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Land use and land cover study of the savannah ecosystem in the Upper West Region (Ghana) using remote sensing

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To my parents, wife (Enyonam Agbavitor-Duadze), children (Sedor Duadze, Asiwome Duadze and Yram Duadze), primary school headteacher (Mr. Sampson K. Dzobo) and middle school headteacher (the late Mr. Charles Dotse Hodey)

ABSTRACT

Land use and land cover information constitutes key environmental information for many scientific, resource management and policy purposes, as well as for a range of human activities. It is so important that it has become a major focus for the International Geosphere-Biosphere Programme (IGBP) and the International Human Dimensions Programme (IHDP) at global, regional and local levels. Land use and land cover information is currently not available for many areas of the Volta Basin, which is currently undergoing rapid and wide-ranging changes in land use and vegetation due to the practice of slash-and-burn or shifting cultivation. The study of these conversions necessitates the use of remote sensing because it provides data at synoptic scales and facilitates the discerning of large-scale ecosystem patterns. Although remote sensing technology has been used for mapping in Ghana for sometime now, attempts to use unsupervised and supervised classification methods for LANDSAT images for large areas have so far yielded unsatisfactory results. Yet unsupervised and supervised classification have advantages over manual classification.

Therefore, this study was formulated as a component of the GLOWA Volta Project, the main theme of which is "*Sustainable water use under changing land use, rainfall reliability and water demands in the Volta Basin*". The project is to generate data for the development of a decision support system. This study sought to find a suitable unsupervised or supervised method of land use and land cover mapping by remote sensing, to determine land use and land cover changes and to assess the relationships, if any, between land use and land cover change on the one hand and rainfall, soil fertility and population on the other.

The objectives of the study, therefore, involved (i) the adaptation of an unsupervised or supervised classification method for land use and land cover mapping in the Volta Basin, (ii) production of land use and land cover maps of the Upper West Region, (iii) land use and land cover change assessment for the region for the periods of 1986 to 1991, 1991 to 2000 and 1986 to 2000, (iii) evaluation of the fertility status of the soils under the various land cover categories for crop production, (iv) evaluation of the rainfall regime for crop production, (v) assessment of changes in the population of the region between 1984 and 2000 and (vi) determination of the extent to which changes in soil fertility and population under rainfall variability have effects on land use and land cover change of the region during the 15-year period.

The Upper West Region was selected for this study because, being the most recently created administrative region of Ghana, it is undergoing rapid biophysical and socio-economic transformations. Situated in the north-western corner of Ghana, it covers 1,850 km^2 and falls into the Guinea savannah vegetation zone. The total population of the region in 2000 was 576,583, with a density of 31.2 km^{-2} and a growth rate of 1.7% (the relatively low growth rate being due to emigration to the south of the country).

The methodology used for image classification involved the stratification of different geocorrected LANDSAT-satellite images (1986, 1991 and 2000) and the classification of the various strata, using a classification scheme derived from the *Ghana Land Use and Land Cover Classification Scheme* (Agyepong *et al.,* 1996). The stratification procedure scaled down the complex vegetation patterns on the images and therefore improved the classification accuracy. The classified image strata were mosaicked to form a map, and the statistics of the various land use and land cover categories were generated. Prior to this, detailed analyses were made to compare visual/manual and unsupervised classification of the satellite data for land use and land cover. The results showed that visual interpretation cannot be compared with supervised and unsupervised classifications, because some of their mapping units are different. Unsupervised classification could not discriminate between water bodies and shaded closed savannah woodland and wet or dark dry riverbeds. However, unsupervised clustering was used to generate training samples, which were then used together with those collected in the field for a final maximum likelihood supervised classification. Change detection was done by comparing

the area of each land cover class over the various periods. The changes were related to soil fertility, rainfall and population of the region. Thus, the fertility of the soils under the various land cover types was evaluated for the traditional crops being grown in the region. The mean annual rainfall and mean farming-season rainfall from 1980 to 2000 were also evaluated for these crops. The change in population over the study period was also determined.

Six broad land use and land cover classes were mapped for 1986, 1991 and 2000, namely: (i) *Farmland/bare land or constructed surface*, (ii) *Closed savannah woodland or riparian vegetation*, (iii) *Open savannah woodland with shrubs and grasses*, (iv) *Mixture of grasses and shrubs with scattered trees*, (v) *Reserved woodland*, and (vi) *Water body*. The over-all accuracy of the classification was 92 %. The results of the analyses showed that in 1986 and 1991, the respective extent of the various land cover categories was *Open savannah woodland with shrubs and grasses* (60% and 58.8%), *Mixture of grasses and shrubs with scattered trees* (16.8% and 17.7%), *Reserved woodland* (8.9% for both dates), *Closed savannah woodland/riparian vegetation* (7.33 and 7.32), *Farmland/bare land or constructed surface* (6.98% and 7.2%) and *Water body* (0.021% and 0.047%). In 2000, the extent of the land cover categories were *Open savannah woodland with shrubs and grasses (58.1%), Mixture of grasses and shrubs with scattered trees (19%), Reserved woodland (8.9%), Farmland/bare land or constructed surfac*e (7.6%), *Closed savannah woodland/riparian vegetation* (6.3%) and *Water body* (0.054%). Thus, while *Closed savannah woodland/riparian vegetation* and *Open savannah woodland with shrubs and grasses* decreased in extent from 1986 to 2000, *Farmland/bare land or constructed surface*, *Mixture of grasses and shrubs with scattered trees* and *Water body* increased spatially. Reserved savannah woodland was assumed to not have changed. Based on information collected from the interview of farmers, agricultural extension workers and foresters working in the region, the dynamics of land use and land cover conversions and inter-conversions in the region were determined.

The soils under *Closed savannah woodland* were more fertile than those under *Open savannah woodland*, which, in turn, were more fertile than those under *Mixture of grasses and shrubs with scattered trees*. The *Farmland* soils were the lowest in fertility. The soils of the region are generally low in fertility and *marginally suitable* to *suitable* for millet, sorghum, groundnut, rice, legumes, maize and cotton. The rainfall pattern is erratic, variable and unreliable, sometimes causing reduction in yield or total crop failure and imposing restriction on the choice of crops. The rainfall is *moderately suitable* to *suitable* for these crops. About 75% of the economically active population are farmers. The population increased from 1984 to 2000 by 32%. Obviously, given that such a high proportion of the population is in agriculture, an increase of 32% in population has serious implication for the degradation of the woodland, which is known to be more fertile. Declining soil fertility in the farmlands and increasing population, therefore, cause pressure on land, which leads to land degradation. This, in turn, causes the farmers to move to other areas to farm. This practice results in the progressive loss of woodland.

The study shows that (i) supervised classification can be applied to derive accurate land use and land cover maps for the savannah ecosystem in the Volta Basin of Ghana, (ii) generally, supervised maximum likelihood classification of LANDSAT images for a large area can be done successfully with a high level of accuracy and, more important, (iii) this is the first time sit has been carried out for a large area in the complex savannah ecosystem in Ghana, (iv) land use and land cover of the region have changed over the past 15 years, and (v) changes in land use and land cover in the Upper West Region are related to the driving forces of declining soil fertility and increasing population under rainfall variability.

Landnutzung und Landbedeckung im Savannenökosystem der Upper West Region (Ghana) unter Verwendung von Fernerkundung

KURZFASSUNG

Informationen zu Landnutzung und Landbedeckung bilden die entscheidenden Umweltinformationen für zahlreiche Zwecke der Wissenschaft, des Ressourcenmanagements und der Politik sowie für einige menschliche Aktivitäten. Diese Informationen sind so wichtig, dass sie zu einem Schwerpunkt des Internationalen Geosphären-Biosphären-Programm (IGBP) und des International Human Dimensions Programme (IHDP) auf globaler, regionaler und lokaler Ebene geworden sind. Informationen zu Landnutzung und Landbedeckung sind z.Zt. für viele Gebiete des Voltabeckens nicht verfügbar. Das Voltabecken erlebt gegenwärtig schnelle und weit reichende Veränderungen in der Landnutzung und der Vegetationszusammensetzung als Folge des Brandrodungsfeldbaus. Die Untersuchung dieser Veränderungen macht die Anwendung der Fernerkundung erforderlich, da diese Daten in synoptischen Maßstäben liefert werden können und sie die Erkennung von großräumigen Ökosystemmustern erleichtern. Obwohl die Fernerkundungstechnologie in Ghana seit einiger Zeit zur Kartierung eingesetzt worden ist, haben Versuche, rechnergestützte Klassifizierungsmethoden für LANDSAT-Bilder von großen Gebieten zu nutzen zu unbefriedigenden Ergebnissen geführt. Die rechnergestützte Klassifizierung hat jedoch Vorteile gegenüber der manuellen Klassifizierung.

Diese Studie wurde daher als Teil des GLOWA-Volta Projektes „*Nachhaltige Wassernutzung bei Veränderungen in Landnutzung, Niederschlagsbeständigkeit und Wassernachfrage im Voltabecken*" durchgeführt. Dieses Projekt wurde konzipiert, um Daten für die Entwicklung eines „decision support system" zu entwickeln. Die vorliegende Studie sucht nach einer geeigneten rechnergestützten Methode zur Kartierung der Landnutzung und -bedeckung und zur Bewertung der Beziehungen, wenn vorhanden, zwischen Änderungen der Landnutzung und Landbedeckung auf der einen Seite und Niederschlag, Bodenfruchtbarkeit und Bevölkerung auf der anderen.

Die Ziele dieser Studie umfassten daher (i) die Entwicklung einer geeigneten rechnergestützten Methode zur Klassifizierung der Landnutzung und Landbedeckung der Savanne des Voltabeckens in Ghana, (ii) Erstellung von Karten über Landnutzung und Landbedeckung im Maßstab 1:250,000 (iii) Bewertung der Veränderungen in der Landnutzung/Landbedeckung in der Upper West Region für die Jahre 1986, 1991 und 2000, (iii) Bewertung des Fruchtbarkeitsstatus der Böden unter den verschiedenen Landbedeckungskategorien für die Produktion der angebauten Kulturpflanzen, (iv) Bewertung des Niederschlagregimes in Beziehung zur Produktion der angebauten Kulturpflanzen, (v) Bewertung der Bevölkerungsveränderungen zwischen 1984 und 2000 und (vi) Bewertung der Veränderungen in der Bodenfruchtbarkeit und Bevölkerung unter Berücksichtigung der Niederschlagsvariabilität; dabei wird untersucht, ob diese Auswirkungen auf die Landnutzung/Landbedeckung der Region während in den letzten 15 Jahre hatten.

Die Upper West Region wurde für die Studie ausgewählt, da sie erst vor Kurzem als Verwaltungsregion definiert wurde und einer sehr schnellen biophysikalischen und ökonomischen Wandlung erfährt. Die Upper West Region umfasst ca. 1.850 km^2 und liegt in der nordwestlichen Ecke von Ghana in der Vegetationszone Guinea-Savanne. Die Gesamtbevölkerung der Region beträgt 576.583 (2000 Zensus) mit einer Dichte von 31.2 Personen km^{-2} und einer jährlichen Zunahme von 1.7% (die relativ geringe Wachstumsrate ist die Folge der Emigration der Menschen in den Süden des Landes).

Die Methode umfasst die Interpretation von geometrisch korrigierten LANDSAT-Satellitenbilder (1986, 1991 und 2000) und die Klassifizierung der verschiedenen Schichten auf der Grundlage des *Ghana Klassifizierungsschema für Landnutzung und Landbedeckung*.

Im Stratifizierungsverfahren wurden die komplexen Vegetationsmuster in den Bildern zur Verbesserung der Klassifizierungsgenauigkeit reduziert. Die einzelnen Schichten wurden dann in Mosaiken überführt, Statistiken wurden generiert und Karten entwickelt. In einem zweiten Schritt wurden detaillierte Analysen durchgeführt, um die visuelle/manuelle und nicht-bewachte Klassifizierung der Satellitendaten für die Landnutzung und Landbedeckung zu vergleichen. Die Ergebnisse zeigen, dass die visuelle Interpretation aufgrund der Unterschiede in einigen der Landnutzungs-/Landbedeckungseinheiten nicht mit der der nicht-bewachten bzw. bewachten Klassifizierung verglichen werden können, da sich einige der Karteneineiten unterscheiden. Die nicht-überwachte Klassifizierung war nicht in der Lage, zwischen Gewässer, beschattetem, geschlossenem Savannenwald und nassen bzw. dunklen trockenen Flussbetten zu unterscheiden. Jedoch wurde die nicht-bewachte Klassifizierung eingesetzt, um Trainingsgebiete zu bestimmen, die dann zusammen mit den Felddaten zur abschließenden „größte Wahrscheinlichkeit"-Klassifizierung eingesetzt wurden. Die Ermittlung von Veränderungen wurde durch einen Vergleich der räumlichen Statistiken der verschiedenen Landbedeckungsklassen über die einzelnen Zeiträume in bezug auf Bodenfruchtbarkeit, Niederschlag und Bevölkerung durchgeführt. Die Fruchtbarkeit der Böden bei den verschiedenen Landbedeckungstypen wurde außerdem für die traditionellen Kulturpflanzen in der Region bestimmt. Der mittlere Jahresniederschlag und mittlere Niederschlag der Anbausaison von 1980 bis 2000 wurden hinsichtlich der dort angebauten Kulturpflanzen bestimmt.

Insgesamt wurden sechs Landnutzungs- und Landbedeckungsklassen für die Jahre 1986, 1991 bzw. 2000 kartiert. Diese waren: (i) *landwirtschaftliche Anbaufläche/bewuchsfreies Land oder bebaute Oberfläche*, (ii) *geschlossener Savannenwald oder Ufervegetation*, (iii) *offener Savannenwald mit Sträuchern und Gräsern*, (iv) *eine Mischung von Gräsern und Sträuchern mit vereinzelten Bäumen*, (v) *geschützte Waldflächen* und (vi) *Gewässer*. Die Gesamtgenauigkeit der Klassifizierung betrug 92 %. Die Ergebnisse der detaillierten Analysen zeigen für die Jahre 1986 bzw. 1991 den Anteil der Landbedeckungskategorien als *offener Savannenwald mit Sträuchern und Gräsern* (60% bzw 58.84%), *eine Mischung von Gräsern und Sträuchern mit vereinzelten Bäumen* (16.8% bzw. 17.7%), *geschützte Waldflächen* (8.9% für beide Jahre), *geschlossener Savannenwald oder Ufervegetation* (7.33 bzw. 7.32%), *landwirtschaftliche Anbaufläche/bewuchsfreies Land oder bebaute Oberfläche* (6.98% bzw. 7.2%) und *Gewässer* (0.021% bzw. 0.047%). In 2000 betrugen die Anteile *offener Savannenwald mit Sträuchern und Gräsern* 58.13%, *eine Mischung von Gräsern und Sträuchern mit vereinzelten Bäumen* 19%, *geschützte Waldflächen* 8.9%, *landwirtschaftliche Anbaufläche/bewuchsfreies Land oder bebaute Oberfläche* 7.6%, *geschlossener Savannenwald oder Ufervegetation* 6.30% und *Gewässer* 0.054%. Folglich nahm der Anteil *geschlossener Savannenwald oder Ufervegetation* und *offener Savannenwald mit Sträuchern und Gräsern* von 1986 bis 2000 ab, während die Kategorien *landwirtschaftliche Anbaufläche/bewuchsfreies Land oder bebaute Oberfläche*, *eine Mischung von Gräsern und Sträuchern mit vereinzelten Bäumen* und *Gewässer* zunahmen. Es wird angenommen, dass sich der Anteil des geschützten Savannenwaldes nicht verändert hat. Auf der Grundlage der Informationen aus den Interviews mit den Farmern, der landwirtschaftlichen Berater und den Förstern aus der Region wurde die Dynamik der Landnutzungs- und Landbedeckungsänderungen bestimmt.

Die Böden unter *closed savannah woodland* waren fruchtbarer als die unter *open savannah woodland*, die wiederum fruchtbarer waren als die unter *mixture of grasses und shrubs with scattered trees*. Das *farmland* zeigte die geringste Fruchtbarkeit. Die Böden in der Region sind im Allgemeinen von geringer Fruchtbarkeit und *geringfügig geeignet* bis *geeignet* für den Anbau von Hirse, Sorghum, Erdnuss, Reis, Hülsenfrüchte, Mais und Baumwolle. Der Niederschlag zeichnet sich durch Unbeständigkeit, Variabilität und Unzuverlässigkeit aus; dies führt oft zu Ertragsminderung oder kompletten Ernteausfällen und beschränkt die Auswahl der Kulturpflanzen. Der Niederschlag ist *mäßig geeignet* bis *geeignet* für diese Pflanzen. Ca. 75% der wirtschaftlich aktiven Bevölkerung sind Bauern. Die Bevölkerung nahm von 1984 bis 2000 um 32% zu. Die nachlassende Bodenfruchtbarkeit und wachsende Bevölkerung führen zu einem verstärkten Landdruck, der wiederum zur Landdegradation führt. Als Folge ziehen die Farmer in andere Gebiete. Diese Praxis führt zu einem fortschreitenden Verlust von Waldgebieten.

Die Studie zeigt, dass (i) die rechnergestützte bewachte Klassifizierung zur Erstellung von genauen Landnutzungs- und Landbedeckungskarten für die Upper West Region eingesetzt werden kann, (ii) im Allgemeinen kann die bewachte „größte Wahrscheinlichkeit"-Klassifizierung von LANDSAT-Bildern für ein großes Gebiet erfolgreich durchgeführt werden und, noch wichtiger, sogar in einem komplexen Savannenökosystem; dies ist das erste Mal, wo diese Klassifizierungsmethode in einem großen Gebiet in Ghana eingesetzt wurde, (iii) die Landnutzung und Landbedeckung der Region haben sich in den vergangenen 15 Jahre verändert und (iv) Veränderungen in der Landnutzung/Landbedeckung in der Upper West Region hängen mit abnehmender Bodenfruchtbarkeit und zunehmendem Bevölkerungswachstum unter variablen Niederschlagsbedingungen zusammen.

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1 INTRODUCTION

1.1 Background of the study

This study is an integral part of an on-going GLOWA-Volta Project, the main theme of which is '*Sustainable water use under changing land use, rainfall reliability and water demands in the Volta Basin*". The Volta Basin, which spans across six countries in West Africa (Figure1.1) and covers some 400,000 km^2, lacks biophysical and socio-economic information for effective environmental and socio-economic management (GLOWA Volta, 1999). The project has, therefore, been designed to generate data for the creation of a decision support system that will provide a comprehensive monitoring and simulation framework to enable decision makers to evaluate the impact of manageable systems, such as irrigation, primary water use, land use change, power generation and trans-boundary water allocation, as well as the less manageable attributes, such as climate change, rainfall variability and population pressure on the social, economic, and biological productivity of water resources. Thus, the project is expected to equip decision makers with the ability to weigh alternative development strategies and answer questions such as: (1) Is there an increase in rainfall variability, and if yes, what would be the economic and ecological consequences? (2) How can the present population growth be reconciled with water resource management? (3) What are the feedback loops between land use intensification, reduced rainfall and soil fertility? (4) What are the returns in terms of productivity and downstream availability of water

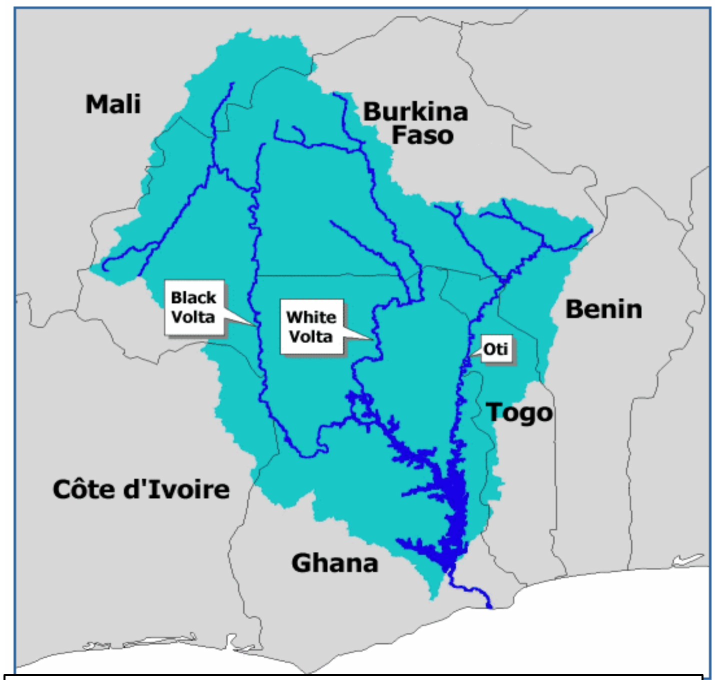


Figure1.1: The Volta Basin, showing the various countries it covers (*Source: GLOWA Volta, 1999*)

resources yielded by large-scale irrigation schemes along major rivers or hydraulic development of small valleys in the upper reaches? and (5) what are the trade-offs between increased hydro-power production (helping industries around Accra) and agricultural productivity through irrigation in the North (reducing rural poverty)?

The GLOWA-Volta Project is being implemented through research, the activities of which focus on data collection, monitoring methodologies, data standardization, information institutionalisation, and model selection. The research is being organized in three clusters, each covering one theme associated with a complex set of interactions (Figure 1.2). The first cluster, "*Rainfall and Climatic Change*", deals with atmospheric redistribution of moisture and heat. The second cluster, "*Land Use and Land Cover Change*", seeks to analyse the multiple feedback loops between population pressure, agricultural development, soil degradation, and land cover and the consequences for the distribution of rainfall between actual evapotranspiration (ETa) and aquifer recharge. The third cluster, "*Water Use and Institutional Change*", is to project future water supply and demand under different policies and institutional arrangements. The clusters have been chosen in such a way that their interfaces have a relatively simple structure.

Together, these structures are expected to provide inputs into a basin model, which will be able to play out dynamic interactions and feedback loops. These will, as a final objective, lead to the development of a management system, which will allow the extrapolation of rainfall and population trends as well as the consequent change in land pressure, agricultural productivity and water demands, which in turn translate into migration patterns and changes in land cover. The scientific innovation of the model lies in the fact that none of these "global change factors" (rainfall patterns, land cover, population and hydrologic cycle) are taken as an entity, but rather treated as being dependent on internal dynamics as well as on boundary conditions.

This study falls within the *Land Use Cluster* (Figure 2.1), and it is being handled by the Remote Sensing Research Group (RSRG) of the Geography Institute, University of Bonn. The study has sought to adapt commonly used computer-based methods of land use and land cover classification, using remote sensing, to produce historical and current land use and land cover information of the Basin and to determine whether there have been land use and land cover changes over the past fifteen years (1986-2000).

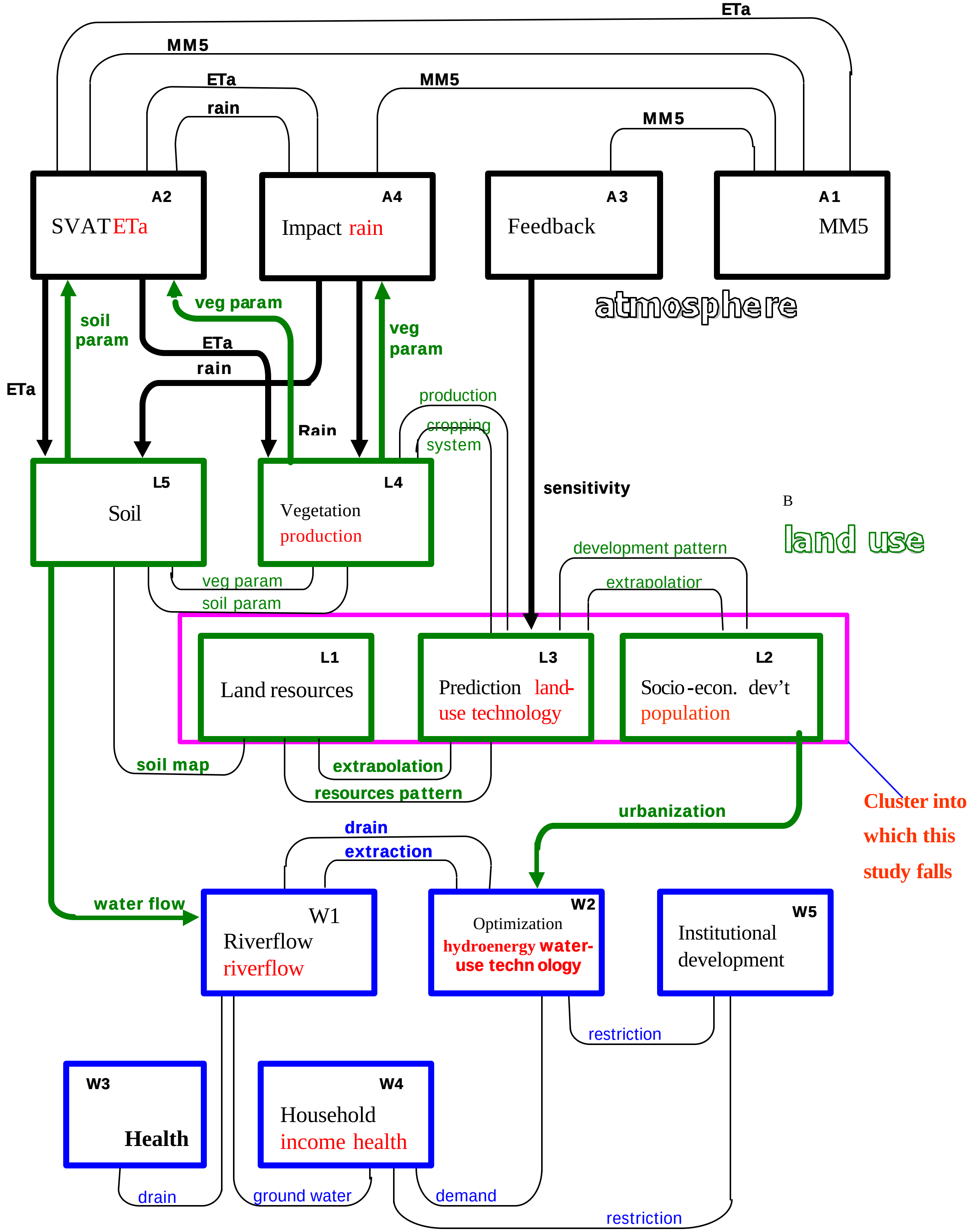


Figure 1.2: Overview of GLOWA-Volta project structure with sub-project names and codes, information exchange and state variables (GLOWA-Volta, 1999)

and assess the relationships, if any, between the changes in land use and land cover with rainfall, soil fertility and population.

