of the biological or economic productivity and complexity of rain-fed or irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns."

The connection between land degradation caused by land use practices and its effect on land productivity is fundamental to almost all published definitions of land degradation. Most importantly the central points of all the definitions are based on ecosystem functions and services. Thus a land is considered degraded if it is unable to perform these functions or provide the necessary ecosystem services for human well-being.

2.2 Overview of Land Degradation in the White Volta Basin

The White Volta Basin cuts across the Guinea and Sudan savanna agro-ecological zones that are most susceptible to degradation (Asiamah *et al*., 2000). In these environs, the traditional systems of soil fertility restoration such as bush fallowing, shifting cultivation and nomadic grazing, have broken down due to over population of both human beings and animals (Asiamah *et al.*, 2000; Sant 'Anna, 2001; Tamene *et al.*, 2006; Ciampalini *et al.*, 2008; Nyssen *et al.*, 2009). This has resulted in the use of marginal lands with serious degradation problems (Asiamah & Quansah, 1992). This goes a long way to exacerbate the problem of land degradation in the basin.

The main types of land degradation in the WVB include soil degradation (soil erosion and nutrient depletion), vegetation degradation and water resources degradation (Environmental Protection Agency, 2005; Le *et al*., 2012; Adanu *et al.*, 2013; UNEP-GEF Volta Project, 2013). According to Le *et al.* (2012) about 65 % of the basin is losing some of its vital attributes such as soil quality or vegetation productivity due to land degradation. This is likely to get worse if mitigation measures are not put in place.

Soil degradation in the basin

The majority of the soils in the basin are Arenosols, Lixisols, Regosols, Leptosols and Plinthosols (EPA, 2011). These soil are characteristically light-textured and intrinsically low in fertility, poor in structure, low organic matter and have low buffering capacity (Agboola & Aiyelari, 2000; Asiamah *et al*., 2000; Sant 'Anna, 2001). These features make the soils highly susceptible to accelerated erosion (Agboola & Aiyelari, 2000).

The major forms of soil erosion in the basin include splash, rill, inter-rill and gully. Though absolute figures are not available, large tracts of land have been reported destroyed by rill, inter-rill and gully erosion in some parts of the basin (Quansah, 1990).

These types of erosion are influenced by the topography, mainly slope gradient and surface characteristics of the land, including the size of the soil particles, degree of particle cohesion and the nature of vegetation cover (Stocking & Murnaghan, 2001). Raindrops detach soil particles through splash erosion which are further transported through inter-rill erosion. Inter-rill erosion transports the fine nutrient-rich top soil particles and organic matter down slope which can be transported up to thousands of kilometres (Stocking & Murnaghan, 2001). The turbulence of inter-rill flow can be increased by wind driven rain drops falling into the flow. Clay, silt, nutrients and organic matter are selectively carried away by inter-rill erosion over gentle slopes, which are typical of the White Volta Basin (Roose and Barthes, 2001).

It has been reported that severe erosion has reduced topsoil thickness by over 30% within a period of 24 years in the basin (Senayah *et al.*, 2005; Amegashie *et al., 2012*). Tamene *et al.* (2008) reported a mean soil loss within the basin to be 35 tons per hectare per year. A major consequence in the loss of soil depth due to erosion is the length of time it takes to replace the lost soil. Hudson (1995) reported that, under optimal soil conditions in the tropics, the rate of soil formation was about 2.5 cm in 30 years (i.e. 0.83 mm/y). Lal (1987) also reported that new soil is formed at the rate of about 2.5 cm in 300 to 1000 years (i.e. 0.083 to 0.025 mm y^{-1}) under normal conditions. In general, it takes barely one year to lose 1 cm of topsoil but 1000 years to replace it (Lal, 1987). According to Amegashie *et al.* (2012), between 9 to 13 years, 1.1 to 8.4 cm of the topsoil was lost in certain parts of the basin and will take between 1000 to 8000 years to replace.

Inappropriate land use practices such as those that lead to the exposure of soil surfaces facilitate the erosion process in the basin (Quansah *et al*., 1990; 1997). Accelerated erosion has a negative effect on soil quality and its agronomic productivity (Lowery *et al.*, 1998; Lal *et al*., 1998). For instance, Adama (2003) reported the marginal effect of soil loss on yield loss of maize to be equivalent to 14 kg/ha in Ghana.

Apart from soil erosion, soil nutrient depletion is also a major constraint in the basin (Senayah, 1994; Amegashie *et al.*, 2012). In their study, Senyah *et al. (2005)* found that soil chemical degradation through loss of nutrients including organic matter was ranked second to soil erosion. The loss of soil nutrient was attributed to crop removal in harvested crops and residues, leaching, erosion, burning and nitrogen volatilization. These losses have reduced soil productivity, thus, leading to declining food production, food insecurity, reduced farm family incomes and livelihoods, slow economic growth against the background of increasing population and urbanization (Shetty *et al.*, 1995; EPA, 2011).

Vegetation degradation in the basin

Forest and woodland resources in the WVB have experienced extensive degradation in recent decades and this has led to serious loss of vegetative cover. A report by EPA (2005) indicated that the vegetation in the basin has declined both in quantity and quality. There has been a large transformation of natural vegetation cover to agricultural lands with annual change of 5% (Ademola, 2004). Other noticeable change in the basin is the conversion of agricultural lands and natural vegetation to artificial surfaces. An NDVI image analysis also showed evidence of remarkable vegetation cover degradation in some parts of the basin (CERSGIS, 2010).

Furthermore, investigations in Bolgatanga and Talensi- Nabdam districts of northern Ghana revealed a decline in the healthy vegetation from 1990 to 2004 resulting in about 600 km^2 of the land being degraded (Agyeman, 2007). These reductions in vegetation cover occur greatly in areas that had high tree density and these areas have changed to less tree density cover which means that a lot of trees have been felled for various reasons e.g. fuel wood, timber and other purposes (Yiran *et al.*, 2011). A study in Burkina Faso, between 1965 and 1995 also indicated that the natural vegetation had declined from 43 to 13 % of the total basin area, whilst the cultivated areas increased from 53 to 76 per cent and the area of bare soil nearly tripled from 4 to 11 per cent (Droogers *et al*., 2006).

Water resources degradation in the basin

Both ground and surface water is of significance to the inhabitants of the WVB. About 60% of the total drinking water supply in rural areas of Burkina Faso comes from groundwater whiles in Ghana about 52 % of the rural population depended on groundwater as the source of their drinking water (Gyau-Boakye, 2001). Changes in the availability of water across the basin are however pronounced. Most of the rivers in the basin have great temporal variations under natural conditions (UNEP-GEF Volta Project 2013). Many of the water bodies naturally dry up for lengthy periods and flooding also occurs naturally Water Resources Commission (WRC, 2010). Increasingly, water shortages have become more intense and less predictable in the basin. The protracted and frequent water scarcity or droughts in the Volta Basin lead to soil moisture deficits, increased soil temperatures, heat stress, bushfires and destruction of habitats, formation of iron-pans, and reduced biomass production. Consequently, loss of biodiversity or permanent loss of certain species that cannot cope or adapt to the changing conditions is the result of the prolonged drought.

Water quality degradation has also been identified as an important issue in the basin. A survey conducted by the International Union for Conservation of Nature and Natural Resources (IUCN, 2011) on the White Volta Basin surface and ground waters reported deterioration in water quality as a result of the presence of phosphates and nitrates from agriculture. The deterioration was reported to be generally more predominant in the northern part of the basin than in the south because of the effects of dilution in the south due to the ever-increasing water supply from upstream downwards.

Causes of Land degradation in the basin

As discussed in chapters 1 and 3, the basin's population is heavily dependent upon the land resources for subsistence farming and livestock production (Awotwi *et al*., 2014). The increasing demographic pressures have resulted in the overuse and misuse of land resources (Gyasi *et al.*, 2011; IFAD, 2013; UNEP-GEF Volta Project, 2013) and hence their degradation. Crop production practices in the basin have in the past included crop rotation and bush fallowing. The rise in population has resulted in reduced fallow periods and decline in crop rotation leading to the loss of soil fertility and reduction in productivity per unit area.

Livestock population is also reported to be high in the basin (UNEP-GEF Volta Project, 2013). This is exacerbated by nomadic pastoralism which has also resulted in land degradation due to trampling and overgrazing. The annual bushfires and continual removal of vegetation for fire-wood and charcoal production has contributed to deforestation of large tracts of land in the basin (Senayah, 1994). Other human activities such as sand and gravel winning, and small scale mining, contribute immensely to the destruction of the vegetation cover (Agyemang, 2007).

The consequence of land degradation is greatly felt by the inhabitants in the basin. Low soil fertility coupled with climate change has resulted in low crop yields or farm losses. For instance, the average annual yield for maize within the basin is about 0.8 t/ha (Ministry of Food and Agriculture, 2006). This figure is far below the expected average of about 1.5 t/ha under normal conditions resulting in food insecurity and high poverty rates in the riparian countries (National Development Planning Commission, 2005;

Ministry of Food and Agriculture, 2006). Other resultant effects of land degradation in the White Volta Basin are well documented by UNEP-GEF Volta Project (2013).

2.3 Land Degradation Types and Processes

FAO (2011) identified three major types of land degradation that may occur either singularly or in combination in a particular land use type. These include: Soil, vegetation and water resources degradation (Figure 2.1). The three blocks of degradation can further be subdivided based on a specific sub-set of degradation processes which may be interrelated (Bai *et al.*, 2008; McDonagh & Bunning, 2009) as a result of physical, chemical and biological processes (Stocking & Murnaghan, 2001; Bai *et al.*, 2008).

The Physical processes involve the alterations of soil structure, environmental pollution and unsustainable use of natural resources. The chemical processes that result in land degradation include leaching, acidification, salinization, low cation retention capacity, reduction in soil fertility and the biological processes embrace decline of biomass (Loss of vegetation cover) and biodiversity (Eswaran *et al.*, 2001; Bai *et al.*, 2008).

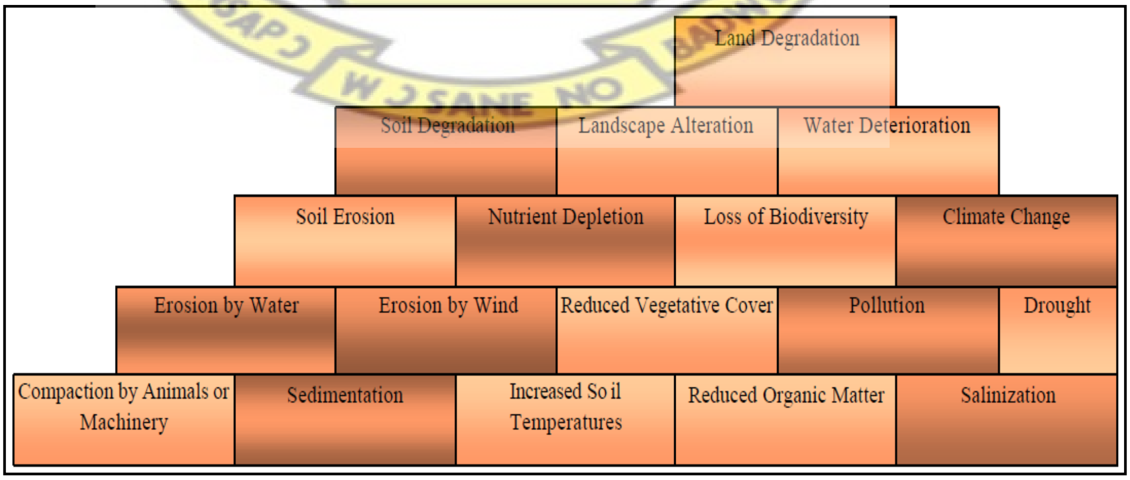

Figure 2.1: "The Land Degradation Wall"(*Source*: Stocking & Murnaghan, 2001)

2.3.1 Soil Degradation

Soil degradation is an important component of land degradation especially in Africa. It involves the decline in the productive ability of the soil due to unfavourable changes in its biological, chemical, physical and hydrological properties. It can also be attributed to the loss of soil through erosion by wind or water (Bai *et al.*, 2008; McDonagh & Bunning, 2009; FAO, 2011).

Soil Erosion

Soil erosion involves the removal of soil particles by the action of either water or wind. The incidence of soil erosion is a serious threat to agricultural and pastoral productivity and is a major indicator of soil degradation in many ecosystems. Soil erosion by water in particular is the commonest form of soil degradation that occurs in all part of dry lands (Oldeman *et al.*, 1991). It is mostly pronounced in years and areas when and where rainfall is sufficiently intense for surface runoff to transpire (Rosister, 2001; Stocking & Murnaghan, 2001; Bai *et al.*, 2008; McDonagh & Bunning, 2009). The onset of water erosion is splash erosion which progressively leads to Inter-rill erosion and consequently rill and gully erosion. At the gullies phase, restoration of the land becomes very difficult, expensive and sometimes not achievable (Eswaran *et al.,* 2001; FAO, 2011; Stocking & Murnaghan, 2001). Early detection of the onset of soil erosion will avoid financial losses as results of erosion control which will lead to increase profit for land users especially farmers.

Like water erosion, wind erosion is also prevalent throughout dry land areas that are especially exposed to strong winds. According to McDonagh and Bunning (2009), wind erosion is prominent in areas with very loose sandy soil and can result in the formation of sand dunes that can cause considerable economic losses through engulfing adjacent farm land, pastures, settlements, roads and other infrastructure. In the tropics and sub-tropics, wind erosion is reported to be severe in the latter part of the dry season when the topsoil is at its driest state and the vegetative cover has died back or destroyed by wild fires (Eswaran *et al.,* 2001; Bai *et al.*, 2008; Ezeaku & Davidson, 2008; FAO, 2011). Wind erosion is mainly driven by a decrease in the soil vegetative cover either due to overgrazing, removal of vegetation for domestic use or for agricultural purposes (Oldeman *et al.*, 1991; Senayah *et.al.*, 2005).

The scope of soil degradation in Africa due to water and wind erosion is reported by Oldeman *et al* (1991). It was estimated that 227 and 217 million hectares of land were eroded by water and wind respectively and that represents 16% of the total land area seriously eroded. This might have reduced the production capacity of soils hence leading to food insecurity that has bedeviled the continent. It is obvious that assessing land degradation in Africa will be incomplete and inaccurate without considering the subject of soil erosion as an indicator of land degradation.

Soil Physical Properties Degradation

Soil physical degradation is as a result of improper land use and management. Common among them is the use of heavy machines on unstable soils or from cattle trampling on rangelands. Soil compaction, surface sealing and crusting are major features of this degradation process (FAO, 2011; Kosmas *et al.*, 2012). Sealing and crusting may also occur due to natural processes such as the impact of raindrops. Areas that lack vegetative cover are directly devoid of protective coat over the soil surface and are therefore prone to surface sealing and crusting (FAO, 1995) due to raindrops. These conditions increase cost of land preparation, impede seedling emergence and consequently low ecosystem productivity. Water infiltration is also low in soils that exhibit the above characteristics, thereby accelerating run-off and water erosion leading to soil degradation.

Soil Hydrological Degradation

Water logging and aridification are the important aspect of soil degradation in the discipline of soil hydrology. Waterlogging involved the rise of the water table to the root zone of plants, caused by an excessive input of water with respect to drainage capacities of the soil (FAO, 1995, 2011). Waterlogging can be a natural phenomenon as in the case of flooding which is prominent in the White Volta Basin (Integrated Regional Information Networks-IRIN-UN, 2007; UN Country Team, 2007). Mostly, soils that are waterlogged are also saline in nature and naturally exclude some particular plants from growing and developing on them. So the absence and/or presence of some plant species in a particular soil are good indicators of land degradation.

On the contrary, aridification is marked by decrease in soil moisture availability due to reduced rain water capture and infiltration. Aridification is a general problem to land users and managers especially in the arid and semi-arid zones in the tropics. Many times, aridity is manifested in the plant conditions. Thus, plants on arid soil are moisture stressed and many times wilting and dying off is the end results. Again this leads to low ecosystem productivity and consequently food insecurity for human well-being (Millennium Ecosystem Assessment, 2005; Ministry of Food and Agriculture, 2006, National Development Planning Commission, 2005; International Food Policy Research Institute- IFPRI, 2011).

Soil Chemical Degradation

Soil chemical degradation consists of soil nutrients depletion, salinization and acidification, and soil pollution. The reduction in the amount and availability of soil nutrients such as nitrogen, phosphorus and potassium or organic matter as well as secondary and trace elements through leaching, gaseous losses, and removal in harvested products are key indicators of soil chemical degradation (Lemenih *et al.*, 2005; Kosmas *et al.*, 2012). Soil chemical imbalances and toxicities especially through the application of inappropriate types and quantities of agro-chemicals are all forms of soil degradation (FAO, 2011).

It has been reported that nutrient balances on most smallholder farms in Sub-Saharan Africa (SSA) were negative (-22 kg N, -2.5 kg P and -15 kg K per hectare) over the last three decades (Stoorvogel & Smaling, 1990; Smaling *et al.*, 1993). The yearly loss has been estimated in economic terms to be equivalent to US$ 4 billion in fertilizer (InterAcademy Council (IAC), 2004). It has also been reported that fertilizer use efficiency is usually low in degraded land (Vanlauwe *et al.*, 2006; Tittonell *et al.*, 2007).

In the White Volta Basin, land degradation has rendered soils so humus deficient that they no longer respond to chemical fertilizers (EPA, 1992; Ministry of Food and Agriculture, 1998). The effect of reduced soil fertilizer use efficiency is low crop productivity despite high investment in inorganic fertilizers. This therefore calls for the addressing of the land degradation problem especially soil chemical deterioration in order to improve food productivity and security as a whole in the area.

2.3.2 Vegetation Degradation

Vegetation degradation encompasses complex processes that may be natural (e.g. climate change) that may result in the obliteration of some species and habitats, reduction in biomass or the intrusion of invasive species (Eswaran *et al.,* 2001; FAO, 2011). Key vegetation degradation types and processes classified by FAO are summarized in Table 2.1.

Degradation of vegetation is mainly induced by human activity through the over use or inappropriate management of forests, grazing and croplands, as well as uncontrolled bush fires (FAO, 2011). It is estimated that land use for crop cultivation especially in Ghana has increased by 24.9% with marginal increases in yields from 2006 to 2010 (Pagett & Acquah, 2012). The expansion of agricultural lands for crops at the expense of forest and woodlands has been attributed to loss of soil fertility and low productivity resulting from land degradation and non-sustainable land use in subsistence agricultural practices.

Table 2.1: Key vegetation and biodiversity degradation types and processes

Vegetation degradation	Key processes/indicators
Degradation of vegetation quantity	• Reduction in vegetative ground cover in area • biomass decline (Reduced vegetative production for different land use)
Degradation of vegetation quality	• Reduction in the quality of the vegetative biomass (plant species of high value replaced by a species of lower, or no value; • Plant parts damaged or their health affected through excessive removal of specific parts.
Degradation of plant diversity	• Reduction in the numbers/populations of specific species in natural plant communities • Reduction in the diversity of local crop varieties and land-races • Reduction in habitat for associated species (e.g. pollinators, beneficial predators etc.)
Degradation of animal productivity	• Reduction in livestock or wildlife stocking capacity and productivity

Adapted from FAO (2011)

2.3 Causes of Land Degradation

Land degradation involves two interconnected, multifaceted systems: the natural ecosystem and the human social system (World Meteorological Organization-WMO, 2005). The natural forces, through periodic stresses of extreme and persistent climatic events, and human use and abuse of sensitive and vulnerable dry land ecosystems, often act in agreement, creating feedback processes, which are not fully understood (WMO, 2005). Understanding the factors that cause degradation in ecosystems and their services is vital to the design of interventions that boost positive and minimize negative impacts. The factors causing land degradation can be classified as pressures/proximate and drivers/underlying cause (Figure 2.2). The pressures are those factors that have direct effect on the terrestrial ecosystem (Lambin *et al.*, 2003; Von Braun *et al.*, 2012). They are further divided into biophysical pressures (natural e.g. topography, climate, pest and diseases, soil erodibility etc.) and unsustainable land management practices (anthropogenic e.g. infrastructure development, land use/cover change, deforestation and overgrazing).

Drivers or underlying causes of land degradation are primary forces that fuel the proximate causes of land degradation. Drivers operate from a distance in scale, often altering one or more proximate causes (Lambin *et al.*, 2003). Land degradation drivers consist of social, political, economic, demographic, technological, cultural, and biophysical variables that constitute initial conditions in the human-environment relations and are systemic in nature (Contreras-Hermosilla, 2000; Geist & Lambin, 2002; Schwilch *et al.*, 2012). Pressures generally operate at the local level (individual farms, households, or communities) whiles drivers perpetuate from regional (districts, provinces, or country) with complex interplays between levels of organization (Lambin *et al.*, 2003).

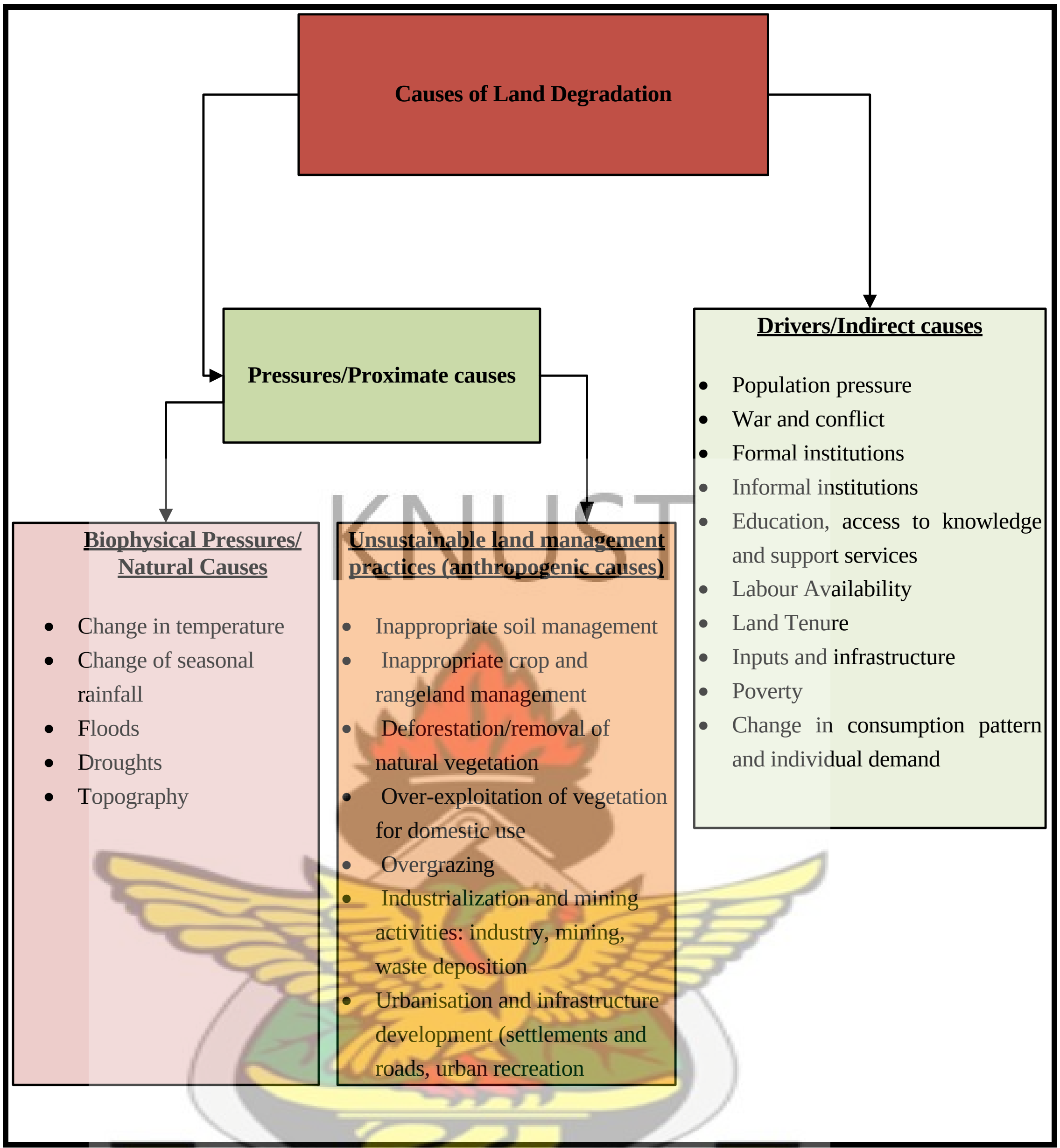

Figure 2.2: Causes of land degradation

2.4.1 *Biophysical Pressures*

To efficiently combat land degradation, naturally induced disasters in the area must be known. According to WMO (2005) "only when climate resources are paired with potential management or development practices can the land degradation potential be assessed and appropriate mitigation technology considered". The involvement of climate and land information is key to developing sustainable management practices to combat land degradation as climatic variation is one of the major contributory factors to land degradation (WMO, 2005). The major natural causes of land degradation include changes in rainfall, temperature, flood, drought and topography (WMO, 2005; FAO, 2011). Climatic factors which are erratic in the WVB drive land degradation in the basin (Gyasi *et al.*, 2011; UNEP-GEF Volta Project, 2013 Awotwi *et al.*, 2014).

Change in Seasonal Rainfall

Rainfall is the most essential climatic factor in determining areas at risk of land degradation (WMO, 2005; FAO, 2011). This is because rainfall determines the development and distribution of vegetation (D'Odorico *et al.*, 2007); however its extremes and variability can lead to soil erosion and land degradation. Too much or too little rainfall can lead to soil erosion which is a form of land degradation. Researchers regard rainfall to be the most urgent erosion factor among the other factors that cause soil erosion (Ritter and Eng, 2012). It can erode soil by the force of raindrops, surface and subsurface runoff, and river flooding.