1.2 Land use and land cover: definitions and concepts

In order to appreciate the definitions and concepts of land use and land cover, it may be necessary to, first of all, define the term "land". According to the FAO (1998), "*land*" is any delineable area of the Earth's terrestrial surface involving all attributes of the biosphere immediately above or below this surface, including those of the near-surface climate, the soil and terrain forms, the surface hydrology (including shallow lakes, rivers, marshes and swamps), near-surface layers and associated ground water and geo-hydrological reserves, plant and animal populations, human settlement patterns and physical results of past and present human activities (terracing, water storage or drainage structures, roads, buildings, etc.). Land is the basic life supporting system that supplies the majority of living forms with space, energy and nutrients that are essential for all biochemical metabolisms occurring in any organism. Land plays a key role in major biogeochemical cycles both within ecosystems and globally (FAO, 1998). Generally, land can be considered in two domains: (1) land in its natural condition and (2) land that has been modified by human beings to suit a particular use or range of uses. The natural capability of land to meet a certain anthropogenic activity in a broad sense is referred to as *land quality*, and this is traditionally interpreted in terms of land resources, which determine land use. Historically, land has been exploited in different ways, from a simple watching of landscapes and primitive collection of herbs to intensive land management based on massive distortion of land by heavy machinery and artificially generated industrial areas (Stolbovoi, 2002). In these ways, humans are adapting to land capacity or rebuilding land to fit their demands.

Many authors or groups have defined "**land use**" and "**land cover**". The UNEP-WCMC (2001) have concisely defined "**land use"** as the human activity carried out to obtain goods or benefits from the land, and "**land cover"** as the vegetation or the construction, that cover the Earth's surface. Cracknel and Hayes (1993) have referred to "**land use"** as the current use of the land surface by man for his activities, and "**land cover**" as the state or cover of the land. Smits *et al.* (1999) have used the term "**land cover"** to refer to any type of feature present on the surface of the Earth, such as trees, grasses, open water, and wetlands, but does not assume the specific use of land. They have used the term "**land use"** to refer to a human activity associated with a specific piece of land, which may include characteristics that often cannot be inferred directly from the remote-sensing data alone.

The International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme (IHDP) and the Land Use and Land Cover Change Project (LUCC) have referred to "**land use and land cover change"** as follows (IGBP/IHDP, 1999):

Land cover refers to the physical or biophysical characteristic or state of the Earth's surface and the immediate subsurface, captured in the distribution of vegetation, water, desert, ice, and other physical features of the land, including those created solely by human activities such as mine exposures and settlement.

Land use is the intended use or management of the land cover type by human beings. Thus, land use involves both the manner in which the biophysical attributes of the land are manipulated and the intent underlying that manipulation (the purpose for which the land is used, e.g., logging, ranching, agriculture, wildlife reservation, etc.). The biophysical manipulation refers to the specific way in which the resources (e.g., vegetation, soil, and water) are used for a particular purpose, for example, logging, the cut-burn-hoe-weed sequence in many slash-and-burn agricultural systems, the use of fertilizers, pesticides, and irrigation for mechanized cultivation on arid lands; or the use of an introduced grass species for pasture and the sequence of movement of livestock in a ranching system. Biophysical manipulation can be seen as the techno-managerial system.

***Land cover and land use changes*:** Shifts in intent and/or management constitute land-use changes. Land cover and land use changes may be grouped into two broad categories: (1) *conversion or (2) modification* (Stolbovoi, 2002). Conversion refers to changes from one cover or use type to another. For instance, the conversion of forests to pasture is an important land use and land cover conversion in the tropics. The abandonment of a piece of land that has been permanently cultivated over a period in the past to regenerate to forest is a land use and land cover conversion. Land use and land cover modification, on the other hand, involves the maintenance of the broad cover or use type in the face of changes in its attributes. Thus, a forest may be retained while significant alterations take place in its structure or function (e.g., involving biomass, productivity, or phenology). Likewise, slash-and-burn agriculture, a use, may undergo significant changes in the frequency of cropping, and use capital and labour inputs while retaining the rotation, cutting, and burning that constitute such uses.

Land use class is a generalized land use description, defined by diagnostic criteria that pertain to land use purpose(s) and the operation sequence followed; it has no location or time indications (de Bie, 2000).

Land use classification is the process of defining land use classes on the basis of selected diagnostic criteria (de Bie, 2000).

Land use type is a use of land defined in terms of a product, or products, the inputs and operations required to produce these products, and the socio-economic setting in which production is carried out (FAO, 1998).

Notwithstanding these definitions, it is sometimes difficult to differentiate between land cover and land use. Therefore, Stolbovoi (2002) stated that land use is closely interrelated with land cover in the sense that land cover provides additional information on human activity and specifies this activity in terms of commodity identification, timing, etc. This information, when spatially explicit, may lead to the breakdown of land cover categories into sub-entities, which under various conditions can facilitate further linkages of land use data with other natural characteristics. Land use encompasses a wide range of natural and socio-economic aspects and their interrelations (Stolbovoi, 2002). Land use and land cover information has become so important that it is often parts of studies relating to the environment.

1.3 Importance of land use and land cover

Land use and land cover information is important for many planning and management activities concerned with the surface of the Earth (Smits *et al.*, 1999; Lillesand and Kiefer, 1994), because it constitutes a key environmental information for many scientific, resource management and policy purposes, as well as for a range of human activities. This information is significant to a range of themes and issues that are central to the study of global environmental change. For example, alterations in the Earth's surface hold major implications for the global radiation balance and energy fluxes, contribute to changes in biogeochemical cycles, alter hydrological cycles, and influence ecological balances and complexity. For example, large-scale deforestation increases the atmospheric carbon level (IPCC, 2001). Through these environmental impacts at local, regional and global levels, land use and land cover changes, driven by human activity and biophysical factors, have the potential to significantly affect food security and the sustainability of the world agricultural and forest product supply systems (Mas and Ramirez, 1996 and IIASA, 2001). Land cover is an important determinant of land use and hence the value of land to society (Mucher *et al.*, 2000). Therefore, with the need for environmental planning and management becoming increasingly important, the need for land cover information has emerged parallelly (Cihlar, 2000) at local, regional and global levels. It is, therefore, generated on global, regional and local scales. Figure 1.3a shows a global land cover map and Figure 1.3b its legend. Figures 1.4 and 1.5 show historical land use and land cover information for Ghana.

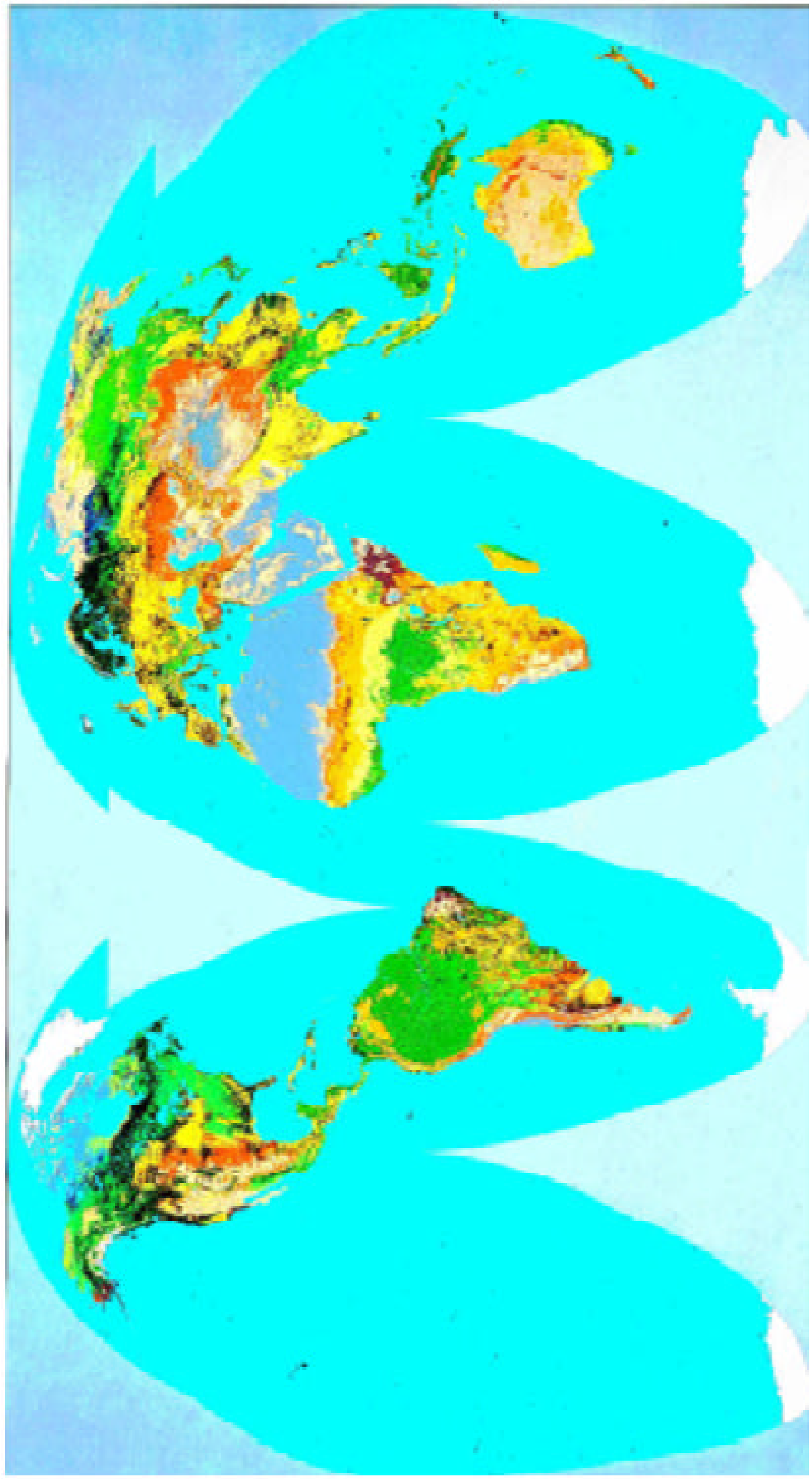


Figure 1.3: Global land cover characterization map (Loveland *et al.,* 2000)

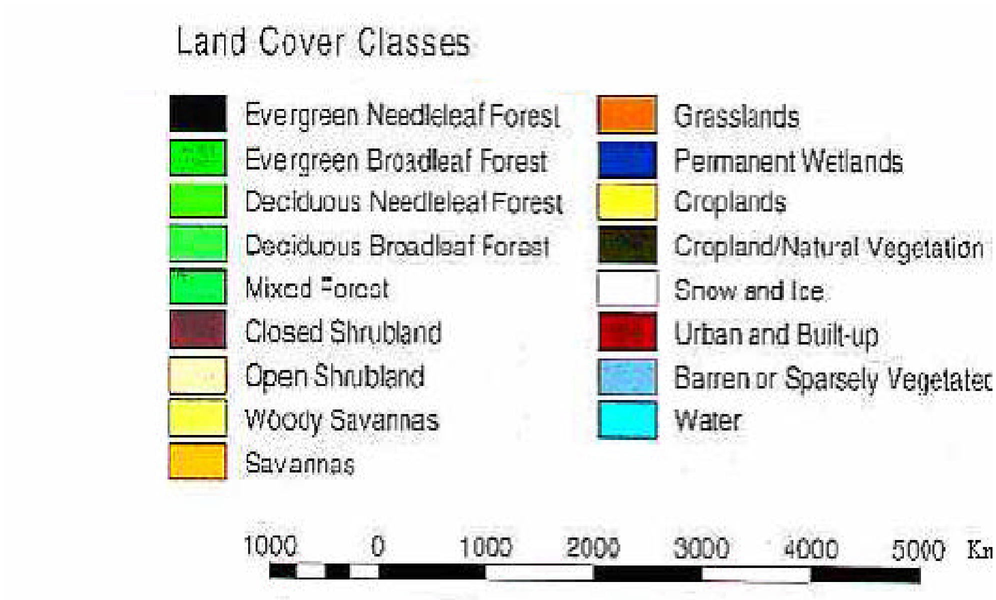


Figure 1.3b: Legend to the Global land cover characterization map by Loveland *et al.* (2000)

KEY

Interior savannah

1. *Compound farming area.1 & 3. Compound farming mixed with land rotation cultivation as in 3.*
2. *Grazed grassland with rare land rotation cultivation*
3. *Land rotation with grazed tree savannah regrowth fallow*
4. *Less intensive land rotation with sparsely grazed tree savannah regrowth fallow and scattered patches of 5*
5. *Little-cultivated ungrazed tree savannah, including forest reserves*

Derived savannah

6. Land rotation with cocoa in forest outliers mixed with less intensive land rotation in more *extensive patches of savannah*
7. ***Less intensive land** rotation with tree savannah regrowth fallow and some small cultivated forest outliers*
8. ***Little cultivated,** ungrazed tree savannah mixed with occasional patches of incompletely developed closed forest or secondary forest*

Forest zone

*9. **Intensive land rotation** with negligible forest remaining: area of most commercialised food cropping*

10. Land rotation with a small percentage of forest remaining: area of most extensive cocoa, including area of newest cocoa planting, especially in the northwest.

11. Less intensive land rotation with much forest remaining.

12. Little-farmed closed forest, including forest reserves: area (outside the reserves) of most active timber exploitation. (owing to limitations of scale 11 and 12 have been mapped together over much of the zone.

Coastal thicket and sav. zone

Coastal thicket; 14. Grass savannah, 15. Tree savannah, 16. savannah-thicket transition, 7.Lagoons and marshes

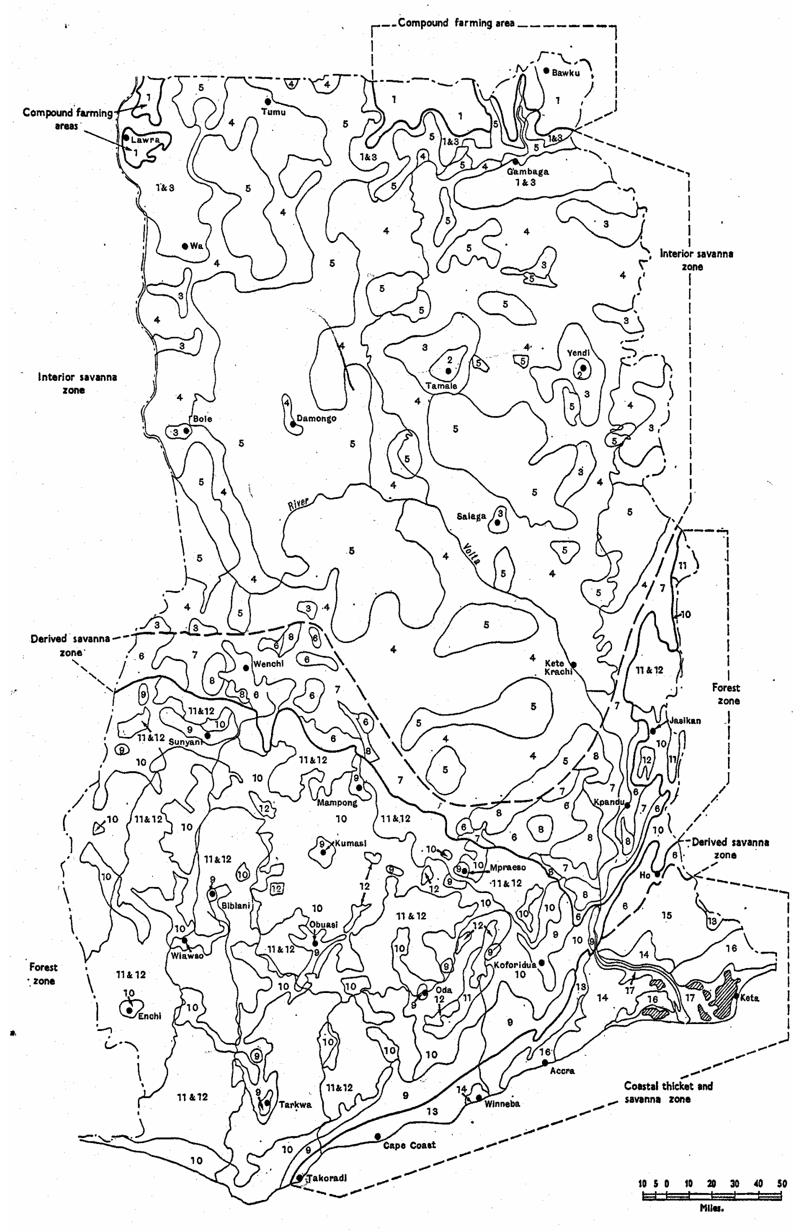


Figure1.4: Land use and land cover map of Ghana (Wills, 1962)

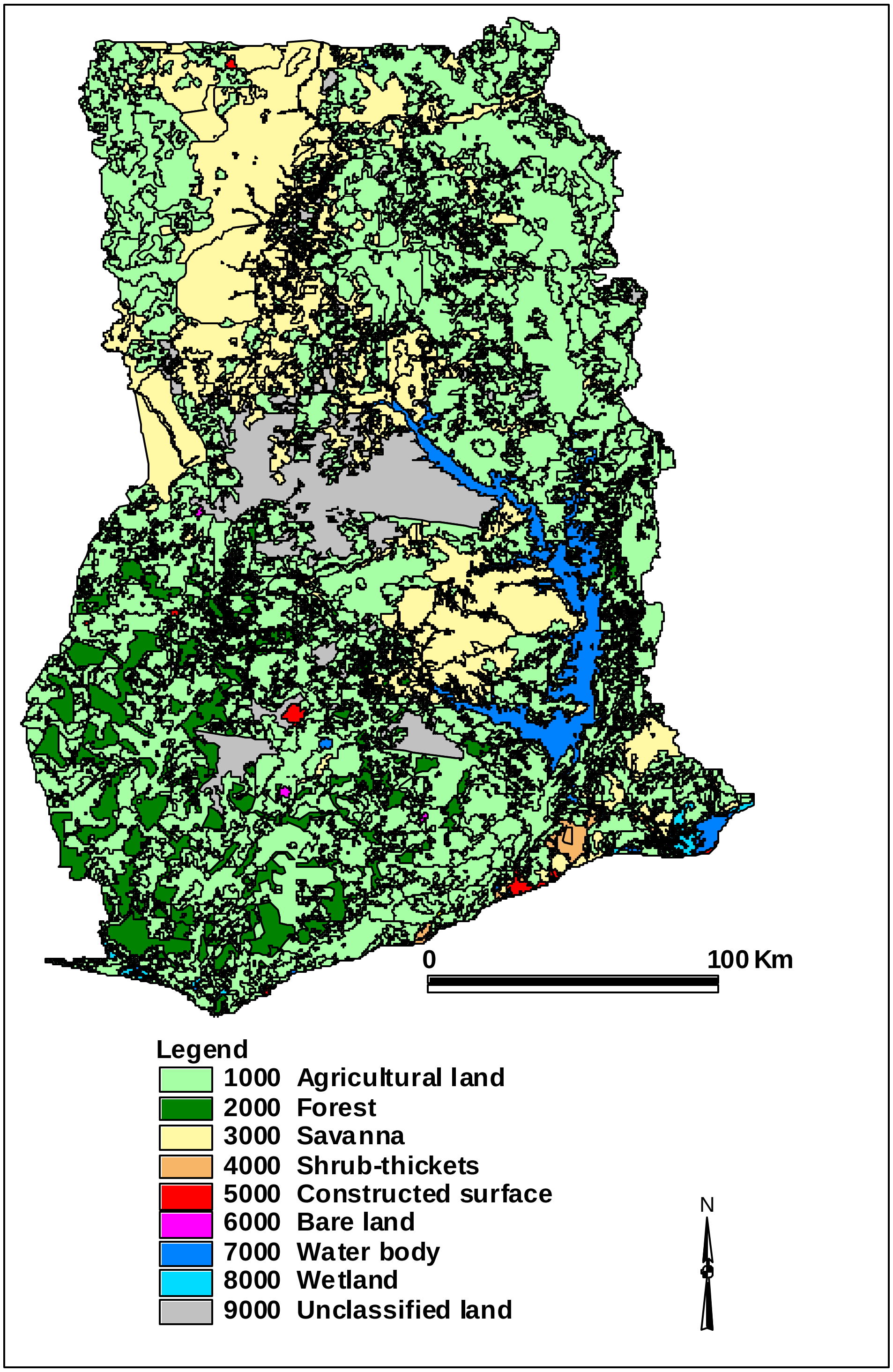


Figure 1.5: Land use and land cover map of Ghana (Level I), 1990/1991
Source: Agyepong et al. (1999) (Dark areas are vector layers of higher land use and land cover levels (Levels II-IV) of Level I classes)

Quite often, the study of land use and land cover is necessitated by the need to know, in quantitative terms, the nature, extent and rate of their changes and objective baseline information on which to build and evaluate future environmental policy (Wright and Morrice, 1997). This need has been identified as the first priority data among the minimum data sets required for the development of a spatial information system for natural resource management systems. An accurate knowledge of land use and land cover features represents the foundation for land classification and management, and the absence of accurate land use and land cover information is a critical problem in making sound decisions concerning the Earth's resources and the environment (Dai and Khorram, 1998). Therefore, a wide range of scientists and practitioners, including Earth systems scientists, land resource managers and urban planners, as well as business persons seek information on the location, distribution, type, magnitude and currency of land use and land cover change (Stow, 1999). This search places emphasis on the timeliness and reliability of land use and land cover information. Such databases, which are expected to be characterized by a high spatial accuracy and easy updating, are currently not available for many places of the world (Mucher et al., 2000), especially the developing world including the Volta Basin of West Africa. Many of the land use and land cover studies that have been carried out around the world, for example those of Helmer *et al.* (2000); Apan (1997); Baban and Luke (2000) and Borak and Strahler (1999), concern changes in vegetation, mostly the deforestation and/or degradation of tropical forests and woodlands.

1.4 Degradation of vegetation

Several regions around the world are currently undergoing rapid and wide-ranging changes in the environment, especially in land use and vegetation (Mas, 1999). Current rates of global land cover changes are most dramatic in the African rainforests and woodlands, where slash-and-burn agriculture is widely practised (de Moraes *et al.*, 1998 and Yang and Prince, 2000). According to Rose-Innes (1963) and Hall and Swaine (1976), the natural vegetation of the interior savannah of Ghana, of which the Upper West Region is a part, was woody formations. However, there has been a great deal of conversion of the natural vegetation in many places due to shifting cultivation (Agyemang and Brookman-Amissah, 1987). Increased pressure on land leads to its intensive human over-utilization and shorter fallow periods, which lead to rapid changes in vegetation productivity, structure and composition of the savannahs (Yang and Prince. 2000). These changes are important in the regional and global context so far as biogeochemical cycles, climate and biodiversity losses are concerned (Di Maio Mantovani and Setzer, 1997).