Rainfall amount, distribution, energy and intensity are the main factors controlling soil erosion caused by water. Precipitation in the White Volta Basin is intrinsically erratic in amounts and intensities (Barry *et al.*, 2005; Droogers *et al.*, 2006; Ofosu-Addo *et al.*, 2008) and so is the subsequent runoff. This often results in heavy down pour at a certain period of the year leading to flooding and its attendant problem of soil erosion, crops and animal damage as well as loss of human lives in the basin. The unpredictable rainfall in the basin area also results in reduced production, wastage of seed and inputs, and makes planning difficult for farmers in the area (Droogers *et al.*, 2006).

Areas with sparse vegetation cover and/or thin litter are at risk of topsoil detachment and transport by raindrop impact and surface runoff. Furthermore, the timing of the rainfall is important in soil erosion. For instance, an erratic start of the rainy season coupled with heavy downpour will have a greater consequence as the seasonal vegetation might not have been established to intercept the rainfall or bind the soil particles with their root structures (WMO, 2005).

Flooding

Flood has been a perennial problem in the White Volta basin which destroys several hectares of productive agricultural lands and other properties (Kanchebe, 2010; UNEP-GEF Volta Project, 2010; 2013). Farmlands around the basin are washed away by flooding. Crops, animals as well as human beings are ruined annually by flood (Integrated Regional Information Networks (IRIN-UN, 2007). For example the heavy rainfall events and floods between August and September 2007 destroyed late crops such as sorghum, rice and groundnut (Kanchebe, 2010). The consequence of this event was economic loss and food insecurity in the study area.

Flooding in the basin is attributed to the torrential rainfall and the creation of uncoordinated dams without appropriate management practices (GEF, 2002; UNEP-GEF Volta Project,2010; 2013). The uncontrolled release of dam water from Burkina Faso to Ghana is reported to be one of the major causes of floods which consequently result in environmental degradation and socio-economic mishaps (GEF, 2002, UNEP-GEF Volta Project, 2010; 2013). The removal of vegetation cover in headwaters of rivers due to land use/cover conversions is reported to have exacerbated the flooding problem in the area (GEF, 2002; UNEP-GEF Volta Project, 2010, 2013). Soils that lack or have reduced vegetation cover have little infiltration capacities to reduce storm-water runoff and hence exposed to soil erosion agents and other soil degradation.

Drought

Drought is a climatic irregularity, which is expressed by deficit in supply of moisture emanating from abnormally low rainfall, erratic rainfall distribution, higher water demand or a combination of all aforementioned factors (NOAA, 2008).

Drought affects many aspects of life and therefore different definitions have been developed by a variety of disciplines. The agriculturalists visualize drought as a shortage of moisture within the root zone for plant growth and development, while the hydrologists consider drought as a severe reduction in stream, lake and reservoir water levels (Hisdal *et al*., 2001; American Meteorological Society 2003). On the other hand, the economists take droughts to be severe water shortage that adversely affects the socio-economic wellbeing of the people in a place (American Meteorological Society 2003).

The Meteorologists however, regard droughts as a protracted period of precipitation deficiency that cause serious hydrological imbalance (Hisdal *et al*., 2001; American Meteorological Society 2003). Thus, drought can generally be defined as a prolonged period of abnormally low precipitation which creates a shortage of water for different uses; such as for sanitation and drinking, agriculture, hydrological needs, industry, forests, recreation, cities and power generation (Toth & Hillger, 2012).

The American Meteorological Society (2003) has therefore categorized droughts into four main disciplines and is summarized in Table 2.2. All these types of droughts are reported to be prominent within the WVB (Rodgers *et al.*, 2007; Ofosu-Addo *et al.*, 2008).

Table 2.2: Types of drought

Type of drought	**Definition**
Meteorological	Measure of the departure of precipitation from the normal and the duration of the dry period
	Precipitation shortages leading to differences between actual and potential evapotranspiration, and soil moisture deficits; moisture in the soil is no longer *Agricultural* sufficient to meet the needs of the crops growing in the area
Hydrological	Extended periods of inadequate precipitation causing surface and subsurface water supplies (stream flow, reservoir/lake levels, ground water) to drop below normal
Socioeconomic	Occurs when water shortages begin to affect people and their lives; it is different than the other definitions in the fact that this drought is based on the process of supply and demand - a socioeconomic drought takes place when the supply of an economic good cannot meet the demand for that product (in this case water)

Source: American Meteorological Society, 2003

Historical records evidently proved that prolonged and widespread droughts have badly affected Africa, with its associated mishaps in 1965-1966, 1972-1974, 1981-1984, 1986- 1987, 1991-1992, and 1994-1995 (Toth & Hillger, 2012). The cumulative impact of drought on the economies of Africa can be huge. For instance the drought events in the early 1970s in Burkina Faso, accompanied by the weak institutional situation after independence; the droughts in northern part of Ghana in 1981 and 1984 and the resultant famines and outmigration (Yaro, 2004) or the dry spell in May 2007 negatively affected the early millet yields. Also in the Kasena-Nankana district of northern Ghana, the pervasiveness of drought resulted in stunted growth, drying up and obliteration of tree plantations (Callo-Concha *et al.*, 2012). The consequential effect of drought is low productivity and food insecurity in its region of occurrence.

According to Toth and Hillger (2012), land degradation in certain parts of the arid regions were initiated or aggravated by prolonged droughts. The White Volta Basin is not an exception and even though management measures were put in place to fight drought and its repercussion (MLF, 2001; GEF, 2002; Ofosu-Addo *et al.*, 2008; Gyasi *et al.*, 2011) their full impact could not be fully achieved. This could be due to inappropriate application of the interventions in space and time.

Change in Temperature

Beside rainfall, temperature is a key factor determining climate and consequently the distribution of vegetation and soil formation. Soil formation is the aggregate action of many factors including: the parent material, topography, climate, biological activity, and time (Jenny, 1941). Daily as well as Seasonal changes in temperature affect moisture effectiveness, biological activity, rates of chemical reactions, and kinds of vegetation in space and time (Jenny, 1941; Dudal, 2004; Bockheim *et al.*, 2014).

Temperature also plays a vital role in mineral weathering, the biological processes of growth and decomposition. Weathering is accelerated by high temperatures; therefore weathering is believed to be stronger in the tropics due to higher temperatures than in humid regions. An increase in temperature also increases biological processes within the soil and plants. High temperatures and low precipitation in the dry lands lead to poor organic matter production and rapid oxidation (WMO, 2005; Stocking & Murnaghan, 2001). Low organic matter content in the soil leads to poor aggregation and low aggregate stability rendering such soil vulnerable to wind and water erosion (WMO, 2005). Also during the dry season, surface soil temperatures increases as high as 40°C in White Volta Basin (Ouédraogo, 2004; Sandwidi, 2007) and this intense heat contributes to cracking of highly-clay soils that expose both soil surface and the soil subsurface to water or wind erosion (Sivakumar & Stefanski, 2007).

Increase in soil water evaporation is a consequence of high temperatures. In the basin, it has been reported that evaporation exceeds rainfall except during the rainy season when the basin is recharged (Ouédraogo, 2004; Sandwidi, 2007; Bagayoko, 2006). This is likely to reduce the available soil moisture for plant growth and development.

Topography

Topographic attributes affect soil moisture by governing the proportions of surface runoff to infiltration. Topography also determines the vulnerability of a soil to erosion (Nkonya *et al.*, 2011). Soils on steep slopes are vulnerable to severe water-induced erosion. It is well established that steep slopes cause higher velocities of overland flow which in turn increases its erosive forces (Voortman *et al.*, 2000). Therefore soils on steep slopes are generally shallower and their nutrient and water storage capacities are limited (Tefera *et al.*, 2002). Thus, soils in these areas, when exposed to soil eroding agents, face greater degradation consequences compared to soils in flat areas (Tefera *et al.*, 2002).

The length of the slope also determines the extent of water that runs off superficially (Voortman *et al.*, 2000). An increase in slope is also associated with a reduction in; leaching, organic matter content, clay translocation and mineral weathering.

The White Volta basin is relatively flat seldom above 0.1 % (Wagner *et al.*, 2006). Flat topography generally have very slow drainage characteristics and can lead to flooding and waterlogging which are the major attributes of the white Volta basin. Topography has also been reported to be one of the main factors that determines the existence and evolution of a vegetation types (FAO, 2011).

2.4.2 Unsustainable Land Management Practice

This encompasses practices that abuse the land use/cover types which renders them degraded. Common among such practices include; inappropriate soil management, inappropriate rangeland management, deforestation, over-exploitation of vegetation for domestic use and overgrazing. These are discussed in the next sections.

Inappropriate Soil Management

Lands under arable use require management practices to maintain the quality of the soil. According to Doran *et al*. (1994), a quality soil is a soil that has the capacity to sustain biological productivity, maintain environmental health, and promote plant and animal health". They reported that a quality soil should have good texture and depth, optimum infiltration rate and bulk density, better water holding capacity, rich in soil organic matter, optimum soil pH and good electrical conductivity. Any land management practices that deprive the soil of these qualities are considered as inappropriate soil management practices. Such practices include cultivation of unstable soils, the lack of/ or inadequate soil conservation or erosion control measures in the farming practices, or the inappropriate use of farm equipment (Schwilch *et al.*, 2012). Inappropriate soil management has been reported as the most important direct cause of land degradation

(Millennium Ecosystem Assessment, 2005; McDonagh & Bunning, 2009; FAO, 2011; Gyasi *et al.*, 2011; Odendo *et al.*, 2011; Kosmas *et al.*, 2012; Lal *et al.*, 2012) .

Continuous cultivation of soils coupled with other poor management practices such as wrong application of agro-chemicals (herbicides and pesticides), crop residue removal result in reduced soil organic matter content and aggregate stability, soil crusting, overland flow and erosion (Kosmas *et al.*, 2012). Cultivation of highly vulnerable soils such as steep sloping land; areas of shallow or sandy soils, or with laterite crusts due to land hunger, which is evident in the study area are all forms of improper soil management that accelerate land degradation (FAO, 2011).

The advancement of technology has also led to a dramatic change in soil management. The introduction of new land cultivation implements such as heavy, powerful machinery favoured deep soil ploughing and high speeds in directions generally perpendicular to the contour lines (Kosmas *et al.*, 2012). Such cultivation practices have greatly contributed to the deterioration of soil quality by changing soil depth, structure and consequently water holding capacity, nutrient availability, organic matter content, and crop yields (Kosmas *et al.*, 2012).

The non-adoption of soil conservation practices (e.g. creating terraces, applying green manure, zero/minimum tillage, crop rotation and agroforestry) which may be due to inadequate resource availability, lack of tenure security and education can lead to inappropriate soil management and hence land degradation.

In the White Volta Basin, soils on croplands are generally poor in organic matter. This has been attributed to rampant burning of biomass in the prevailing-slash-and burn agriculture and high temperatures that accelerate organic matter decomposition (Yilma, 2006). This has also been reported to have been exacerbated by low organic inputs during the cropping season, crop residue removal (e.g. as fodder and fuel), leading to a continual decline in soil organic matter content (Callo-Concha *et al.*, 2012). Soils with low organic matter content generally have low fertility due to low reserves of nitrogen and phosphorus and low cation exchange capacity (Callo-Concha *et al.*, 2012) which are essential for plant growth and vigour.

Inappropriate Rangeland Management

Rangeland ecosystems play essential roles in the lives of many societies especially in the Sub-Saharan Africa (SSA). This is because they provide goods and services to the society which includes food, forage, medicines, fuel, building materials and industrial products (Davies *et al.*, 2012). Rangelands also provide services that are related to nutrients, storing and purifying water. In West Africa and in the White Volta Basin, rangelands are the major source of fodder for both livestock and wildlife throughout the year (Mirza *et al.*, 2006; Davies *et al.*, 2012).

Despite the enormous importance of rangelands, they face the menace of degradation due to inappropriate grazing management plans (e.g. overstocking), overexploitation of vegetation for fuel wood and lack of clear-cut ownership (Ahmad & Ehsan, 2012). Though rangeland degradation may differ from region to region, the most widespread ones are bush encroachment, occurrence and spread of weeds and invader plants (FAO, 2011), decline in plant cover, reduction in biodiversity and forage production as well as increased soil erosion (Ahmad *et al.*, 2012).

Deforestation

Deforestation is a serious global environmental problem. It involves the loss of forests, woodland and savanna areas to other land uses as a result of over-cutting of trees and other vegetation forms (FAO, 2005, 2011). There has been a drastic decrease in the world's forest area due to deforestation since the twentieth century. Total world's forest area as of 2005 was estimated to be less than 4 billion hectares (ha) or 30 percent of total land area and this corresponds to an average of 0.62 ha of forest per capita (FAO, 2005). The net global change in forest area to other cover types estimated by FAO between the periods of 2000–2005 was at 6 million hectares per year (FAO & JRC, 2012).

The degree of deforestation and forest degradation is more swift and vast in the developing tropical countries. ITTO (2002), estimated that 350 million hectares of tropical forest land have been so severely damaged that forests will not grow back naturally. Africa in particular, accounted for more than half the area of the global deforestation. Between 1990 and 2005, Africa lost more than 9% of it forest area (FAO, 2007). It was estimated that about 3.4 million hectares of African forest was lost annually between 2000 and 2010 (FAO, 2010; 2012).

Ghana is reported to be among the countries with the highest deforestation rate in Africa and the world. Ghana's deforestation rate was estimated to be 2% per annum (FAO, 2010). An average of 135,000 hectares of Ghana's forest was lost annually between 1990 and 2000, which amounted to an average annual deforestation rate of -2% (FAO, 2007). Further research revealed that Ghana's forests had decreased by 115,000 hectares between 2000 and 2005, with a rate of forest change of -2% per annum (FAO, 2010). Between 1990 and 2010, Ghana lost 33.7% of its forest and woodland, or around 2,508,000 ha (FAO, 2010).

Burkina Faso which shares a boundary with Ghana and is also located within the White Volta Basin shares similar ecological and socio-economic characteristics with Ghana (Paréa *et al.*, 2008) and experiences a similar trend of deforestation. A study conducted by the Burkina Faso's Ministry for the Environment and Sustainable Development shows that between 1992 and 2002, about 110,550 hectares of forest was destroyed annually and this trend continues (Ouedraogo, 2011). Between 1990 and 2010, Burkina Faso lost a total forest area of 17.5% or around 1,198,000 ha (FAO, 2007; 2010).

The proximate causes of deforestation in both regions are not different (FAO, 2007; Ouedraogo, 2011). They include cutting down of trees for lumber and urbanization, illegal logging, agricultural extensification, gold mining and fuel wood extraction (Contreras-Hermosilla, 2000; FAO, 2007; Gyasi *et al.*, 2011; Ouedraogo, 2011). The underlying causes of deforestation identified by various authors comprise growth in poor rural population, lack of land tenure security, poor governance practices and implementation of the relevant provisions of public policies (World Bank, 2012).

The consequences of deforestation are felt in all aspects of lives. Major impacts include, climate change, loss of biodiversity, soil erosion, flooding which are all attributes of land degradation. Livelihoods of forest/woodland dependent communities are affected, important environmental functions are disrupted and the biological integrity of the original ecosystem is severely disturbed. The reduction in area of the tropical forest due to deforestation affects not only the production of timber but also the global environment. The loss of biological diversity, both plants and animals threatens the sustainable and harmonious development of the global ecosystem (Lamb & Gilmour, 2003). It was approximated that 2.5–8 million biological species, including a large number of as-yet unknown species, will be extinct by the end of the 21st century due to deforestation (Kobayashi, 2004). Information on deforestation is necessary for awareness creation to inform the different groups of stakeholders of the land as when and where to tackle or mitigate land degradation in the area.

Over-Exploitation of Vegetation for Domestic Use

Vegetation removal by households, for fuel wood, local timber, fencing materials, fodder and other domestic consumption is a major contributory factor to land degradation in the Sub-Saharan Africa. To fulfill their energy and other requirements, most households in the rural setting cut natural forests, woodlands, rangelands and shrub lands to obtain timber, fuel wood and other forest products (FAO, 2011; Gyasi *et al.*, 2011). Such vegetation removals sometimes become unsustainable when the harvesting exceeds the rate of natural regeneration. Destruction of the natural vegetation has been identified to be a major factor causing loss of key local species, habitat destruction, biomass loss and both water and wind erosion (FAO, 1995).

Fuel wood consumption projection by Arnold and Persson (2003) rated Africa to be the top fuel wood consumer in the world in the 2010, 2020 and 2030 world energy projections. They further indicated that by 2030, fuel wood consumption in Africa is expected to stand at 544.8 million m^3 and 46.1 million tons for firewood and charcoal respectively. With these projections and the already devastating nature of the natural vegetation, if care is not taken more land will be degraded by the 2030 beyond restoration.

Vegetation removal and population increase are linked. Regions where the inhabitants heavily depend on the natural biomass, trees and shrubs for their livelihood especially those within and around the White Volta Basin of both countries (Ghana and Burkina

Faso), increase in population as it is already reported high in the area (Awotwi *et al.*, 2014) will lead to an increase in the demand for biomass and other vegetation resources. This will consequently enhance land degradation in the area.

Overgrazing

According to Baartman *et al.* (2007), overgrazing is an 'excess of grazing animals that leads to degradation of plant and soil resources'. Thus it involves the grazing of rangelands by animals at stocking densities above the carrying capacity. This mismatch leads to direct decline in the quantity and quality of the rangeland vegetation cover (Ahmad *et al.*, 2012). Reduction in rangeland vegetation cover eventually leads to wildlife habitat destruction and soil erosion.

Overgrazing has been reported to be the most important cause of land degradation in dryland areas of Africa (UNEP, 1997). Apart from environmental factors such as drought and the distribution of vector-borne diseases, other reasons for overstocking animals in some areas, with their intendant problems such as loss of vegetation cover and trampling of the soil surface, may be political, cultural or socio-economic reasons (UNEP, 1997).

2.4.3 Drivers of Land Degradation

Drivers of land degradation serve as fuel that influences the pressures/ proximate causes to effect degradation at their levels of operation. Key among them include: human population, land tenure system, poverty and institutional factors.

Population Pressure

The extreme of population whether high or low will have a negative consequence on land and its resources. High population pressure may trigger degradation by increasing pressure on resources or ecosystem services while low population pressure may lead to degradation due to inadequate supply of labour to manage resources (FAO, 2011). It has been reported that land degradation is more severe at high population density areas in sub-Saharan Africa (FAO, 2001). Increasing population increases interrelated processes such as accelerating deforestation, declining land holdings and rising food insecurity (FAO, 2001).

The removal of forests and other vegetation cover is partly caused by land clearance for agricultural purposes to feed the ever increasing population. "Both slash-and-burn agriculture and shifting cultivation involves "cutting trees, shrubs and tall grasses, burning the litter, growing crops for 2 to 5 years on the cleared land, and then allowing the natural cover to rejuvenate the soil. The fallow period may last from 5 to 15 years, depending on the soil and type of vegetation" (FAO, 1995). These systems of farming (slash-and-burn agriculture and shifting cultivation) are principally driven by population growth, which eventually leads to high demand for food and other agricultural products. Furthermore, an increase in human population has led to reduced fallow period therefore giving the land no time or very short period to rejuvenate for the next rotation (Gyasi *et al.*, 2011). It has been estimated that about 60 % of the expansion of farmland between 1973 and 1988 in the basin was as a result of the above farming practices driven by high population (FAO, 1995). The anticipated increase in human population coupled with outmoded farming systems can be contributory factors of land degradation in the White Volta basin (Gyasi *et al.*, 2011).

A Malthusian view of high population density and its effect on land degradation due to agriculture is well presented by Mortimore (1993) and is summarized in figure 2.3. An increase in population density leads to proportionate increase in the frequency of cultivation, and hence shortening of the fallow period that is required to rejuvenate soil. According to Mortimore (1993) as fallow length is reduced, soil fertility inevitably will decline, and this also results in declining crop yields. The consequence of yield decline is food insecurity. The problem of food insecurity subsequently leads to further cropland expansion, leading to accelerated degradation. A sure coping strategy will be that land users may migrate to work on marginal lands as a result of a decrease in arable land.

High population growth will also lead to high demand for fuel wood especially in developing countries where households resort to "free" gathered biomass fuels (FAO, 1995). Around the 80s, it was estimated that about 2 billion people from the developing countries depended on biomass for their energy requirement but about 1.4 billion of these could not meet their energy needs without compromising future fuel wood supplies (FAO, 1995). When the annual use of wood exceeds the allowable yield, forests and other vegetation are gradually destroyed.

More importantly, the role of population in vegetation loss is significant in areas with limited land reserves and energy sources. In the high population density areas, e.g. some districts of the Upper East Region of Ghana, which are experiencing land scarcity (Callo-Concha *et al.*, 2012) concentrations of demand for arable land and fuel wood lie at the root of resource over-exploitation and hence land degradation.

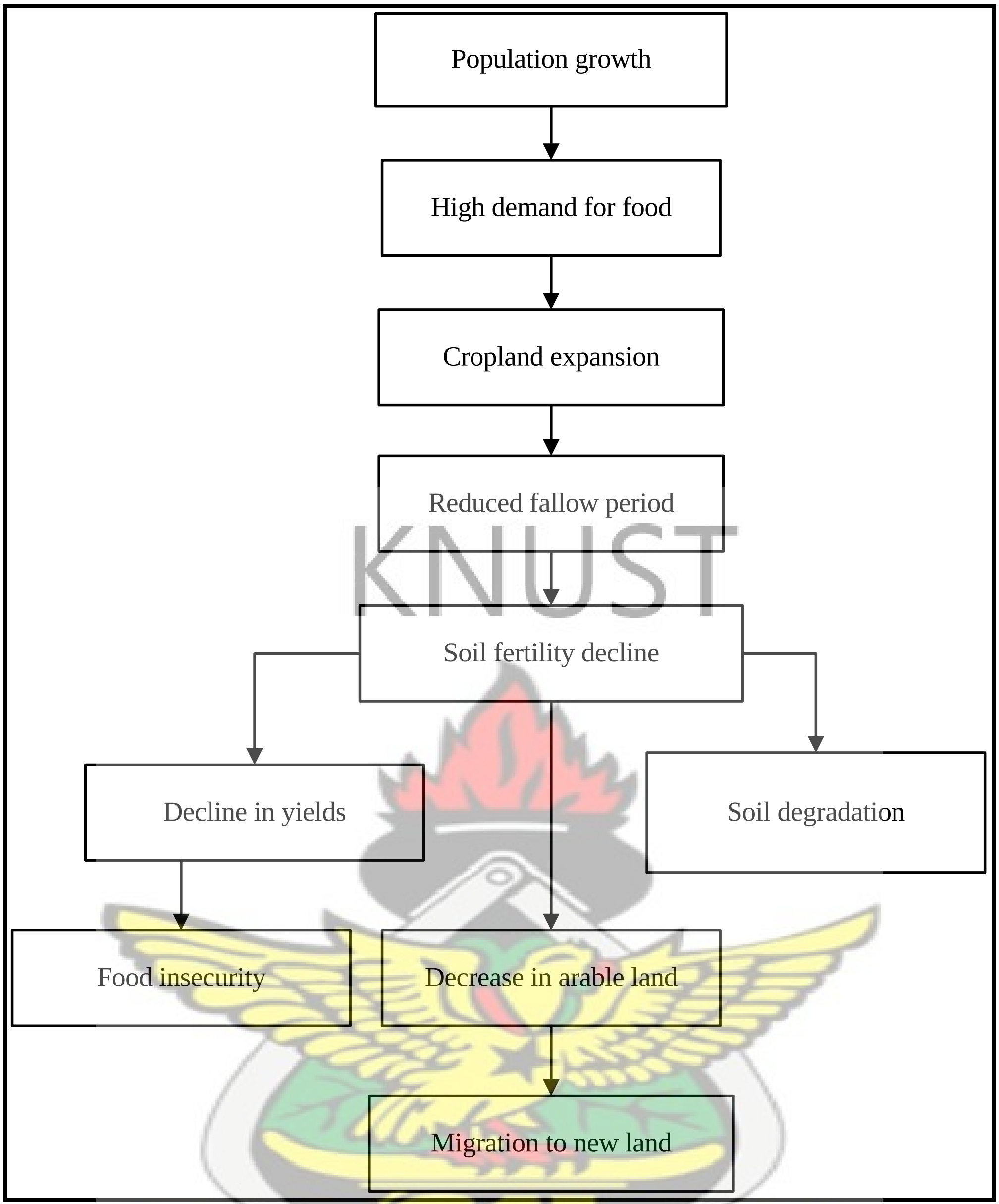

Figure 2.3: Malthusian view of the link between population growth and LD
Source: Modified from Mortimore (1993)

The increase and decrease of a given population over timescale also have a great impact on land use over time. Population change has an influence on the development of households and features of their life cycle. The family features here refer largely to labour availability at the level of households, which is linked to migration and health. Deficit of rural labour through migration and diseases (e.g. HIV/AIDS pandemic) (WMO, 2005; Ezeaku & Davidson, 2008; Gyasi *et al.*, 2011), can lead to abandonment of traditional resource conservation practices such as compost preparation and terrace maintenance (FAO, 2011; Gyasi *et al.*, 2011). On the contrary the deficit may also lessen pressure on land resources.

Boserup (1965) however argued that population growth can induce responses, in terms of agricultural intensification and technological and institutional innovation, that act to reduce poverty and natural resource degradation. From his point of view, population density is not the automatic cause of land degradation but rather, it is how population interacts with the land and its resources that determine the extent of degradation.

Land Tenure

Rights to land can influence land users positively or negatively on how to invest on the land. Poorly defined tenure security may lead to land degradation, as land-users are unwilling to invest in management when proceeds are not certain (Sunderlin *et al.*, 2001; Stringer & Reed, 2007; TerrAfrica, 2009; Stocking & Murnaghan, 2001; Von Braun *et al.*, 2012; Waswa, 2012). Thus the lack of tenure security is a disincentive undermining technological adaptations and de-investments in land management initiatives (WMO, 2005; Ezeaku & Davidson, 2008). In areas where secure land tenure systems are practiced for example among the Chaga farmers on Mount Kilimanjaro, trees was planted to improve vegetation cover and soil protected (FAO, 1990). The same source reported the case of Mount Kenya where insecurity of tenure led farmers to dig ditches to delineate their plots and in an attempt to establish ownership, led to severe erosion and gully formation.