1.4.1 Causes of deforestation and degradation of woodland

Environmental changes are often the result of anthropogenic pressure (e.g., population growth) and natural factors such as inter-annual or decadal variability in climate and intrinsic vegetation dynamics (Janetos and Justice, 2000; Guerra *et al.*, 1998). Tropical forests and woodlands are exploited for such varied purposes as timber and fuel wood extraction, slash-and-burn cultivation, industrial crop plantations and pasture development (de Moraes *et al.*, 1998). Due to increasing population growth rate, there have been increasing rates of conversion of rain forest and woodlands in developing economies all over the world, mainly for the slash-and-burn farming practice (FAO 1999). In tropical Africa, the practice of slash-and-burn cultivation is responsible for the deforestation and fragmentation of rainforests (Thenkabail, 1999). According to Agyepong *et al.* (1999), by 1990, only about 6% of Ghana was covered by undisturbed primary high forest. The rest had been cleared for the cultivation of cocoa or degraded as a result of timber extraction. Extensive grazing and the incidence of frequent wild bushfires are also important causal agents of degradation of woodlands in Ghana. The same applies to surface mining and the expansion of settlements, at least, on local scales.

1.4.2 Effects of deforestation

Changes in vegetation cover have potential effects on both the local and global environment with regard to the increase in the concentration of atmospheric carbon dioxide (greenhouse effect), changes in temperature and precipitation, loss of biodiversity, increased run-off and flooding, soil erosion, watershed processes and biogeochemical cycles (Helmer *et al.*, 2000).

1.4.2.1 Greenhouse effect and climatic implications

The "greenhouse effect" is a natural phenomenon by which gases in the atmosphere "trap" heat from the Earth, thereby preventing them from escaping into space (IPCC, 2001). Industrialization and deforestation have dramatically increased greenhouse gases (mainly carbon dioxide (IPCC, 2001)). According to Goldammer (2002), large-scale and frequent burning in the tropics constitutes a major global source of a number of gases, including carbon dioxide (CO_2), nitrous oxide (NO), carbon monoxide (CO), and methane (CH_4), as well as aerosols. Atmospheric CO_2 concentrations have increased by approximately 25 per cent since 1870 and may double between now and the middle of the next century (Rodriaguez *et al.* (2000) (Figure 1.6). Many scientists believe that unusually high concentrations of these gases are increasing the greenhouse effect and thereby warming the Earth (IPCC, 2001).

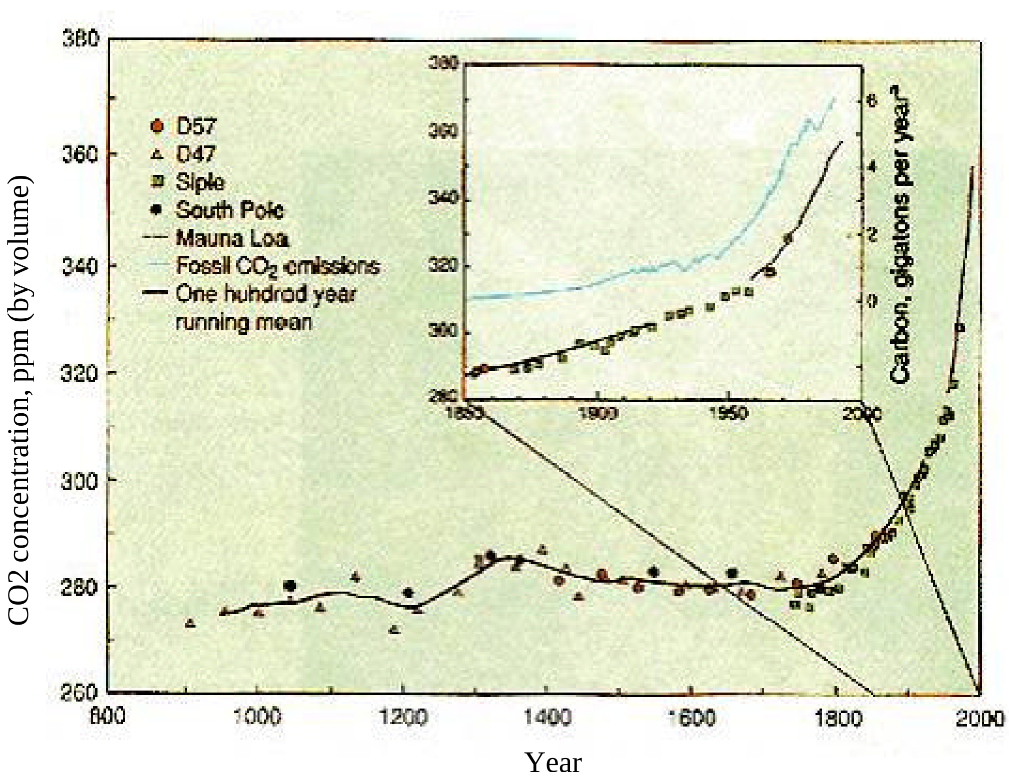


Figure 1.6: Increase in atmospheric carbon dioxide emission since 1800.
Atmospheric CO2 has increased 30% since 1800 (IPCC, 2001)

Through the process of photosynthesis, trees and other plants convert carbon dioxide from the atmosphere into energy (Raghavendra, 1998). About 50 per cent of a living tree is carbon, which has been fixed from the atmosphere, and for every ton of carbon a tree stores, it removes 3.667 tons of CO_2 from the atmosphere (Winrock, 2002). Forests are known to sequester higher amounts of carbon than the agricultural crops or grassland, which replace them after deforestation (Houghton 1990). A large-scale conversion of forest to pasture, shrubland or grassland leads to changes in the amount of carbon stored in vegetation biomass and soils (de Morales *et al.*, 1998, Helmer *et al.* (2000) and Houghton, 1995) and consequently, the global carbon budget. This means that deforestation of forests and woodlands in the tropics is significantly increasing the concentration of atmospheric carbon dioxide and other trace gases (Fearnside, 1996). Globally, land use and land cover change is known to be the second largest source of CO_2 after the combustion of fossil fuel (Rodriaguez *et al.*, 2000 and Okamoto *et al.*, 1997). The magnitude of this flux is, however, questionable (Kimes *et al.*, 1999).

The concentrations of greenhouse gases are expected to increase in future, since their production is related to food production and energy conversion (Novo and Shimabukuro, 1997), which are directly related to population growth (Figure 1.7).

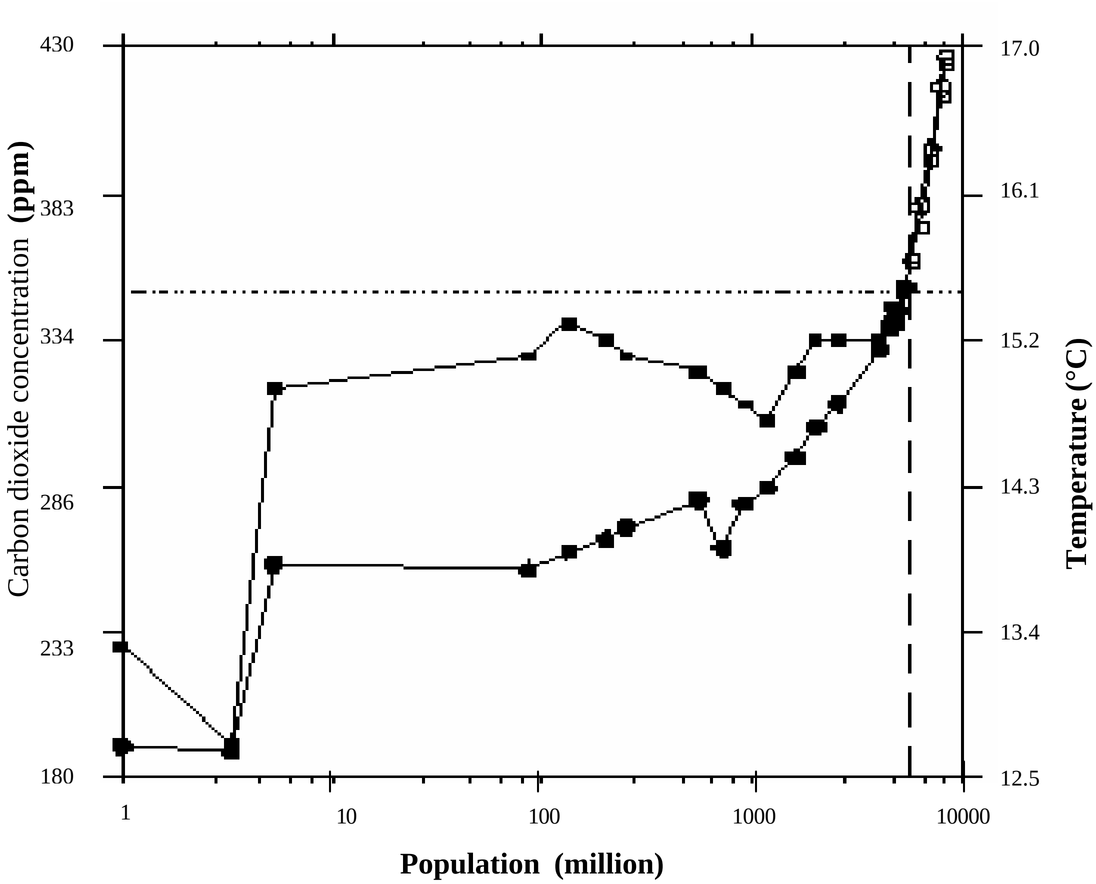


Figure1.7: Effect of population (log-population) on CO_2 concentration (circles) and mean global temperature(squares). Vertical dashed line at 1995. *Source (Gribbin, 1990 and Khalil and Rasmussen, 1992)*

1.4.2.1 Deforestation and biodiversity

Deforestation causes climate change, which, in turn, may have a large negative impact on habitats (Sannier *et al.*, 1998). Deforestation, therefore, leads to loss of biodiversity (Thenkabail, 1999) in tropical forests and woodlands and has been responsible for massive extinction of many species of flora and fauna (Prance, 1982). Increases in CO_2 concentration have effects on temperature. Okamoto *et al.* (1997) have observed that the increase in greenhouse gases has already been responsible for a rise in mean global temperature by 0.3°– 0.6°C since the latter half of the nineteenth century.

Large-scale deforestation in the tropics normally results in decreasing humidity and rainfall, which in turn decreases agricultural and forestry or woodland yields and increases the probability of large-scale bush fires (Hill, 1999). Apart from affecting the ground surface albedo, there is the likelihood that a total degradation of the forest or woodland ecosystem may revert it to a grassland ecosystem, which might encourage weed infestation and appearance of grasses (Salami *et al*., 1999).

1.4.2.2 Effects on hydrology and soil erosion

The degradation of forest or woodland also impacts watershed processes and biogeochemical cycles (Helmer *et al*., 2000; Houghton, 1995 and Thenkabail, 1999) and leads to soil erosion and water shortage not only in the regions immediately affected by deforestation, but also in reasonably distant areas (Hill, 1999). Personal observation in Ghana has shown that the massive removal of forest and woodland cover has led to the drying up of many springs and some waterfalls or to the reduction in their volumes of water. The Huhunya Water Fall near Asesewa, for example, has become seasonal and flows only during the rainy season.

1.5 Need for land use and land cover mapping

From the foregoing, it can be seen that the problems posed by land cover changes are numerous and have serious consequences. Therefore, the spatial dimensions of land cover needs to be known at all times so that policy-makers and scientists will be amply equipped to take decisions. According to Ringrose *et al.* (1997), land cover change in Africa is currently accelerating and causing widespread environmental problems and thus needs to be mapped. This is important because the changing patterns of land cover reflect changing economic and social conditions. Monitoring such changes is important for coordinated actions at the national and international levels (Bernard *et al*., 1997). For example, frequent mapping of reserved forests and woodlands by remote sensing is important for quick generation of information for governments to inform them of the magnitude of encroachment. The mapping of land cover change and the percentage of woody canopy cover change in savannahs is needed to manage the savannahs more effectively (Yang and Prince, 2000), particularly with regard to desertification.

As decision making for resource and environmental management becomes more complex, the need for more precise maps (e.g., at scales of 1:50,000 or larger) with greater positional and thematic accuracy increases. For national natural resources management in Ghana, there is currently a need for greater spatial resolution of digital maps covering large areas at medium scales, e.g., 1:250,000 or larger (NRMP-EPA, 1999). The need for such accurate information for decision making on a temporal basis necessitates the use of remotely sensed data for the production of maps. This requires the formulation of a classification scheme or system in which the various land use and land cover categories are well defined and standardized to facilitate the comparison of maps of different places and dates (FAO, 1998; ERDAS, 1998; Anderson *et al.*, 1976 and Dai and Khorram, 1998).

Maps of natural resources are important tools for land management and conservation planning (Nilsen *et al.*, 1999). For example, the estimation of vegetation cover for extensive grasslands (both natural and derived) is very important for livestock and crop production (Purevdorj *et al.*, 1998), as well as for the monitoring of desertification of arid and semi-arid lands. The assessment of the status and categories of the vegetation in a given locality is also very important for the general environment, because it gives information on indicators for land degradation. Mapping the distribution of land cover across large areas at different periods of the year is a prerequisite for informed natural resource management (Rogers *et al*., 1997), because it provides information on the phenology of the vegetation. Land degradation can be so fast that even local authorities, more often than not, do not know its extents and impacts; hence the need for information (Rogers *et al*., 1997). In order to ensure timely and accurate information, remote sensing is needed for mapping.

1.6 Remote sensing and land use and land cover mapping.

The use of remote sensing techniques in resource inventory is primarily due to the high reflectances from such resources in different regions of the electromagnetic spectrum recorded by various sensors (Trotter, 1998). This makes the use of remote sensing in land use and land cover mapping one of the most important applications of modern satellite sensor technology. Satellite remote sensing is capable of providing data at synoptic scales and facilitates the discerning of large-scale ecosystem patterns (Roughgarden *et al.*, 1991). It is particularly important for the study of tropical deforestation due to the inaccessibility of many areas and the difficulty in the use of aircraft-based survey methods (Tucker and Townshend, 2000) and the fact that traditional methods are fraught with many inherent difficulties (Thenkabail, 1999).

Although land cover mapping is one of the most frequent applications of remote sensing technology, mapping large areas using this technology has only come into consideration relatively recently (Cihlar, 2000). In particular, the digital technique of mapping vegetation using satellite remote sensing has not been widely used in developing countries until recently (Trotter, 1998). The increasing desire to use remote sensing in resource mapping has arisen out of the requirements for new information and also the fact that there are new developments in the technology (Cihlar, 2000). The most reliable, accurate and detailed local and regional land cover classifications have been obtained from the use of multi-temporal imagery (Wright and Morrice, 1997). Researchers ask questions such as, `what is the amount of green biomass over this region?' or, `what is the spatial distribution of the fraction of canopy cover?' To answer these and similar questions, remote sensing is needed, because it is the only practical means of obtaining spatially extensive and exhaustive data (Dungan, 1998).

Remotely sensed imagery plays a major role in many spatial information systems (Wright and Morrice, 1997). It provides a viable source of data from which updated land cover information can be extracted efficiently and cheaply for effective change detection. Multi-temporal information about the vegetation cover is also important for monitoring the rates of biotic resources and vegetation response to drought conditions. This is particularly important for crops, pasture and rangelands.

There are several sources of satellite data, which allow objective analyses of ecological variables. Some of the current sources or types of satellite images have been described in Table 2.1 in Chapter 2 and Appendix 9.1. Among them are the Advanced Very High Resolution Radiometer (AVHRR) from the National Oceanic Atmospheric Administration (NOAA), which plays a significant role in monitoring global processes (Schmidt and Gitelson, 2000); the LANDSAT series (LANDSAT 1, 2 and 3, which are called the Multi-spectral scanner (MSS) and LANDSAT 4, 5 and 7, which are also called Thematic Mapper (TM plus ETM for LANDSAT 7); the French SPOT (multispectral and panchromatic); IKONOS; Moderate Resolution Imaging Spectroradiometer (MODIS); the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) sensors and the Indian Remote Sensing satellites (IRSS). All these systems offer the opportunity to study vegetation at various scales. The multi-spectral data provided regularly by high-resolution Earth observation satellites constitute a tool for characterizing and monitoring the vegetation of tropical forest ecosystems (Guerra *et al.*, 1998). More often than not, satellite data are used in conjunction with other data types. For example, Salami *et al.* (1999) used a combination of multitemporal aerial photographs and high-resolution satellite imagery (SPOT XS) to detect forest reserve incursion in south-western Nigeria.

1.7 Remote sensing and land use/land cover change detection

Changing land use patterns necessitate frequent updating of existing land use and land cover maps, especially in developing regions, where they are often inadequate and outdate rapidly (Rogers *et al.*, 1997). There are many land use and land cover change detection procedures in use. But the one used in a given situation has a significant impact on subsequent decisions based on the data so derived (Sunar, 1998). Remote sensing technology provides the most accurate means of measuring the extent and patterns of changes in landscape conditions over time (Defries and Belward, 2000 and Miller *et al.*, 1998). Therefore, the use of satellite images, as an effective technique to study changes in vegetation cover, is growing (Damizadeh *et al.* 2000).

Satellite data have become a major application in change detection because of the repetitive coverage of the satellites at short intervals (Mas, 1999). According to the IGBP/IHDP (1999), change detection studies seek to know the (i) patterns of land cover change, (ii) processes of land use change, and (iii) human responses to land use and land cover change. The knowledge of these is then (iv) integrated into global and regional land use and land cover change models and used for (v) the development of databases on land surface, biophysical processes and their drivers. Remote sensing is important in such integrated studies, because of its provision of multispectral and multi-temporal synoptic coverage of any area of interest, enabling details of the changing landscape or phenomenon to be detected and mapped. The satellite data provide permanent and authentic records of land use patterns of a particular area at any given time, which can be re-used for verification and re-assessment. Automated change detection using satellite data allows for timely and consistent estimates of changes in land use and land cover trends over large areas (Potter and Brooks, 1998).

1.8 Ecological factors and land use/land cover change

Vegetation is a function of rainfall regime, soil conditions, geomorphology, fire occurrence rates and differential grazing pressures (Weiss and Milich, 1997). Man is also an important factor, because he alters the landscape through practices such as cultivation, especially slash-and-burn agriculture.

The spatial distribution of the vegetation and agricultural land use systems in West Africa is predominantly determined by rainfall (Ahn, 1970). Schroth and Sinclair (2003) have observed that rainfall and soil fertility are two important factors that regulate the growth and development of plants, including crops. Most of West Africa experiences high temperatures, which, relatively, do not vary much throughout the year, so that differences in climate are largely due to differences in rainfall regimes. The distribution of vegetation and crops types is generally determined by rainfall, which in Ghana, decreases from the forest zone in the south to the savannah zone in the north (Dickson and Benneh, 1988) (Figure 1.8). Rainfall is the basis of the agro-ecological zoning of the country. In the Upper West Region, like most parts of the savannah, rainfall quantities and distribution cannot be relied on for all-year-round growth of crops and vegetation (Asiamah and Seneya, 1988).

Soil is an important component of terrestrial ecological systems. Soil physico-chemical and climatic processes, which are fundamental to plant growth, development and yields are closely related and influence land use and vegetation processes. Of particular importance is the synergy of soil fertility and rainfall in determining crop yields in the savannah zones. The soils of the Upper West Region are low in fertility due to erosion and long periods of cultivation with shortened fallows (Titriku, 1982 and Senaya *et al.*, 1998). This phenomenon is believed to be leading to the extensification of cultivation into areas of primary woodlands, and hence the shrinking of woodland areas, which has environmental and economic implications for the region and beyond.

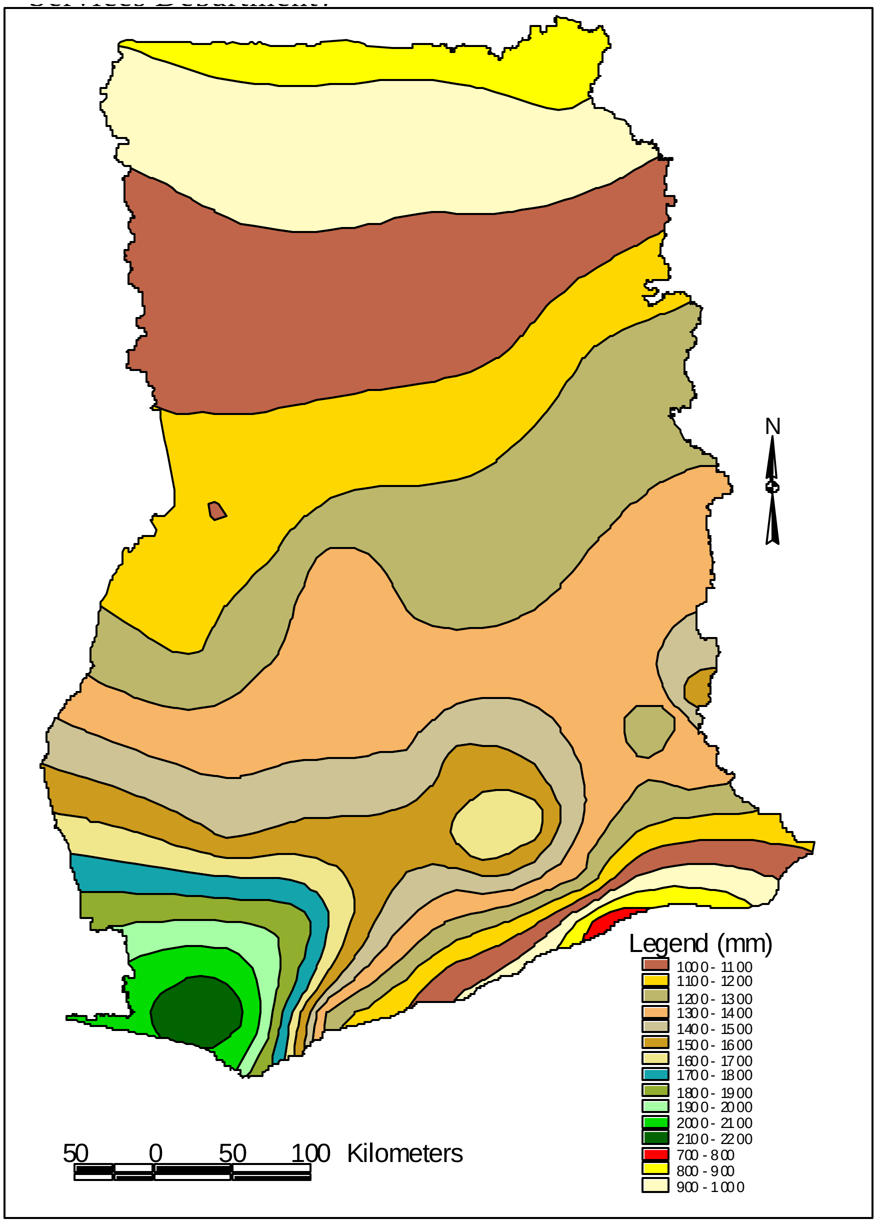


Figure 1.8: Rainfall map of Ghana based on data from the Meteorological Services Department (Agyepong *et al.,* 1999)

1.9 Land use and land cover mapping in Ghana

There is an increasing desire to optimise the production of food, fibre and services, as well as to address the urgent concerns for a sustainable use of land in Ghana (Agyepong, 1995). This has created the need for land use and land cover information. Together with the recommendations of the Rio Summit, popularly known as "Agenda 21", these needs have resulted in the drawing up of a National Environmental Action

Plan (NEAP) in 1991 by the Government to address the various environmental issues. In order to implement the plan, the Ghana Environmental Resources Management Project (GERMP) was formulated. Among other data sets, land use and land cover data for the whole country were to be produced. As a follow-up study to that of GERMP, the Natural Resource Management Project (NRMP) was started in 2000. It also has a land use and land cover mapping component. It is still in progress and expected to end in 2003. It is to update the land use and cover information of the country as at 2000.

Before the GERMP, efforts had been made at various points in time to provide information on land use and land cover in Ghana. However, the picture that emerges from the examination of available environmental information shows the lack of a systematic and reliable national coverage. What exists is widely fragmented with respect to time, space and methodology for generating the data. The map produced by Wills (1962) (Figure 1.4) was the most serious attempt to cover the whole country. Apart from the fact that the map was too generalized (1:5,000,000), it took 10 years to compile, with the result that by the time the map was compiled, it had already become outdated. This situation was recognized as a serious gap in the national resource monitoring system, and which needed to be corrected. Thus, under the GERMP a digital and hard copy national land use and land cover map (1:250,000) (Figure 1.5) was produced, using the visual or manual classification method of on-screen digitisation. This was achieved within a period of four years, which also included the period of training of the mapping team who were computer-illiterates at the start of the project.