Poverty

Poverty can be defined in diverse ways depending on the field of interest. The economists consider income or consumption poverty, but poverty may also be measured by lack of assets, access to infrastructure and services, education, inputs or other factors that determine a household or community's livelihood status (FAO, 2011). . For the purpose of this study poverty is considered as the impacts of limited endowments of financial capital as well as poor access to services; on land degradation.

Poverty has a direct implication to land use and management. Poor people are often compelled to overuse their environment to meet short term goals, without the ability to plan for the long term effects of their actions. They often have no alternative but to use marginal land that may be particularly prone to degradation (FAO, 2011). This is the situation within the White Volta basin especially in the northern Ghana where averagely 9 out of every 10 people are poor (National Development Planning Commission, 2005).

National and international economic forces can also motivate poor indigenous people to overexploit their natural resources. Both national and International trade patterns can lead to the short-term exploitation of local resources for urban markets and export, leaving little profit at the community level for managing or restoring the resources (Nkonya *et al.*, 2008, 2011). Land users who have access to knowledge and support services are unlikely to be poor because they often have higher returns from their land and are more likely to adopt technologies that safeguard the land against degradation (Nkonya *et al.*, 2011). Additionally, education can provide off-farm income opportunities which reduce the risk of land mining by its users.

Availability and accessibility of Inputs and infrastructure (e.g. roads, markets, distribution of water points) play a significant role in land management. Lack of access to or high prices for key agricultural inputs such as fertilizers will lead to low investment in the land leading to land degradation (WMO, 2005). The quality of infrastructure will affect access to input and product markets. Poor quality infrastructure will definitely hinder the free movement of inputs and farm products to and fro which consequently affect production. According to Nkonya *et al.* (2008; 2011) farmers with greater market access adopt better land management practices than those in remote areas. Access to market could also raise the incentive for farming and hence lead to land degradation, especially common lands (Benin & Pender, 2006).

Institutional Factors

Institutions such as political, legal, economic, and traditional have a significant influence on individual decision making (Agrawal & Yadama, 1997; Ostrom *et al.*, 1999; FAO, 2011). Accessibility to land, labour, capital, technology, information and other factors of production are often controlled by local and national policies and institutions (Sunderlin *et al.*, 2001). Land degradation in many areas is as a result of ill-defined policies and weak institutional enforcement (Jepson *et al.*, 2001).

The lack of popular respect for relevant land use policies and related regulations in Ghana, including the northern savanna zone such as the Environmental Action Plan; the Forest and Wildlife Policy; the National Land Policy, and weak enforcement of relevant rules and regulations, notably: Anti-bush fire legislation and the lack of rigidity in their implementation (Gyasi *et al.*, 2011; UNEP-GEF Volta Project, 2013) could be the driving force of land degradation in the area. A related factor is failure by officials to consult farmers in the design of farming and other land management packages (Gyasi *et* *al.*, 2011; Stocking & Murnaghan, 2001). However conservation measures can only be successful if land managers have the control and commitment to maintain the quality of the resources (WMO, 2005).

Conversely, restoration of land is also possible with appropriate land-use policies (Lambin *et al.*, 2003). Policies that influence land use decisions include government policies to achieve food security (Xu *et al.*, 1999; MLF, 2001; 2004); taxation, financial incentives, subsidies, and credits (Hecht, 1985; Becker, 1999; Deininger & Minten, 1999); price controls on agricultural inputs and outputs (Deininger & Minten, 1999; MLF, 2001); low investments in monitoring and formally guarding natural resources structural adjustment and recovery measures (MLF, 2001; 2004) and international environmental agreements (Lambin *et al.*, 2003).

Cultural factors also play a role in decision making on land use. Land users have various motivations, collective memories, and personal histories (Lambin *et al.*, 2003). Their attitudes, believes, values and perceptions influence land-use decisions either positively or negatively (Lambin *et al.*, 2003; Yiran *et al.*, 2011). Culture is often linked with political and economic disparities, e.g., the status of women or ethnic minorities (Leemans *et al.*, 2003), that affect resource access and land use. Understanding the controlling models of various actors will help in the management of resources, adaptive strategies, compliance or resistance to policies, or social learning and therefore social resilience in the face of land degradation.

Even though several and diverse studies have been done in the White Volta Basin on its resources and management challenges like land degradation (Andreini *et al.*, 2000; GEF, 2002; Andah *et al.*, 2003; Barry *et al.*, 2005; Amisigo, 2005; Droogers *et al.*, 2006; Compaoré *et al.*, 2007; Rodgers *et al.*, 2007; Gyasi *et al.*, 2011; Le, 2012), there still remains the question "what are the drivers that fuel the degradation within the basin". To answer this question, there is the need to examine the socio-ecological determinants that influence the degradation processes in order to assess the state of land degradation within the White Volta Basin.

2.5 Assessment of Land Degradation

The complex nature of land degradation (Bai *et al.*, 2008) poses a great challenge in its appraisal partially due to unavailability of effective methods to quantitatively evaluate the degradation process (Lu *et al.*, 2006; Le, 2012). Diverse methods have been employed in assessing land degradation. Expert opinions, land users' opinions, field monitoring, observations and measurement, modelling, estimates of productivity changes and remote sensing are the widespread methods used for assessing land degradation in different ecosystems (Kapalanga 2008). These methods of assessing land degradation however seldom integrate different components of land degradation. They often focus on single issues such as soil degradation while ignoring other types of land degradation (Van Lynden & Kuhlmann, 2002). In addition, many of the degradation assessment methods are space and time static, preventing comparability and trend analysis (Baartman *et al.*, 2007). Recognizing these limitations, there is an increased interest of the scientific community to consider multi-scale, multi-method approach that can measure land degradation in the context of varied and dynamic socio-economic, cultural and environmental conditions.

There have been many attempts to tackle this complex methodological challenge, each with its own strengths and weaknesses and are well documented by Reed *et al.* (2011). These vary from qualitative approaches based on local knowledge at local scales (Thomas & Twyman, 2004; Reed *et al.*, 2008) or 'expert' knowledge at global scales

(UNEP, 1997), to more quantitative approaches using field-based and remotely sensed data, analysed and interpreted using models and Geographic Information Systems (Oldeman *et al.*, 1991; Myneni *et al.*, 1997; Reynolds *et al.*, 2007; Bai *et al.*, 2008; Vlek *et al.*, 2008; Le *et al.*, 2012).

2.5.1 Modeling land degradation

A model is an abstraction of reality or a representation of a real world situation. Real-world decisions involve an overwhelming amount of detail, much of which may be irrelevant for a particular problem or decision (Encyclopedia of Management, 2009). Models allow the user to eliminate the unimportant details so that the user can concentrate on the relevant decision variables that are present in a situation (Stevenson, 2002).

Models have been used for many years to understand land degradation. In the domain of soil erosion assessment, many models exist and they differ greatly in terms of their complexity, inputs requirements, the processes they represent and the manner in which these processes are represented, the scale of their intended use and the types of output information they provide (Merritt *et al.*, 2003). The Universal Soil Loss Equation (USLE), developed in the 1970s by the USDA is a soil erosion model that is widely used in estimating soil loss due to erosion (Merritt *et al*., 2003). The USLE model has however undergone a series of research and consequently a number of modifications which finally resulted in the Revised Universal Soil Loss Equation (RUSLE, Renard *et al.*, 1994; Kinnell and Risse, 1998).

The RUSLE still retains the basic structure of the USLE, which is represented as:

A=RKLSCP

Where **A** is the computed soil loss, **R** is the rainfall-runoff erosivity factor, **K** is the soil erodibility factor, **L** is the slope length factor, **S** is the slope steepness factor, **C** is the cover management factor and **P** is the supporting practices factor.

This empirically based equation, derived from a large mass of field data, computes combined inter-rill and rill erosion using values representing the four major factors affecting erosion. These factors are: climatic erosivity represented by R, soil erodibility represented by K, topography represented by LS, and land use and management represented by C and P. Although the basic USLE structure has been retained, the algorithms used to calculate the individual factors have been changed significantly in RUSLE. Most important has been the computerization of the technology to assist with the determination of individual factors (McCool *et al.*, 1995). This allows computation of the soil loss ratio (SLR) by 15- day intervals rather than by longer crop stage periods, and improves estimates of the factors affecting the SLR, such as surface roughness, crop growth and residue decomposition (Merritt *et al.* 2003). The main advantage of RUSLE over the USLE is that it has the capacity to estimate the *C* factor from information on vegetation form, decay and tillage practices rather than from experimental plot data as used in the USLE (Merritt *et al.* 2003).

2.5.2 Indicators of Land Degradation

The use of indicators is informed by the complex nature of land degradation processes which makes it impossible to measure in simple units. Indicators are measured parameters that give information about the state of an object. In this case, they are parameters or attributes measured to show whether land degradation is occurring in a particular land use system or not. According to Pellant *et al.* (2005) indicators are components of a system whose characteristics (e.g., presence or absence, quantity, distribution) are used as an index of an attribute that is too difficult, inconvenient, or expensive to quantify. The use of indicators is becoming increasingly important tools for assessing environmental performance and disseminating findings to decision makers and the public (Kosmas *et al.*, 2012).

A wide range of land degradation indicators have been proposed and used in the literature. Among the widely used are soil erosion features, crop yields, soil quality indicators and vegetation/biomass decline, land use and land cover changes, presence of parasitic weeds such as Striga (USDA, 1996; Pellant *et al.*, 2005; FAO, 2011). To establish whether land degradation is actually occurring in an ecosystem, direct assessment can be done by using indicators that may be qualitative or quantitative and it involves categorizing or rating the indicators along ordinal or categorical scales (Waswa, 2012).

A good indicator to reveal the state of the system assessed should meet the SMART criteria of being Specific, Measurable, Achievable, Relevant, and Time-bound (OECD, 2003; FAO, 2011). OECD further suggested that the indicators should at least demonstrate policy relevance, utility for users, and analytical soundness as well as measurability. They should also be comparable in spatial and temporal scales (OECD, 2003).This is a major aspect of this study, i.e. testing and evaluating indicators over time and space in assessing land degradation at both basin and sub-basin scales of the WVB.

Remote sensing data have been successfully used to derive indicators for measuring land degradation. For instance, the Normalized Difference Vegetative Index (NDVI) is often used as a proxy of land degradation derived from satellite imagery (Bai *et al.*, 2008; Vlek *et al.*, 2008; 2010; Le *et al.*, 2012). The NDVI is computed as the ratio between measured reflectivity in the red and near-infrared region of the electromagnetic spectrum (Tucker *et al.*, 1985; NOAA, 1988). Other derived vegetation indices from the NDVI include net primary productivity (NPP), leaf-area index and the fraction of photosynthetically-active radiation absorbed by vegetation (Asrar *et al.*, 1984; Alexandrov & Oikawa, 1997; Rasmussen, 1998). These indices can be used to identify areas undergoing degradation, especially vegetation stress, leading to identification of possible degradation hotspots (Barrow, 1991).

2.5.3 Land Use/Cover Change as Proxy of Land Degradation

Land degradation has been associated with land use/cover conversion. Land use represents the human uses of the land, or immediate actions modifying or changing land cover (FAO, 1997; de Sherbinin, 2002). On the hand, land cover refers to the biophysical characteristics of the earth surface, such as vegetation, water, desert, ice and other physical feature of the land including those created solely by human activities such as mine exposures and settlement (FAO, 1997). There is an overlap in the description of land use and land cover.

Land use/cover change can be broadly classified into two classes. They are conversion and modification (Butt & Olson, 2002). Conversion refers to the changes from one cover or use to another, e.g. conversion of forests to cropland. Modification however refers to the retention of the original land cover or use with alterations in its characteristics. For instance, a forest may remain a forest but significant alterations may be made in its structure or function.

According to Butt and Olson (2002), the key Land use/cover change pathways include deforestation, desertification, agricultural extensification and wetland drainage. These changes reflect the complex interaction of human activities and environmental processes over time and space on the land. Humans play a key role in contributing to the process and are equally affected by these changes (Lambin & Geist, 2006). Understanding these changes and their implications is therefore crucial for the design of effective land management programmes (Waswa, 2012).

The examination of land use/cover changes help to pinpoint areas that are undergoing degradation (Gyawali *et al.*, 2004). Land use/cover change analysis provides information on relinquishment, conversion of agricultural land and deforestation (Gyawali *et al.*, 2004). In the White Volta Basin, land cover change is accelerating and causing persistent environmental and socio-economic mishaps (Ringrose *et al.*, 1997; Barry *et al.*, 2005; Gyasi *et al.*, 2011; UNEP-GEF Volta Project, 2013; Awotwi *et al.*, 2014). Assessment of the current land use/cover conversion in the basin is essential as it is an important indicator of land degradation (Agyepong *et al.*, 1996; Duadze, 2004).

2.5.4 Scale of Land degradation Assessment

Scale is an important consideration in providing accurate information of land degradation. This is because ecological and socio-economic activities have causes and consequences that reveal different characteristics at multi-temporal and spatial scales. These underscore the need for the incorporation of multiple knowledge sources and types using a variety of methods operating at different temporal and spatial scales (Reed *et al.*, 2011) for a better understanding of the land degradation in the area. Such methods must encompass both biophysical and socio-economic aspects of land degradation processes at varying spatial and temporal scales (OECD, 2003; FAO, 2011; Reed *et al.*, 2011; Stocking & Murnaghan, 2001).

Different authors have stressed the need for scale consideration in land degradation assessment (Verburg *et al.*, 2004; Stein *et al.*, 2001). This is due to the fact that land degradation differs intrinsically in its interactive natural, economic and socio-political processes at different scales. Therefore, analyzing land degradation requires a systematic framework that takes into consideration the spatio-temporal variations of the degradation processes. Unfortunately such a framework is lacking in WVB to assist in the direction and organization of scale-specific land degradation assessments and their incorporation into knowledge for supporting mitigation policies.

2.6 Land Degradation Mitigation Measures

The evaluation of land degradation is incomplete if potential mitigation measures are not identified. So land degradation assessment should not be seen as an end in itself but a means for providing mitigation measures and useful outcome for a specified user of information such as planners, professionals, development practitioners, field staff, farmers or the rural poor (Stocking & Murnaghan, 2001).

If human factors are the most fundamental causes of land degradation, application of appropriate technology holds the key to reversing land degradation through sustainable land management (SLM) practices (Gyasi *et al.*, 2011; Liniger *et al.*, 2011). SLM is '*the combination of technologies, policies and activities aimed at integrating socio-economic principles with environmental concerns so as to simultaneously maintain or* *enhance production, reduce the level of production risk, protect the potential of natural resources and prevent soil and water degradation, be economically viable and be socially acceptable'* (Kloss *et al.*, 2004). Thus SLM encompasses three dimensions: ecological, economic and social dimensions (Figure 2.4) which are interrelated in a way (Liniger *et al.*, 2011).

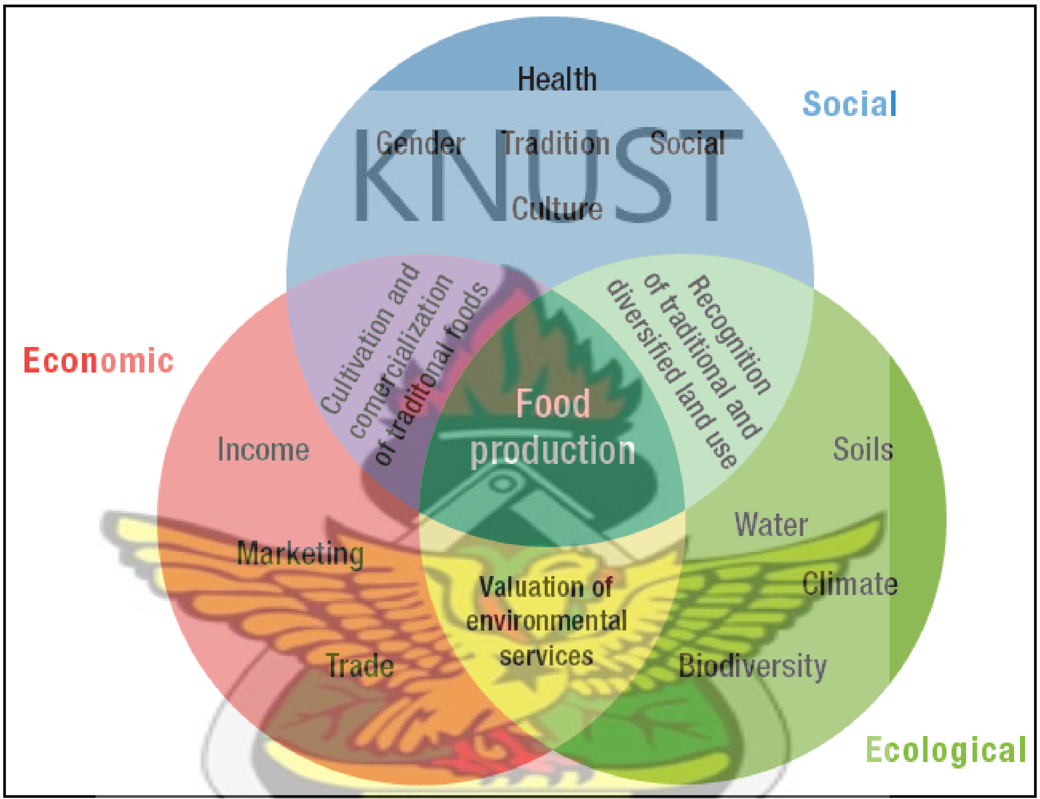

Figure 2.4: The Three Pillars of Sustainability (Liniger *et al.*, 2011)

Ecological Sustainability: It is the ability of the ecological system to support a defined level of environmental quality and natural resource extraction rates indefinitely. *Ecologically*, SLM technologies in all their diversity should effectively combat land degradation.

Social Sustainability: It is the ability of a social system, such as a country, family, or organization, to function at a defined level of social wellbeing and harmony indefinitely. Problems like war, endemic poverty, widespread injustice, and low education rates are symptoms a system is socially unsustainable. Socially, SLM technology should help secure sustainable livelihoods by maintaining or increasing soil productivity, thus improving food security and reducing poverty, both at household and national levels.

Economic Sustainability: It is the ability of an economy to support a defined level of economic production indefinitely. Economically, SLM technology should be able to pay back investments made by land users, communities or governments. Agricultural production is safeguarded and enhanced for small-scale subsistence and large-scale commercial farmers alike. Furthermore, the considerable off-site benefits from SLM can often be an economic justification in themselves.

Sustainable Land Management is crucial in the White Volta basin to minimize land degradation, rehabilitate degraded lands and ensure the judicious use of land resources for the benefit of present and future generations.

3.0 MATERIALS AND METHODS

3.1 Description of the Study Area

The study was conducted in the savanna zone of the WVB in West Africa at two different scales: the whole basin's scale and the Nawuni sub-basin (Figure 3.1). The WVB covers mainly Burkina Faso and Ghana. It lies between latitude 9° 30′ N to 14° 00′ N and longitude 2°30′ W to 0°30′ E. It is the second largest catchment after the Black Volta Basin in the Volta Basin. It covers a total land area of about 106,000 km^2 (Diekkrüger & Obuobie, 2008) and represents 28 % of the total Volta catchment area (Awotwi *et al*., 2014). The basin is inhabited by about 7 million people (Balk & Yetman, 2004) whose activities have both positive and negative effects on the basin. It is also an ecosystem that suffers severe degradation varying from land use/cover conversion, vegetation degradation to soil loss by erosion (Droogers *et al.*, 2006; UNEP-GEF Volta Project, 2013).

The Nawuni sub-basin which is a sub-basin of the White Volta basin stretches from lat. 9° 87′ N to 11° 15′ N and Lon. 0° 5′ W to 1° 26′ W (Figure 3.1). Over 95% of the sub-basin lies in Ghana and hence the study at this scale focused on only the Ghana part. In Ghana, it covers two political regions (the Northern and Upper East Regions) and 16 districts. It is home to nearly two million people with most communities being rural and the people mainly depend on agriculture for their sustenance (Ghana Statistical Service, 2010; UNEP-GEF Volta Project, 2013). The Nawuni sub-basin is part of the WVB and hence the general description of the WVB also applies to the sub-basin. Land degradation is one of the challenges within this sub-basin. Soil erosion, decline in soil fertility, vegetation degradation among others are the different types of land degradation in the sub-basin.

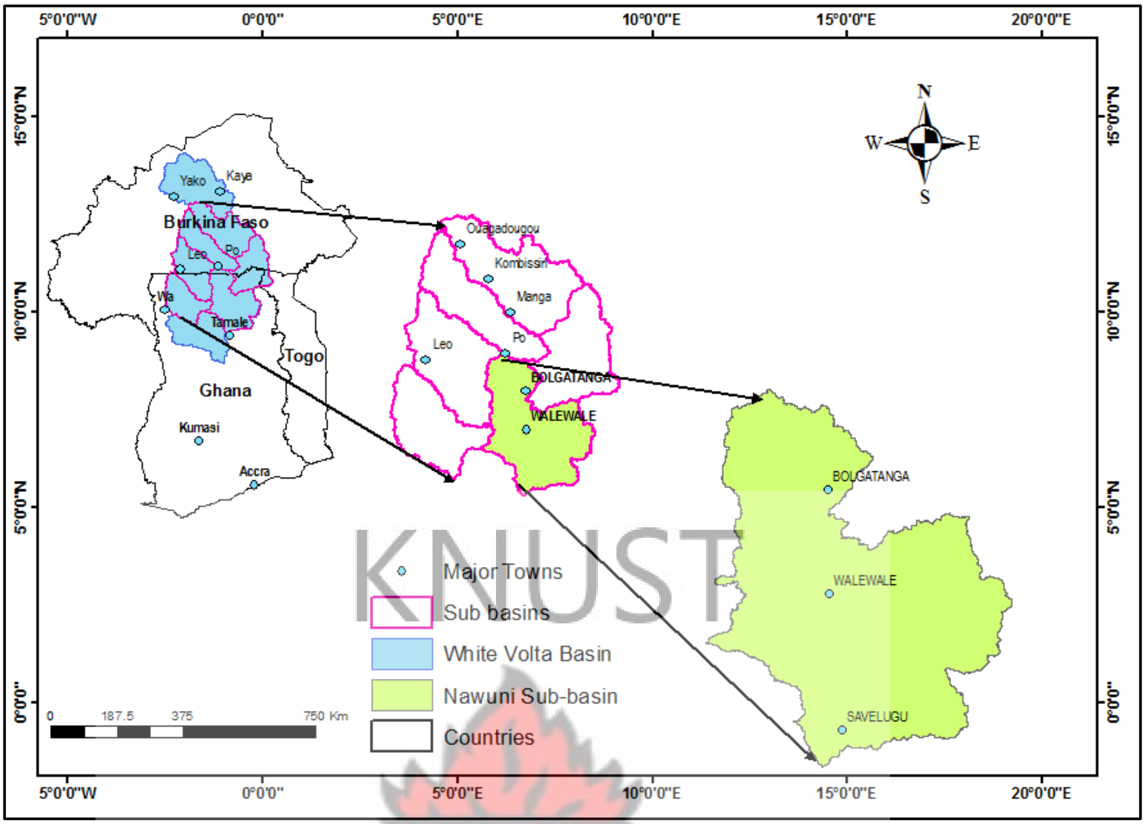

Figure 3.1: Map showing the study area at the different scales

3.1.1 *Agro-ecology*

The Basin is located within the Guinea and Sudan savanna agro-ecological zone which experiences two main seasons: wet and dry. The seasons in the basin are as a result of the movement of the North-East and the South-West monsoon air masses. The dry season is characterized by a dry, warm and dust-laden wind referred to as *Harmattan* which blows from North-East and extended across the Atlantic Ocean (Awotwi *et al*., 2014). This phenomenon, severe can lead to soil degradation due to wind erosion. The wet season on the other hand is typical of the moist southwest monsoon, blowing from the Gulf of Guinea across the West African inland giving rise to precipitation.

3.1.2 Precipitation

The rainfall pattern in the WVB is mainly convectional. It is associated with the Inter-tropical Convergence Zone (ITCZ) where monthly total rainfall increase gradually from March till September, and then decrease suddenly in October. Generally the rainfall period is approximately five months, starting from May to September during which over 76 % of the total annual rainfall occurs (Amisigo, 2005) with the rest of the months being dry and hot. The peak of the rainy season is therefore between June and September. The annual average rainfall varies between 900 mm in the northern part of the basin to about 1,100 mm in the southern part (Kasei, 1990). As a sub catchment of the Volta Lake, about 17% of its rainfall results in runoff to the Lake (Andreini *et al.*, 2000). This could be a contributory factor to soil erosion and other forms of land degradation in the area.

3.1.3 Land Use and Land Cover

The main natural vegetation cover is savanna woodland. It is characterized by short, closed and scattered drought resistant trees and grasses of about 3m high. *Adansonia digitata*, *Ceiba pentandra*, *Parkia biglobosa*, *Faidherbia albida*, *Khaya senegalensis*, *Tamarindus indica* are the indigenous trees commonly found in the area. Exotic tree species also found in the area include: *Tectona grandis, Magifera indica, Azadirachta indica, Anacardium occidental, Eucalyptus spp. and Moringa oleifera.* These trees are interspersed with a variety of annual grasses such as *Panicum maximum, Pennisetum purpurem and Andropogon gayanus.*

The predominant land use in the basin is agriculture. This involves the cultivation of annual crops such as: *Vigna unguiculata* (beans), *Oryza sativa* (rice), *Sorghum bicolor,* (sorghum) *Pennisetum glaucum* (millet), and *Arachis hypogaea* (groundnuts). The cultivation of tree crops such as *Anacardium occidental* (cashew) and *Magifera indica* (mango) is gaining prominence in the study area. The vegetation cover is reported to have been degraded over the years partly due to agricultural land expansion, fuel wood harvesting and cattle overgrazing (Gyasi *et al.*, 2011; UNEP-GEF Volta Project, 2013; Awotwi *et al.*, 2014). Bush fires are rampant in the area and contribute to land degradation through destruction of vegetative cover (UNEP-GEF Volta Project, 2010; Gyasi *et al.*, 2011; UNEP-GEF Volta Project, 2013).