1.10 Problem of land use and land mapping in Ghana

Even though remote sensing has been applied in Ghana for a long time, its development is still in an infant stage, due to the lack of finance, expertise, and more important, a low level of political will. To change this state of affairs, a considerable depth of the efficacy of the technology needs to be demonstrated to convince politicians and administrators, so that they can include it in their policy schemes. The objective of the land use component of the GLOWA Volta Project has a potential in this direction. The demonstration of the efficacy of the use of remote sensing must be seen in its cost-benefit advantages. This means that the production of land use and land cover data sets, for example, must be done less laboriously, consistently and rapidly. This calls for an unsupervised or supervised method, which are known to give more accurate and cost-effective results than those obtained by on-screen digitizing.

The interpretation of remotely sensed data for land use and land cover can be done visually (manually) or automatically (ERDAS, 1999), but the important consideration is that of consistency and reproducibility (Cihlar, 2000). That is, given the same input data, various analysts should obtain the same result or ideally even with different input data of the same area. In practice this means that, as far as possible, the analysis should be done with objective, analyst-independent procedures (Cihlar, 2000). Given the subjectivity of visual classification, the elements of consistency and reproducibility cannot be guaranteed for databases derived with that kind of method. Thematic classes obtained from visual interpretation are too generalized, and the technique cannot be cost-effective for implementation over large areas such as the Volta Basin, because it is labour- and time-consuming and also requires more equipment compared with unsupervised or supervised classification (Trotter, 1998 and Shimabukuro *et al.*, 1998). It does not produce consistent and analyst-independent boundaries. In areas where small fields or features with intricate patterns such as the 'fish-bone' pattern predominate, high accuracy becomes even more difficult to attain with visual interpretation (Shimabukuro *et al.*, 1998).

Notwithstanding, visual interpretation has been used all over the world and has produced acceptable and relatively accurate results. Many ecological, hydrological and biogeochemical models that require high spatial resolution and georeferenced digital data have employed visual and manual classification classification (Shimabukuro *et al.*, 1998). Shimabukuro *et al.* (1998) used visual interpretation of LANDSAT TM imagery to assess the extent of deforestation at regional scales in the Amazon Basin. Duadze *et al.* (1999) also used visual interpretation to generate land use and land cover information of Ghana.

Unsupervised or supervised classification of remotely sensed data in the tropics is an arduous task, because of the diverse and complex structure and composition of natural vegetation communities and land use patterns (Trotter, 1998). Most wet-season images are often cloud-obscured and therefore difficult to use for classification, while the dry-season ones, though much better, miss the observation of growing crops. In many cases, the size of fallow land and farmlands are too small to be detected by most low-resolution images, making their use over large areas ineffective (Duadze *et al.*, 1999). The differentiation of vegetation on satellite images is also not easy, because varying effects of dry weather, bush fires, different stages of fallow regrowth and background soils, causes differences in spectral responses of the same or similar features over relatively short distances. The landscape of the Volta Basin is characterized by this heterogeneity and complexity of vegetation, so that attempts at applying straightforward conventional methods of digital classification have, so far, produced unsatisfactory results (Duadze *et al.*, 1999).

However, there is now an increasing desire to apply unsupervised or supervised classification of remotely sensed data worldwide (Trisura *et al.*, 2000 and Thompson, 1998). This has arisen as a result of the demand for quicker production of environmental information. The ever-increasing availability of new remotely sensed data (e.g., ENVISAT, ASTER, TERRASAT, MODIS, etc.) and new methods in digital image processing, such as Neural Network and object-oriented classifications procedures, as well as spatial modelling, GIS and the development of more powerful computers are also important factors that facilitate the application of unsupervised or supervised methods of image processing.

In this study, land use and land cover maps of the Upper West Region for 1986, 1991 and 2000 (Figure 4.8, 4.10 and 4.12 in Chapter 4) were produced using supervised classification of LANDSAT images. The interpretation of these images has, by no means, been easy, due to the varying effects of the drying and burning of the vegetation as well as to the effect of background soil.

The Upper West Region was selected for this study because, being the most recently created administrative region of Ghana, it is undergoing rapid biophysical and economic transformation. The other regions in the Volta Basin have been more widely settled for a much longer period and therefore seem to have a lower proportion of undisturbed or primary vegetative cover. The eastern part of the Upper West Region had, until recently, been very sparsely populated compared to the western part, and less intensively cultivated due to the infestation with tsetsefly fly (*Glossina* species), which causes trypanosomiasis in humans and livestock, and the *Simulium* black fly, which causes “river blindness” or onchocerciasis. The flies have now been controlled and there is a rapid expansion of cultivation and grazing to the east, resulting in a rapid disappearance and degradation of the primary woodland in this part of the region. The trend and intensity of this change in vegetation and how it is conditioned by changes in rainfall and declining soil fertility in old and frequently cultivated fields constitute the focus of this study.

1.11 Objectives

1.11.1 General objectives

The general objectives of this study include the evaluation and comparison of visual, unsupervised and supervised classification methods in the savannah (Upper West Region) of the Volta Basin of Ghana and the assessment of land use and land cover changes of the region over a period of fifteen years. This also included the assessment of a change in each of the land use and land cover categories. In cases of changes, the direction of change was also determined. The study also assessed the general fertility of the soils under the various land cover categories to see whether it was capable of supporting crop production, which is related to the loss in the area of primary or virgin woodland. It also assessed whether the rainfall regime had changed over the years to the extent of affecting the cultivation of the traditional crops grown in the region. Finally, the study also investigated the growth of population of the region and compared its trend with the changes in the area of farmland and primary or virgin savannah woodland.

1.11.2 Specific objectives

The specific objectives of the study were:

- To find a suitable unsupervised or supervised method for land use and land cover classification of the Interior (or Guinea) Savannah of the Volta Basin of Ghana.
- To assess whether there have been changes in land use and land cover of the Upper West Region over a period of fifteen years.
- To evaluate the fertility of soils under various land cover categories and the rainfall of the Upper West Region for crop production.

- To assess whether soil fertility decline and population growth under rainfall variability have effects on land use and land cover in the Upper West Region of the Volta Basin of Ghana.

1.12 Research questions

The study was to provide answers to the following research questions:

- Can unsupervised or supervised methods be used to derive a more accurate land use and land cover mapping than that produced by the visual classification method for the Volta Basin?
- Which digital land use and land cover mapping methodology can best be adapted for the Volta Basin?
- Have there been spatial changes in the primary woodland, arable land or other natural savannah categories of the Upper West Region over the period of fifteen years?
- Are there any relationships between land use and land cover change, on the one hand, and soil fertility, rainfall and population, on the other hand, in the Upper West Region?

1.13 Hypotheses

The study established the following hypotheses:

- Digital image interpretation can be applied to derive more accurate land use and land cover maps than visual interpretation for the Upper West Region.
- Land cover categories of the Upper West Region have changed over the past fifteen years.
- Changes in land cover in the Upper West Region are related to declining soil quality and increased population under rainfall variability.

Figure 1.8 shows the components of this study and their interrelationships.

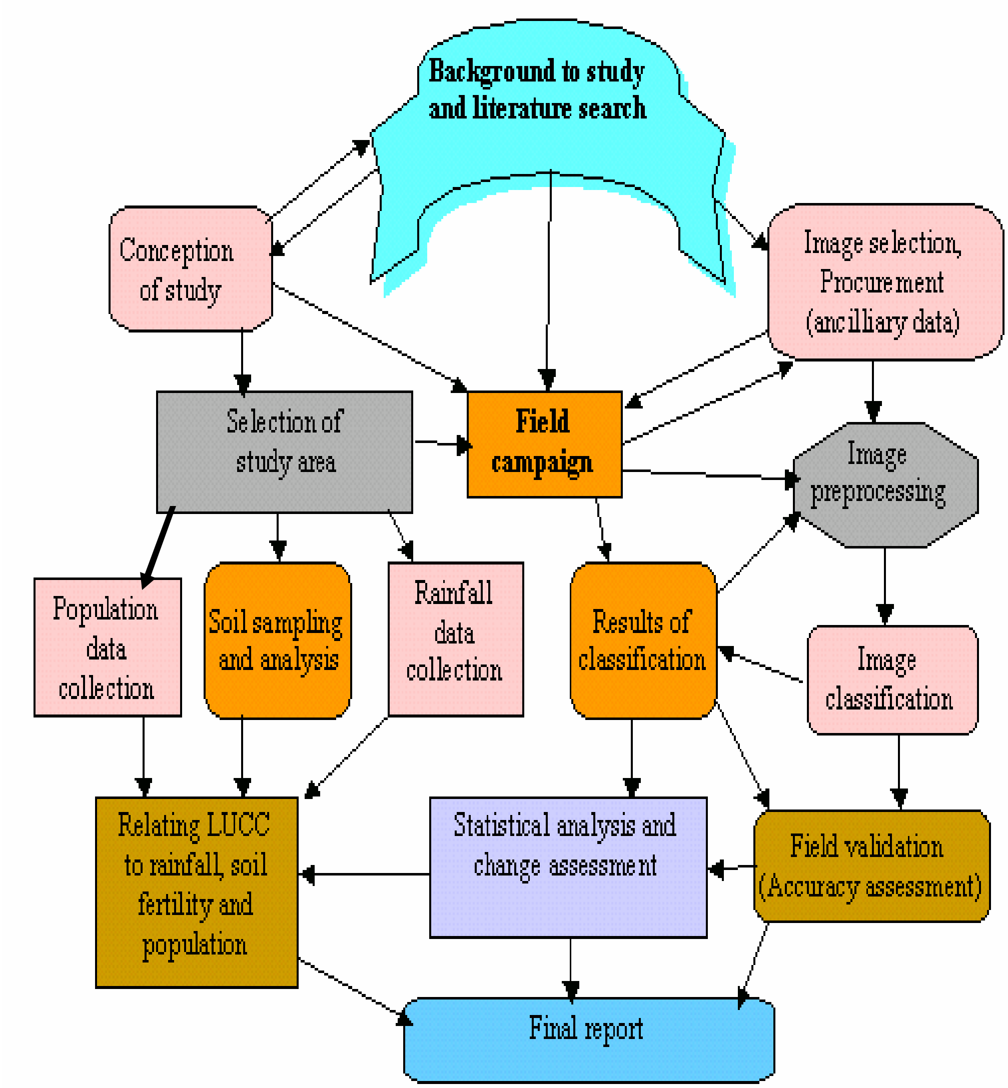


Figure 1.9: Schematic diagram showing the interrelationships between the various components of this study

2 LITERATURE REVIEW

2.1 Image type and land use/ land cover mapping

Technological advances have made available various types of remote sensing data from earth observation satellites, thus making it increasingly possible to map, evaluate and monitor land use and land cover over wide areas (FAO, 1998). The satellite-borne sensors, which have different properties and imaging capabilities, scan the surface of the earth repeatedly, with frequencies that vary with the satellite types (Table 2.1). There are many different satellite systems; the key ones whose data are most commonly used for the study of the Earth's resources are shown in Table 2.1. Appendix 9.1 shows the cost of some of these data sets as at June 2002 (Telsat Guide, 2002).

High resolution sensors, like LANDSAT Thematic Mapper (TM, 30m resolution) or the Systeme Probatoire d'Observation de la Terre (SPOT, 20m or 10m resolution) and the Multispectral Scanner (MSS, 79m resolution), are suitable for the study of land use and land cover, and have been used to derive detailed classification of many parts of the world including the tropics (Purevdor *et al.*, 1998). Major changes to the surface of the planet such as desertification, deforestation, pollution, volcanic activities, and other natural and anthropogenic events can be detected, examined, measured and analysed using LANDSAT data. The information obtainable from historical and current LANDSAT data play key roles in the study of surface changes through time (ERDAS, 1999). Prakash and Gupta (1998) used LANDSAT TM and found it to be particularly well suited for detecting changes in land use.

Some scientists such as Su (2000) and Turner and Congalton (1998) have, however, observed that high-resolution satellite data (e.g., LANDSAT MSS, LANDSAT TM and SPOT) have some drawbacks, which restrict their usefulness for studying vegetation dynamics. For example, Duadze *et al.* (1999) observed that the use of satellite imagery data to accurately map individual agricultural fields in Ghana has proved to be difficult due to the small size of cropped fields. Turner and Congalton (1998) observed this in the semi-arid zone of Africa and attributed it to the low

Table 2.1: Selected satellite remote sensing systems and major characteristics (Jensen, 1996; TELSAT-Guide, 2002)

REMOTE SENSING SYSTEM	RESOLUTION								
Satellite	**Spectral**							**Spatial (m)**	Temp. (days)
	B	**G**	**R**	**NIR**	**IR**	TIR	**MW**		
NOAA-VHRR	-	-	1	1	1		-	1100	14.5/day
IKONOS	1 – 4 m								
Landsat MSS	-	1	1	2	-		-	79	16-18
Landsat TM	1	1	1	1	2		-	30	16
Landsat 7 (ETM)	1	1	1	1	2		-	30	16
Landsat 7 panchro.	-	0.50 – 0.90			-		-	15	16
SPOT HRV Multi	-		1		-		-	20	Pointable
SPOT HRV Pan.		0.51 - 0.73 µm			-		-	10	Pointable
SM S/GOES Series (east & west)	-	0.55 – 0.72 µm			-		-	700	0.5/hr
Active microwave SAR for image/ wave mode	C-band (5.3 GHz)					1		30	-
Scatterometer for wind mode	-		-	-	-		1	5000	-
Radar Altimeter 13	-		-	-	-		1	-	-
Along track scanning radiometer (ATSR)	4 IR Bands (1.6, 3.7, 11, 12 µm					-		1000	-
RADARSAT (active microwave operates in several modes)	HH C-band (5.3 GHz)					1		-	1-6
Standard mode (range x azimuth)								25 x 28	
Wide 1 mode								48-30x28	
Wide 2 mode								32-25x28	
Fine resolution mode								11 x 9	
ScanSAR (N) mode								50 x 50	
ScanSAR (W) mode								100 x 100	
Extended (H) mode								22-19x28	
Extended (L) mode								63-28x28	
Shuttle Imaging Radar (SIR-C)								40	Var.
Sea-WiFS	1		1		-			1000	1
Moderate Imaging Spectrometer (MODIS)	0.4	36 bands			14.54	-		250/500/1000	2
ASTER	0.5	3 bands 0.9µm						15	16
ASTER	-		-	8.0 -------12.0				90	16
ASTER	-		-	1.6-----6 bands----2.5				30	16
IRS-1A	0.45 – 0.86µm							36.25 m	22
IRS-1B	0.45 – 0-86µm							71.5 m	22
IRS-1B LISS-I IRS-1B LISS-II	4 bands: 0.45-0.52, 0.52-0.59, 0.62-0.68 and 0.77-0.86 3 bands: 0.45 – 0-86, 0.77-0.86, 1.55-1.69 µm							36.26	22
IRS-P3 MOS	3 bands: 0.755-0.768µm, 0.408-1.01µm and 1.5-1.7							1569 x1395, 23x523m 523x644m	24
IRS-P3 WIFS Camera	3 bands: 0.62-0.68 µm, 0.77-0.86 µm and 1.55-1.69 µm							188x188, 188x246m	24
IRS-Liss-III	4 bands: 0.52-0.59, 0.62-0.68, 0.77-0.86, 1.55-1.70							23.5 (vis. & IR)	24
IRS 1C Pan. camera	0.5.0.75 µm							5.8 m	5

contrast between the vegetative cover within and outside cropped areas, as well as the high correlation between the seasonal trajectories in the signatures of cropped and uncropped surfaces. Cloud and haze cover are also limitations and dry season images of the savannah landscape can be prone to obscurity by fire scars caused by annual bushfires (Duadze *et al.*, 1999). The NOAA-AVHRR satellite data seem appropriate in terms of temporal resolution (Prince and Tucker, 1986). However, their one-kilometer-by-one-kilometer resolution and spectral characteristics have rendered them not to be ideally suitable for detailed studies of vegetation (Achard *et al.*, 1994). This is especially critical in tropical landscapes where the landscape within a kilometer square is characterized by a mosaic of different vegetation formations and fallow regrowths of different ages (Foody and Hill 1996). Another problem is the large data volume to be processed (Su, 2000). Notwithstanding, this satellite imagery has been used for the mapping of tropical forest and non-forest land covers, as well as for change detection (Thenkabail, 1999).

2.1.1 LANDSAT images (MSS and TM 4 and 5 Systems)

The LANDSAT multispectral scanner (MSS) system provided a historical database of the Earth's surface between Latitudes 81° North and South from the early 1970's to the early 1990's (Table 2.2). The system was initially designated as the Earth Resources

Table 2.2: Background information and status of LANDSAT satellites (Created from Handbook, USGS, 1979, 1984).

Date launched	Date decommissioned	Sensors	Temporal resolution
LANDSAT 1: Jul. 23, 1972	Jan. 6, 1978	MSS and RBV	18 days
LANDSAT 2: Jan. 22, 1975	Feb. 25, 1982	MSS and RBV	18 days
LANDSAT 3: Mar. 5, 1978	Mar. 31, 1983	MSS and RBV	18 days
LANDSAT 4: Jul.16, 1982	*	TM and MSS ***	16 days
LANDSAT 5: Mar. 1, 1984	**	TM and MSS ***	16 days

* in standby mode used for range and command as of December 14, 1993
** currently operational
*** MSS data acquisition suspended in 1992

Technology Satellite-A (ERTS-A), later re-designated ERTS-1 and finally renamed LANDSAT 1. The satellite continued to function beyond its designed life expectancy of one year and finally ceased to operate on January 6, 1978, more than 5 years after it had been launched. The second in the LANDSAT series of Earth resources satellites, designated ERTS-B and later renamed LANDSAT 2, was launched on January 22, 1975. Three additional LANDSAT satellites, LANDSAT 3, 4, and 5 were launched in 1978, 1982, and 1984, respectively. Each successive satellite system had improved sensor and communication capabilities over the previous ones. For example, the Thematic Mapper (TM) is a nonphotographic imaging system, which utilizes an oscillating mirror and seven arrays of detectors, which sense electromagnetic radiation in seven different bands as against the four bands of the MSS sensors. The Thematic Mapper sensor is a derivative of the multispectral scanner (MSS) generation of scanners, achieving greater ground resolution, spectral separation, geometric fidelity, and radiometric accuracy (Handbook, 1979 and 1984, USGS). Figure 2.1 shows a

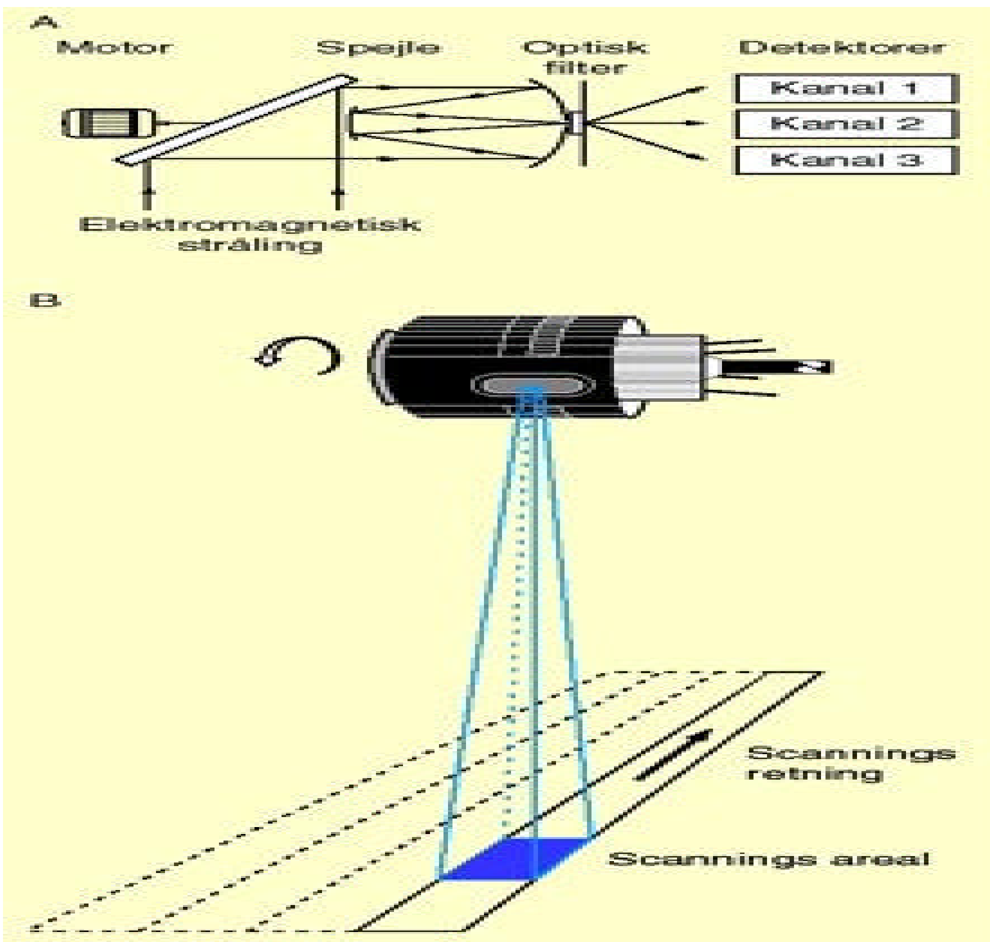


Figure 2.1: Satellite with multispectral scanner. Radiation from the scan area on the ground passes through the detectors that measure it in different channels (http://jointmission.gsfc.nasa.gov/documents/pdf/CERESUIID12-1702a.pdf)

satellite with a multispectral scanner that measures radiation from the Earth's surface in different channels.

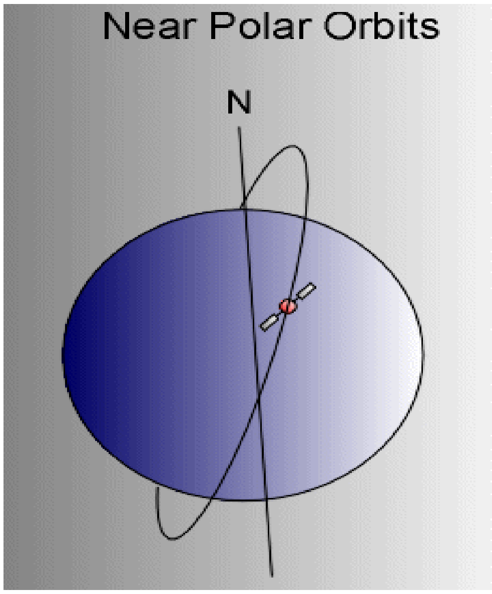


Figure 2.2a: A satellite orbiting around the earth.
(http://jointmission.gsfc.nasa.gov/documents/pdf/CERESUIID12-17-02a.pdf)

Figure 22b: Indian Remote Sensing satellites orbiting the earth.
(http://www.csre.iitb.ac.in/isro/irs-1d.html)

LANDSATS 1, 2 and 3 operated in a near-polar orbit at an altitude of 920 km with an 18-day repeat coverage cycle. These satellites circled the Earth every 103 minutes, completing 14 orbits a day (Figure 2.2a and 2.2b). Eighteen days and 251 overlapping orbits were required to provide nearly complete coverage of the Earth's surface with 185 km wide image swaths. The amount of swath overlap or sidelap varies from 14 percent at the Equator to a maximum of approximately 85 percent at Latitude 81° N and S. The MSS sensor scanned the Earth's surface from west to east as the satellite moved in its descending (north-to-south) orbit over the sunlit side of the Earth. The resolution of the MSS sensor was approximately 80 m with radiometric coverage in four spectral bands from the visible green to the near-infrared (IR) wavelengths. Only the MSS sensor on LANDSAT 3 had a fifth band in the thermal-IR wavelength (Handbook, 1979 and 1984, USGS). Temporal coverage information on the satellites is shown in Table 2.2.

LANDSATS 4 and 5 carry both the MSS and the TM sensors. However, routine collection of MSS data was terminated in late 1992. The MSS sensors flown aboard LANDSATS 4 and 5 are identical to the ones that were carried on LANDSATs 1 and 2. LANDSATS 4 and 5 orbit at an altitude of 705 km and provide a 16-day, 233-orbit cycle with a swath overlap that varies from 7 percent at the Equator to nearly 84 percent at Latitude 81° N and S. These satellites were also designed to collect data over a 185-km swath. The MSS and TM sensors primarily detect reflected radiation from the Earth's surface in the visible and near infra-red (NIR) wavelengths, but the TM sensorprovides more radiometric information than the MSS sensor. The wavelength range for the TM sensor is from the visible (blue), through the mid-IR, into the thermal-IR portion of the electromagnetic spectrum. The TM sensor has a spatial resolution of 30 meters for the visible, near-IR, and mid-IR wavelengths and a spatial resolution of 120 meters for the thermal-IR band (Handbook, 1979 and 1984, USGS).

All of the LANDSATs have been in sun-synchronous orbits (Figure 2.2a and 2.2b) with equatorial crossing times of 8:30 a.m. for LANDSAT 1, 9 a.m. for LANDSAT 2 and 9:45 a.m. for LANDSAT 5. The LANDSAT platforms operate from a sun-synchronous, near-polar orbit imaging the same 185 km (115 miles) ground swath every 16 days (formerly 18 days on LANDSATs 1 through 3) (Handbook, 1979, 984, USGS).

2.1.2 Mapping capabilities of MSS and TM data

The characteristics of the MSS and TM bands were designed to maximize the band's capabilities for detecting and monitoring different types of Earth resources (Table 2.3).

Table 2.3: Capabilities of MSS bands for detecting and monitoring earth resources (created from ERDAS, 1999)

MSS Band	Capability
1	Can be used to detect green reflectance from healthy vegetation
2	Is designed for detecting chlorophyll absorption in vegetation
3 and 4	Is ideal for recording near-IR reflectance peaks in healthy green vegetation and for detecting water-land interfaces

For example, MSS band 1 can be used to detect green reflectance from healthy vegetation, while MSS band 2 is designed for detecting chlorophyll absorption in vegetation. MSS bands 3 and 4 are ideal for recording near-IR reflectance peaks in healthy green vegetation and for detecting water-land interfaces (Handbook, 1979 and 1984, USGS).

MSS Bands 4, 2, and 1 (RGB) can be combined to make false-color composite images, where band 4 controls the amount of red (R), band 2 the amount of green (G), and band 1 the amount of blue (B) in the composite. This band combination makes vegetation appear as shades of red with brighter reds indicating more vigorously growing vegetation (A in Figure 2.3). Soils with no or sparse vegetation will range from

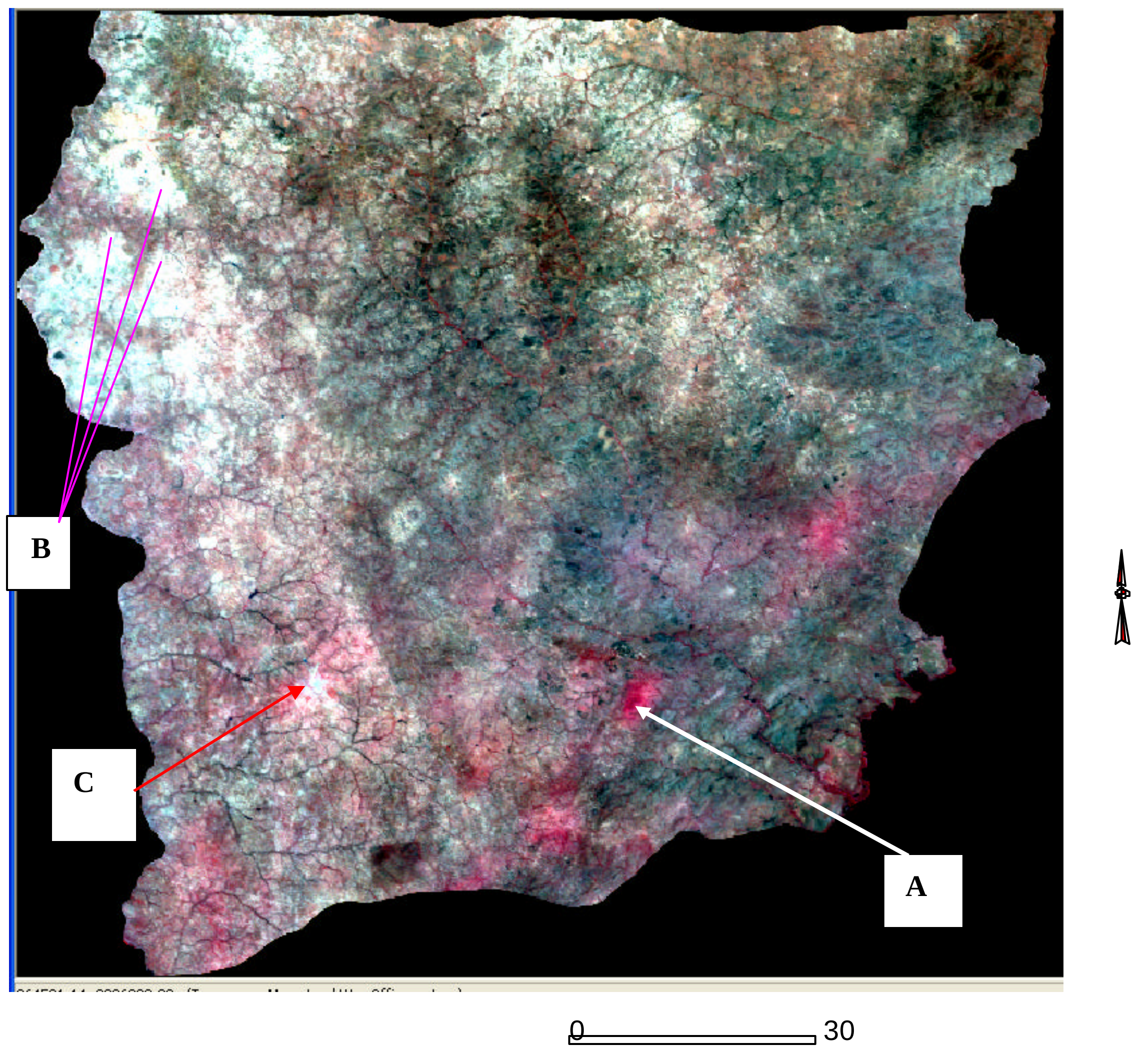


Figure 2.3: Landsat 7 image of the Upper West Region displayed with a 4,3,2 (RGB) band combination

white (sands) to shades of green or brown (B in Figure 2.3), depending on moisture and organic matter content. Water bodies appear blue. Deep, clear water appears dark blue to black in color, while sediment-laden or shallow waters appear lighter in color. Urban areas appear blue-grey in color (C in Figure 2.3). Clouds and snow appear as bright white, and they are usually distinguishable from each other by the shadows associated with the clouds (Handbook, 1979 and 1984, USGS).

MSS scenes from LANDSATs 4 and 5 have an instantaneous field of view (IFOV) of 68 meters in the cross-track direction by 82 meters in the along-track direction (223 by 272.3 feet, respectively). LANDSATs 1, 2 and 3 provided Earth coverage similar to LANDSATs 4 and 5. However, the higher altitude of LANDSATs 1, 2 and 3 resulted in a different swathing pattern, with the IFOV being 56 meters in the cross-track direction by 79 meters in the along-track direction (183.7 feet by 259.2 feet, respectively) (Handbook, 1979 and 1984, USGS).

2.1.3 Spatial and temporal resolutions (LANDSATs 1-5)

The radiometric range and spatial resolutions of bands for the MSS sensor is shown in Table 2.4 (Handbook, 1979 and 1984, USGS).

Table 2.4: Spatial, radiometric and altitude characteristics of LANDSAT 1-5 (Created from Handbook, USGS, 1979, 1984)

LANDSAT		Wavelength (µm)	Resolution (m)		Nominal altitude	
1-3	**4-5**					
Bands			LANDSAT			
			1-3	**4-5**	**1-3**	**4-5**
Band 4	Band 1	0.5 - 0.6	79	82	920 km	705 km
Band 5	Band 2	0.6 - 0.7	79	82		
Band 6	Band 3	0.7 - 0.8	79	82		
Band 7	Band 4	0.8 - 1.1	79	82		
*Band 8		10.4 - 12.6	237			

** LANDSAT 3 only*

2.1.4 LANDSAT 5 Thematic Mapper (TM)

The LANDSAT TM is a multispectral scanning system and records reflected/emitted electromagnetic energy in the visible, reflective-infrared, middle-infrared and thermal-infrared regions of the spectrum. It has a radiometric resolution of 8 bits, a spatial resolution of 28.5 x 28.5 meters for all the bands except band 6, which has a spatial resolution of 120 m, but this is re-sampled to 28.5 x 28.5m to match the other bands (ERDAS, 1999). It is generally useful for the study of vegetation type/health, soil moisture, discrimination between rock types and between snow and clouds (Table 2.5). Bands 1, 2 and 3 are in the visible portion of the electromagnetic spectrum and

Table 2.5: LANDSAT image spectral bands and their importance (created from ERDAS, 1999)

Band #	Colour		Range (μm)	Some important uses
1	Blue	Visible	0.45– 0.52	Useful for differentiating between soil and vegetation, mapping coastal water areas, forest type and detecting cultural features.
2	Green	Visible	0.52– 0.60	Corresponds to the green reflectance of healthy vegetation. Useful for identifying cultural features.
3	Red	Visible	0.63– 0.69	Useful for discriminating between plant species and mapping of soil, geological and cultural features.
4	Reflective Infrared		0.76 –0.90	Responsive to amount of vegetation biomass. Useful for crop identification and emphasizes soil/crop and land water contrasts.
5	Mid Infrared		1.55– 1.75	Sensitive to the amount of water in plants, hence useful for crop drought studies and plant health analyses. Also used to discriminate clouds, snow and ice.
7	Mid-infrared		2.08– 2.35	Important for discriminating geologic rock types, soil mapping, and soil and vegetation moisture content.
6	Thermal-infrared		8.50– 13.0	Useful for detecting vegetation and crop stress, heat intensity, insecticide applications and for locating thermal pollution and geothermal activity.

are useful for detecting cultural features such as roads. They also show details of water. Bands 4, 5 and 7 are in the reflective-infrared portion of the spectrum and can be used in discriminating between land and water. Band 6 is in the thermal portion of the spectrum and is used for thermal mapping (Jensen, 1996; Lillesand and Kiefer, 1994 and ERDAS, 1999).

2.1.5 LANDSAT 7

This satellite was launched in 1999 and uses Enhanced Thematic Mapper Plus (ETM+) to observe the Earth. The capabilities new to LANDSAT 7 include: (i) an additional band, which is panchromatic and has a spatial resolution of 15m and (ii) a 60m spatial resolution thermal infrared channel. LANDSAT 7 has a swath width of 185 km. The repeat coverage interval is 16 days (NASA, 1998). The spectral bands and their respective resolutions are listed in Table 2.6.

Table 2.6: LANDSAT 7 image characteristics (derived from ERDAS, 1999)

Band		Range (µm)	Ground resolution (m)
Number	Colour		
1 2	Blue Green	0.45 – 0.515 0.525 – 0.605	30 30
3	Red	0.63 – 0.690	30
4	Reflective infrared	0.75 – 0.90	30
5	Mid-infrared	1.55 – 1.75	30
6	Thermal-infrared	10.40 – 12.50	60
7	Mid-infrared	2.09 –2.35	30
Panchromatic		0.52 to 0.90	15

2.1.6 Seasonality of images

For images with low temporal resolution, it is important to choose those that enhance the discrimination between the various land use and land cover features. The spectral response or landscape appearance does vary from season to season and a variation in the regional growing cycle could also have a considerable effect on the classification accuracy of both agricultural and semi-natural cover features (Wright and Morrice, 1997). Images of the same time of year minimize differences in reflectance of same features caused by seasonal changes (Yang and Prince, 2000). Ideally, field data should be collected at the same date when the satellite data were acquired (Yang and Prince, 2000). However, this is usually not possible in most studies.

Munyati (2000) used dry season images to map wetlands in Zambia and reported that the seasonality of images has the advantage of enhancing the distinction between the various vegetation classes. He also observed that dry season images have the following advantages:

- Change detection errors arising from seasonal differences (vegetation phenology or cycle) can be minimized by using near-anniversary (dry season) images.

- Change detection errors arising from sensor differences can be partly minimized by holding the sensor system (LANDSAT) and season constant, although other imaging systems, like SPOT, can be used.

However, dry season images do not permit the observation of certain features of the landscape such growing crops, green vegetation in all locations and certain water bodies.

2.1.7 Band combinations for displaying TM data

Images can be displayed in black and white (monochrome or one band) or in colour (multiband, which is a combination of three colours called colour composites) (ERDAS, 1999). Colour composites can be true or false. In a true colour composite, objects look as they would to the naked eye – similar to colour photograph from high altitude aircraft (ERDAS, 1999). False colour composites appear similar to an infrared photograph where objects do not have the same colours or contrasts as they would naturally. For instance, in an infrared image, vegetation appears red; water appears navy blue or black, etc. (ERDAS, 1999). A pseudo-colour composite (e.g., a thematic image) does not reflect the features in natural colours. For instance, roads may be red, water yellow and vegetation blue (ERDAS, 1999). ERDAS (1999) gives examples of band combinations to show three types of colour composites that are commonly used (Table 2.7).

False colour composites (FCCs) of various types are in use (Prakash and Gupta, 1998 and ERDAS, 1999). Three of them that are of special interest are *(*a) standard FCC (bands 4,3 and 2 (RGB); (b) FCC of TM bands 5, 4 and 2 (RGB); *(*c) FCC of TM bands 7, 5 and 3 (RGB) (Prakash and Gupta, 1998). It has been found that LANDSAT TM false colour composites of bands 4, 3 and 2; bands 7, 5 and 3; bands 5, 4 and 2, and ratio images provide very useful information for land-use mapping (Prakash and Gupta, 1998). A false colour composite of 5, 4 and 2 (RGB) is particularly suitable for discriminating burnt areas and coal bodies from water bodies (Table 2.7). Trotter (1998) used bands 4, 3, 2 (RGB) and 5, 4, 3 (RGB) for supervised classification by the maximum likelihood decision rule. Combination of bands 4, 3 and 2 (RGB) is the standard technique of visual interpretation for forest mapping in the tropics

(Trotter, 1998). Despite these observations, the band combination to use often varies with the particular application (Trotter, 1998).

Table 2.7: False composites used in land use and land cover mapping and their usefulness (Prakash and Gupta, 1998)

FCC (TM)	Uses
4,3,2 (RGB) (standard)	(1) Vegetated areas appear in shades of red and sparsely vegetated areas in faint red. (2) Water bodies and burnt areas appear black and are indistinguishable from each other. (3) Transport network also appears black. (4) Bare land and wastelands appear in shades of dirty white and grey. (5) Surface settlements appear in shades of grey (bluish-grey, steel grey etc.) and show typical checkered pattern associated with built-up areas.
5,4,2 (RGB)	(1) Vegetation appears in shades of green and yellow. (2) Burnt areas appear brown to brownish-black. (3) Water bodies appear in deep blue to bluish-black shades. (4) Bare land appears greyish-pink and settlements in shades of blue. (5) Transport network, drainage pattern and lineaments are also distinct.
7,5,3 (RGB)	(1) Vegetation appears in shades of green. (2) Dense vegetation shows relatively darker shades of green, but distinguishing the classes of vegetation is rather difficult.

2.2 Classification scheme

There is an increasing need to be able to precisely describe and classify land use and land cover in order to define sustainable land use systems that are best suited for a given place (FAO, 1998). Usually, such a classification is performed with a set of target classes in mind, which is called a classification scheme or system (Anderson *et al.*, 1976; FAO, 1998; ERDAS, 1998 and Dai and Khorram, 1998). The purpose of such a scheme is to provide a framework for organizing and categorizing the information that can be extracted from the data, e.g., satellite imagery (ERDAS, 1998). Therefore, a land cover classification system or scheme (LCCS) can be defined as a comprehensive framework for the description, characterization, classification and comparison of any land cover identified at any scale anywhere in the world (FAO, 1998). Land cover classification systems or schemes are needed because of the requirement for a harmonized and standardized collection and correlation or comparison of land use and land cover data for a wide range of applications and users (FAO, 1998). The relevant classification scheme will include classes that are both important to the study and discernible from the image data available.

A classification system should be applicable to the classification of data from both conventional sources and remote sensors on high-altitude aircraft and satellite platforms. According to Dai and Khorram (1998), such a scheme must take care of all the representative land use and land cover categories of the area, since each class has its own management challenges, as well as different impacts on global phenomena. The various categories or classes of land use or land cover influence the carbon, nutrient and water cycles as well as biodiversity, which controls the products and services of vegetation (Thenkabail, 1999).

A land use and land cover classification scheme should also have a hierarchical framework into which the categories of more detailed land use and land cover could be fitted and aggregated in order to describe a study area at several levels of detail, e.g., from Level IV (most detailed) toward Level I (least detailed) (Tables 2.8 and 2.9) (ERDAS, 1998; Dai and Khorram 1998 and FAO, 1998). There is no one ideal classification scheme for land use and land cover mapping, and it is unlikely that one will ever be developed. It is therefore important that classification schemes meet the classification purposes (Anderson *et al.*, 1976), e.g., mapping for hydrological modelling. Thus, there is no global land use and land cover classification scheme. For example, classification schemes such as those of IGBP, FAO and USGS are not applicable to the detailed classification at certain local levels in Ghana. As a result many classification systems and innumerable map legends exist. This leads to maps and statistics from different countries, and even from the same country, being incompatible with each other (FAO, 1998). In Ghana, the Remote Sensing Applications Unit (now Centre for Remote Sensing and Geographic Information Services) has developed the *Ghana Land Use and Land Cover Classification Scheme for Visual Classification of Remotely Sensed Data* (Agyepong *et al.*, 1996) (Appendix 9.2). The savannah agricultural land and other savannah categories of this scheme are shown in Tables 2.8 and 2.9 respectively.

Table 2.8: Savannah agricultural land categories of the Ghana land use and land cover classification scheme (Agyepong *et al.,* 1996)

LEVEL I	LEVEL II	LEVEL III	LEVEL IV
1000 Agric. land	1300 Grass/herb fallow & crop cover (<10 trees/ha)	1310 Mixed bush fallow cropping (short fallow)	1311 Mixed arable crops
			1212 Mixed arable and tree crops
			1313 Vegetable crops
		1320 Mixed bush fallow cropping (LF)	1321 Mixed arable cropping
		1330 Compound farming	1331 Mixed arable
	1700 Mixture of closed savannah woodland and crop cover (>150 trees/ha)	1710 Mixed bush fallow cropping (SF)	1711 Mixed arable crops
		1720 Mixed bush fallow cropping (LF)	1721 Mixed arable crops
	1800 Mixture of closed savannah woodland and crop cover (75-150 trees/ha)	1810 Mixed bush fallow cropping (SF)	1811 Mixed arable crops
		1820 Mixed bush fallow cropping (LF)	1821 Mixed arable crops
	1900 Mixture of closed savannah woodland and crop cover (10-75) trees/ha)	1911 Mixed bush fallow cropping (SF)	1911 Mixed arable crops
		1920 Mixed bush fallow cropping (LF)	1921 Mixed arable crops

Table 2.9: Savannah land categories of the Ghana land use and land cover classification scheme (Agyepong *et al*., 1996)

LEVEL I	LEVEL II	LEVEL III	LEVEL IV
3000 Savannah	3100 Closed savannah woodland (>150 trees /Ha)	3110 Reserved closed savannah woodland	3110 Reserved closed savannah woodland
		3120 Open-access closed savannah woodland (+/- farms/grazing)	3121 Livestock
			3122 Gathering
	3200 Open savannah woodland (<150 trees/ha)	3210 Reserved open savannah woodland (+/- farms/grazing)	3211 Conservation
			3212 Wildlife
			3213 Gathering
		3220 Open-access open savannah woodland (+/- farms/grazing)	3221 Livestock
			3222 Gathering
	3300 Grassland +/- scattered trees (<10/ha)	3310 Reserved grassland (+/-farms/grazing)	3311 Conservation
			3312 Gathering
	3400 Riverine vegetation	3410 Riverine vegetation (+/-farms/grazing)	3411 Conservation
			3412 Livestock
			3413 Gathering

The *Ghana Land Use and Land Cover Classification Scheme for Visual Classification of Remotely Sensed Data* (Agyepong *et al.*, 1996) was derived from the *USGS Land Use and Land Cover Classification System* (Anderson *et al.*, 1976). Like that of Anderson *et al*. (1976), it is a four-level hierarchical classification system that is applicable to all the ecological zones of the country. The details of the levels are given as follows:

Level I

Level I depicts primary vegetation and other cover categories, e.g., forests, savannah, non-biotic constructed surfaces and water bodies. An agricultural land cover class has been recognized at Level I on the basis of its spatial dominance in the landscape, its unique ecology and economic significance. The agricultural cover class comprises the complex mixture of crops, fallow regrowth and remnant elements of the primary cover.

Level II

This level indicates the vegetation and other sub-categories of Level I on the basis of the type of agricultural conversion and modification they have undergone, the presence, quantity and distribution of the elements of the primary cover such as canopy, tree and shrub density on the basis of the management system such as forestry. Specific information can be extracted at this level for specific applications. For example, the various types of forest and their respective sizes can easily be analysed for planning purposes.

Level III

Level III classifies land use in terms of general utilization and/or management systems, such as plantation cropping, mono-cropping, irrigation cropping, mixed bush fallow cropping, etc. A large number of classes is identified at this level.

Level IV

Level IV classes are land use categories defined in terms of products and services, e.g., cocoa, pineapple, mixed food crops, traditional grove, conservation, etc. The number of features to classify is extremely large. They are most easily understood in association with the corresponding level III classes.

2.3 Geometric correction of images

Raw remotely-sensed images, taken from imaging sensors, cannot be considered as maps of the radiometric properties of the Earth's surface, because of the geometric distortions and flaws or deficiencies they contain and because they do not have projections (Lillesand and Kiefer, 1994, Sunar and Kaya, 1997, Mather, 1993). The distortions need to be corrected and the flaws or deficiencies removed in order to create a more faithful representation of the scene (Lillesand and Kiefer, 1994). This is important because the spatial, spectral, radiometric and temporal attributes of remotely sensed data affect the type and quality of information that are extracted from them (Phinn, 1998).

The distortions and degradation of remotely sensed images are unsystematic errors in the geometry and measured brightness values of pixels. Image geometry errors can arise, for example, from the curvature of the earth's surface, uncontrolled variations in the position and attitude of the platform, and sensor anomalies (Richards, 1995). Some corrections are made at the receiving stations, but there may still be the need for further pre-processing. The transformation (removal of geometric distortions and reconstruction) of a remotely sensed image so that it has the scale and projection properties of a map is called geometric correction. A related technique, called registration, is the fitting of the coordinate system of one image to that of a second image of the same area, e.g., multitemporal images of the same area. This is important because quite often, remotely sensed data and information derived from them are used in association with other data sets such as roads and settlements within the context of a geographical information system (GIS) (Mather, 1993 and Roy, 1997).

Different application purposes require different methods and different levels of geometric precision (Bingfang and Haiyan, 1997). Therefore, the types of rectification that the raw image should be subjected to will largely depend on the application in question (Lillesand and Kiefer, 1994; Chavez, 1986). This means that the decision as to what should be considered a deficiency and what is not a deficiency in a particular data depends on the use to which it is to be put (Mather, 1993). However, in nearly all applications, high precision geometric correction is desirable (Bingfang Wu and Haiyan Liu, 1997). Hence, satellite data are often geometrically and radiometrically corrected prior to their use (Sunar and Kaya, 1997). The corrections become more relevant when the data are to be used for quantitative vegetation change studies. Rectification and radiometric correction are needed to ensure a precise spatial and temporal inter-scene comparison (Owen *et al.,* 1998). For example, Yang and Prince (2000) carried out geometric registration between MSS scenes and performed atmospheric rectification on them to adjust for differences in atmospheric composition, sun angle and sensor gain prior to their vegetation change detection studies. Applications involving land cover mapping, image mosaicking, and multi-temporal studies often require geometrically correct images.

2.3.1 Satellite type and magnitude of distortion

According to Bingfang and Haiyan (1997), pixel distortion for high spatial resolution satellite data like those from MSS, TM and SPOT, etc., is rather small owing to the relatively stable satellite orbits and small scan angle (<6°). Therefore, pixels of the image scene of such satellites can be treated as regular. Accurate geometric correction of such data can be performed using the method of polynomial transformation through the selection of ground control points (Bingfang and Haiyan, 1997). Exact pixel-to-pixel agreement is not mandatory when the image is to be used for a classification that concerns general patterns only (Weishampel *et al.*, 1998). For relatively flat study areas, correction for sun-angle or atmosphere correction may not be necessary (Todd *et al.*, 1998).

2.3.2 Geometric correction techniques

Parametric and non-parametric methods (Roy *et al.*, 1997) can be used to correct the various types of geometric distortions present in digital image data (Sunar and Kaya, 1997). The parametric method involves the modelling of the nature and magnitude of the sources of \`systematic' or \`predictable' distortions, such as those caused by the rotation of the earth, and using these models to establish a correction formula. It requires information concerning the sensing geometry and the sensor exterior orientation parameters (attitude and position), which describe the circumstances that produced the image (Roy *et al.*, 1997).