Other human activities such as small scale surface gold mining, sand and gravel winning, quarrying, infrastructure development and expansion are also emerging land uses which are on the ascendency partly due to increasing population, urbanization and developmental projects of these two countries (Ghana and Burkina Faso) to achieve middle income status by the year 2020 (Centre for Democratic Development, 2002). This quest for development by both countries is likely to create pressure on the natural resource base and consequently their degradation within the basin.

3.1.4 Soil

The major soil types in the basin comprised of Leptosol, Levisols, Lixisols, Gleysols and Planosols to Luvisols (EPA, 2011). The Luvisol was reported to be the predominant soil type in the basin (Andah *et al.*, 2003). The main components of the parent materials include shale, sandstone, granite and igneous.

The low vegetative cover coupled with the rampant annual bush fire during the dry season exposes the soils to various forms of erosion. The soils have suffered leaching over a long period of time (Benneh *et al.*, 1990) making it deficient in major nutrients.

Nitrogen and phosphorous which are macro nutrients for plant growth are the most deficient nutrients of which the depletion rates are 35kg/ha/y and 4kg/ha/y, respectively (Asiamah & Dedzo, 1999).

3.1.5 Demographic and Socio-Economic Activities

There has been a dramatic increase in human population within the basin. In 1960, human population within the basin was 518,569 (Figure 3.2). This had increased to 877,037 in ten years' time (Ghana Statistical Service, 2005). According to the recent population census in 2010, the population in the basin is estimated to be 2,516,790 people (Ghana Statistical Service, 2010). These figures are for the Ghana part only and the rest of the countries also exhibit similar population growth characteristics (UNEP-GEF Volta Project, 2013). This increase in population with fixed land resources will undoubtedly increase pressure on the land resources and consequently their degradation.

The population density in the basin is reported to vary between 8 and 104 persons /km^2 (Awotwi *et al*., 2014). Areas with high population density are likely to be the hard hit in terms of land and other natural resources degradation. There is still the expectation that human population in the basin will increase by 80 % by 2025 due to the high average population growth rate of 2.54 % in the area (Ghana Statistical Service, 2005; UNEP-GEF Volta Project, 2010).

The major occupation of the people in the basin is agriculture (crop and animal farming). Some of the agricultural practices are however outmoded and unsustainable leading to over-exploitation of natural resources, and if not checked may jeopardize the land and the environment as a whole. Apart from agriculture, the people in the basin engage themselves in other economic activities such as fishing, lumber, charcoal production, agro-industry (e.g. Shea butter processing, rice processing and others), mining and quarrying. All these activities have influence on the natural resource base.

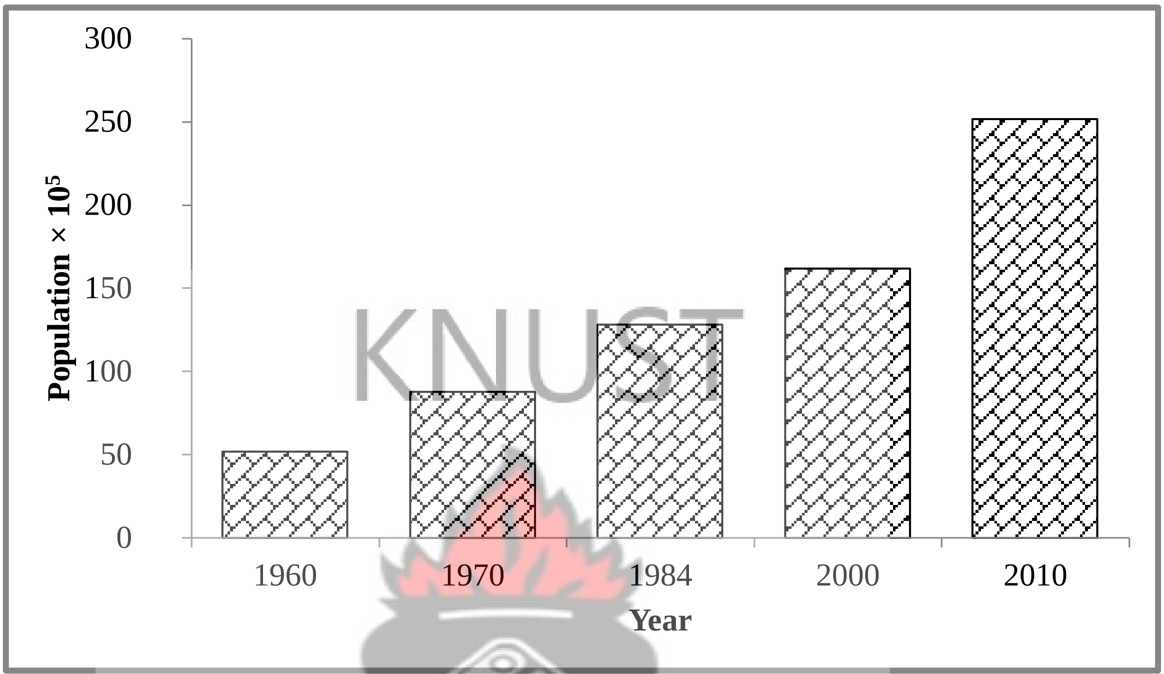

Figure 3.2: Human population within the White Volta basin of Ghana from 1960 to 2010. *Source:* Ghana Statistical Service (2005, 2010)

3.2 Methodology

The methods used to achieve the objectives of the research are summarised in Figure 3.3 and elaborated in the subsequent sections. This involves a multi-scale approach in knowledge, space and time in identifying indicators of land degradation and analysis.

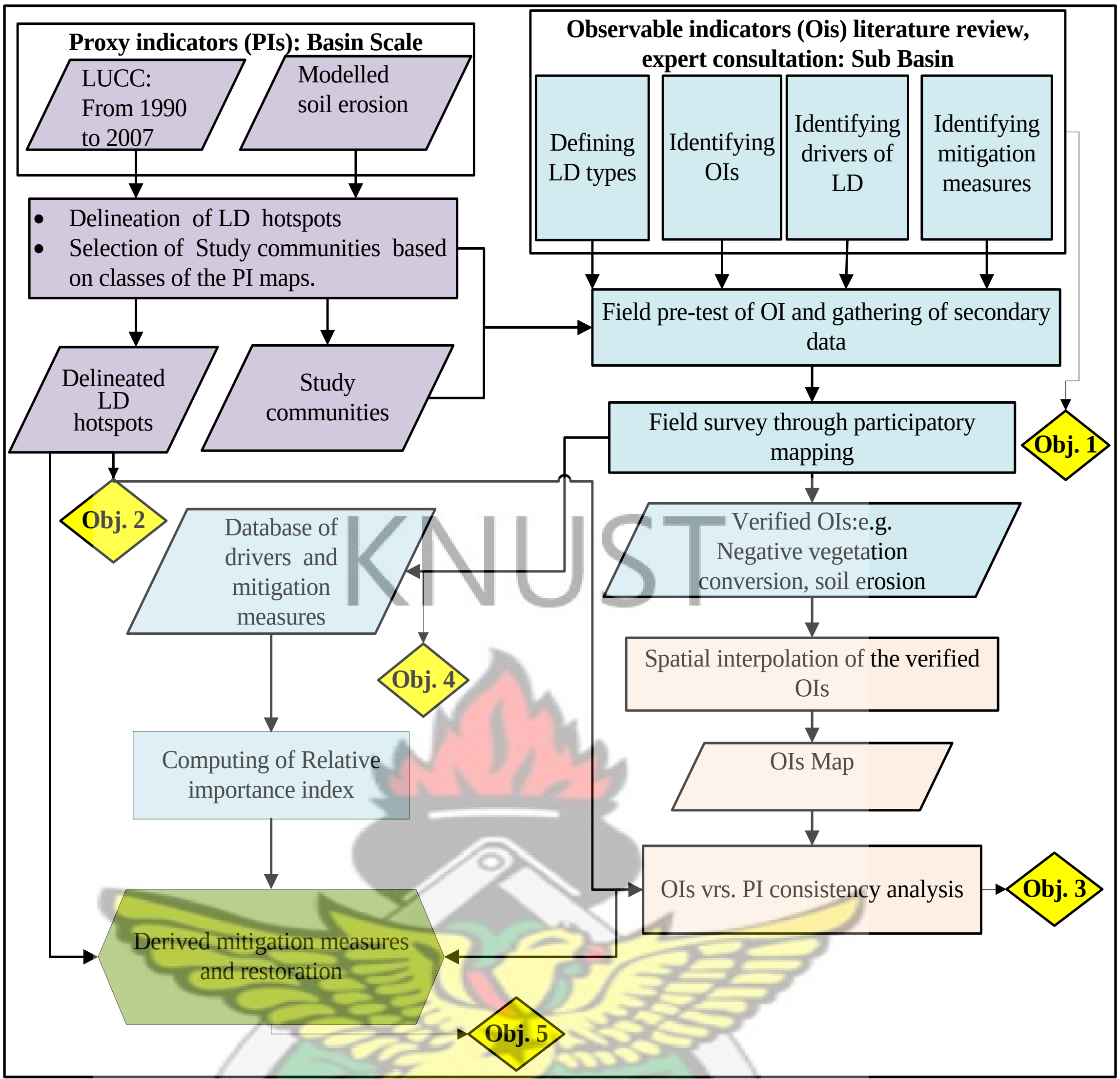

Figure 3.3: The general research analytical framework

3.2.1 Multi-Dimensional Indicative Assessment Framework

The proposed multi-dimensional approach of assessing land degradation encompasses multi-scale, multi-indicators and actor-based framework (Figure 3.4). The multi-scale of the framework centered on combining basin and sub-basin scale indicators in the evaluation of land degradation in the WVB. At each scale, the area of coverage and the depth of analysis are different, resulting in information complementarities. This is because land degradation is sturdily scale-dependent as ecological systems are complex in nature and operates at a broad spectrum of spatiotemporal scales. Observations and measurements made at a particular scale may be contradicted by same observations and measurements at different scales (Gray, 1999). For instance a pattern detected as relatively homogenous on a coarse scale might disappear when a finer resolution is applied or vice versa (O'Neil *et al.*, 1989; Gibson *et al.*, 2000). Hence detection of a land degradation phenomenon depends on the scale at which they are measured.

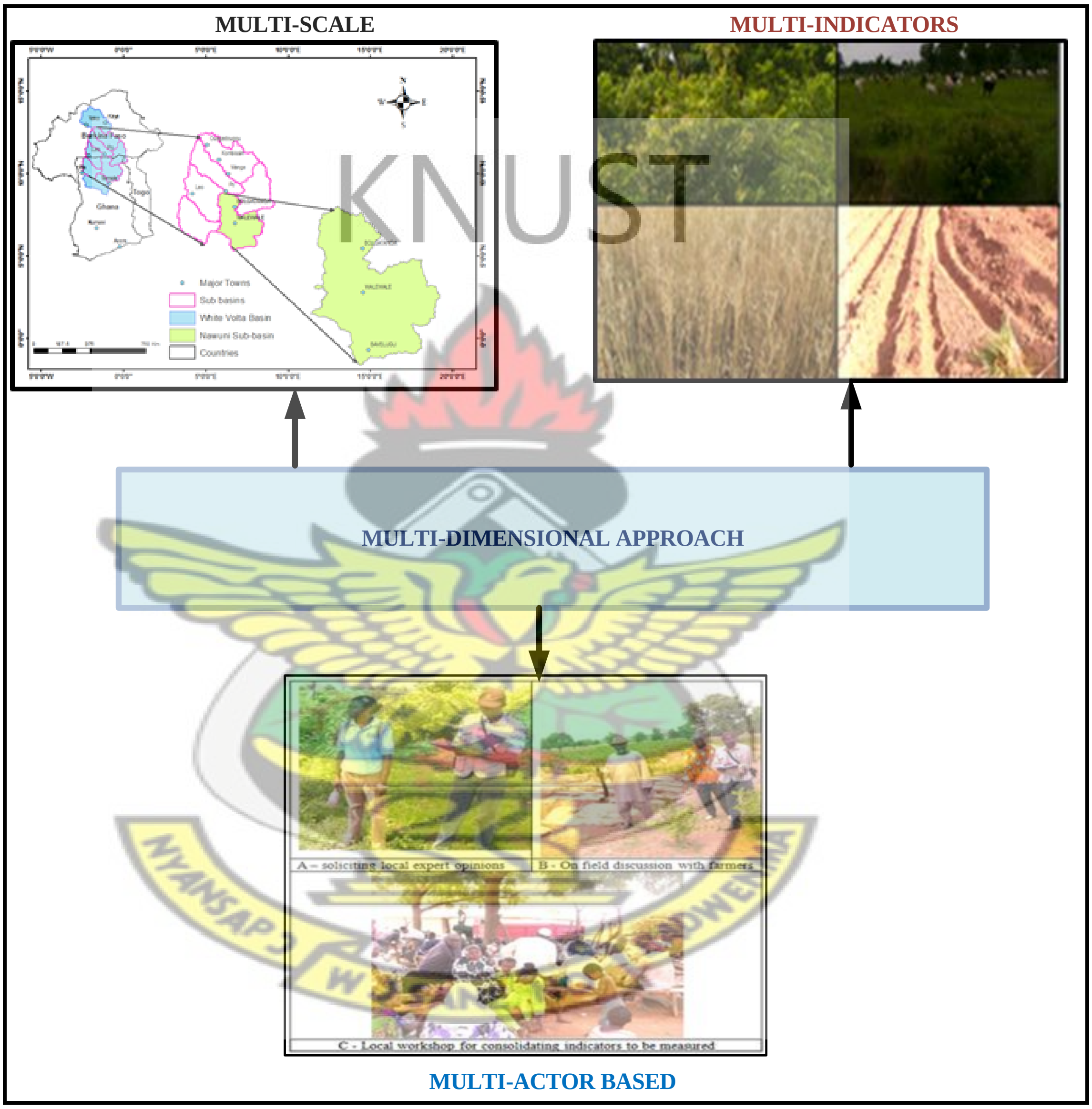

Figure 3.4: Multi-dimensional approach

The basin’s scale analysis was characterized by large coverage (WVB) resulting in quick coarse resolution information; whereas the sub-basin scale analysis was characterized by small area coverage (Nawuni sub-basin) but with fine resolution information. The incorporation of information of the different scales is expected to provide an in-depth understanding, as well as an overview of land degradation in the White Volta basin.

The multi-indicator approach used different indicators for the land degradation assessment. The use of single indicator, often gives singular expression of land degradation or its impact and is susceptible to errors, misinterpretation, and chance (Stocking & Murnaghan, 2001) and consequently, wrong conclusions. Combination of indicators allowed a more robust conclusive and comparison of different types of measures to obtain a comprehensive understanding of land degradation in the area.

The actor-based component of the framework sought the viewpoint of land degradation from land use experts and stakeholders. They included agricultural extension workers, local leaders and different resource user groups within the area (e.g. crop farmers, livestock farmers, herbalists' and fuel wood harvesters).

3.2.2 Desk Study and Preliminary Selection of Indicators

Identifying and testing indicators that best reveal the state of the land in the White Volta basin is a key component of this study. This was achieved through an in-depth literature review, analysis of relevant secondary data and expert consultation on land degradation. Thus, it encompasses the conceptualization of the spectrum of successive phases of land degradation (e.g. Lal *et al.*, 1989) across the White Volta basin. Ecosystem succession theory was adapted to define the main phases of land degradation and the main indicators for assessing the various stages of degradation. Here, two-fold system of indicators was considered: (1) Observational indicators (OIs) set (e.g. Species composition/diversity decline, loss of soil life, increase of pests/diseases and soil nutrient deficiency) and (2) Proxy indicators (PIs) set (e.g. type of land conversion and modeled soil erosion).

The former indicator system is based on field and landscape observation with expert eyes and clear protocol. These are solid, but difficult to use in a regular, large scale and practical manner due to high cost and resource scarcity. The latter is based on either remotely sensed or model-driven data, which are easy to obtain but poorly known regarding scientific credibility.

The review also revealed a number of social and ecological determinants of land degradation across the White Volta basin. As a result, a mapping tool consisting of a field protocol that outlined the indicators and causes of land degradation as well as current mitigation measures was developed for mapping land degradation in the area (see Appendix 1).

3.2.3 Reconnaissance Survey and Pre-testing for Observable Indicators

A reconnaissance survey was carried out to have a better understanding of the state of natural resources (vegetation, soil and water), types of degradation and processes that are associated with land use types in the area, and also to obtain secondary information from relevant institutions to aid the research. Information from the survey was used as one of the guiding principles in selecting locations for transects and detailed sampling for assessing vegetation, soils and other resource conditions. Pre-testing for the relevance and workability of the candidate OI set derived from literature was also done during the reconnaissance survey. Responses from the pre-testing were used to improve the quality of the OI sets.

3.2.4 Proxy Indicators

To assess land degradation at the basin scale, two major proxy indicators were used. They included Negative Land Use/Cover Conversion (NLUCC) and soil losses through erosion. Negative land use/cover conversion is the land use transfer whereby the quantity and quality of the natural vegetation cover is reduced far beyond the original land cover due to agricultural extensification and intensification as well as other land uses. Decline in crop yields puts pressure on farmers to open more vegetative lands to meet their needs (Kaihura and stocking, 2003). These areas that suffer vegetation degradation are also prone to biodiversity loss, soil erosion and soil nutrient depletion. The analysis of land use/cover is therefore essential in assessing the state of the land in the area.

3.3 Basin Scale Assessment of Land Degradation

3.3.1 Data and Data Analysis

Land cover conversion information was obtained from GLOWA-Volta land cover maps at 250 m resolution between 1990 and 2007. The original data for the land cover maps were extracted from LANDSAT (1990) and MODIS (2007). These were already classified into ten aggregate classes: Forest, Woodland, Shrubland, Grassland, Cropland, Wetland, Bare Soil, Urban Area, Water and Burnt Area. These were reclassified and cross examined to improve their accuracies. Personal knowledge of the area, unchanged land cover types (e.g. forest/game reserve cover shape files of Ghana) as well as historical information from the local community members was used to validate the land use/cover maps.

For the purpose of this study, the land cover maps were further analyzed using post classification comparison techniques where decline vegetation cover is used as a surrogate of land degradation in the area. All classes that remained unchanged or indicated improvement of vegetation cover are grouped under the class 'Unchanged/Improved' since they are not core to the land degradation analysis in the area. Three classes of NLUCC were considered. They include: LUCC level 1, LUCC level 2 and LUCC level 3 (Table 3.1).

Loss of soil due to erosion is one of the key indicators of a degraded land. It has been widely used to assess the status of the land in terms of degradation (Oldeman *et al.*, 1991; Stocking & Murnaghan, 2001; Stringer & Reed, 2007; Reed *et al.*, 2011; Kosmas *et al.*, 2012; Le *et al.*, 2012). Estimation of soil loss in the basin was based on the Revised Universal Soil Loss Equation (RUSLE) model output by Le *et al.* (2012). The model was adjusted for Sediment Delivery Ratio (SDR) to have an erosion severity pattern that indicates areas of relatively high soil loss compared to others, using severity classes of soil erosion rather than absolute soil loss values. Detailed description of the model and the criteria for its inputs can be found in Le *et al.* (2012). This output was used because, it coincided with the time window that this study was done and at the same time it covers the entire basin. The output was reclassified into four (4) soil loss classes and used to define land degradation severity within the basin. The classes are: Very low erosion, slight erosion, high erosion and very high erosion (Table 3.1).

Table 3.1: Degradation severity classes of individual basin scale indicators

Negative land use/cover conversion	
Class	**Description**
LUCC level 1	Modification of natural vegetation; that is the alteration of forest to woodland by human induction or natural causes
LUCC level 2	The transformation of natural woody vegetation (e.g. forest, woodland and scrubland) to non-woody natural vegetation (e.g. grassland)
LUCC level 3	The conversion of natural vegetation to cropland
Unchanged/Improved	Areas that remained unchanged or indicated improvement of the vegetation cover
Net soil loses	
Very low erosion	Net soil loss by water erosion (< 500t/km2/y)
Slight erosion	Net soil loss by water erosion (500 - 1500 t/km2/y)
High erosion	Net soil loss by water erosion (1500 - 3000 t/km2/y)
Very high erosion	Net soil loss by water erosion (> 3000 t/km2/y)

3.3.2 Analysis of Land Degradation Hotspot at the Basin Scale

Land degradation hotspots were analyzed for the entire WVB based on the NLUCC coupled with net soil losses (NSL). This involved the integration of the NLUCC map with that of the NSL maps (Table 3.2 and Appendix 3). Land degradation is said to be at its minimum stage or not occurring in an area where very low erosion and other LUCC occur (LD class 0). On the other hand, it is at its worse stage when an area manifests both very high soil loss and LUCC Level 3 (LD class 6). This analysis was done in an ArcGIS environment.

Table 3.2 Scheme for overlaying indicators to calculate LD classes and hotspots at the basin scale

NSL \ LUCC	*LUCC level 1*	*LUCC level 2*	*LUCC level 3*	*Unchanged/ Improved*
Very low erosion	LD class 1	LD class 2	LD class 4	LD class 0
Slight erosion	LD class 1	LD class 2	LD class 4	LD class 1
High erosion	LD class 2	LD class 3	LD class 5	LD class 2
Very high erosion	LD class 4	LD class 5	LD class 6	LD class 4

3.4 Land Degradation Assessment at the Sub-Basin Scale

The purpose at this level of assessment was to complement the basin scale analysis of the degradation to provide information complementarities. This permitted a more robust conclusion and comparison of the results at the different scales. The sub-basin assessment was carried out for the Nawuni's catchment of the White Volta Basin.

3.4.1 Identification of Sub-Basin's Scale Indicators

A variety of observable indicators were pulled together from various sources of literature (FAO, 1990; UNEP, 1997; LADA, 2001; Stocking & Murnaghan, 2001; FAO, 2003; Millennium Ecosystem Assessment, 2005; FAO, 2007; Bai *et al.*, 2008; FAO, 2011; Stocking & Murnaghan, 2001; UNCCD, 2012) in addition to expert consultation for the study. A group of nine (9) potential indicators were identified for further screening and refinement (see Appendix 2).

In order to refine the list of potential indicators for relevant and objective assessment, a multi-stakeholder consultative discussion was held with stakeholders at three levels (Figure 3.5). First, experts such as extension workers and researchers were contacted to elucidate information about land degradation and to prioritize the most eminent observable indicators in the area. This was achieved through one-on-one expert consultation.

Furthermore, there was an on-field discussion with farmers and other resource users to obtain their input on key indicators of land degradation. Lastly a community forum which involved all the land resource user groups and experts (farmers, agricultural extension workers, local leaders, fuel wood harvesters and herbalist) was held to consolidate the observable indicators to be measured in the field. The consolidation involved agreement among the stakeholders on the importance of a particular indicator for the degradation assessment based on simple ranking. These consolidated indicators were used to assess land degradation at the sub-basin scale. Negative land use/cover conversion assessment was based on remote sensing techniques and field observation, while the rest were based on field observation using participatory mapping approach.

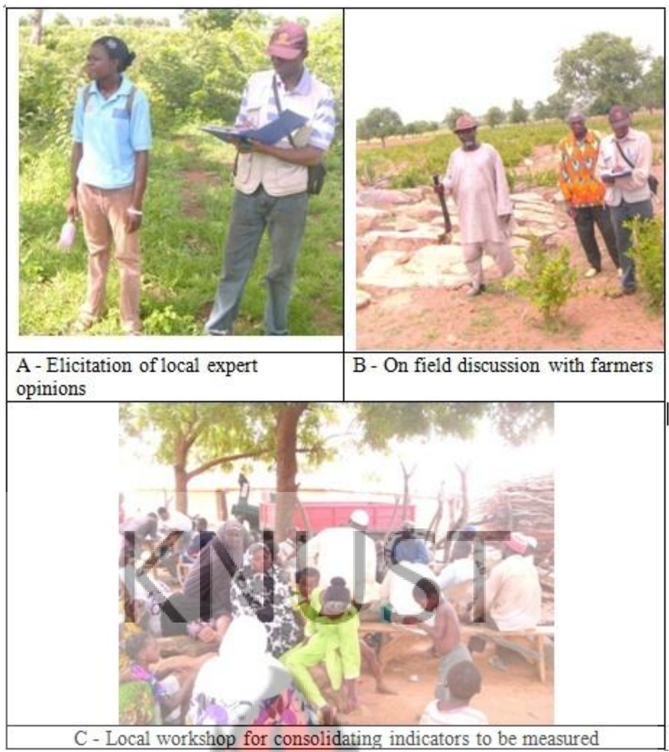

Figure 3.5: Multi-stakeholder consultative process to refine the indicators

3.4.2 Participatory Mapping of LD Using Selected Field Indicators

Mapping of fields where degradation is taking place is key to successful and accurate assess of land degradation. This involved taking inventory of the evidence of degradation across the sub-basin. The physical aspects: vegetation, soils and other resources of the landscape and fields were observed and evaluated in terms of degradation and management practices. A standard field protocol proposed by FAO-LADA and Stocking (Stocking & Murnaghan, 2001; FAO, 2011) was adopted and used for the assessment. A transect of 5 km was used to assess land degradation based on the identified indicators. A minimum of three transects were used in each of the 23 community/village for the mapping exercise. Transects were chosen to cut across the different land use and cover types within the community/village.

Additionally, a farmer toolkit was designed to engineer farmers and other land users' knowledge to evaluate land degradation within their vicinity (see Appendix 4 and 5).

This toolkit with other materials such as base maps, Global Positioning System (GPS), measuring tape and digital cameras were employed to capture information of land degradation at appropriate points along the transects. Information was captured across the various land use/cover types in the area. At each point the land use/cover was determined and the area estimated. Estimating and scoring of land degradation indicators was done in relation to the area of the particular land use/cover (see Appendix 6 and 7). For instance, Soil erosion was mapped across the landscape based on its types, state, extent and severity. Erosion types considered in this case included; Splash, inter-rill, rill and gully erosion. For each erosion type, one of four classes (i.e. active, partly stabilized, decreasing and stabilized) was used to describe the erosion state (see Appendix 7).

Erosion extent implies the proportion of a stated area that is affected by the recorded erosion type and this was defined by five terms: negligible (0-2% of the area under study), localized (3-15% of the area), moderate (16-30% of the area) and widespread (typically 31-50% of the area).

Erosion severity was estimated as the rate or "average amount of soil that is moved by water", expressed as units of mass/area/time. Based on this definition, a field usable estimate of erosion severity is made using four classes, recognizing that the mass of soil loss will rarely be known (Stocking & Murnaghan, 2001; FAO, 2011).

- ✓ Low – minimal erosion types evident; most commonly splash or rill erosion
- ✓ Moderate – evidence of erosion but eroded sediment remains within the area under study
- ✓ Severe – sediment is exported off site and surface lowering < 0.1 m
- ✓ Extreme – sediment exported off site and surface lowering > 0.1 m.

Also coordinates of the different land use/cover were captured using Garmin-*GPSMap*-62s for remote sensing based land use/cover analysis.

3.4.3 Assessment of Socio-Ecological Determinates and Mitigation Measures

Twenty-three (23) communities were selected within the catchment to evaluate their perception of socio-ecological causes of land degradation and possible mitigation measures to combat the degradation in the area. The sampling frame follows the pattern of degradation mapped at the basin's scale. Communities that fall within the degrading pixels of the basin scale results were purposely selected for the socio-ecological study.

Group discussion with local people in the communities was employed to gather data on direct and indirect causes of land degradation as well as possible mitigation measures to the degradation problem. Group discussion is the most appropriate means of addressing the problem identified through consensus (Lindlof & Taylor, 2002; Bai *et al.*, 2008). The group size was however variable depending on the population of the community and the willingness of the people to participate in the discussion. A minimum of ten and maximum of twenty-five people in a group have been used through all the communities. The groups entailed both men and woman within the communities who make use of land resources in one way or the other. This composition was appropriate for the study as different interest groups may have divergent perception about land degradation (Stocking & Murnaghan, 2000) and needed to be captured.

The group discussion began with brainstorming exercises to identify (1) perceived direct and indirect causes of land degradation and (2) perceived mitigating measures (Plate 3.1). These perceived direct and indirect causes as well as mitigating measures were further ranked in order of importance using simple ranking method by the groups

(Plate 3.2). The activities of the groups were guided by trained facilitators to avoid over dominance of elite group members.

Plate 3.1: Participatory brainstorming

Plate 3.2: Participatory ranking

3.4.4 Sub-Basin's Scale Data Analysis

Data on land degradation indicators, direct and indirect causes of land degradation as well as sustainable land management techniques collected in each of the 23 communities were coded, entered and analyzed using Statistical Package for the Social Sciences (SPSS) software. Descriptive statistical methods were used to explore the data. Point maps of the erosion features were produced and were used as inputs for the cross-scale analysis with the basin scale proxy indicators.

Relative Importance Index (RII) (Kometa & Olomolaiye 1997) of the degradation indicators, direct and indirect causes was computed (Equation 3.1) in order to prioritize these issues in the study area. This was computed based on weights assigned to the various ranks of each variable (degradation indicator, causes and mitigation measures). The overall rank was then assigned based on the RII. The value ranges from 0 to 1. Weights were assigned based on rank reversal and in this case, the most important variable by rank was assigned the highest weight while the least important variable was assigned the least weight (Aabeyir *et al.*, 2010). The RII of each variable was computed as follows:

Relative importance Index (RII), $RII = \frac{\sum w}{A*N}$ [3.1]

Where w = weight assigned to each rank (based on reversal of ranks), A = highest weight and N= total number of communities.

Kendall tau-b correlation analysis (Field, 2006) was further performed to explore the relationship between the perceived land degradation indicators, direct and indirect causes of land degradation in the area.

3.4.5 Sub-basin's Scale Land Use/Cover Analysis

The data used for the analysis of land use/cover of the study area were Landsat TM for 1990 and Landsat 8 for 2013. These images were captured on 30/11/1990 and 05/11/2013 for the TM and Landsat 8 respectively. This makes them ideal as analysis of satellite images taken at different times over the same area is the most classical way to assess changes in landscape. Two scenes ranging from path 194/row 52 and path 194/row 53 were downloaded for each year from Global Land Cover Facility (GLCF) website.

The images acquired for the studies were already geo-referenced to the UTM projection system of the World Geodetic System, 1984 (WGS84) datum. Cloud cover which hinders feature extraction from images was insignificant (i.e. less than 10%). Fire scars were visible on both images, but these were also not significant, hence still useful for the study. A mosaic of the image scenes was produced and a subset of the area of interest (Nawuni's sub-basin) used for analysis. Spectral enhancement using histogram equalization was applied to increase the image contrast on both images. All these analysis were carried out using ERDAS Imagine Version 10 image processing software.

Rigorous ground truthing with the aid of Global Positioning System (GPS) was carried out to collect training and validation samples for the image analysis. The ground-truth data were gathered during field work at homogenous locations between March and December 2013. Historical land cover description was also collected through interviews, focus group discussions and participatory mapping for the validation of the 1990 image. Permanent land covers, being areas that remained unchanged between the time the images were captured and the time of the field survey, such as sacred grooves and grave yards, were used to assist in the classification and validation of the results of 1990 image. Forest cover from Ghana at a glance data was also used to aid the classification and validation.

Image Classification

Supervised classification technique using maximum likelihood algorithm was applied to the images to produce the land use/cover maps. Maximum likelihood algorithm was chosen because it takes into consideration many variables which result in more accurate classifications compared to other classification algorithms such as parallelepiped, nearest neighbour and minimum distance (Lillesand & Kiefer, 2000).

The classification was achieved through the use of training data set which represents the desired classes. The selection of the training classes was also based on field checks, previous knowledge of the study area and knowledge of the local community members. The images were classified into 5 major classes depicting the land use/cover characteristics of the study area (Table 3.3). These were further analyzed for land degradation assessment.

Table 3.3: Land use/cover classification scheme

Land use/cover category	**Description**
Forest/dense woodland	Trees usually over 5m tall with crowns interlocking (generally forming 50-100% cover or more than 150 trees per hectare). Shrubs, herbs, and non-vascular plants may be present with any cover value
Open woodland	Open stands of trees usually over 5m tall with crowns not usually touching (generally forming 25-60% cover or with approximately 75-150 trees per hectare). Shrubs, herbs, and nonvascular plants may be present with any cover value
Water bodies	This include inland waters, streams and reservoirs
Settlement/cropland/barren land	Areas of human settlements, commercial and industrial developments, annual crops production areas and areas devoid of vegetation including deserted and cleared areas
Grassland/burnt area	Complex mixture of grasses and shrubs with or without scattered trees with less than 10 trees per hectare (rangelands), as well as areas burnt through natural and anthropogenic causes

Adapted from Agyepong et al.(1996)

Classification Accuracy Assessment

For the accuracy assessment of the land use/cover map produced from the 2013 image, half of the collected ground truth data (i.e. 622 points) was used for the accuracy assessment. These test points were carefully chosen to ensure that they were evenly distributed. The classified image was then linked to the test data from which the overall classification accuracy and kappa statistics were determined.

Stratified random points were generated using the random point generator in Erdas to assess the accuracy of the 1990 classified image. Fifty (50) random points were generated for each of the five classes making a total of 250 points for the accuracy assessment. Additional sources of information that aided in the validation process included personal previous knowledge of the area, unchanged land cover types (e.g. forest/game reserve cover shapefiles of Ghana) as well as knowledge from the local community members.

Analysis of LUCC as a Surrogate of Land Degradation

Image post-classification comparison techniques were adopted to quantify spatial changes for the two processed images (Figure 3.6). Land use/cover conversion was analyzed for the two land use/cover maps as a surrogate of land degradation in the area. Like the basin scale analysis, all classes that remain unchanged or indicated improvement of the vegetation cover were grouped under the class 'Unchanged/Improved' since they were not core to the analysis of land degradation in the area.

In this case the indicators of land degradation included: modification of natural vegetation (LUCC Level 1) which involves the alteration of forest or dense savanna woodlands to opened savanna woodland or Shrubland; transformation from natural woody vegetation to non-woody natural vegetation (LUCC Level 2) such as the alteration of forest, savanna woodlands and shrubland into grasslands; conversion from natural vegetation (forest, woodland, shrub land and grassland) to Settlement, cropland and barren lands (LUCC Level 3) is the third level of vegetation degradation.

As a proxy, each level indicates to what extent the natural vegetation is negatively affected by land use/cover change. LUCC level 3 is considered to be the class that is in a severe or worst state of degradation while LUCC level 1 is considered least degraded. The whole process of image processing and analysis is illustrated in Figure 3.6. Cross-tabulation was further employed for relational analysis between the basin and sub-basins scales.

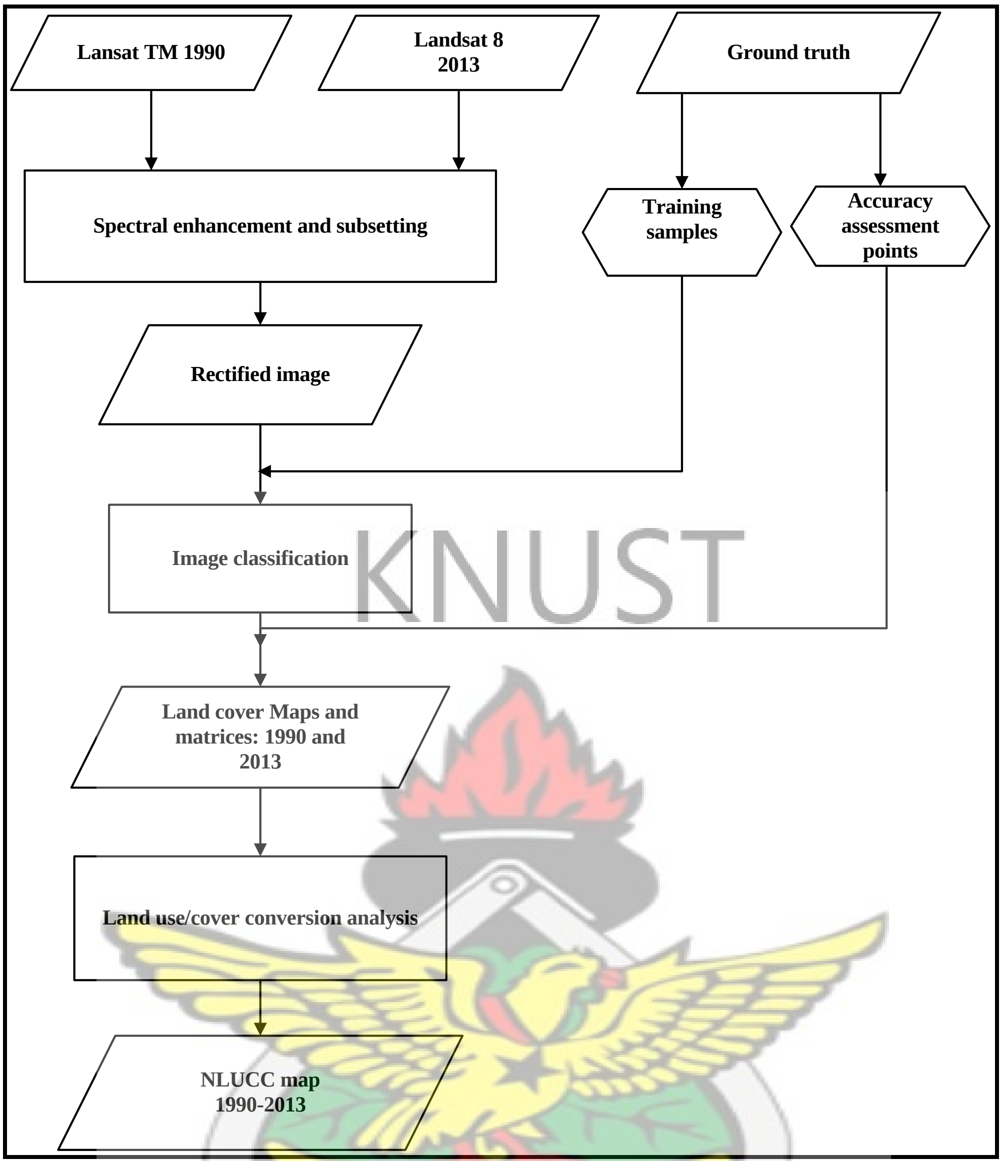

Figure 3.6: Image processing and NLUCC analysis at the basin and sub-basin scale

3.5 Relational Analysis between Basin and Sub-Basin Scales

The purpose of the cross-scale analysis was to identify commonalities or divergence of the different indicators at the two scales in mapping land degradation in the area. To achieve this, the output of the basin scale indicators was crossed-examined with that of the output of the local scale through cross-tabulation. Qualitative matches and divergences between the different scale indicators were estimated.

3.6 Limitations

Ideally the relational analysis and comparison should have been appropriate at both scales for data collected at the same time. This was however not possible especially with the land use/cover information as data were not available to cover the current years. Nevertheless, the analysis is still useful as it is within the same time window and changes are still minimal.

Also, since some of the indicators were based on observation and estimation, the individual subjectivity can be a limitation to this study but nonetheless this finding is still useful for policy formulators, researchers and other users.

4.0 RESULTS AND DISCUSSION

4.1 General Indicators for Identifying Degraded Land in the Study Area

Indicators used by the farmers and other land users to identify degraded land are summarized in Table 4.1. Eight of them were identified and ranked by the 23 communities. Generally they are readily observable indicators and are similar in characteristics to those scientists commonly use (UN/FAO, 1997; Stocking & Murnaghan, 2001; Kosmas *et al.*, 2012; Waswa, 2012). The results showed that soil erosion, soil fertility decline and vegetation cover decline were the most common observable indicators used in identifying degraded land in the study area. These three indicators were ranked the same by 21 out of the 23 communities. Wildlife habitat loss and poor species composition were considered the least observable indicators although widespread as they occur in 12 out of the 23 communities surveyed.

The range of the rankings emphasizes the agreement among the communities in identifying an indicator as being important. This implies that, there is high agreement between the communities in ranking soil erosion as a major observable indicator of land degradation in the area than the others. However, the range in the ranking of increase in pest and diseases showed high disagreement in the communities ranking as there is wide disparity between the minimum and the maximum ranks.

The significance of these ranks was better reflected in the magnitude of the relative importance indices and overall ranks (Table 4.1). Based on the RII, soil erosion was ranked as the most important observable indicator of land degradation in the area with RII of 0.88. This was followed by soil fertility decline with RII of 0.78. The least perceived observable indicators were loss of soil macro organisms and negative land use/cover conversion which had RII of 0.29 each. Though the two had the same range and RII, loss of soil macro organisms had an overall rank of 6 while negative land use/cover conversion had an overall rank of 8 because the minimum and maximum ranks of loss of soil macro organisms are better than negative land use/cover conversion.

Table 4.1: Rank scores and RII of observable indicators in the White Volta sub basin

Observable indicators	Ranks					***SW***	***RII***	***OR***
	F	*M*	*Min*	*Max.*	*R*			
Soil erosion	21	1	1	2	1	162	0.88	1
Soil fertility decline	21	2	1	5	4	143	0.78	2
Vegetation cover decline	15	3	1	6	5	93	0.51	3
Wildlife habitat loss	12	4	2	6	4	60	0.33	5
Poor species composition	12	4.5	3	6	3	55	0.30	6
Loss of soil macro organisms	14	5	3	7	4	54	0.29	7
Increase in pest and diseases	21	4	3	8	5	87	0.47	4
Negative land use/cover conversion	15	5	4	8	4	54	0.29	8

F: Frequency, M: Median, R: Range, SW: Sum of weight, RII: Relative importance index, OR: Overall rank

The ability of the communities to agree on these indicators may stem from the fact that the criteria used are common to and well understood by all of them and easily discernable by the land users. For instance degradation features such as rills, gullies, change in soil colour, presence of stones and weed species in the area were used as signs of degradation. Also, local people were able to discern these indicators because they are directly linked to ecosystem productivity. They know that the soil fertility is declining due to the persistent decline in the yields of crops, the general health of the crops and other vegetation. A similar study done in Kenya revealed that farmers were able to discern the degrading nature of the land by the use of similar indicators (Odendo *et al.*, 2011).

Communities ranked loss of soil macro organisms and negative land use/cover conversion to be the least important observable indicator in identifying land degradation in the area. One reason why communities perceived these to be less important in the area could be that, these indicators are not directly linked to tangible ecosystem services of their interest as land users are more aware and concerned about the immediate effects of the degradation than its indirect effects (Stocking & Murnaghan, 2001).

Also, the ranking of negative land use/cover conversion to be less important in the area may also be due to security reasons. Local communities are being blamed for ill land use practices that lead to land degradation (GEF, 2002; Barry *et al.*, 2005; Gyasi *et al.*, 2011; Anzagira, 2012). Because of this notion, many communities are afraid that they will either be punished or be deprived of their productive lands by the government if they rank this particular type of indicator high in the area.

The importance and validity of the above statement are evident in the results of the correlation analysis (Table 4.2). The results reveal that there is a moderate to strong positive significant correlation between soil fertility decline and wildlife habitat loss ($r = 0.76$, $p = 0.05$), and also negative land use/cover conversion ($r = 0.50$, $p = 0.05$). There is also a significant positive correlation between vegetation cover decline and loss of soil macro organisms ($r = 0.60$, $p = 0.05$). The positive correlation is expected since the decline in soil fertility in croplands pushes farmers to open more vegetated areas to increase crop production. The removal of natural vegetation through various means such as crop production, infrastructural development, mono plantations development could also have a significant negative implication on the species composition as reported by Maitima *et al*. (2004) that the loss of native vegetation leads to the loss of indigenous plant and animal biodiversity as well as the plant cover.

There is however a significant negative correlation between soil erosion and soil fertility decline ($r = - 0.58$, $p = 0.05$). This could be the masking effect of chemical fertilization as it was recognized as one of the mitigation measures to land degradation (Table 4.12).

Table 4.2: Kendall tau-b coefficients for correlation between observable indicators of LD in the basin

Observable indicators	*Soil erosion*	*Soil fertility decline*	*Vegetation cover decline*	*Wildlife habitat loss*	*Poor spp composition*	*Loss of soil macro organisms*	*Increase in pest and diseases*	*Negative land cover conversion*
Soil erosion	-	-.575*	-0.273	-0.375	-0.164	-0.267	-.483*	-0.372
Soil fertility decline		-	-0.501	.757*	-0.129	0.289	0.12	.501*
Vegetation cover decline			-	-0.739	-0.39	.602*	0.249	0.332
Wild-life habitat loss				-	-0.037	0.471	0.071	0.267
Poor species composition					-	0.101	.926*	0.085
Loss of soil macro organisms						-	0.22	.748*
Increase in pest and diseases							-	0.345
Negative land use/ cover conversion								-

**Correlation is significant at the 0.05 level (2-tailed).*

4.2 Mapping LD at the Basin Scale Using Selected Indicators

At the basin scale, two indicators were successfully applied in the mapping of land degradation in the area. Negative land use/cover conversion (NLUCC) was used to assess vegetation losses while soil loss due to erosion was used as an indicator for soil degradation. The findings are presented in the next sections.

4.2.1 Preliminary Land Cover Classes at the Basin between 1990 and 2007

Figure 4.1 shows the land cover for both 1990 and 2007. It was noted that in 2007, the forest area has increased dramatically from 4773.69 km^2 to 22260.9 km^2 which represents 6.4 and 29.5 % respectively of the total area. About 23.2 % of the area has become forest in 2007. This increase in the forest area is visible in the southern part of the basin (Figure 4.2 and 4.3). On the other hand, woodland which was 62.9 % of the total land area has been reduced to 23.1%. Thus, 39.7 % of the woodland was converted to other land use or cover by 2007. This is also clear in Figure 4.3 as greater part of the area was covered by woodland with little forested and shrub area in 1990 but diminished in 2007. It can be inferred that, woodland which is next to forest in ecological succession (Schoonmaker & Mckee, 1988) has been transformed to a forest within the 17 year period thereby increasing the forest area in 2007.

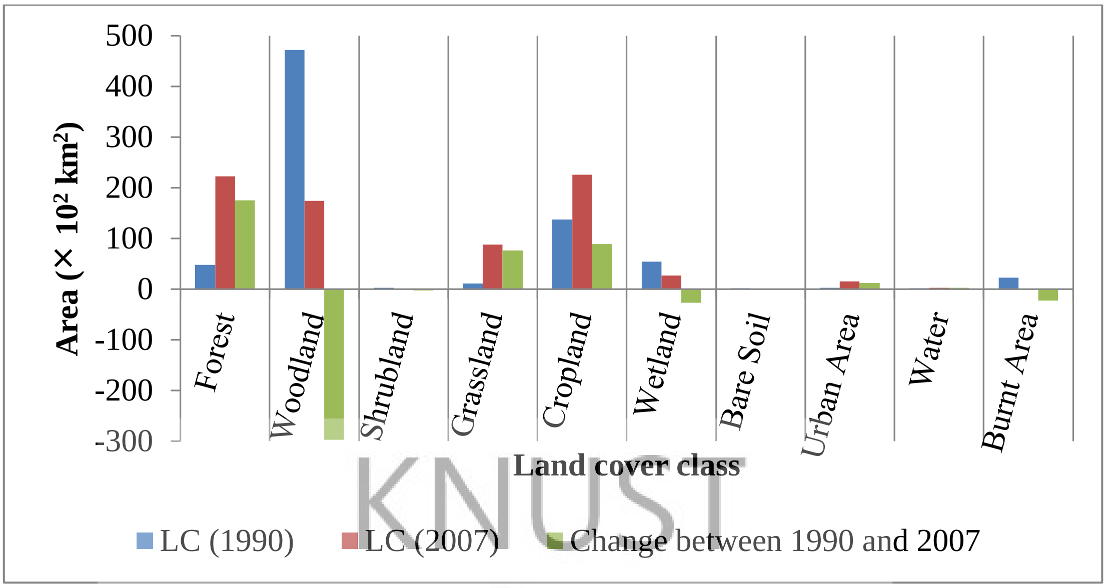

Figure 4.1: Land use/cover statistics between 1990 and 2007 in the WVB

Notwithstanding, other policy interventions leading to plantation and woodlot development could have accounted for this change. It was reported by the then Ministry of Land and Forestry (MLF, 2004) that Ghana by 2003 had a plantation area of about 97,000 ha. This expansion of plantations involved re-vegetating degraded forests and marginal lands which were indicated as bare soil, shrubland and burnt areas but no more visible in the 2007 land cover. Nevertheless, crop production which involves opening of vegetation cover was in ascendancy in the 2007 land cover (Figure 4.3). Cropland had increased from 18.3% (13713.5 km^2) in 1990 to 29.9% (22547.8 km^2) in 2007. The change was 11.6% of the total area which represents 8834.3 km^2. The croplands are most dominant in the mid-eastern zone of the basin (Figure 4.3).