The non-parametric method requires the identification of features common to the remotely sensed image and a map, or another image of the same area that has already been geocorrected. Conventionally, distinct point-like features, termed ground control points (GCPs), are used. Confluences of deep narrow channels can be used as GCPs for registration in a semi-arid area in West Africa (Turner and Congalton, 1998). The spatial relationships between corresponding GCPs are assumed to be representative of the image distortion and are therefore used to calculate mapping functions between the image and the map (or image). This is done by establishing a mathematical relationship between the locations of pixels in an image and the corresponding co-ordinates of those points on the ground (via a map or another image) for 'random distortions' and 'residual unknown systematic distortions'. It involves the performance of a coordinate transformation by the application of a least-squares regression analysis to the set of GCPs and then determining the coefficients of the transformation matrix for linear or non-linear transformations. After calculating the transformation coefficients, various *resampling* methods (nearest neighbour, bilinear, or cubic convolution) are used to determine the pixel values to fill into the corrected output image file from the original distorted image file (Lillesand and Kiefer, 1994). This is to maintain the radiometric values of the pixels (ERDAS, 1999).

The non-parametric method is said to be capable of correcting all geometric deficiencies of an image. However, its dependence upon the collection of GCPs is a key problem, because it is labour-intensive and may not be feasible because of factors such as poor map accuracy or homogeneous or unstructured scene content (e.g., ocean or jungle), or because of the low spatial bandwidth of the sensor (e.g., spectrometers) (Roy *et al.,* 1997).

To compare the multi-temporal data acquired by the same sensor, an image to image registration is preferred (Prakash and Gupta, 1998). As images from the same sensors have similar geometry, the transformation (registration) is carried out with minimal changes in the original image. Registration brings all data to the same scale and geometry (Prakash and Gupta, 1998). Misregistration has effects on image differencing, especially for multi-temporal data sets of regions that are spatially heterogeneous (Townshend and Justice, 1992).

2.3.3 Accuracy of spatial registration

The accuracy of geometric co-registration of multi-temporal data sets is a critical requirement for their analysis for change detection (Richards 1995). Therefore, accurate spatial registration has become the most critical image-processing requirement for reliable assessment of land cover changes at various spatial scales, especially at the pixel level. Su (2000) observed that the success of change detection may be dependent on the precision of the relative alignment between images that compose a multi-temporal data set. According to Prakash and Gupta (1998), two images must be registered within an accuracy of one pixel or less (i.e., RMS error of one or less), since registration errors could potentially be interpreted as land cover change. This is particularly important for achieving subpixel level accuracy (Prakash and Gupta, 1998).

Dai and Khorram (1997) showed that highly accurate change detection studies based on multi-temporal LANDSAT Thematic Mapper (TM) images require that the magnitude of misregistration be less than 0.2 pixel. However, Bingfang and Haiyan (1997) have suggested a half-pixel accuracy in general, except for some extreme cases, i.e., huge relief displacement, when such accuracy may not be attained through a polynomial transformation. Turner and Congalton (1998) linearly transformed images and used the nearest-neighbour resampling algorithm to avoid the modification of (i.e., to maintain) the radiometric values of the pixels. Sunar and Musaogilu (1998) performed geometric registration of LANDSAT data by the non-parametric method and obtained an accuracy of a root-mean-square error (RMSE) of +/-0.1 of a pixel. Wright and Morrice (1997) also performed a registration of images, using nearest neighbour interpolation for resampling and had a root mean square (rms) value of 0.9. Trotter (1998) had an RMSE of 0.5 pixels, using second-order transformation. Townshend *et al*. (1992) registered MSS scenes to a master image using a third-order polynomial equation and nearest neighbour resampling and obtained an RMSE of 0.73 pixel (about 4m on the ground).

2.4 Atmospheric correction of images

Remote sensing of the Earth's surface requires the correction of atmospheric effects (Schmidt and Gitelson, 2000) or contamination (Roy, 1997). This is commonly referred to as atmospheric correction, which is a broad term that covers one or more of several processes designed to bring multi-date image scenes at par so that a direct comparison of the grey values gives an indication of an actual or 'true' change (Jensen 1986 and Prakash and Gupta, 1998). In practice, images acquired on different dates 'appear' different due to several reasons, the main ones being variations in reflectance due to different sun elevation angles, changes in atmospheric conditions, variation in gain setting of various sensors and land cover changes. Thus, a topographic effect on the radiance of surface feature is one of the reasons that necessitate this correction, and this has long been recognized as an important component of radiometric correction for optical imagery of hill-country and mountainous areas (Trotter, 1998). The red channel is the most sensitive to the effects of molecular absorption and aerosol scattering, whereas the near-infra red (NIR) channel is sensitive mainly to water vapour absorption. These create radiometric differences between multi-temporal images of a given scene. Therefore, the images need to be atmospherically corrected to ensure that the radiometric differences are due only to the land cover change (Su, 2000).

However, although many authors apply atmospheric corrections as a matter of course, they are really only essential for the comparison of results obtained from different image types (De Wulf *et al.*, 1990). According to Wright and Morrice (1997), radiometric correction may not be necessary when no direct multi-temporal spectral comparisons are to be made prior to image processing. However, for studies involving NDVI, a simple radiometric correction of the image scene is necessary and may be performed simply by referencing one image or images to another, using the darkest pixel method discussed by Chavez (1988). The effectiveness of radiometric correction over large areas is limited by the unavailability of data that quantify the absorbing and scattering of atmospheric constituents (Roy, 1997).

Prakash and Gupta (1998) observed that for multi-temporal LANDSAT TM data of monotonously flat areas, where the relative variation in solar elevation angle is not significant (e.g., in the equatorial regions), and when the images belong to the same season (e.g., dry season), the atmospheric, phenological and seasonal factors can be assumed to be quite comparable.

2.5 Field campaign

An effective interpretation of images, using supervised procedures, requires *a priori* knowledge of the scene (Sunar, 1998). This knowledge can be derived with help from sources such as aerial photographs, ground truth data, GPS points or topographic maps. All these help the analyst to select distinct pixels that represent identifiable features of the categories of the landscape. These pixels become the training samples. Field data collection during field campaigns (ground truthing) has the advantage of first-hand observation and acquisition of accurate locational data. It requires clear recording (e.g., on ground-truth forms) to facilitate subsequent digital analyses and the use of imagery in the field to reconcile features on the ground with spectral responses. It also provides the opportunity to contact local expertise, farmers and other land users (Campbell and Browder, 1995).

2.6 Image stratification

Image stratification is a pre-classification process, which divides the scene to be classified into a number of smaller sub-scenes or strata. This procedure is used for images, especially those of the tropics, which are difficult to classify by signature extension (Novo and Shimabukuro, 1997). The discrimination of vegetation types in the tropics by the use of remote sensing techniques is a very difficult task, even with the use of air photography (Trotter, 1998). This is because of the diverse and complex structure and composition of vegetation communities (variety of vegetation species). In many cases, land cover units are too small to be detected by LANDSAT TM (Trotter (1998). In areas where peasant agriculture is practiced, individual fields can be small, with most of them measuring less than one hectare (Nyanteng *et al.*, 1986). Such small fields are often spectrally heterogeneous and scattered in distribution. Within certain farming systems, vegetative cover within and outside fields is low, increasing the confounding influence of background soil (Ezra *et al.*, 1984, Huete and Tucker, 1991). Furthermore, the short growing season in semi-arid and arid areas leads to a necessarily high correlation in the spectral trajectories of cultivated and uncultivated areas (Turner and

Congalton, 1998). Certain agronomic management practices such as localized flood control, ploughing and harvesting of different crops at different periods may produce distinctive cropped signatures during the cropping season (Turner and Congalton, 1998).

Digital classifications are mostly performed using algorithms based on statistical procedures such as the ones commonly used in unsupervised and supervised techniques (Jensen 1996 and ERDAS 1999). Such a conventional digital analysis of remotely sensed data is limited, because it takes into account only the spectral variation of the scene, missing the potentially important contextual information of the objects (Shimabukuro *et al.*, 1998). The result is that in areas where there are different land use and land cover classes with very similar or overlapping signatures, conventional supervised classification has its limitations (Prakash and Gupta, 1998) due to the complexity of the vegetation and land use. This makes the mapping of tropical areas based on spectral characteristics alone extremely confusing (Trotter, 1998).

Some of these problems, especially at large scales, are caused by autocorrelation (Mather, 1993). Considered generally, spatial autocorrelation arises when the value of a variable *x* recorded at a location is related to values of the same variable at nearby locations (Wulder and Boots, 1998). Radiation, as reflected from a heterogeneous field of view on the ground, can be considered as the result of the mixing of a number of spectrally pure materials (Van der Meer, 1998). This is a significant, but usually ignored, problem with per-pixel characterization of land cover. A substantial proportion of the signal apparently coming from the land surface represented by a pixel comes from the surrounding pixels (Townshend, 1981). This is a consequence of many factors including the optics of the instrument (detector and electronics), as well as atmospheric effects (Townshend *et al.,* 2000). This creates difficulties in the characterization of land use land cover based solely on the spectral response of individual pixels. It implies that land cover properties should be reported at spatial resolutions coarser than the individual pixels or that the signal from individual pixels should be deconvolved. An alternative is to use contextual procedures in which observations from surrounding pixels are used to assist the characterization (Townshend *et al.,* 2000).

Another problem encountered when using TM for mapping large areas is that of signature extension from one scene to another, from one acquisition date to another and from one image path to another. The spectral characteristics of vegetation types do vary over distance and as variance increases, the likelihood of confusion between spectrally similar objects also increases (Kloer, 1994). Furthermore, significant variations in soil colour due to differences in soil moisture, soil organic matter and mineralogy across a given landscape influence classification of image data (Bertrand, 1974). The problem of two or more land use or land cover types having high potential for being misclassified is common. For example, recently burned areas (less than three months old) and the exposed muddy bottoms of floodplain basins or channels, which are ubiquitously trampled by cattle, can be misclassified (Turner and Congalton, 1998). Such variations may complicate the determination of spectral responses or signatures associated with a particular land use or land cover category.

All these attributes of the landscape call for alternative approaches to classify and label land use and land cover classes correctly (Thenkabail, 1999). Such an approach must be simple, intuitive (e.g., expert-system-oriented) and intelligent and involve visual interpretations and more sophisticated automated unsupervised and/ or supervised classification techniques (Haack and Jampoler, 1995 in Thenkabail, 1999).

Stratification of images prior to classification is a key to increasing the discrimination of land cover and land use classes (Thenkabail, 1999). The essence of stratification is to utilize a series of steps that progressively divide the image scene into strata, thereby reducing the heterogeneity of an image in such a way as to improve its interpretation and comparison with training data (Sannier *et al.* 1998 and Kloer, 1994). Another reason is the practical convenience of dealing with smaller subsets of the full image scene (Kloer, 1994).

The subsetting of the images into a number of relatively homogenous discrete subunits (subsets or strata) is based on extensive ground-truth data and field knowledge of the study area, topographic and geological information and image interpretation techniques (Sannier *et al.,*. 1998). Each stratum of the image is then classified separately (Thenkabail, 1999). Finally, all the component subsets are mosaicked to constitute a single whole (Thenkabail, 1999). This piecemeal approach improves the distinguishing and identification of the spectral classes, and therefore leads to the mapping of an increased number of classes with increased classification accuracies (Thenkabail, 1999).

The stratification approach has been adopted by workers such as Turner and Congalton (1998), who stratified LANDSAT TM images prior to classification and achieved a-71% classification accuracy of ploughed fields. Where confusion still remains, further subsets can be delineated (Harris and Ventura (1995). Furthermore, the problem classes can be masked and post-classification procedures adopted to improve classification accuracies (Thenkabail, 1999). According to Rodriâguez *et al.*, (2000), image stratification and supervised classification by regions, with consideration of the spectral and spatial characteristics of the image data, is useful in discriminating different vegetation types on a regional scale. By image stratification, they performed unsupervised classification of land use and land cover of a region, using LANDSAT Thematic Mapper (TM) data to assess land use and land cover change (Alves *et al.*, 1996 and Shimabukuro *et al.* 1998). Thenkabail (1999) also used stratification and achieved an overall mapping accuracy of 82.4% with the individual classes; user's accuracy was more than 72.9%, and producer's above 66.7% (Thenkabail, 1999).

2.7 Digital classification

Digital (spectrally-oriented) classification forms the backbone of most classification activities. For vegetation mapping, it has been found to give better results than visual classification, because it allows a more detailed interpretation of smaller and complex mapping units. In the visual technique, mapping units are generalized (Viovy, 2000). The overall objective of image classification procedures is to automatically categorize all pixels in an image into classes or themes based on the spectral pattern or signature of the surface materials belonging to each class or theme (Lillesand and Kiefer, 1994). Mather (1993) describes the digital classification process as the identification of the pattern associated with each pixel position in an image in terms of the characteristics of the objects or materials at the corresponding point on the Earth's surface.

There are many digital classification procedures, but there is not a single "right" one that deals with image classification problems. The particular approach one might use depends on the nature of the data being classified, the computational resources available, and the intended application of the classified data (Lillesand and

Kiefer, 1994). Digital classification is divided into unsupervised and supervised procedures, based on whether the analyst specifies training data or not.

2.7.1 Unsupervised classification

Unsupervised classification is a method of clustering. It is self-organizing in that the image data are first classified by being aggregated into the natural spectral groupings or clusters present in the scene. It enables the user to specify parameters that the computer uses to determine statistical patterns inherent in the data. These patterns do not necessarily correspond directly to meaningful characteristics of the scene, such as contiguous, easily recognizable areas of a particular soil type or land use. They are simply clusters of pixels having similar spectral characteristics (ERDAS, 1999).

ISODATA clustering uses a minimum spectral distance algorithm to assign a cluster for each candidate pixel (ERDAS, 1999). The procedure begins with a specified number of cluster means, and then it processes the image data repetitively, assigning each of the pixels to one of these class means. After each iteration, the initial cluster means shift to represent the new statistical means of the clusters in the data. This happens until there is no significant change of cluster means. Then the image analyst determines the land cover identity of these spectral groups by comparing the classified image data to the ground reference data (Mather, 1993; Lillesand and Kiefer, 1994; ERDAS, 1999 and (Wright and Morrice, 1997).

Results of unsupervised classification are useful only if the classes can be correctly interpreted. The unsupervised classification technique is usually used when little is known about the data before classification (ERDAS, 1999). It helps to overcome the problem of the requirement of a normal distribution of pixel values needed for supervised maximum likelihood classification.

The unsupervised classification method has two limitations. (i) The number of clusters must be fixed *a priori*, and this makes the classification not really ‘unsupervised’. It supposes that the users know *a priori* the number of distinct groups of points to be found, which is not, generally, the case. The choice of the number of clusters is arbitrary. As a result, if the number of clusters chosen is too small, some clusters will represent several distinct groups of points, whereas if the number of clusters chosen is too high, different clusters will in fact represent only one homogeneous group (Viovy, 2000). (ii) It is very slow and does not work correctly when the number of samples become large, which is typically the case for the classification of remotely sensed data of a large area (Viovy, 2000). In assigning the number of spectral classes into which the image should be classified, it is advantageous to keep it fairly large and use the strength of ground truth data to aggregate the class information (Thenkabail, 1999 and Thomson, 1998).

Trotter (1998) performed an ISODATA unsupervised clustering, using a convergence threshold of 95% and selecting a maximum number of 24 iterations. His preliminary unsupervised classifications produced 50, 80 and 110 spectral classes, which were visually interpreted and compared with reference information (aerial photographs and forest type maps) (Trotter, 1998). Extensive field checking and advice from in-country experts can be used to relate the classes to the real world (Townshend *et al.,* 1995). Unsupervised classification of different vegetated surfaces with similar reflectances did not produce consistent results (Thomson *et al.,* 1998). This was due to significant intermixing of classes, e.g., between secondary and primary forests, and also between secondary forests and old fallows. This did not allow the labelling and merging of a large number of spectral classes to a manageable and meaningful number of information classes. This is a constraint in unsupervised classification and therefore calls for alternative methods (Thenkabail, 1999).

Trotter (1998) observed that unsupervised classification could not discriminate between dry evergreen forest and old secondary growths and these were therefore merged into one class, which was labelled as dry evergreen forest. Similarly, the separation between dry mixed deciduous forests, deciduous dipterocarp forest and scrub or shrub savannah was difficult in all feature sets or band combinations. Hence, they were also combined into a mixed deciduous forest class. Supervised classification of the same data gave a higher overall classification accuracy than the unsupervised classification method (Trotter, 1998). This may be due to the analyst's increased control in defining signatures for the classification decision rule (Joria and Jorgenson 1996). Thomson *et al.*, (1998) also observed that unsupervised classification has serious deficiencies in comparison with supervised maximum likelihood classification, because there is poor differentiation between woodland and other semi-natural vegetation types, between urban and arable, between bare soils and some rough grazing cover types and between water and shaded woodland (Thomson *et al.*, 1998). To eliminate confusion among certain classes, e.g., between bare soil categories and some grazing cover types, an agriculturally suitable and unsuitable soil masking can be used to segment and re-aggregate the classification (Wright and Morrice, 1997).

2.7.2 Supervised classification

Supervised classification is the procedure most often used for quantitative analysis of remotely sensed data (Lillesand and Kiefer, 1994). In this procedure the image analyst supervises the pixel categorization process by specifying, to the computer algorithm, class definitions, or signatures (numerical descriptors) of the various land use and land cover types present in a scene to train the classifier (Lillesand and Kiefer, 1994). To do this, representative sample sites of known cover types, called training areas, are used to compile a numerical "interpretation key" that describes the spectral attributes of each feature type of interest (Lillesand and Kiefer, 1994). During the classification process, the spectral patterns on the image data set are evaluated in the computer, using the pre-defined decision rule to determine the identity of each pixel (Lillesand and Kiefer, 1994). Each pixel in the set is thus compared numerically to each category in the interpretation key and labeled with the name of the category it "looks most like". The algorithms used in supervised classifications are parametric or non-parametric, depending upon whether the decision rule is based on normal distribution of the pixel values or not (Jensen, 1996 and Lillesand and Kiefer, 1994).

2.7.2.1 Parametric classification algorithms

The parametric classification algorithms are based upon statistical parameters (mean and standard deviation) and make assumptions of the probability distribution functions of each class to establish decision boundaries between them. The maximum likelihood classifier, for example, which is a primary algorithm for supervised classification of image data, is parametric because it uses a decision rule based on statistical theory (Swain and Davis, 1978). Minimum distance and Mahalanobis distance algorithms are also parametric approaches. The parametric approach has the benefit of assigning every pixel to a class since the parametric decision space is continuous (Kloer, 1994).

With the parametric technique, the classifier must be trained with class signatures defined by a statistical summary (mean vector and covariance matrix) acquired either by the analyst selecting samples on the image or by an unsupervised clustering algorithm (Kloer, 1994). The maximum likelihood classifier has mathematical limitations because it assumes certain properties of the sample data (Snedecor and Cochran, 1989), e.g., normal distribution of the pixel values. The sample covariance matrix must be invertible, i.e., not singular. A singular covariance matrix may result if the sample is too homogenous in any one band, if the sample size is too small, or if there is a high degree of linear dependence between bands. The classifier also assumes that the distribution of the sample data is normal in all bands, a condition which is sometimes violated for certain classes such as urban, residential, and some types of vegetation (Ince, 1987). The maximum likelihood classifier consists of two steps:

1) ***Estimation of model parameters***, which determines the '*a posteriori*' probability that a given pixel belong to class '*i*', given that the pixel has the feature '*f*'. This probability is calculated using *Bayes' Rule* of conditional probability:

$$p(i|f) = \frac{p(f|i)p(i)}{\sum_j p(f|j)p(j)}$$

Where $p(f|i)$ is the probability of a pixel having feature f, given that it belongs to class i, and $p(i)$ is the probability that class i occurs on the image of interest (also referred to as the '*a priori*' probability).

2) ***Discriminant functions***, which establish the decision rule to classify a pixel. It is usually set to be equal to the '*a posteriori*' probability for optimal results. It is stated as follows: If a pixel satisfies the equation:

$$D_i(f) \geq D_k(f)$$

then, it is assigned to class *i*.

2.7.2.2 Non-parametric classification algorithms

The non-parametric algorithm is not statistically based and thus makes no assumptions about the properties of the data. It is based upon objects (polygons) in feature space. It assigns pixels to classes based on the pixel's position in discretely partitioned feature space. The feature space partitions could be thought of as objects, such as polygons, ellipses, or rectangles, which have been derived from image samples or directly defined by the analyst. Parallelepiped classification is an example of a non-parametric decision rule using parallelepipeds (N-dimensional rectangular objects) (Jensen, 1996). With this method of classification, the decision rule simply determines whether a pixel lies inside or outside a feature space object.

The non-parametric classification method has also limitations. The feature space object-based classifier has the problem of overlap. This problem is most acute for parallelepipeds and polygons. If the non-parametric test results in one unique class, the pixel will be assigned to that class. If it results in zero classes (i.e., if a pixel lies outside the decision boundaries) the “unclassified rule” applies (it is either left unclassified or classified by the parametric rule). It is possible for a pixel to lie inside more than one feature space object, since no probabilities are computed. One means of resolving this situation is to consider the order in which the classes are processed (Kloer, 1994). The pixel in an overlapping region is assigned to the first or last class for which it is tested. Otherwise, it is left unclassified or the parametric rule should be applied. Another disadvantage for non-parametric classifiers is that many of the pixels in an image will not be assigned to any class; this situation produces a classified image output with a percentage of unclassified pixels. Due to these limitations, the non-parametric classifier is often used only as a first pass, coarse classification to help define broad class categories or it is used for specific, easily discriminated, classes (Kloer, 1994 and Lillesand and Kiefer, 1994).

2.7.3 The hybrid classification technique

Considering the observations for and against supervised and unsupervised classification, some workers, such as Garcia and Alvarez (1994) have suggested a hybrid (supervised plus unsupervised) classification approach. In this way, statistics from unsupervised clustering can be used as input into a maximum likelihood classification.

Experiments with different classification methods, i.e., unsupervised cluster analysis, parallelepiped, minimum distance and maximum likelihood classifiers, have indicated that the maximum likelihood classifier offers the best results (Su 1993). The application of a rejection threshold in a classification has been considered theoretically necessary, i.e., pixels which have probabilities for all classes above a certain value are to be classified correctly and those with probabilities below that value are to be rejected (Swain and Davis 1978 in ERDAS, 1999, Richards 1995). Maximum likelihood classification assumes that the statistics for each class in each band are normally distributed, and assigns a given pixel belonging to a specific class that has the highest probability (Sunar, 1998).

Supervised classification involves three major steps: (1) selection of training areas, (2) analysis of training signature statistics and spectral patterns and the actual (3) image classification (Trotter, 1998).

2.7.4 Training samples

The maximum likelihood classifier (MLC), used for supervised classification, requires the interactive definition of several spectrally distinct subclasses or 'training areas' of each land use and land cover category (Lillesand and Kiefer 1994). The 'training areas' are then evaluated and extrapolated to classify the whole scene (Thomson *et al*., 1998). Training samples are normally located by fieldwork or from air photographs or map interpretation (Mather, 1993). Following the recommendation of Garcia and Alvarez (1994), classes generated during unsupervised classification can be used alongside field records to identify training samples on the image. Unsupervised training allows many classes to be easily defined and identified (ERDAS, 1999). Having been identified on the images, they are then digitized on the image display device (Trotter, 1998). The training areas of each land use or land cover class should be selected throughout the study area in order to obtain good representatives (Lillesand and Kiefer 1994 and Trotter, 1998).

The accuracy of the classification of a given land use or land cover category depends on the size of the training sample and its representativeness (Mather, 1993). For multivariate classification, the size of a training sample should be at least 30p pixels (preferably more) per class, where ***p*** is the number of features (spectral bands) (Mather, 1993). The minimum samples (pixels) of a class, where possible, can be chosen to be more than 300 to enable a meaningful calculation of statistics (Mather, 1993). It has been suggested that the optimum number of samples of between 10 times and 100 times the spectral bands be used for classification (Richards 1995). Experiments in this study have revealed that for a complex and heterogeneous land use or land cover class, the higher the number of pixels in the training sample, the better is the result of the classification.

Training signatures need to be evaluated before being used for a supervised classification. Standard procedures normally used for such an evaluation include feature space plotting (using Jefferies-Matusita distance and Transformed Divergence separability listing for band pairs), thresholding and the use of the alarm function (ERDAS, 1999). Ringrose *et al.* (1997) applied the feature space ellipse separation procedures prior to a supervised classification. Thomson *et al.* (1998) observed that plots in feature space (red *versus* infrared wavebands) show the spectral range of Maximum Likelihood Classifier-based target classes and subclasses; vegetated surfaces with high infrared reflectance compared to red, are separated from unvegetated surfaces that have a red-infrared ratio closer to unity. Trotter (1998) observed that, based on the calculated spectral distances between classes (best average separability and best minimum separability), pairs of only four bands: 1, 3, 4 and 5, show better separability for vegetation types among original bands.