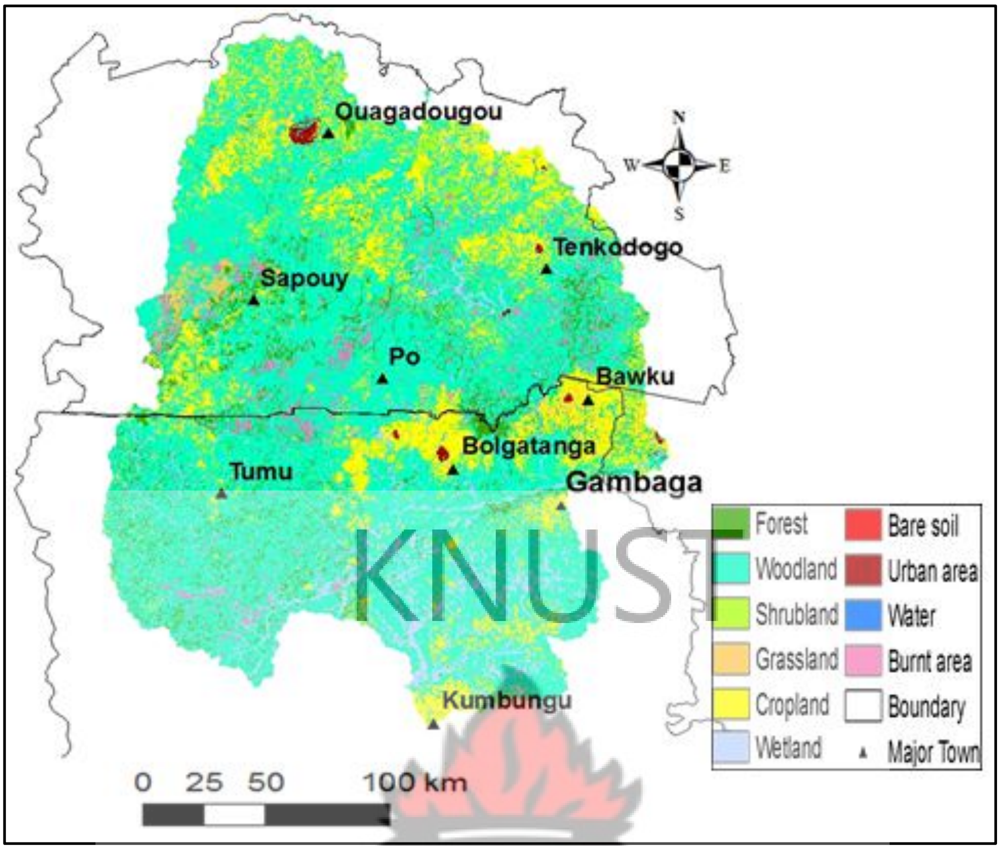

Figure 4.2: Land use/cover map of the WVB in 1990

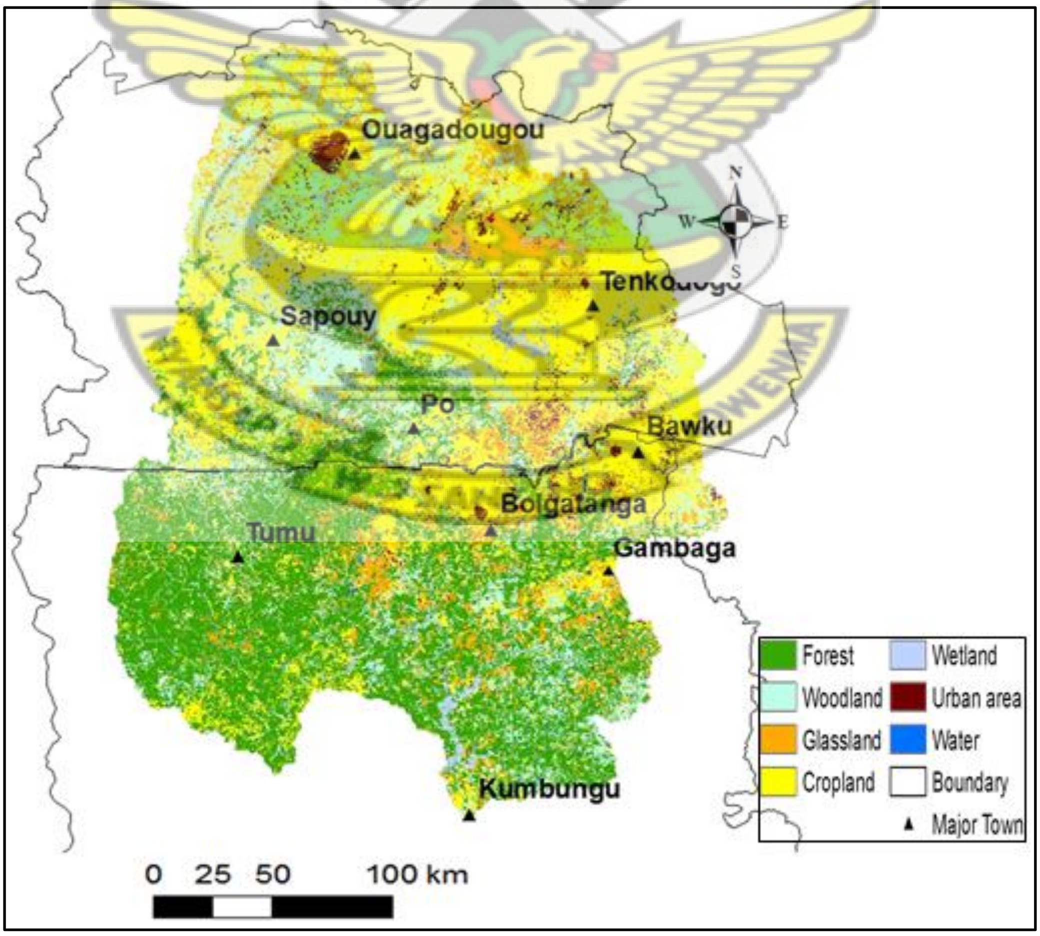

Figure 4.3: Land use/cover map of the WVB in 2007

4.2.2 Negative Land Use/Cover Conversion as a Proxy of LD at the Basin's Scale

The results of negative land use/cover conversion indicated that about 30 % of the area is affected by NLUCC (Table 4.3). The conversion of areas with natural vegetation cover to cropland (i.e. LUCC level 3) is the most serious form of land use/cover conversion in the area. About 14016.2 km^2 which represents 18.7% of the area covered by natural vegetation has been converted to agricultural lands between 1990 and 2007. This finding is in consonance with that of Awotwi *et al*. (2014) who reported that areas with natural vegetation cover have been degraded and that was partly due to agricultural field extension with poor management and over grazing. Decline in crop yields in previous cultivated fields often compelled farmers to open more vegetative areas to meet their production targets as also reported in Kenya, Tanzania and Uganda by Kaihura and stocking (2003). These areas deprived of vegetation cover can be exposed to other ecological stresses which will hamper the ecosystem productivity.

Table 4.3: Negative Land use/cover conversion at the basin scale

NLUCC class	**Area (km^2)**	**Area (%)**
LUCC level 1	1163.7	1.6
LUCC level 2	5875.3	7.8
LUCC level 3	14016.2	18.7
Unchanged/Improved	53879.8	71.9

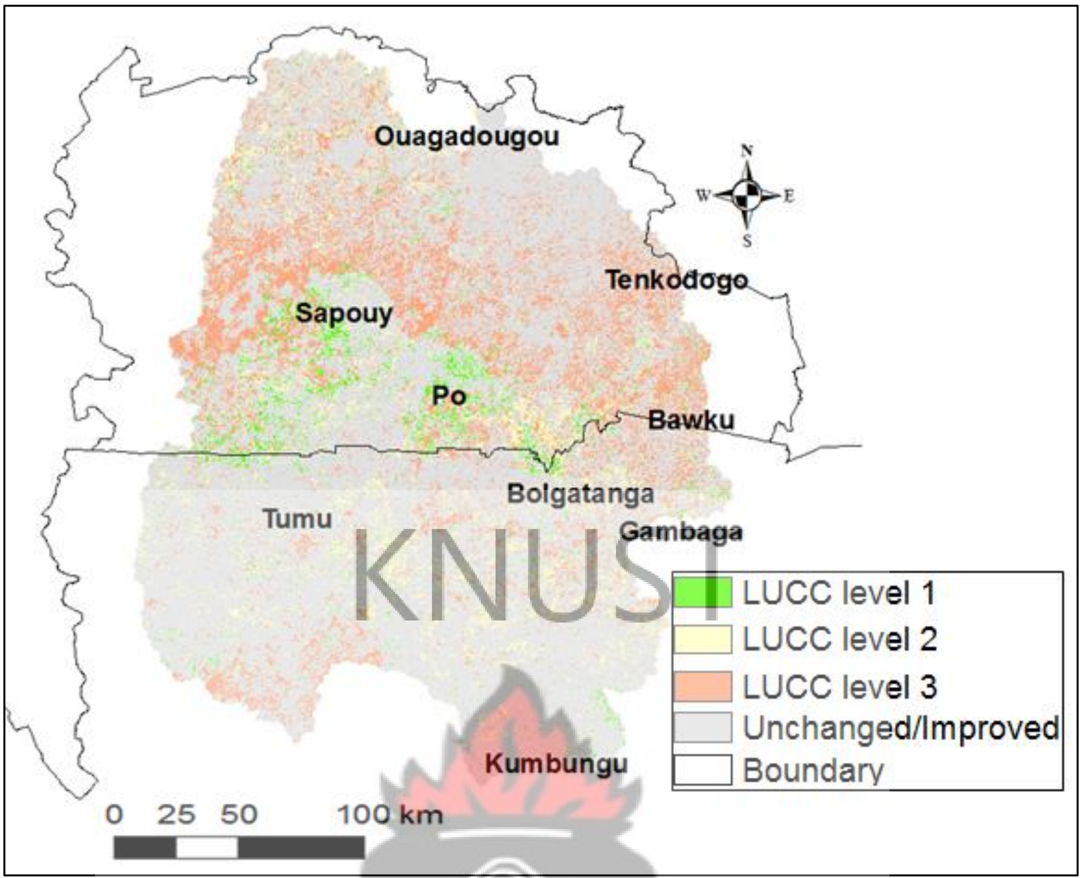

Figure 4.4: Map of negative land use/cover conversion at the basin scale from 1990-2013

Also, transformation of natural woody vegetation to non-woody natural vegetation (mostly grassland) was estimated to have been affected with about 5875.3 Km^2 (7.8 %) of the total area. The northern part (areas around Bolgatanga and Bawku in Ghana, Sapouy and Tenkogo in Burkina Faso) of the catchment was the most severely affected by the negative land cover conversion (Figure 4.4). Cutting down of trees for lumber and urbanization, illegal logging, agricultural extensification, gold mining and fuel wood extraction (Contreras-Hermosilla, 2000; FAO, 2007; Gyasi *et al.*, 2011; Ouedraogo, 2011) which are common in the area may be blamed for this degradation.

The conversions of the natural vegetation cover to croplands have a negative implication to the environment. Natural vegetation cover, especially forest serves as carbon sink and the expansion of croplands to the detriment of forests and woodlands results in an increase in atmospheric CO_2 (IPCC, 2001; 2007). This decreases the sink capacity of the global terrestrial biosphere, and thereby amplifies the atmospheric CO_2 rise due to fossil and other land use carbon release (IPCC, 2001; 2007). Grassland conversion into croplands was also widespread in the White Volta Basin due to land hunger. These dramatic changes in land use with widespread reduction of forest, woodland and grasslands have increased carbon emission (Chuluun and Ojima 2002; IPCC, 2001; 2007). This land degradation phenomenon may however be influenced by increase in poor rural population, lack of land tenure security, poor governance practices and implementation of relevant provisions of public policies (World Bank, 2012).

4.2.3 Soil Erosion

About 42 % (31, 440 km²) of the study area suffered from high to very high soil erosion (Table 4.4) with annual net soil loss above 1500 t/km^2/y. The high erosion class which denotes a net soil loss between (1500 -3000 t/km^2/y) affected a total area of 16,001 km^2 (21.3 %) while the very high class that denotes soil loss above 3000 t/km^2/y affected 15,439 km^2 (20.3 6%).

Table 4.4: Soil erosion classes

Soil loss class	**Area (km²)**	**Area (%)**
very low erosion	18,138	24.2
Slight erosion	25,401	33.9
High erosion	16,001	21.3
Very high erosion	15,439	20.6

The spatial distribution of the soil loss in the basin (Figure 4.5) showed soil loss from the south western corner (i.e. around Tumu in the Upper West Region of Ghana) to the mid north-eastern (i.e. around Bolgatanga and Bawku in the Upper East Region of Ghana) zone of the basin to be over 1500 t/km^2/y. On the other hand, the north-western part which is in Burkina Faso and the southern part (Northern Region of Ghana) yielded less than 500 t/km^2/y of sediment indicating less pronounced soil erosion in these regions. Soil and water conservation (SWC) techniques such as *zaï*, method, contour stone bunds and vegetative barriers, half-moons and permeable rock dams were introduced on cultivated fields in both Burkina Faso and Niger after the recurrent droughts of the 1970s and 80s (International Fund for Agricultural Development – IFAD, 2011). These methods do not only conserve moisture in the soil but also reduce runoffs and hence prevents soil erosion by water.

For the Southern part, the less evidence of soil loss can be attributed to the influenced of vegetative cover. Soils covered with vegetation are less prone to soil erosion. Vegetation intercepts raindrops causing absorptive and evaporative losses that reduce surface runoff and erosion (Menashe, 2004). Also roots of vegetation bind soil particles together thereby reduce their susceptibility to surface erosion.

Generally, the rate of soil loss in the basin is above the soil formation rate (Amegashie *et al.*, 2012). Therefore, if this rate of loss continues, it will render the basin soils seriously degraded for the survival of biological resources. The high rate of soil loss due to erosion also implied an increased in CO_2 emission into the atmosphere. Soil serves as a carbon sink and erosion by water cause displacement and redistribution of soil organic carbon which may increase mineralization and release of C to the atmosphere (Lal, 1995; Kimble *et al.*, 2001; Van Hemelryck *et al.*, 2010).

The spatial pattern of the soil loss by erosion follows the NLUCC. Gyasi *et al.* (2011) reported a similar soil loss in areas where the vegetation cover was disturbed. This is because the soil erodibility is highly dependent on the surface cover. Thus land covered with vegetation or mulch will have a high propensity to reduce surface runoff and increase infiltration and vice-versa (Bull *et al.*, 2003). In all, continuous cultivation and expansion of croplands contributed most to the soil erosion. The residual effects of cultivation are reduction in aggregate stability of the soil through continuous ploughing and reduction in the soil organic matter content and enhanced erosion.

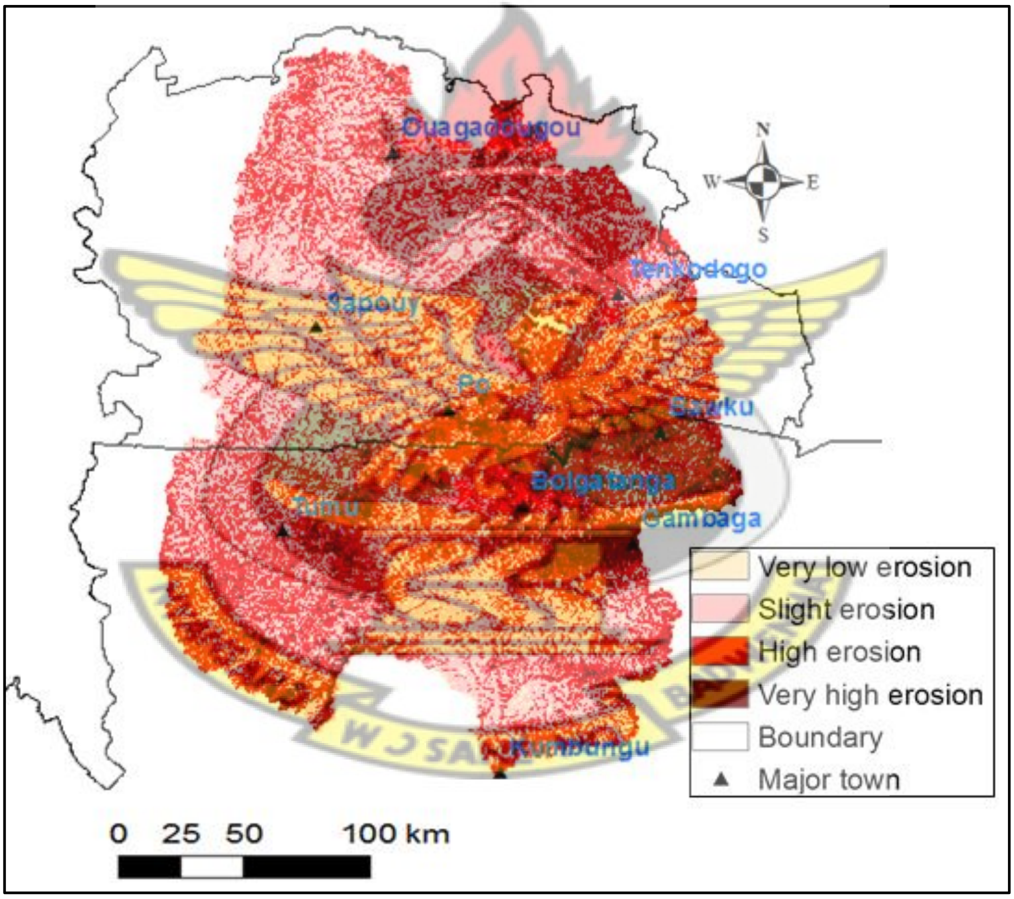

Figure 4.5: Spatial pattern of net soil loss in the WVB

4.2.4 Land Degradation Classes and Hotspots in the Basin

Based on the negative land use/cover conversion between 1990 and 2007 coupled with net soil loss analyses, the land degradation classes and hotspots identified are shown in Figures 4.6 and 4.7 and Appendix 10. It is noted that about 85% of the area is either affected by negative land use/cover conversion or soil erosion. Out of this, about 33% (24, 688 km^2) of the area suffers both severe soil erosion and very high negative land use/cover conversion.

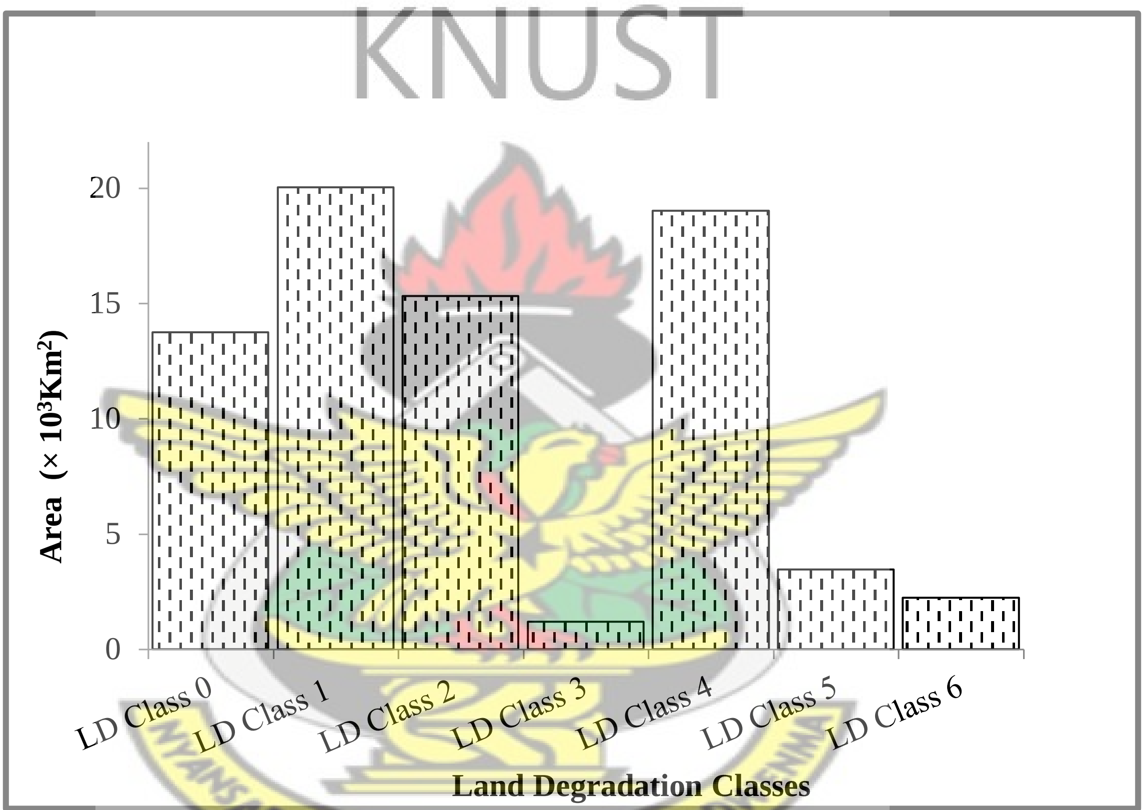

Figure 4.6: Land degradation classes in the WVB

Spatially, the degradation hotspots are found around major towns and cities. Areas around Ouagadougou, Manga, Po and Kombissiri in the Burkina Faso, as well as areas around the Upper East Region (Bolgatanga, Bawku and Bongo) of Ghana, were the areas most affected by degradation (Figure 4.7). Cutting down of trees for lumber and urbanization, illegal logging, agricultural extensification, gold mining and fuel wood extraction (FAO, 2007; Gyasi *et al.*, 2011; Ouedraogo, 2011), which are common in the area are the main causes of land degradation. Land degradation in the area had also been attributed to land tenure insecurity, poor governance and implementation of the relevant provisions of public policies (World Bank, 2012).

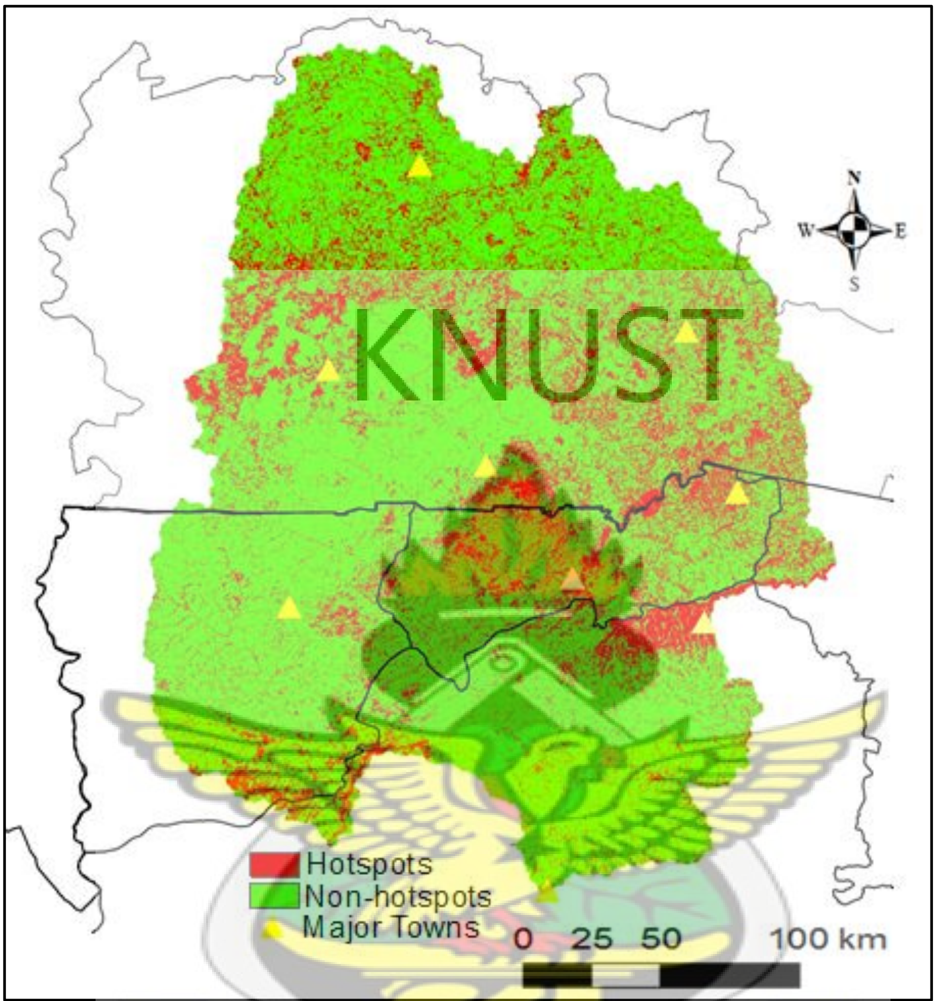

Figure 4.7: Land degradation hotspots in the WVB

4.3 Mapping Land Degradation at the Sub-Basin Scale

4.3.1 Land Cover Classes of 1990 and 2013 at the Sub-Basin Scale

Results of the error matrix of the image classification revealed that the overall accuracy and the kappa statistics for both maps were high. The 2013 classification had the highest overall accuracy of 90% (kappa= 0.86) while the 1990 had 85% (kappa= 0.79) These accuracy figures were within the acceptable target of 85% overall accuracy (Scepan, 1999). Therefore the output could reliably be used for further analysis.

The results indicated that there is land use/cover alteration in the sub-basin (Figure 4.8). Between 1990 and 2013, there has been a decrease in the forest/dense wood land area by 487 km^2. On the other hand, Settlement/cropland/barren land exhibited an opposite trend between 1990 and 2013. It increased from 7461 km^2 (46.5%) in 1990 to 7879.3 km^2 (49.2 %) in 2013. Water and wetlands also declined by 303 km^2. This is visually clear at the southern part of the sub-basin where the water and wetlands were lost to other land use/cover (Figure 4.9 and 4.10).

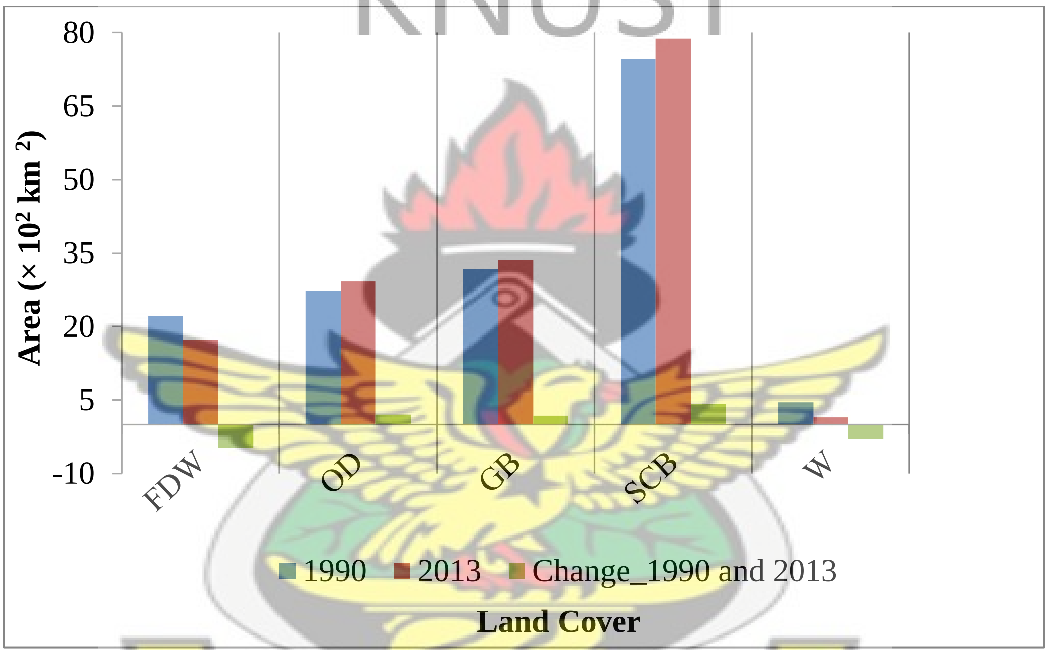

Figure 4.8: Land use/cover statistics between 1990 and 2013 in the Nawuni sub-basin

FDW: Forest/dense woodland, **OD**: Opened woodland, **GB**: Grassland/burnt area, **SCB**: Settlement/cropland/barren, **W**: Water

Spatially, there was improvement of forest/dense woodland cover at the northern part of the sub-basin. This improvement could be due to policy interventions leading to plantation and woodlot development in the area (Ministry of Land and Forestry MLF, 2004)

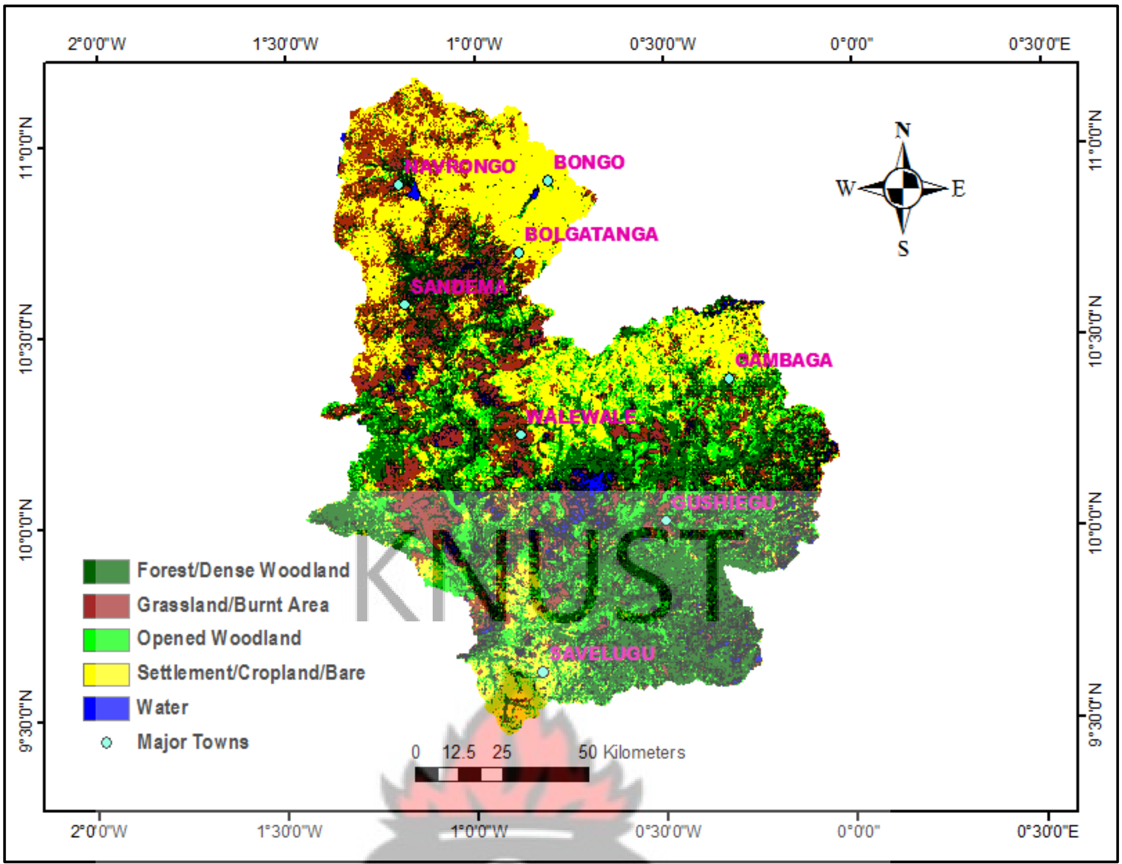

Figure 4.9: Land use/cover map of Nawuni sub-basin in1990.

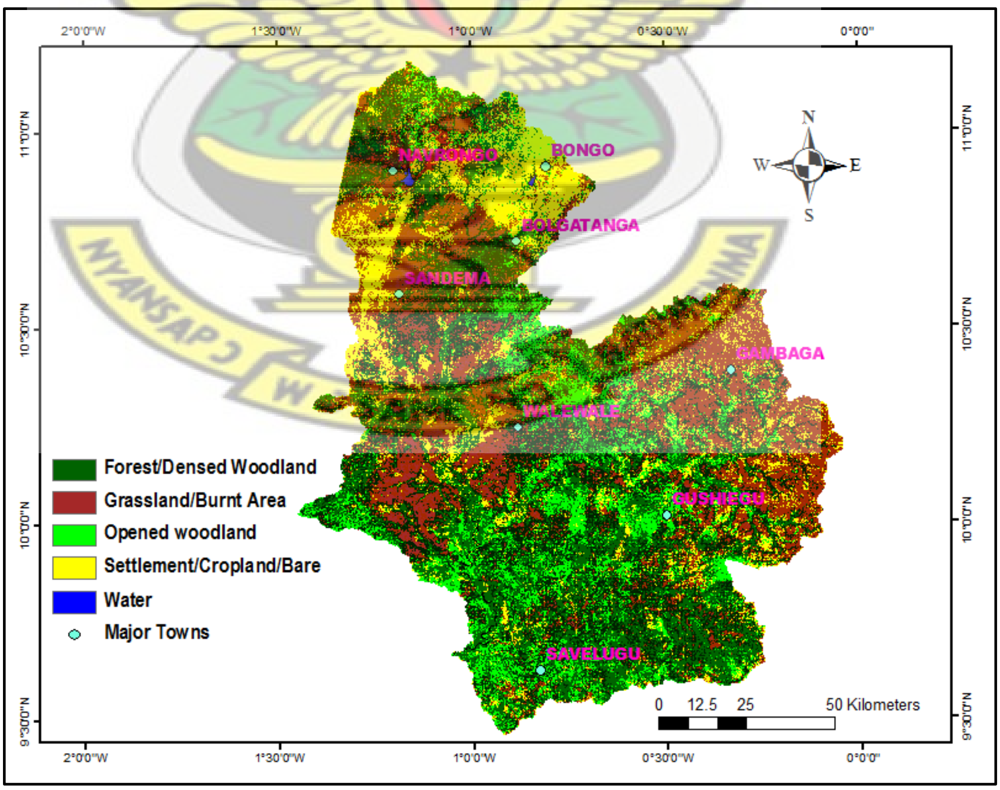

Figure 4.10: Land use/cover map of Nawuni sub-basin in 2013

4.3.2 Negative Land Use/Cover Conversion

At the sub-basin scale, LUCC level 3 was the prominent negative land use/cover conversion in the area (Table 4.5 and Figure 4.11). This class covered a large portion of about 48 % of the total area. LUCC level 2 was the next serious NLUCC in the area which covered about 11 % of the total area. These conversions were more pronounced in the Builsa North and South Districts, Bolgatanga and the Bongo districts of the Upper East Region. Also, the East Mamprusi and parts of the Gushiegu and Karaga Districts of the Northern Region were the mostly affected areas in the basin (Figure 4.11).

This means that a lot of areas with natural vegetation cover (especially tree cover) have been converted to either croplands or other non-vegetative supported land uses. One major consequence of this NLUCC is the shortage of wood for domestic energy as the majority of the inhabitants in the area depend heavily on biomass fuel. Also, the implication of NLUCC is destruction of wildlife habitat which eventually leads to reduction in wildlife population and extinction. Wildlife is beneficial to mankind, as some play the role of ecosystem engineers, thereby increasing ecosystem productivity and services. Therefore reduction of these important organisms will lead to low ecosystem productivity which are essential for human well-being and development.

Table 4.5: Negative land use/cover conversion at the Nawuni sub-basin

Class Name	Area (km^2)	Area %
LUCC level 1	1338.6	8.4
LUCC level 2	1762.1	11
LUCC level 3	7689.7	48
Unchanged/Improved	5241.6	32.7
TOTAL	**16032**	**100**

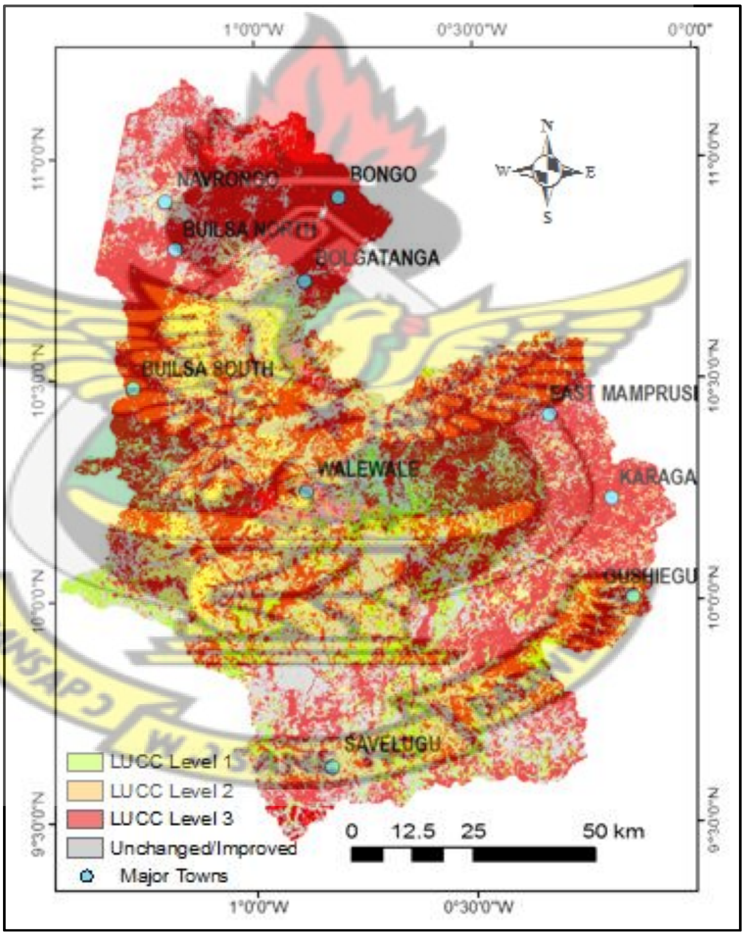

Figure 4.11: Negative land use/cover conversion at the Nawuni sub-basin

4.3.3 Soil Erosion

The most prevalent type of soil erosion in the area was rill erosion (Table 4.6). Rill had the highest frequency of 68 (29.7 %) while inter-rill erosion had the least frequency of 40 (17.5 %). Generally the erosion types recorded in the area were in their active state (i.e. features are increasing in size or extent). About 76 % of the occurrences were recorded to be in the active state. Only 0.5 % of the occurrences were in their stable state (historic features from past climate and land use, or a more recent erosion features for which recent control measures are applied). Also about 102 (44.5 %) of the erosion occurrences were in a severe condition. These erosion features recorded varied from moderate (41.9 %) to widespread (42.4%) in spatial extent.

These findings in the sub-basin were not too different from that reported by Gyasi *et al.* (2011) that the area was prone to very severe rill erosion. Asiamah *et al*. (1996) also reported that rill erosion was the most prevalent type of erosion in the area. This could be attributed to the relatively flat nature of the land and extensive cropping which exposed the soil to the agents of erosion such as wind and water due to crop residue removal for fuel wood and bush burning (Senayah *et al*., 2005; Yiran, *et al*., 2011).

Table 4.6: Soil erosion at the Nawuni sub-basin

Erosion Types			***Erosion State***		
Class	*Frequency*	*Percent (%)*	*Class*	*Frequency*	*Percent (%)*
Splash	63	27.5	Stable	1	0.5
Inter-rill	40	17.5	Decreasing	2	1
Rill	68	29.7	Partially stable	53	23
Gully	58	25.3	Active	173	76
Total	**229**	**100**	**Total**	**229**	**100**
Erosion Severity			**Erosion Extent**		
Class	*Frequency*	*Percent (%)*	*Class*	*Frequency*	*Percent (%)*
Low	13	5.7	Negligible	2	0.9
Moderate	50	21.8	Localized	34	14.8
Severe	102	44.5	Moderate	96	41.9
Extreme	64	28	Wide spread	97	42.4
Total	**229**	**100**	**Total**	**229**	**100**

It was noted that the incidence of erosion on the increase in space and magnitude with little effort to reverse it. If measures are not put in place, it will render a greater portion of the land degraded and unproductive in the future. This will consequently lead to decline in crop yields and other ecosystem services for sustenance of the people in the area. The end result will be poverty and food insecurity in the area.

4.4 Relational Analysis of Land Degradation across Scales

The cross-scale analysis showed some matches and divergences of indicators at the different scales (Table 4.7 and Appendix 8) in mapping land degradation. The best indicator matches was between the net soil loss at the basin scale with that of soil erosion state at the sub-basin scale (92.6%) and erosion extent (92 %). Composite land degradation indicators at the basin scale also revealed a similar trend as net soil loss with erosion state and extent. The least match was between negative land use/cover conversions at the basin scale and erosion severity at the sub-basin scale with high divergent value of 87 %. Apart from the latter observation, the matches of indicators at the basin scale with that of the sub-basin implied that the former can, to some extent measure land degradation appropriately at the sub-basin's scale. Thus the use of basin's scale indicators which are easier and robust in land degradation mapping has the capability of estimating land degradation at the sub-basin scale which can compare well with the results of field measurement/observation that are really laborious, expensive and sometime impossible. This is useful for generalization and up-scaling of land degradation information as well as mitigation measures.

The divergence between the indicators at the basin and the sub-basin scales also confirms the findings of Gray (1999) that observations and measurements made at a particular scale may be contradicted by the same observations and measurements at different scales and that pattern detected as relatively homogenous on a coarse scale might disappear when a finer resolution is applied or vice versa (O'Neil *et al.*, 1989; Gibson *et al.*, 2000).

Table 4.7: Matches and divergence between basin and sub-basin scale indicators

Basin Scale Indicator		**Sub-basin Scale Indicators**			
	Matches and Divergence	*Erosion State (%)*	*Erosion Extent (%)*	*Erosion Severity (%)*	*NLUCC (%)*
Modelled net soil loss	m	92.6	92.0	88.0	69.5
	d_s	7 .0	7 .0	7.0	24.5
	d_b	0.4	1.0	5.0	6 .0
NLUCC	m	13.5	14.0	12.0	26.0
	d_s	86.5	86 .0	87 .0	66 .0
	d_b	0 .0	0 .0	1.0	5.0
Composite LD class	m	92.6	92.0	88.0	69.5
	d_s	7 .0	7.0	7.0	6 .0
	d_b	0.4	1.0	5 .0	24.5

Note: *m= Match, d_s= Divergence at sub-basin scale, d_b = Divergence at basin scale*

4.5 Socio-Ecological Determinants of Land Degradation

4.5.1 Perceived Land Degradation Causes by Communities

The perceptions of the direct causes of land degradation by communities in the White Volta Basin are presented in Table 4.8. Communities perceived that, there are seven major direct causes of land degradation in the area. Among the seven, climate change had the highest frequency (23), followed by Poor soil management with a frequency of 22. Even though climate change had the highest frequency, there is a wide variation between its minimum and the maximum ranks (Min. =1, Max. = 7) indicating a disagreement between the communities in ranking this cause. On the other hand, poor soil management with a frequency of 22 had a better range between the minimum and maximum ranks (min. =1, max. =5) indicating a good agreement between communities in ranking this variable. Infrastructural development had the least frequency of 10.

The RII revealed that, poor soil management is the most important cause of land degradation perceived by the communities in the area followed by deforestation with RII of 0.84 and 0.63 respectively. Infrastructural development had the least RII index of 0.21.

Table 4.8: Median of rank score of the perceived direct degradation causes

Direct Causes of LD	***Rank Statistics***					***SW***	***RII***
	F	*M*	*Min.*	*Max.*	*R*		
Poor soil management	22	1	1	5	4	136	0.84
Poor range management	14	2	1	3	2	83	0.52
Deforestation	19	3	1	6	5	102	0.63
Mining and industry	15	4	1	4	3	72	0.45
Infrastructural development	10	4.5	3	6	3	34	0.21
Climate change	23	5	1	7	6	70	0.43
Overgrazing	20	4	2	6	4	81	0.50

F: Frequency, M: Median, R: Range, SW: Sum of weight, RII: Relative importance index.

Based on field observation and personal communication, cultivation of highly vulnerable soils and insufficient soil conservation measures were key characteristics of the basin. Cultivation along river banks, slopes and water courses similar to reports by other authors was evident in the area (GEF, 2002; Gyasi *et al.*, 2011). These resulted to soil erosion by water and consequently loss in soil fertility.

Also, deforestation which was ranked second in the list was due to the persistent clearing of vegetation for farming, excessive gathering of fuel wood (Plate 4.1), local timber, fencing materials, rampant bushfires and removal of fodder (especially the cut-and-carry system; Plate 4.2) (GEF, 2002; Malyon, 2013; Awotwi *et al*., 2014).

Plate 4.1: Saplings cut for firewood

Plate 4.2: Cut-and-carry system of animal rearing

Similarly, communities perceived seven indirect causes of land degradation in the area (Table 4.9). Frequencies of ranked score of the perceived indirect degradation causes indicated that population pressure and poverty recorded the highest ranks of 20. There was a high agreement between the communities in ranking these variables as their minimum and maximum ranks as well as their ranges were close (Table 4.9). Pests and diseases had the least ranked frequency of 12 with wide variation between the minimum and maximum ranks. Population pressure was therefore perceived as the most important indirect cause of land degradation in the area. It had RII of 0.78, followed by poverty which had RII of 0.74. Pests and diseases were perceived as the least important cause of land degradation in the area with RII of 0.17.

Table 4.9: Perceived indirect causes of land degradation in the basin

Indirect Causes of LD	***Rank Statistics***					***SW***	***RII***
	F	*M*	*Min*	*Max*	*R*		
Population pressure	20	1	1	4	3	126	0.78
Change in demand & consumption	13	2	2	5	3	75	0.47
Poverty	20	2	1	3	2	119	0.74
Inadequate labour	14	3	2	5	3	66	0.41
Education & support services	14	4	1	5	4	62	0.39
War and conflict	19	5	2	6	4	63	0.39
Pests & diseases	12	6	4	7	3	27	0.17

F: Frequency, M: Median, R: Range, SW: Sum of weight, RII: Relative importance index.

The Ghana population and housing census data confirmed the increasing trend in the population growth within the WVB (See Figure 3.2) (Ghana Statistical Service, 2005, 2010). The consequential effect of increase in population as identified by some authors (FAO, 2001, 2011; Gyasi *et al.*, 2011); leads to increase in demand for land resources which eventually lead to resource degradation.

Regions located within the White Volta Basin particularly those in Ghana were classified as poor. According to International Fund for Agricultural Development (IFAD, 2013) the poverty rates in the three northern regions of Ghana, encompassing over 90% of the White Volta Basin, were high and this was likely to have negative implication to land management and use. The high poverty rates in these regions also pushed the energetic youth to migrate to areas they could be gainfully employed to earn income. As a result only the ageing and generally less dynamic population especially in the rural areas were left and these were unable to manage the land sustainably. Thus, the deficit of rural labour through migration (WMO, 2005; Ezeaku & Davidson, 2008; Gyasi *et al.*, 2011) can lead to abandonment of traditional resource conservation practices such as compost preparation, stone bunding and terrace maintenance (FAO, 2011; Gyasi *et al.*, 2011) which are healthy practices to land management and use. Poor people also continuously mined the land and more often invested less in their lands leading to over-exploitation and degradation (FAO, 2011; Nkonya *et al.*, 2011).

Results of the Kendall tau-b correlation analysis between perceived direct causes of land degradation are presented in Table 4.10. There was a positive significant correlation between poor soil management and poor range management (r = 0. 68, p = 0.05), poor range management and mining and industry (r = 0. 73, p = 0.05). Mining and industry, and infrastructural development, climate change as well as overgrazing were highly positively correlated (r = 0.91, 0.53, 0.65 respectively at p = 0.05). Also there was significant positive correlation between climate change of degradation and overgrazing (r = 0.49, p = 0.05). On the contrary, a negative correlation existed between poor soil management and the rest of the degradation causes (Table 4.10).

Table 4.10: Kendall tau-b coefficients for correlation between direct causes of LD

Direct Causes of LD	Poor soil management	Poor range management	Deforestation	Mining and industry	Infrastructural development	*Climate change*	Overgrazing
Poor soil management		**.677***	-.440*	-.804*	-.672*	-.417*	-0.39
Poor range management			-.816*	**.730***	0.467	0.175	0.19
Deforestation				0.358	0.311	0.016	0.311
Mining and industry					**.909***	**.533***	**.654***
Infrastructural development						0.412	0.426
Climate change							**.486***
Overgrazing							

**Correlation is significant at the 0.05 level (2-tailed).*

Kendall tau-b coefficients for correlation of perceived indirect causes of land degradation revealed that a perfect positive correlation exist between climate change and education and support services as well as war and conflict (Table 4.11). There was also a significant positive correlation between poverty and inadequate labour (r = 0.86, p = 0.05). Also a significant positive correlation existed between poverty and war and conflict (r = 0.51, p = 0.05). Inadequate labour and war and conflict were positively correlated (r = 0.60, p = 0.05) as well as education and support services, and war and conflict (r = 0.67, p = 0.05). Population pressure, change in demand and consumption showed negative correlation with all the other indirect causes (Table 4.11).

Table 4.11: Kendall tau-b coefficients for correlation between indirect causes of LD

Indirect Causes LD	*Population pressure*	*Change in demand & consumption*	*Poverty*	*Inadequate labour*	*Education & support services*	*War and conflict*	*Pest and diseases*
Population pressure			-.717*	-.640*	-.645*	-0.438	-0.25
Change in demand & consumption			-.667*	-0.51	-0.632	-0.406	.
Poverty				.856*	0.508	.512*	0.41
Inadequate labour					0.419	.603*	0.78
Education & support services						.673*	1.00*
War and conflict							1.00*
Pest and diseases							

**Correlation is significant at the 0.05 level (2-tailed).*

4.6 Preferred Mitigation Measures

The communities' preferred mitigation measures against land degradation are presented in Table 4.12. Controlled burning recorded the highest frequency of 18 followed by stone bunding with frequency of 17. There was a high agreement between communities' perception in ranking these measures as high with their minimum and maximum ranks the same or closed to each other. Controlled burning was perceived as the most important mitigation measure to land degradation in the area as it had a high relative importance index of 0.66. Minimum tillage and stone bunds were perceived to be the next important mitigation measures with RII's of 0.53 and 0.51 respectively.

Table 4.12: Preferred mitigation measures

Mitigation measures	***Rank Statistics***					***SW***	***RII***
	F	*M*	*Min.*	*Max.*	*R*		
Controlled burning	18	1	1	6	5	106	0.66
No burning	10	2	1	4	3	59	0.37
Crop Rotation	6	3	1	4	3	31	0.19
Minimum tillage	15	2	1	5	4	85	0.53
Stone bunding	17	3	1	6	5	82	0.51
Organic manuring	10	3.5	1	6	5	42	0.26
Mineral fertilizers	14	5	3	7	4	44	0.27

F: Frequency, M: Median, R: Range, SW: Sum of weight, RII: Relative importance index

The perception of communities about controlled burning to be the most important mitigation measure in the area could be due to the prevalence and devastating effect of the annual bush fires in the area. Bushfire in the savanna ecological zone had been recognized to be one of the major socio-economic problems hindering the economic progress of the inhabitants in the area. This threat does not only affect the density and diversity of the vegetation in the savanna ecosystem but also reduces agricultural output in the area (Senayah *et al.*, 2005; Yiran *et al.*, 2011; Anzagira, 2012). Several tracts of lands, including farm produce as well as human and animals' lives are reported lost annually due to uncontrolled bush burning in the area. So it is not surprising that controlled burning was been perceived by communities to be the most important mitigation measure in fighting land degradation in the area. It was also considered to be less capital intensive to implement.

Minimum tillage and stone bunds (Appendix 9) were perceived to be the next important mitigation measures in the White Volta basin. These fall within the category of soil and water conservation measures. Looking at the above causes of degradation, local communities perceived that these technologies were the panacea to the degrading nature of their soils. Minimum tillage was reported to have advantages over the traditional tillage system (slash and burn system and hoeing). It was more economical in terms of energy, labour and equipment requirements in crop production (Boahen *et al.*, 2007; Asumadu *et al.*, 2013). Also, since farmers are interested in maximizing profit in their farming business, they would readily prioritize minimum tillage system for adoption in land management and utilization.

Stone bunds on the other hand were reported to protect the land from erosion in heavy rainy years. They also improve rainwater harvesting, retention and infiltration into the soil and thus increase the amount of water available to plants. They also improve diversity and vegetation cover when plants are allowed to grow along the bunds. Stone bunds intervention is perceived to be easy to implement at the local level with very minimum resources (Diabene, 2012). It is a well-known technology use by the people in the area, which can be implemented with available local materials with minimal technical knowhow.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This section presents the conclusions which were drawn from the study on land degradation in the White Volta Basin.

This study had demonstrated the use of multi-dimensional approach which embraces multi-scale, multi-indicators and actor-based framework to evaluate land degradation within the savanna belt of the White Volta Basin.

Both proxy and observable indicator system were developed and used to assess land degradation at the basin and sub-basin scale in the WVB. Two major proxy indicators (i.e. negative land use/cover conversion and soil loss through erosion) based on remote sensing and modeled soil loss are useful at the basin's scale to map land degradation. The findings at the basin's scale revealed that land degradation was a serious issue and can be mapped using these proxy indicators. The study revealed that about 85 % of the White Volta Basin was degraded due to either negative land use/cover conversion or soil erosion. The analysis also gave an overview of the degradation hotspots in the basin. These hotspots were found around areas where urbanization was on the increase due to increase in human population.

At the sub-basin scale, eight (8) observable indicators were identified and developed through stakeholders' consultative process. These observable indicators were similar in characteristics to those commonly used by scientists in mapping land degradation. Soil erosion, soil fertility and vegetation cover decline were the most prominent observable indicators used in identifying degraded land in the area. The analysis showed that a lot of areas with natural vegetation cover (especially tree cover) had been converted to either croplands or other non-vegetative land uses. Soil erosion was observed to be severe in the basin with rill erosion being the most prevalent type of erosion in the basin

(29.7 %). Generally the erosion types recorded in the area were in their active state (i.e. erosion features are increasing in size or extent). The area is prone to widespread severe active rill erosion.

Cross-scale analysis identified commonalities and divergences of the different indicators (proxy and observable) at the two spatial scales in mapping land degradation in the area. The best indicator matches was between the net soil loss at the basin scale with that of soil erosion state at the sub-basin scale (92.6%) and erosion extent (92 %). The least match was between negative land use/cover conversions at the basin scale and erosion severity at the sub-basin scale with high divergent value of 87 %. Apart from the latter observation, the matches of indicators at the basin scale with that of the sub-basin implied that the former can, to some extent measure land degradation appropriately at the sub-basin's scale. This attribute facilitates up-scaling of land degradation and mitigation measures at a reduced labour input and cost.