Signature statistics need to be evaluated and revised until a reasonable degree of separability of the resultant ellipses is apparent throughout the available feature space (Ringrose et al., 1997). The training areas are modified in such a way that the digital value distribution of each class approximates a normal grey level distribution of pixel values (unimodal distribution) to satisfy the fundamental requirement of the maximum likelihood classifier (Su, 2000; Wright and Morrice, 1997; Sannier *et al.*, 1998 and Rogers *et al.*, 1997).

2.8 Post classification enhancement

A post-classification filtering enhancement of the final result of the classification has been recommended (Su, 2000; Trotter, 1998 and Ringrose et al., 1997). Trotter (1998) used a 3 x 3-kernel majority filter to reduce the "salt-and-pepper" effects in the classified image, while Ringrose *et al.* (1997) used a majority 7 x 7 filter. However, great care needs to be taken while filtering, because, the larger the kernel size, the greater the level of generalization (Fung and Chan 1994). According to Su (2000), the majority filter can be applied to all the classes except water and built-up areas, since water and built-up areas usually appear as individual pixels (small water areas and individual houses) or a string of pixels (roads). The use of a majority filter may result in their complete disappearance (Su, 2000).

2.9 Accuracy assessment

The NPS/NBS Vegetation Mapping Project (2002) has defined accuracy as how close an estimate is to its true value. Accuracy assessment of spatial data has three primary objectives (NPS/NBS Vegetation Mapping. 2002). These are:

1. to allow users to assess the data's suitability for a particular application

2. to allow producers of the spatial data to learn more about errors in the data and improve the mapping process

3. to verify conformance to production standards.

2.9.1 Statistical methods for thematic accuracy

Many techniques for measuring uncertainty in mapped classes were developed for remote sensing to provide interpreters with ways to assess the accuracy of remotely sensed land classifications (NPS/NBS Vegetation Mapping Project, 2002). In this kind of accuracy assessment, it is a common practice to select samples of locations and to compare the class assigned to each location with some source of higher accuracy, usually ground truth obtained by direct observation in the field (NPS/NBS Vegetation Mapping Project, 2002). The results are then tabulated in the form of an error or misclassification matrix (also referred to as a contingency or confusion matrix), such as the one shown in Table 2.10 (Congalton 1991). In this table, the columns define the classes in the reference data, and the rows define the classes in the data being evaluated for accuracy. The values in the cells in the table indicate how well the classified data agree with the reference data.

Table 2.10: Sample of misclassification matrix for five classes

		Reference data					
	Sample data	A	B	C	D	E	Total
Classified data	A	**80**	4	0	15	7	106
	B	2	**17**	0	9	2	30
	C	12	5	**9**	4	8	38
	D	7	8	0	**65**	0	80
	E	3	2	1	6	**38**	50
	Total	104	36	10	99	55	**304**

The diagonal elements of the matrix indicate correct classifications. Therefore, a crude overall measure of accuracy is calculated as sum of the percentages of cases that lie on the diagonal, divided by the grand total, in this case (80 + 17 + 9 + 65 + 38) = 209/304, or 68.8%. In other words, overall accuracy can be expressed as follows:

$$\frac{\Sigma(\text{items along diagonal})}{\Sigma(\text{all row or column entries})}$$

This can be misleading as an index, since a certain number of correct classifications will occur by chance, even in the most uncertain situations. A preferred index is the Kappa index, which has a maximum of 1 and a minimum of zero, the latter expected under maximum uncertainty. Kappa is computed as follows (Congalton 1991):

$$\hat{k} = \frac{P_{correct} - P_{chance}}{1 - P_{chance}}$$

where $P_{correct}$ is the proportion of correctly classified entries and P_{chance} is the proportion of samples that could be expected to be classified correctly by chance. P_{chance} is computed as follows (Congalton 1991):

$$P_{chance} = \sum_{i=1}^{n} P_{row(i)} \, P_{column(i)}$$

where $P_{row(i)}$ is the proportion of total entries that are in row i, $P_{column\ (i)}$ is the proportion of all entries that are in column i, and n is the total number of rows or columns. For Table 2.9, the Kappa index is 58.3%, which is somewhat lower than the percent correctly classified. Some evidence exists that the Kappa index in fact underestimates true accuracy in data, and modifications to account for this exist

(Congalton 1991). However, it is recommended that the unmodified Kappa index be utilized to report overall classification accuracy primarily because it is documented and well known within the vegetation mapping community.

An overall statement of accuracy is useful, but it does not say anything about the accuracy of individual classes. Per-class accuracies can be extracted from the contingency matrix, but they can be misleading if they have not been differentiated into producers' and users' accuracy (also referred to as errors of omission and errors of commission respectively). Errors of omission calculate the probability that a reference sample has been classified correctly; this is often the only type of accuracy that is reported. This quantity is computed by dividing the number of samples that have been classified correctly by the total number of reference samples in that class. Errors of commission calculate the probability that a sample from the classified data actually represents that category on the ground. This type of error is computed by dividing the number of correctly classified samples by the total number of samples that were classified as belonging to that category (Table 2.11).

Table 2.11: Users' and producers' accuracy for five classes

Class	**Users' accuracy**	**Producers' accuracy**
A	75.5% (80/106)	76.9% (80/104)
B	56.7% (17/30)	47.2% (17/36)
C	23.7% (9/38)	90.0% (9/10)
D	81.2% (65/80)	65.7% (65/99)
E	76.0% (38/50)	69.1% (38/55)

Producers' accuracy is an important measure because the producers of spatial data are interested in knowing how well a particular area on the Earth's surface can be mapped. Users' accuracy, on the other hand, is important for users of spatial data, because users are principally interested in knowing how well the spatial data actually represent what can be found on the ground (Congalton 1991). Ideally, both users' and producers' accuracy should be similar for all classes. However, as illustrated in Table 2.11, users' and producers' accuracy may differ considerably among classes. For example, Class C has a producers' accuracy of 90%, meaning that 90% of the reference samples were also found to be classified as Class C. Users' accuracy, on the other hand, is only 23%. This means that only 23% of the polygons classified as Class C in the data can be expected to be Class C when visited on the ground. Reporting only the producers' accuracy as the accuracy assessment would give a completely misleading picture of data accuracy to users, who would interpret the 90% figure to mean that 90% of the polygons classified as class C in the data also have this class on the ground.

2.10 Change detection

Land use patterns do change over time in response to economic, social and environmental forces. Understanding the nature of change in the use of land resources is essential to the facilitation of proper planning, management, and regulation of their uses. Change detection has, therefore, become one of the key topics in remote sensing and image analysis (Wong *et al.,* 1997) and is a major application of multi-spectral LANDSAT TM data (Sunar, 1998).

Change detection enables the assessment of changes between images (in general two images) acquired at different dates or times (Sunar, 1998). Data from the LANDSAT TM offers the potential for the detection and inventory of disturbance and other changes that occur in land use and land cover types (Sunar, 1998). Differences in a surface phenomenon over time can be determined and evaluated visually or using digital techniques (Garg *et al.,* 1988). Automated change detection using satellite data can give timely and consistent estimation of changes in land use trends over large areas, and has the additional advantage of ease of data capture into a geographical information system (Prakash and Gupta, 1998).

Different techniques have been developed to detect changes in the environment (Wong, 1997). Nevertheless, there is still no standard method for the quantitative estimation of green vegetation cover; the existing methods are based on different approaches, which are applicable to specific locations or regions and satellite sensors (Purevdor *et al.,* 1998). The change detection procedure most appropriate to a given situation also has significant impact on the result. This, however, depends on the type of application, environment and targets of interest as well as on the amount of detail required. It also demands an extensive knowledge of both the study area and the logical and spectral interrelationships between land use and land cover classes (Sunar, 1998).

The most commonly used change detection procedures include (i) image overlay, (ii) image differencing, (iii) principal component analysis (PCA), (iv) classification comparisons, (v) image ratioing, (vi) differencing of NDVI images, (vii) change vector analysis, and (viii) NDVI (Sunnar, 1998). For almost all these techniques, the images must be co-registered and atmospherically corrected.

2.10.1 Image overlay

The simplest way to produce a change image is via a photographic comparison of a single band of data from the two dates. The image is prepared by making a photographic two-colour composite showing the two dates in separate colour overlays. The colours in the resulting image indicate the changes in reflectance values between the two dates. For instance, features, which are bright (high reflectance) on date 1, but dark (low reflectance) on date 2, will appear in the colour of the first photographic overlay. Features, which are dark on date 1 and bright on date 2, will appear in the colour of the second overlay. Features, which are unchanged between the two dates, will be equally bright in both overlays and hence will appear as the colour sum of the two overlays.

2.10.2 Image differencing

The most common approach to quantifying image brightness change associated with land cover change is image differencing, which involves the subtraction of image brightness values on a pixel-by-pixel basis. The image brightness values may represent spectral radiance values of like wave band images or continuous value derivatives of waveband images (e.g., ratios or linear band combinations) (Su, 2000; Townshend and Justice 1995; Prakash and Gupta, 1998). The procedure simply involves the co-registration of two images of the same area taken at different times to assess the degree of change that has taken place between the dates of imaging and preparing a temporal difference image by subtracting the digital numbers (DN) for one date from those of the other. The difference in the areas of no change will be very low in DN, and areas of change will reveal larger positive or negative values (Lillesand and Kiefer 1994).

Sunar (1998) performed change detection between LANDSAT TM data of 1984 and 1992 and observed that areas of no change were represented by a value of 127 (mid-grey), while areas that were darker in 1992 than they were in 1984 had values between 128 and 255 (Sunar, 1998). Gupta and Prakash (1998) also generated a difference image by subtracting a TM-4 (1990) image from that of TM-4 (1994). The resultant difference image is Gaussian in nature, with no-change pixels centred around the mean, while the tail regions on either side contain information about the changed areas. On such an image, bare areas and areas where vegetation has decreased will appear in dark tones, while areas where vegetation has increased appear in bright tones. No-change areas will also appear in grey tones (Prakash and Gupta, 1998). The converse difference image (TM (1990)–TM (1994) can also give equally useful information. To assist the interpretation and understanding of changes occurring between the dates of imaging, a colour composite of difference images is generated (Sunar, 1998).

2.10.3 Change vector analysis

This procedure, which had been cited by Lillesand and Kiefer (1994), is a conceptual extension of image differencing. The basis for this approach in two dimensions is illustrated in Figure 2.4. Two spectral variables (e.g., data from two bands, two

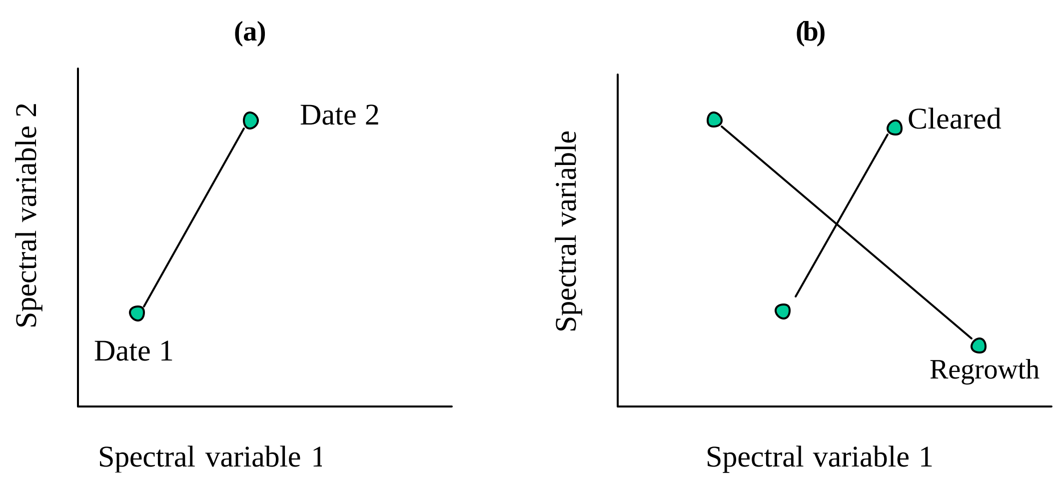


Figure 2.4: Spectral change vector analysis: (a) spectral change vector observed for a single land cover type; (b) length and direction of spectral change vectors for hypothetical “cleared” and “regrowth” area. (*Source: Lillesand and Kiefer, 1994*)

vegetation components) are plotted, e.g., at two dates (dates 1 and 2) for a given pixel. The vector connecting these two data sets describes both the magnitude and direction of spectral change between the dates. A threshold on the magnitude can be established as the basis for determining areas of change, and the direction of the spectral change vector often relates to the type of change. For example, Figure 2.4 (b) illustrates the differing directions of the spectral change vector for vegetated areas that have been recently cleared versus those that have experienced regrowth between images (Malila, 1980).

2.10.4 Classification comparisons

Classification comparisons are done with two or more independent classifications of each scene. The two classifications are then compared pixel by pixel so as to generate an image that shows pixels placed in different classes on the two images. An alternative method is to use all bands of data and classify all the bands as a single data set. The classification identifies not only the original land use and land cover categories, but also classes of pixels that have changed between dates (Richards 1995).

2.10.5 Principal component analysis

Principal component analysis (PCA) can be used to detect and identify a temporal change when registered LANDSAT TM images are merged and treated as a single data set. By this method, a new set of co-ordinate axes are fitted to the image data. The first new axis or component will account for maximum variance. Subsequent axes (components) will account for smaller portions of the remaining variance. Changes to be anticipated are of two types: first, those that would extend over a substantial part of the scene, such as changes in atmospheric transmission and soil moisture status and second, those that were restricted to parts of the scene, such as the construction of roads or the destruction of green areas (Campbell 1995, El-Raey *et al.,* 1995 and Ingebritsen *et al.,* 1985).

2.10.6 Use of vegetation indices

The use of vegetation indices based on the red and near-infrared reflectances recorded in remote sensing data is a common practice (Su, 2000). Vegetation indices directly correlate (linearly related) with biomass or primary productivity and with other biophysical parameters, such as leaf area index (LAI), leaf water content, chlorophyll and other biophysical characteristics (Weiser *et al*., 1986; Kanemasu *et al.,* 1990 and Purevdor *et al.,* 1998). A variety of vegetation indices have been developed (Tucker 1985). The most commonly used ones are image ratioing and normalized difference vegetation index (NDVI).

2.10.6.1 Image Ratioing (Rnir/Rred)

The simple ratio (SR) of near-infrared reflectance (*Rnir)* to red reflectance (*Rred)* is a widely used vegetation index. The method is commonly referred to as image ratioing (Tucker 1979). A strong correlation exists between the ratio of the visible red (R) and near-infra-red (IR) reflectance (IR/R) of vegetation canopy and leaf area index (LAI) and hence biomass (Kanemasu *et al.,* 1974). The ratio (SR) of near-infrared reflectance *Rnir* to red reflectance *Rred* is calculated as follows:

$$SR = Rnir / Rred$$

SR is related to the normalized difference vegetation index (NDVI) through the following relation:

$$SR = (1 + NDVI) / (1 - NDVI)$$

Ratio transforms of visible red (R) and near infra-red (NIR) bands from remote sensing have been used for studying different vegetation types and land uses (Tucker 1979). The visible red spectrum is where chlorophyll absorbs most of incoming radiation, whereas the second NIR channel is in a spectral region where spongy mesophyll leaf structure reflects most of the light (Sellers 1985 and DeFries *et al.,* 1995) (Figure 2.5).

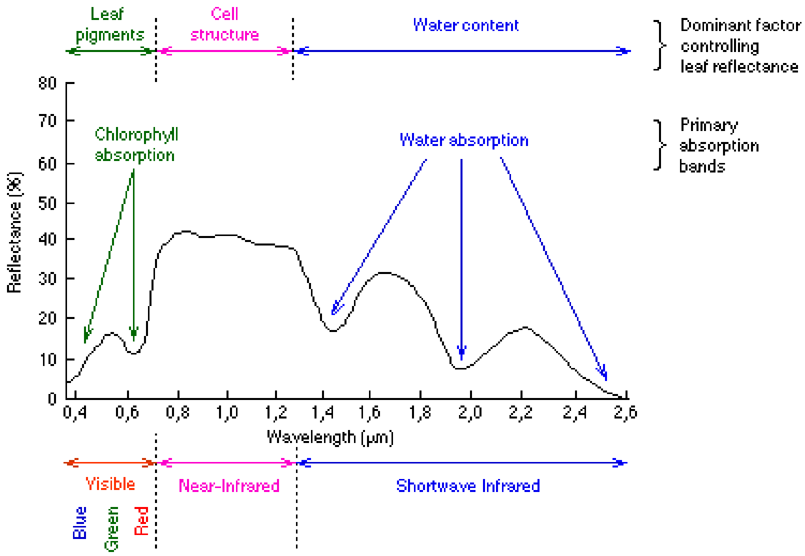


Figure 2.5: Typical spectral response characteristics of green vegetation (after Hoffer, 1978)

2.10.6.2 Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) is popularly used for monitoring vegetation changes and the accurate assessment of vegetation phenology, estimation of net primary production (NPP) as well as the interpretation of the impact of climatic/weather events on the biosphere (Potter and Brooks, 1998). However, vegetation indices are useful in identifying land cover and forest classes only when used in conjunction with ground truth data, bispectral plots and classification procedures (Thenkabail 1999).

The NDVI is defined as reflectance in the near-infrared (NIR) range minus reflectance in the visible red (R) spectrum portion divided by their sum. It is expressed mathematically as follows (Shimabukuro *et al.*, 1997, Potter and Brooks, 1998)

$$NDVI = (\mathrm{Rnir} - \mathrm{Rred})/(Rnir + Rred),$$

where ***Rred***, ***Rnir*** are red and near-infrared reflectances respectively obtained from remote sensing.

2.10.7 Factors affecting vegetation indices

The quality of the result of vegetation-index-based studies of land use and land cover change detection depends on many factors, which include the quality of image used, image pre-processing methods, the density and structure of vegetation and its formation as well as the influence of soil characteristics and properties.

Image registration and atmospheric correction are important, because a temporal brightness change due to misregistration can be taken for a land cover change (Su, 2000). Since vegetation parameters differ from place to place (spatial variability) and from time to time (temporal variability) and the literature values are usually collected in one place at one time, these values cannot be extended reliably to different places where the measurements were not made or to times different from when the measurements were made (Potter and Brooks, 1998). It is, therefore, obvious that a method capable of assessing the spatial and temporal variabilities of vegetation parameters would be advantageous. Remote sensing techniques provide such an alternative. Studies by Kogan (1990) and Maselli *et al.* (1993) showed the influence of geographical variations on the interpretation of NDVI. Temporal variations also pose a limitation to the use of NDVI in global change simulations. Notwithstanding, climate-based predictions of vegetation greenness information represented in NDVI are important for studies of past and future biosphere states (Potter and Brooks, 1998).

It has been found that using NDVI alone for the discrimination among certain transition ecosystem types, such as tropical dry forests and savannahs, or grasslands and cultivated lands is problematic (Potter and Brooks, 1998). A variety of biotic (e.g., canopy phenologic or successional) or abiotic (e.g., atmospheric or sensor calibration) factors cause differences in the NDVI values of different dates (Weishampel *et al.*, 1998). Of particular importance are the factors of soil, vegetation, the atmosphere and the physiological state of the vegetation.

2.10.7.1 Background soil impact on spectral indices

Soil reflectance, as well as soil-vegetation spectral mixing, is a major concern in the use of indices, because soil, plant and shadow reflectance components mix interactively to produce a composite reflectance (Richardson and Wiegand, 1977). Soil reflectance patterns are usually quite different from those of vegetation (Figure2.6). The

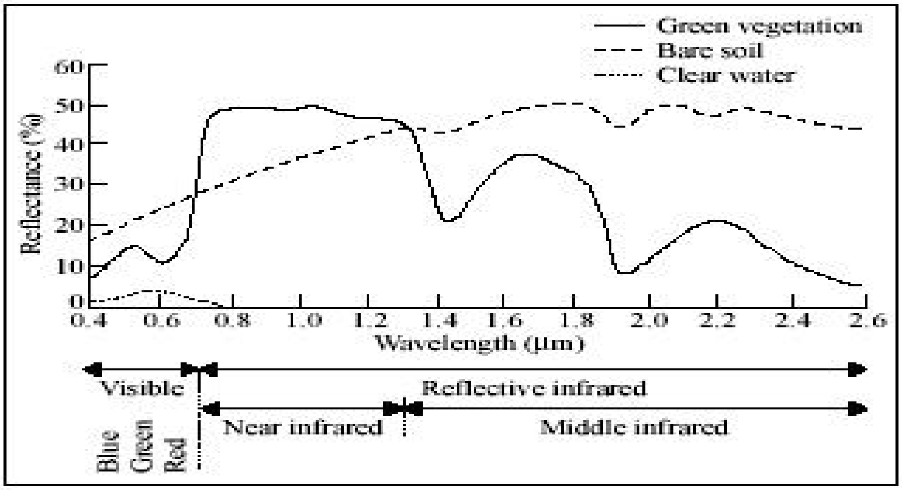


Figure 2.6: Reflectance vs wavelength for soil, vegetation and water
(*source: Hoffer, 1978*)

characteristic reflectance pattern for green vegetation is low in the visible portion of the spectrum (particularly red), but increases sharply in the near-infrared portion, while soil reflectance generally increases linearly with increasing wavelength (from visible to near-infrared to mid-infrared). Thus, soil is usually more highly reflecting in the visible wavelengths and less reflecting in the near-infrared wavelengths than vegetation (Figure 2.7). Vegetation density in grasslands may be relatively low (Purevdor *et al.*, 1998) and

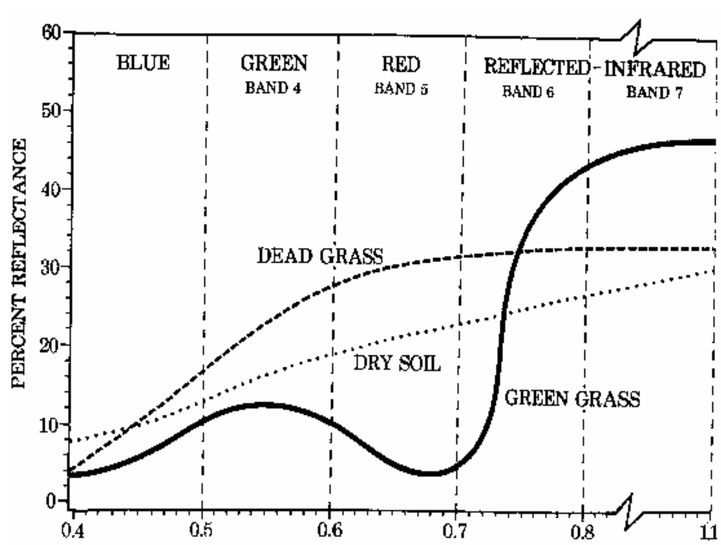


Figure 2.7: Typical spectral reflectance characteristics for healthy green grass, dead grass and bare soil. *Source: Baret and Guyot, 1991*

in semi-arid grasslands, vegetation changes from intermediate density to low density. In such an environment, the use of vegetation indices is problematic because of the effects of background soil and senescent grass (Baret and Guyot, 1991).