Poor agricultural soil and rangeland management, deforestation and climate change were perceived to be the direct drivers of land degradation in the basin. Increasing human population, change in demand and consumption for food and fuel wood, poverty and inadequate labour were perceived to be the indirect drivers responsible for the degradation in the basin.

Key possible mitigation measures to reduce land degradation in the basin include: controlled bush burning or no burning, minimum tillage and stone bunds. Others are crop rotation, organic manuring and mineral fertilization.

5.2 Recommendations

The integration of land users' perceptions and other professionals in a participatory development of a framework for mapping land degradation and identifying mitigation measures is more robust than the conventional armchair textbook methodologies which are singular in focus, space and time.

It is therefore recommended that the appraisal of land degradation should embrace these three pillars (multi-scale, multi-indicators and actor-based) as proposed in this study for effective and accurate results as well as development of appropriate mitigation interventions. Specifically;

- ✓ Indicators should be jointly developed with stakeholders and other professionals for assessing land degradation,
- ✓ Mapping of land degradation features and mitigation measures in the field should be done in a participatory manner.
- ✓ Multi-indicators should be used which will give a holistic picture of the land degradation in the area.

Land degradation hotspots were found mainly in areas with high urbanization (i.e. major cities). Land use zoning could be a solution to reversing the land degradation due to urbanization.

Since human factors such as poor agricultural soil management, deforestation and poor rangeland management are the most fundamental drivers of land degradation in the basin, application of appropriate technology through sustainable land management practices (e.g. controlled burning, minimum tillage and stone bunds) are recommended to reverse the degradation in the basin.

Poverty was identified as one of the key drivers of land degradation in the basin. It is therefore recommended that, government and non-governmental organizations direct their investments towards communities within the basin to alleviate poverty. This will enable land managers to invest in their land and reduce resource over-exploitation. Also, these organizations should support farmers and other land users to adopt the identified mitigation measures to help reduce land degradation

The proxy analysis made use of low resolution images. It is therefore recommended that further analysis using high resolution images (e.g. Quickbird, Ikonos and Orbview) in hotspots areas to improve the quality of the information obtained. Soil fertility analysis should also be done to complement the observable degradation features mapped in the study area.

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7.0 APPENDICES

Appendix 1: Questionnaire Check List for Group Discussion

Country: ……………… District:……………………………………….........

Community: …………………… GPS Readings: N …………….. W………

Date of discussion**:** ……………………Name of record keeper: ………………………...

A. BACKGROUND INFORMATION

1. What is the population size of the community? ………………………………………..

2. What is number of households in the community? ……………………………………

3. What is the history and pattern of settlement in the area?

……

4. What are the major land use types in the community?

   a. ………………………………………………………………………………………

   b. …………………………………………………………………………………………

   c. ………………………………………………………………………………………

B. IDENTIFICATION OF THE MAIN INDICATORS OF LAND DEGRADATION IN THE AREA

Using the list in Table A1, identify the main types of land degradation in the area. First place a cross against all those that are relevant or occur in the area. Then use Table A2 to compare and rank in order of importance the degradation types which are most critical in the area.

Table A1: Main indicators of land degradation in the study area

Type of degradation	**Occurrence in the area**
Soil erosion by water and wind (A)	
Soil fertility decline (B)	
Reduction of vegetation cover/deforestation (C)	
Loss of habitats (D)	
Biomass decline (E)	
Quality and species composition / diversity decline (F)	
Loss of macro-organisms (G)	
Increase in pests / diseases (H)	
Negative conversion of the land use area (I)	

Table A2 : Pairwise comparison of the indicator types.

Indicator type	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
A									
B									
C									
D									
E									
F									
G									
H									
I									

C. IDENTIFICATION OF DIRECT AND INDIRECT CAUSES OF LAND DEGRADATION IN THE STUDY AREA

Using the list in Table A3, identify the main direct and indirect causes of land degradation in the area. First place a cross against all those causes that are prevalent in the area. Then identify and rank in order of importance the direct and indirect causes which are most critical in the given area in terms of both severity and extent using Tables A4 and A5.

Table A3 Direct and indirect causes of land degradation

Direct causes of degradation	**Occurrence in the area**
Inappropriate soil management (A)	
Inappropriate rangeland management (B)	
Deforestation/removal of natural vegetation (C)	
Over-exploitation of vegetation for domestic use (D)	
Overgrazing (E)	
Land used for Industrial activities and mining (F)	
Land use for urbanisation and infrastructure development (G)	
Discharges (H	
Release of airborne pollutants from industrial activities, mining and urbanisation (I)	
Disturbance of the water cycle (J)	
Over-abstraction/excessive withdrawal of water: (K)	
Natural causes of degradation (L)	
Indirect causes/drivers of degradation	
Indirect cause	**Occurrence in the area**
Population pressure (1)	
Land Tenure (3)	
Poverty (4)	
Labour Availability (5)	
Inputs and infrastructure (6)	
Education, access to knowledge and support services (7)	
War and conflict (8)	
Formal institutions (9)	
Informal institutions (11)	
Climate variability and change (12)	
Other environmental changes /stresses (13)	
Others (14)	

Pair wisely compare and rank in order of importance the major direct and indirect causes of land degradation identified in Table A4 using Tables A5 and A6.

Table A4: Pairwise comparison of direct causes of land degradation

Direct cause of degradation	A	B	C	D	E	F	G	H	I	J	K	L
A												
B												
C												
D												
E												
F												
G												
H												
I												
J												
K												
L												

Table A5: Pairwise comparison of indirect causes of land degradation

Indirect cause of degradation	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14														

D. TIME LINE – CROP YIELD TREND

Use 1982 as a reference point in time (That is before the 1983/84 hunger) to complete Table A6 on the major crop yield trend.

Table A6 : Crop yield trend

TIME (YEAR)	YIELDS	KEY EVENT
1982		
1992		
2002		
2012		

Note key events could be: Extreme weather, pests / diseases, fire etc.

Discussion on the yield-time lines with participants; thus, attempting to assess the contributions of soil fertility decline, drought, diseases to the change and fluctuation of crop yield. Discussion topics which should be covered include:

1. If we have good rainfall now, can we get a yield as high as 20 years ago without using fertilizer? Yes/No

2. If no, what inputs are required to get a yield as good as the yields 20 years ago?

a. …………………………………………………………………………………………
b. …………………………………………………………………………………………
c. …………………………………………………………………………………………
d. …………………………………………………………………………………………
e. …………………………………………………………………………………………
f. ………………………………………………………………………………………

E. LIVELIHOODS PROBLEMS AND COPING MECHANISMS

1. Main livelihoods problems relating to land use / management and degradation? Specific issues relating to:

a. Occurrence of conflict(s)…………………………………………………….
b. Food Insecurity…………………………………………………………
c. Poverty…………………………………………………………………….
d. Drought/Flood……………………………………………………………
e. Access rights/tenure………………………………………………

2. What are the main coping mechanisms and strategies?

a. …………………………………………………………………………………………
b. …………………………………………………………………………………………

c. ………………………………………………………………………………………

F. SUSTAINABLE MANAGEMENT TO COMBAT LAND DEGRADATION

Use Table A7 below to indicate the most commonly used and widespread technologies applied within the area to combat land degradation. Further compare and rank these practices using Table A8.

Table A7: Sustainable management to combat land degradation

Land management indicators	**Relevant/available and practice in the area**
Controlled burning / residue burning **(A)**	
Non burning **(B)**	
Fire belts **(C)**	
Conservation agriculture **(D)**	
Minimum tillage or non-tillage **(E)**	
Contour tillage **(F)**	
Vegetation cover enhancement **(G)**	
1. Minimum depth of ploughing **(H)**	
2. Crop rotation **(I)**	
3. Mulching **(J)**	
4. Organic manuring **(K)**	
5. Composting **(L)**	
6. Green manure **(M)**	
7. Mineral fertilizers **(N)**	
8. Rotational system **(O)**	
9. Shifting cultivation **(P)**	
10. Fallow fallowing **(Q)**	
11. Agroforestry **(R)**	
14. Afforestation and forest protection **(S)**	
15. Establishment of structural barriers **(T)**	
12. Terraces **(Y)**	
17 Fencing of rangeland followed either by rotational grazing, or ‘cut-and-carry’ of fodder, **(V)**	
18. Rangeland vegetation improvement management change **(W)**	
19. Protection against natural hazards **(X)**	

Table A8: Pairwise comparison of sustainable land management practices

Land mgt, indicators	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
A																								
B																								
C																								
D																								
E																								
F																								
G																								
H																								
I																								
J																								
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Any other relevant information?

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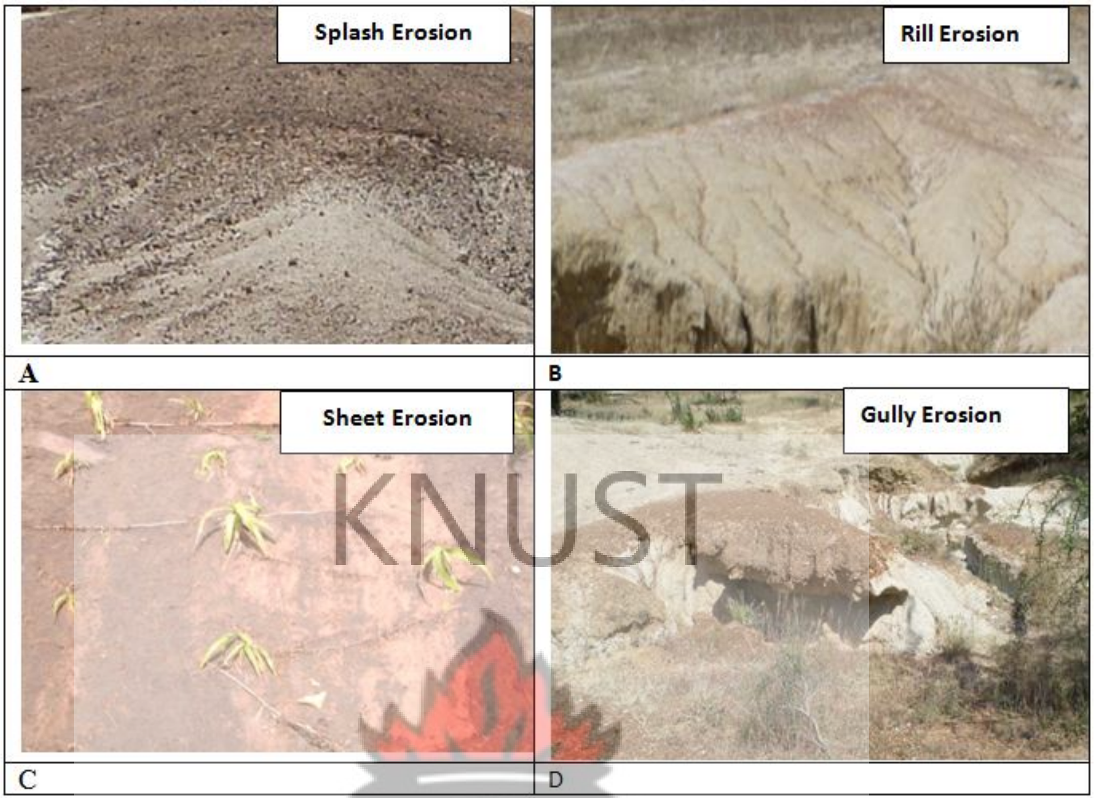
Appendix 2: Land Degradation Indicator

Land Degradation Indicator	**Description**
Soil erosion by water	The washing away of the soil particles by the action of water. This is often observed as sheet rill or gully erosion. Other signs are rock exposure, armor layers, plant root exposure etc.
Soil fertility decline	Deterioration of soil physical, biological and chemical properties.
Loss of soil macro organisms	Decline of soil macro-organisms (earthworms and termites)
Pest and disease	Indicate extent and severity of damage by termites (defoliated vegetation and visible termite nests), rodents, locusts and diseases
Vegetation cover decline	The amount of plant and litter cover on the soil surface.
Negative land cover conversion	Conversion of mostly natural vegetation to crop land
Wildlife habitat loss	Disappearance of wildlife due to lack of home ranges for them
Dominance of useful species	This includes: - Ecological functions (such as canopy cover, deep rooting, resilience to drought, recovery after burning); Palatability (browse / grazing); and Products for human use.
Exposure of rock outcrops	It consists of exposed spots of bedrock and soil. A type of land having little or no soil supported vegetation.

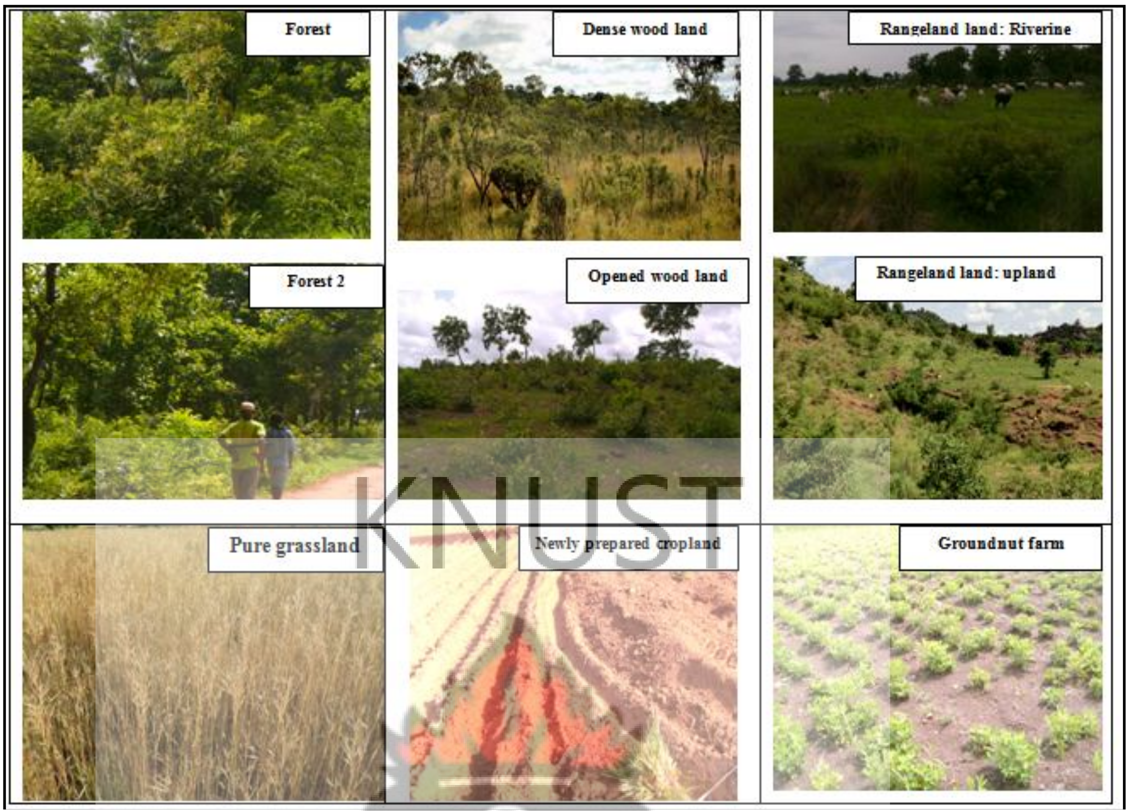
Appendix 3: Integration of Basin's Indicators

LAND DEGRADATION CLASS	COMBINATION OF INDICATORS
LD Class 0	*Other LUCC+ No/very low erosion*
LD Class 1	*Other LUCC +Slight erosion, LUCC Level 1 + No/very low erosion and LUCC Level 1 + Slight erosion*
LD Class 2	*Other LUCC + High erosion, LUCC Level 1 + High erosion, LUCC Level 2 + No erosion, and LUCC Level 2 + Slight erosion*
LD Class 3	*LUCC Level 2 + High erosion*
LD Class 4	*Other LUCC + Very high erosion, LUCC Level 1 + Very high erosion, LUCC Level 3 + No/very low erosion and LUCC Level 3 + 1-slight erosion.*
LD Class 5	*LUCC Level 2 + Very high erosion and LUCC Level 3 + High erosion*
LD Class 6	*LUCC Level 3 + Very high erosion*

Appendix 4: Types of Soil Erosion by Water



Appendix 5: Land Use/Cover Types in the Field



Appendix 6: Field scoring method for soil erosion features

Country: ……………………… District: …………………Area (Ha)……………

Community: ……………………………Field/Land use type……………………

Date: ………………………… Name of record keeper: ………………………

GPS Readings: N ……………………… W ………………………………………

Types of Soil Erosion: For the purpose of this study, four types of erosion will be considered. They include:

1. **Splash Erosion**: Raindrop impact displaces soil particles vertically and down slope. Soil particles on lower parts of plants and/or a compacted (or dispersed) soil surface crust

2. **Sheet Erosion:** Erosion of the top layer /sheet of the soil as differentiated from linear erosion (rill, gully). Indicators include gravel/stones protruding from soil surface; root exposure; loss of darker topsoil horizon; subsoil exposure.

3. **Rill Erosion:** Irregular, downslope, linear channels, shallow (up to 0.3 m deep and wide)

4. **Gully Erosion:** Irregular, V-shaped, steep-sided, linear channel formed in loose material, deep (0.3 – 2.0 m deep) formed by water erosion

Erosion State: For each erosion type, one of four classes below is used to describe the level of activity:

(a. **Active** – erosion feature is increasing in size or extent;

(b. **Partly stabilized** – between active and stable;

(c. **Stable** – it is either an historic feature from past climate and land use, or a more recent erosion feature for which recent anthropogenic interventions (e.g. contour bunds or change in land management) have slowed or stopped the erosion process;

(d. **Decreasing** – where recent anthropogenic interventions have begun to reverse the erosion process i.e. rock, sediment and vegetation filling of gullies, leading to stabilization and increased soil organic matter and plant growth.

Erosion Extent: Estimation is made of the spatial extent of each erosion type. Extent implies the proportion of a stated area that is affected by the recorded erosion type. The five terms used to define extent are:

- **Negligible** (0-2% of the area under study)
- **Localised** (3-15% of the area)
- **Moderate** (16-30% of the area)
- **Widespread** (typically 31-50% of the area)

Erosion Severity: the rate or "average amount of soil that is moved by water or wind", expressed as units of mass/ area/time. Based on this definition, a field usable estimate of erosion severity is made using four classes, recognising that the mass of soil loss will rarely be known.

✓ **Low** – minimal erosion types evident; most commonly splash or rill erosion

- ✓ **Moderate** – evidence of erosion but eroded sediment remains within the area under study
- ✓ **Severe** – sediment is exported off site and surface lowering < 0.1 m
- ✓ **Extreme** – sediment exported off site and surface lowering > 0.1 m.

Table A9: Field scoring method for soil erosion features

Erosion Type	**Erosion State**	**Erosion Extent**	**Erosion Severity**	**The total score**	**Overall erosion class**
Splash= 1, **Sheet** =2, **Rill** = 3, **Gully** = 4	Active = 3, **Partly stabilised** = 2, **Decreasing** = 1, Stable =0	**Widespread** = 3, Moderate =2, **Localised** =1, **Negligible** = 0	**Extreme** =4, **Severe** =3, Moderate = 2, **Low** = 1, **None** = 0	Sums of score of the erosion type, state, extent and severity	**No/very low erosion = 0-2, Slight erosion 3-6, High erosion = 7-12 Very High 13+**

Appendix 7: Visual Assessment of Non-Cropland Degradation

Country: ……………………. District: …………………………. Area (Ha)……………

Community: ……………………………. Field/Land use type……………………………

Date: ………………………… Name of record keeper: ………………………

GPS Readings: N ………………………… W ……………………………

A set of proposed indicators is outlined below for a visual assessment of non-cropland degradation. Read carefully and score the various items with experts in the field. Note that this form is only applicable to non-cropland.

Table A10: Scoring of land degradation indicators in non-crop land.

Indicator	**Meaning/interpretation**
Decline in vegetation cover	
1. Bare spots	Spots without vegetation. In savanna - 2m or larger
☐ None	No bare spot can be seen
☐ Little	Can be seen, but does not characterised the area
☐ A lot	Bare spots characterises the area
☐ Dominating	More bare than covered
Litter cover/Surface organic matter	***The amount of litter on the soil surface (The more, the better soil surface protection).***
☐ Dense	Covers soil beneath tufts.
☐ A lot	Covered with litter but bare soil can be seen
☐ Little	Litter seen but no notable cover effect.
☐ None	No litter seen
Biomass decline	***Growth measurements - height and diameter at breast height (DBh) and growth pattern- e.g. stunted, defoliated) and vigour measurements - stem diameter.***
☐ Good	Vegetation height, diameter and plant vigour compare very well with representative sites.
☐ Moderate	Vegetation height, diameter and plant vigour slightly lower than the representative site.
☐ Poor	Vegetation height, diameter and plant vigour significantly lower than representative site

☐ Very poor	Serious reduction in biomass, resulting in stunted and defoliated growth and very little to no plant vigour.
Proportion of perennial/annual species	***Indication of grazing quality and resilience to drought (herbaceous species – lower lignin and higher protein; woody species- higher lignin, lower protein)***
☐ Dominating	All grasses are perennial
☐ A lot	Single annuals are present
☐ Little	Perennials are present but not important
☐ None	Perennials not seen
6. Proportion (dominance) of useful species	***This could include: - Ecological functions (e.g. canopy cover, deep rooting, resilience to drought, recovery after burning); Palatability (browse / grazing); and Products for human use.***
☐ Dominating	All or most species useful
☐ A lot	Moderately useful species present
☐ Little	some useful species present but not in high quantity
☐ None	Not seen
7. Alien Invasive or weed species	***Identify specific alien invasive or weed species that have reduced Forest/Wood/ Rangeland productivity***
☐ None	None seen
☐ Little	some invasive and weed spp present but not in high quantity
☐ Lot	Invasive and weed spp seen in high quantity but not over whole area
☐ Dominating	Whole area taken over by invasive and weed species.
8. Pest and disease damage	***Indicate extent and severity of damage by termites (defoliated vegetation and termite nests visible), rodents, locusts and diseases***
☐ None	Not seen.
☐ Little	Single localities, no real damage.
☐ A lot	Damage seen, but not over whole area.
☐ Dominating	Whole area damaged.
Loss of soil life	**Decline of soil macro-organisms (earthworms and termites) in quantity**
☐ Dominating	Whole area is dominated by soil macro fauna or their activities
☐ A lot	Considerable amount of the area is colonized by macro fauna or their activities

☐ Little	Some soil macro-fauna present but not in high quantity
☐ None	Not seen
Negative conversion of the land use area	**It is the transformation of a particular land use to another**
☐ None	When the original land use is not changed
☐ Low	When 1-10%, of a hectare of the original land use is been converted to other land uses
☐ Moderate	10-30%, of a hectare of the original land use is been converted to other land uses
☐ High	> 30%, of a hectare of the original land use is been converted to other land uses
Exposure of rock outcrops	**It consists of spots of exposures of bedrock and soil. A type of land having little or no soil supported vegetation.**
☐ None	No rock outcrops seen
☐ Little	Rock outcrops occur, but in single localities
☐ A lot	Considerable amount of rock outcrops seen, but not over the whole area.
☐ Dominating	Whole area is dominated by rock outcrops

Appendix 8: Cross-Scale Analysis

Basin scale indicators	***Class***	***Sub-basin indicators***															
		Ersion State				Erosion Extent				Erosion Severity				Negative land use/cover conversion			
		0	1	2	3	0	1	2	3	1	2	3	4	1	2	3	4
Modeled net soil loss	0	0.0	0.0	2.2	4.8	0.0	1.7	2.6	2.6	0.9	2.2	2.2	1.7	2.6	1.0	0.0	5.0
	1	0.0	0.0	3.9	14.4	0.0	2.6	7.9	7.9	0.9	3.1	10.9	3.5	7.0	0.0	0.0	12.3
	2	0.4	0.0	3.1	16.2	0.4	1.3	9.2	8.7	0.9	3.1	10.9	4.8	6.3	2.3	0.3	11.6
	3	0.0	0.9	14.0	40.2	0.4	9.2	22.3	23.1	3.1	13.5	20.5	17.9	11.3	3.0	0.0	37.4
Negative land use/cover conversion	0	0.4	0.9	22.7	62.9	0.9	13.1	35.8	37.1	4.8	19.7	38.0	24.5	21.9	6.3	0.3	59.3
	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	0	0	0	7.42	0.0	1.3	3.5	2.6	0.0	1.7	3.1	2.6	4.0	0.0	0.0	2.0
	3	0.0	0.0	0.4	5.2	0.0	0.4	2.6	2.6	0.9	0.4	3.5	0.9	1.3	0.0	0.0	5.0
Composite LD class	0	0.0	0.0	2.2	4.8	0.0	1.7	2.6	2.6	0.9	2.2	2.2	1.7	2.6	1.0	0.0	5.0
	1	0.0	0.0	3.5	5.2	0.0	1.7	3.5	3.5	0.0	1.7	5.7	1.3	4.6	0.0	0.0	7.0
	2	0.4	0.0	3.1	19.2	0.4	1.3	11.4	9.6	0.9	3.9	12.7	5.2	8.6	2.3	0.3	11.6
	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	0.0	0.9	12.7	40.6	0.4	8.3	21.8	23.6	3.9	11.8	21.4	17.0	7.9	3.0	0.0	40.7
	5	0.0	0.0	0.0	2.6	0.0	0.0	0.9	1.7	0.0	0.9	0.4	1.3	1.0	0.0	0.0	1.0
	6	0.0	0.0	1.7	3.1	0.0	1.7	1.7	1.3	0.0	1.3	2.2	1.3	2.3	0.0	0.0	1.0

Match between regional and field-observed indicators (m)

Degradation recognized by field-observed indicator, but not by regional indicator (d_a)

Degradation recognized by regional indicator, but not by field-observed indicator (d_b)

Appendix 9: Stone Bunded Field in the Study Area.

Appendix 10: Map of LD Classes in the WVB