Soil reflectance values vary considerably with different features, such as soil texture, moisture content, organic matter content, soil colour, and the presence of iron oxide (Purevdor *et al.*, 1998). Different soil and water types show different reflectance characteristics. (Figure 2.8). Dark soils, high in organic matter or moisture, containing

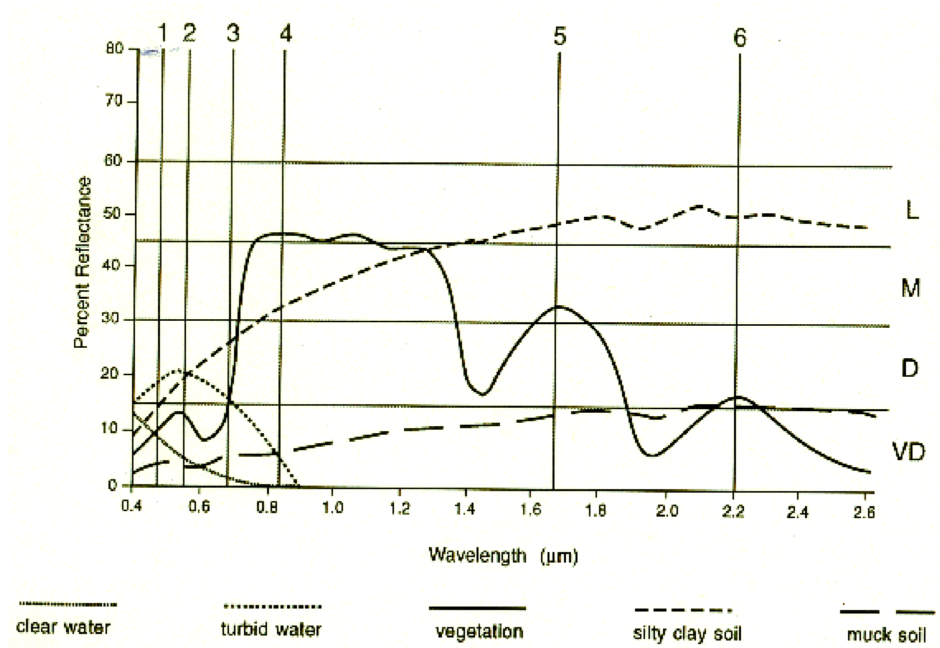


Figure 2.8: Reflectance vs wavelength for soil, vegetation and water (*source: Hoffer, 1978*)

iron oxides, and/or coarse textured are low-reflecting (Hoffer and Johannsen, 1969, Bowers and Hanks, 1965). Dry soils exhibit high reflectance values throughout the reflectance regions of the spectrum: visible, near-infrared, and mid-infrared (Figure 2.9).

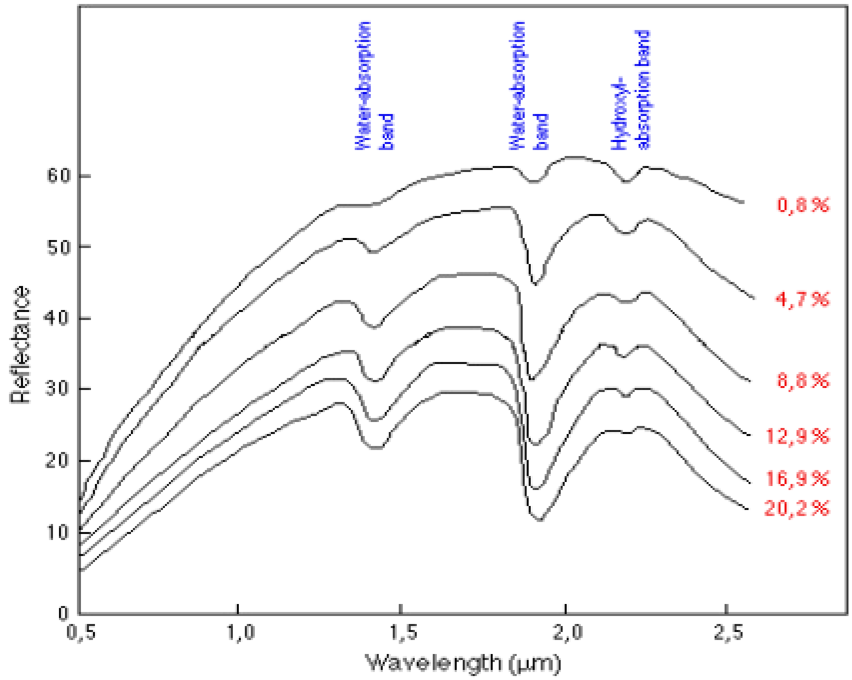


Figure 2.9: Spectral reflectance curves for silt-loam at various moisture contacts (after *Bowers and Hanks,1965)*

In contrast, wet soils exhibit low reflectance values for these regions (Hoffer and Johannsen, 1969; Bowers and Hanks, 1965 in Todd *et al*., 1998). Thus, the differences in soil characteristics and properties influence soil reflectance and consequently vegetation indices values.

NDVI is sensitive to optical properties of the background soil (Baret and Guyot, 1991). Since soil is typically highly reflecting in the visible, near-infrared, and mid-infrared wavelengths and soil background is a large component of pixel reflectance because vegetation may not be densely distributed (Todd *et al.*, 1998), it can be said that differences in soil characteristics and properties affect the pixel values of the images and consequently the NDVI. NDVI and other ratio-based indices tend to increase with dark, or low reflecting background soil. The background soil effect is particularly important when vegetation cover is sparse, as can be the case in arid and semi-arid regions (Purevdor *et al.*, 1998).

2.10.7.2 Vegetation reflectance variation

Leaf reflectance at various wavelengths is correlated with leaf chlorophyll concentration. Thus, reflectance is relatively low in the visible spectral range (400–775 nm) due to increased leaf absorption at this range (Todd *et al.*, 1998). Leaf chlorophyll concentration may change in response to altered plant physiological functions resulting from environmental fluctuations or plant stresses (Trenholm *et al.*, 2000). The drying of vegetation and its resultant loss of pigmentation alter spectral reflectance characteristics (Figure 2.10). These are common occurrences in semi-arid rangelands such as the short-grass steppe (Todd *et al.*, 1998). Loss of pigmentation increases visible reflectance, particularly in the red region of the spectrum. As vegetation dries, reflectance in both the visible and in the mid-infrared regions of the spectrum increases significantly. Dead or dry plant material produces reflectance patterns that are more similar to soil than to healthy green vegetation (Hoffer 1978).

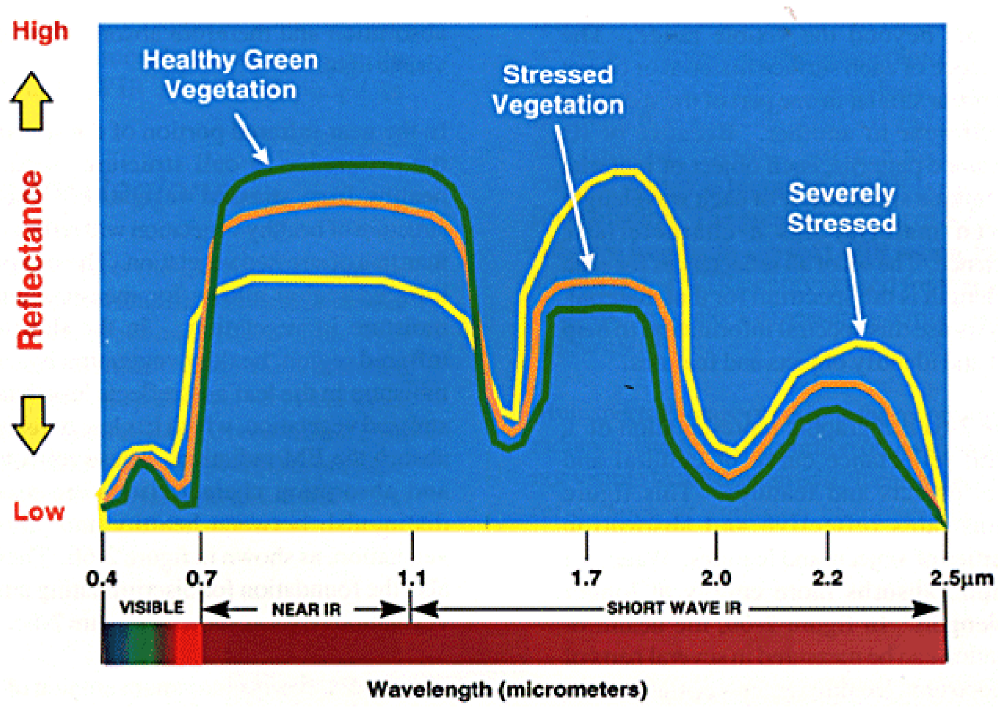


Figure 2.10: Spectral reflectance of stressed and healthy vegetation (Rubinstein, 2002)

2.10.7.3 Effects of dry vegetation

In regions where dry or senescent biomass is a substantial component of the vegetation, the spectral distinction between vegetation and the background soil is altered. Spectral indices are responsive to scene brightness such as the red waveband (RED) or the Tasseled Cap brightness index should aid vegetation discrimination for bright soils, if the dry and/or senescent vegetation is less bright than the soil background. Graetz (1988) found that the RED index, which responds to surface brightness, estimated vegetation cover on high reflecting soils more accurately than vegetation indices because dry vegetation was less bright than the background soil.

2.10.7.4 Vegetation structure and forms

Once an entire field of view is obscured by green vegetation, NDVI increases only slightly with increasing vegetation amount (Todd *et al.*, 1998). This is because light transmission and reflectance from successive leaves decrease as light travels through a series of leaves (Hoffer, 1978). Red light is strongly absorbed by the uppermost leaf layers of a green vegetation canopy, and is therefore not transmitted to successive leaf layers (Todd *et al.*, 1998).

NDVI has been found to have a major limitation for the characterization of deforestation because young regenerating forests tend to have higher NDVI values than mature forest, while other deforestation classes, such as pastures or bare soils, have low NDVI values (Shimabukuro *et al.*, 1998). Biomass of woody plants such as shrubs could also be underestimated by vegetation indices because of the quantity of non-photosynthetically active biomass (Todd *et al.*, 1998). The effectiveness of vegetation indices in estimating green vegetation cover for grasslands in semi-arid and arid regions has not been tested (Purevdor *et al.*, 1998).

2.10.7.5 Poor image quality

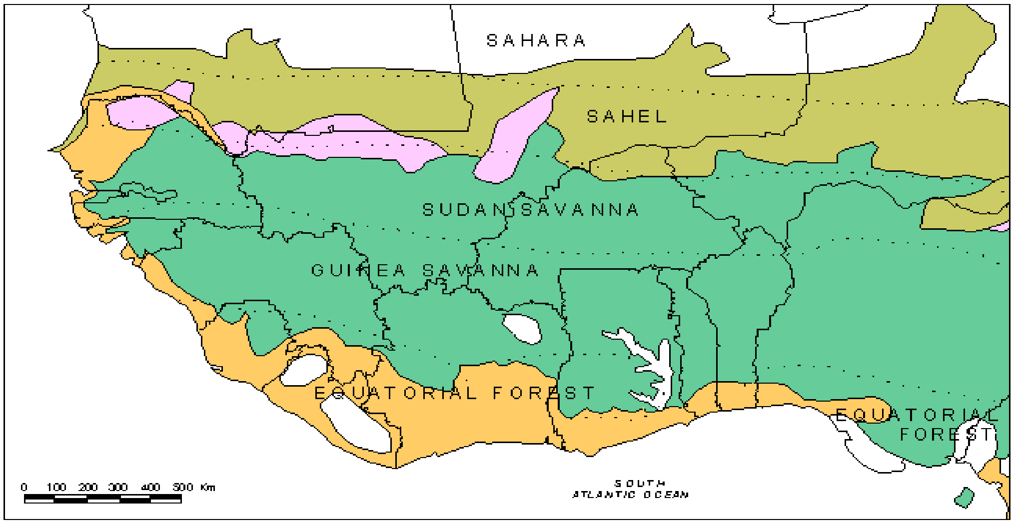
Differences in image quality, e.g., due to poor pre-processing can give inaccurate NDVI results (Potter and Brooks, 1998).

2.11 Rainfall and vegetation

The primary determinants of the vegetation of an area are climate (temperature, rainfall, evaporation, radiation and relative humidity) and the type of soil of the area (Kutiel *et al.*, 2000). These environmental factors work together, but often one is of overriding importance. If the soil conditions of a place are optimum, then the climatic factor that is most limiting will determine the vegetation of the place (Kutiel *et al.*, 2000). Sternberg *et al*. (1999) reported that temperature caused no significant differences in plant cover and species richness of a tropical grassland. In West Africa, temperature and radiation have no limitation on the growth and development of vegetation (Ahn, 1970 and Lawson, 1985).

A variety of climate and soil conditions occur in Africa (de Koning *et al.*, 1998). Plant communities follow roughly the same pattern as the climates (Figure 2.11). There is a great diversity of plant species, each well adapted to and characteristic of the climate of a place. Silvertown *et al*. (1994) observed that relationships exist between variation in grassland plant community composition and annual variation in rainfall and biomass. Based on moisture constraint, West Africa is divided into five agro-ecological zones (ISRIC, 1997), namely, the Sahara, Sahel, Sudan savannah, Guinea savannah and Equatorial rain forest (Figure 2.11). This confirms the fact that the most critical climatic factor that determines vegetation and agriculture in West Africa is moisture availability or rainfall, though limitations imposed by soils are not unimportant.

AGRO-ECOLOGICAL ZONES AND DOMINANT LAND DEGRADATION TYPES



Agro-ecological zones

Agro-ecological zone	Annual rainfall (mm)	Length of growing period (days)	Dominant soils (FAO, 1988)
Sahara	<250<	<60	Arenosols, Regosols
Sahel	250-550	60-90	Arenosols, Regosols
Sudan savanna	550-900	90-165	Lixisols*)
Guinea SavannaG	900-1500	165-270	Acrisols*)
Equatorial forest	>15UU	>270	Ferralsols, Acrisols

*) Including Fluvisols, Gleysols, Vertisols and Leptosols

Land degradation type

- Water erosion: loss of topsoil, terrain deformation/mass movement
- Wind erosion: loss of topsoil, terrain deformation, overblowing
- Chemical deterioration: loss of nutrients and organic matter, salinization/alkalinization, acidification, pollution
- Physical deterioration: compaction/crusting, waterlogging, subsidence of organic soils
- Other: water, non-used wasteland, stable under natural conditions, stable without vegetation, stabilized by human intervention
- · · · Major agro-ecological zone

Sources: Oldeman et. al, 1991, Windmeyer et. al, 1993 - Prepared by ISRIC, May 1997

Figure 2.11: Agro-ecological zones and dominant land degradation types in West Africa (ISRIC, 1997)

As shown in Figure 2.12, rainfall exerts a strong influence on the condition of vegetation cover, and there are varying correlations between vegetation cover and rainfall for semi-arid environments (Thompson, 2002; Damizadeh *et al.*, 2001; Penauelas *et al.*, 1977; Dunn, 2001 and Sternberg *et al.* (1999) also reported that additional water supply had a positive effect on vegetation parameters. There is a close relationship between rainfall and NDVI on seasonal and inter-annual time scales (Schmidt and Giltelson, 2000).

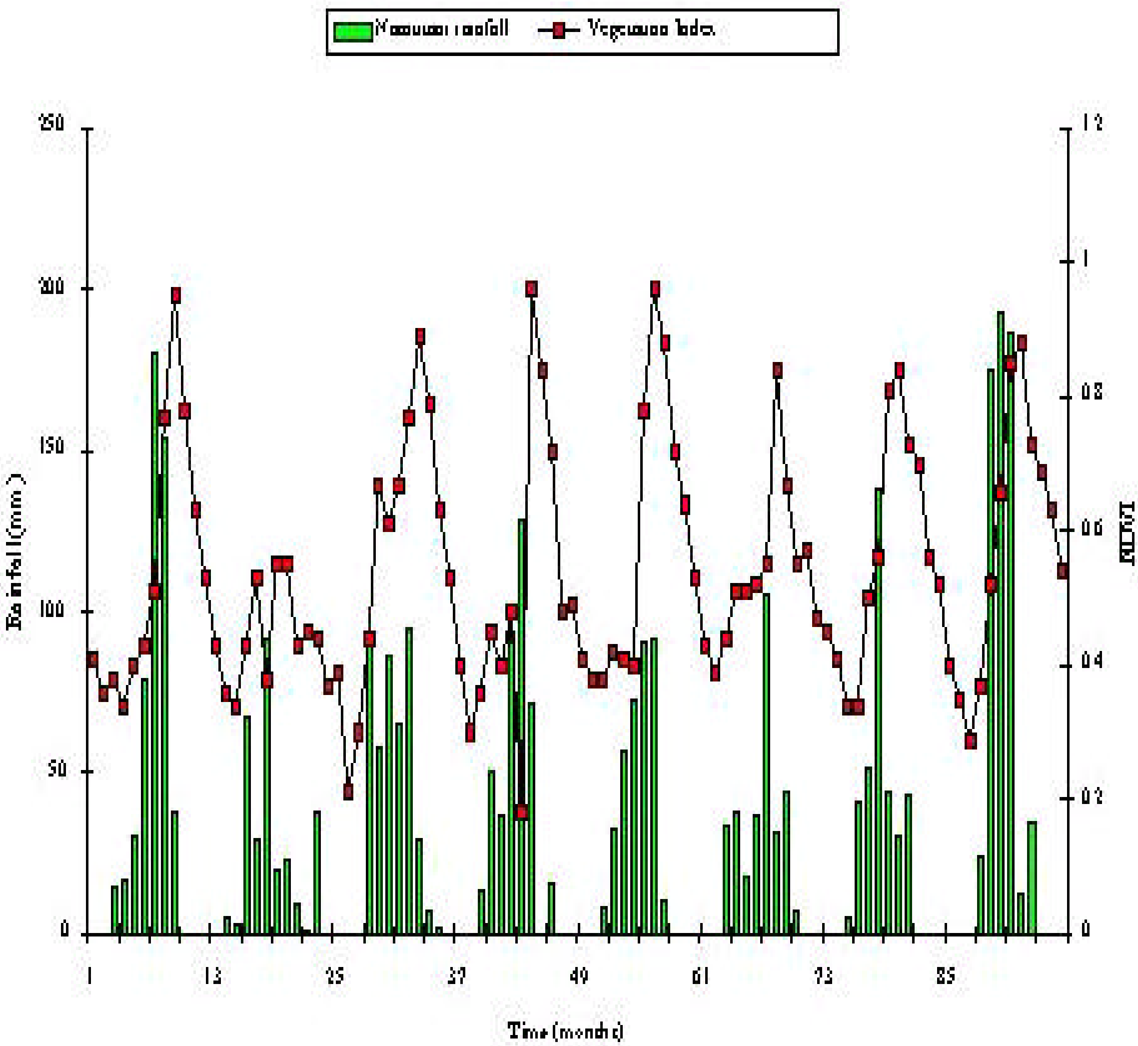


Figure 2.12: Monthly rainfall and vegetation response in Namutoni, Etosha National Park *(Thompsom, 2002)*

required for the effect of rainfall to be shown on vegetation in the Sahel. Kutiel *et al.* (2000) studied the effects of rainfall events on the growth of vegetation cover in the Sahel and Mediterranean region and concluded that a sequence of about four months of rainfall causes significant changes in NDVI. This is, however, dependent on environmental factors such as soil type (Richard and Poccard, 1998), as well as on other climatic factors and the attributes of the vegetation.

The real effect of rainfall on vegetation is determined by the rainfall regime. The term 'rainfall regime' includes at least four components, namely, (1) the total amount of rainfall, (2) its seasonal distribution, (3) its temporal variability (year to year) and (4) its instantaneous intensity distribution. For a given region, relationships exist between the four components. These relationships depend on the rain-producing mechanisms and are characteristics for a given climatic region (Kutiel *et al.*, 2000).

High instantaneous rainfall intensities are more abundant in regions of greater aridity due to increased frequent low-level convective activity. The temporal variability of annual rainfall totals increases as the mean annual rainfall decreases (Kutiel *et al.*, 2000). Another important feature of the rainfall regime of arid areas is the great uncertainty regarding the timing of the maximum rainfall within the rainy season. Smaller amounts of rainfall in higher instantaneous intensities reduce its effectiveness (Kutiel *et al.*, 2000).

Woody vegetation forms do not respond directly to the inter-annual fluctuations of rainfall totals (Kutiel *et al.*, 2000). Plants show decreased water content with the onset of the dry season (Myers *et al.*, 1997). Fully deciduous species have the least capacity to withstand internal dehydration and, therefore, shed their leaves early in the dry season as a response to rapid declines in both soil and atmospheric moisture levels. Shrubs and species with underground storage organs (such as tubers or bulbs), which die back seasonally to ground level and replace virtually all aerial parts with the onset of rain, are common in areas with low rainfall (Kutiel *et al.*, 2000).

Inter-annual differences in rainfall affect vegetation dynamics to a lesser extent. This is because the short-term response of vegetation to rainfall depends on a large number of climatic variables that define available moisture, rather than on the total rainfall. However, if there is a long-term change (several decades) in the rainfall regime of an area, we can assume that the vegetation may change (Richard and Poccard, 1998).

Variations in rainfall produce different changes in NDVI on different soil types. In general, sandy soils show a larger change in NDVI for a given change in rainfall than do soils with higher clay content. Clayey soils retain more moisture in dry years, than do sandy soils, and this difference affects the abundance of vegetation (Fisher and Levine, 1996). Consequently, attempts to predict the effects of climate change in arid and semi-arid regions must take into account differences in soil type and the effects of those differences on the response of vegetation to changes in rainfall (Fisher and Levine, 1996).

Droughts constitute one of the main causes of food shortages in Africa, because drought-stunted plants yield poorly compared to well developed ones (Hutchinson, 1991). Therefore, variation in the annual development of vegetation in agricultural areas is linked, generally, to variation in agricultural production (Sannier *et al.,* 1998). In a dryland ecosystem, only a small percentage of the available rainwater is utilized by vegetation; the greater part is lost through direct evaporation from the soil surface, run-off and drainage (Srivastava *et al.,* 1997). NDVI-soil moisture relation is more sensitive in dryland areas than in moist or humid areas (Prince and Tucker 1986; Townshend *et al.,* 1987 and Prince 1991). Large inter- and intra-seasonal/annual uneven variations of soil moisture and vegetation cover occur in dryland ecosystems (Thiruvengadachari and Gopalkrishnan, 1994). These factors bring in non-linear elements in the relationship between NDVI and soil moisture (Srivastava *et al.,* 1997).

2.12 Soil fertility and vegetation

Soil characteristics and the alternating wet and dry climate in arid and semi-arid ecosystems constitute a major determinant of both vegetation and potential land uses. Soil types affect patterns of vegetation cover change (Shoshany *et al.* (1995). The characteristics of soils are highly dependant on localized factors and so can vary considerably within short distances, leading to many different soil types. Soils vary according to parent material and soil-forming conditions. Thus, soils formed from granites tend to be sandy and infertile, while those formed from basalts will be more fertile and clayey (Tropical Savannahs CRC, 1998). Vegetation contributes organic matter to the soil, and this affects the nutrient levels and the soil structure (Tropical

Savannahs CRC, 1998). Generally, savannah soils tend to be poor in fertility (Ker, 1995).

Lateritic soils are the most weathered and infertile soils in tropical savannahs and tend to be moderately acid (Tropical Savannahs CRC, 1998). Laterite prevents penetration of roots and thus inhibits the growth of most trees. This and the low-fertility of such soils do not favour the development of forest (SLW, October 1996). The nutrient content and biological activity of acid soils are low (Landon, 1991). Lithosols, which are also shallow and generally infertile, are common in tropical savannahs. (Tropical Savannahs CRC, 1998).

Trees, shrubs and grasses (including crops) increase in biomass only if there is enough water and nutrients in their ecosystems (Oren et al., 2001). The decrease of soil fertility due to unsustainable land use systems can force small-holder farmers to clear more fertile new natural forest or woodland for growing crops, which accelerates deforestation (Dechert and Veldkamp, 2002). The fertility of soils following slash-and-burn has been shown to decrease rapidly (Lal, 1986). Forests and closed woodland often develop an organic layer above the mineral soil. This layer generally improves the physical (soil aeration, water retention, resistance to erodability, etc.), biological (build-up of soil microorganisms and chemical (nutrients) and chemical (fertility) properties of the soil. These enhance the productive capacity of the soil (Watson *et al.*, 1999).

Trees differ from agricultural crops in that they store very little of the nutrients derived from the soil in the wood, but rather in the leaves, twigs and barks. By contrast, crops store nutrients in the harvestable parts of the crop (van Wyk and Maltitz, 2000). Again, most arable agricultural crops absorb nutrients mostly in the top 10-20 cm of the soil, but feeding roots of trees may go down to about 40-50 cm. Therefore, over the years of the tree's growth, nutrients are brought up from deep down and then returned to the surface by leaf fall and decomposition (van Wyk et al., 2000).

Human-induced land degradation consists in 'soil mining' (i.e., decreasing soil fertility by agriculture exploitation, (Van der Pol (1992) and water erosion. Soil fertility management in savannah areas is hampered by the low or moderate nutrient-retention capacity of the soil types (Ker, 1995). Fires of high intensity have been found to reduce the growth of the trees in the year following burning but are not expected to have a major impact on stand productivity (SunSITE Southern Africa, 2000). Annual burning of grassland and crop residues reduces soil fertility and increases soil erosion (Korem, 1985).

3 BIOPHYSICAL AND SOCIO-ECONOMIC ENVIRONMENT

3.1 The biophysical environment

3.1.1 Location and extent of the Upper West Region

The Upper West Region is the most recently created administrative region of Ghana. It covers an approximate area of 1,850 km^2 (1,850,032 ha) and is located within the geographic coordinates of Latitudes 9° 45’ and 11° 00’ N and Longitudes 1° 30’ and 2° 50’ W (Figure 3.1 and 3.2).

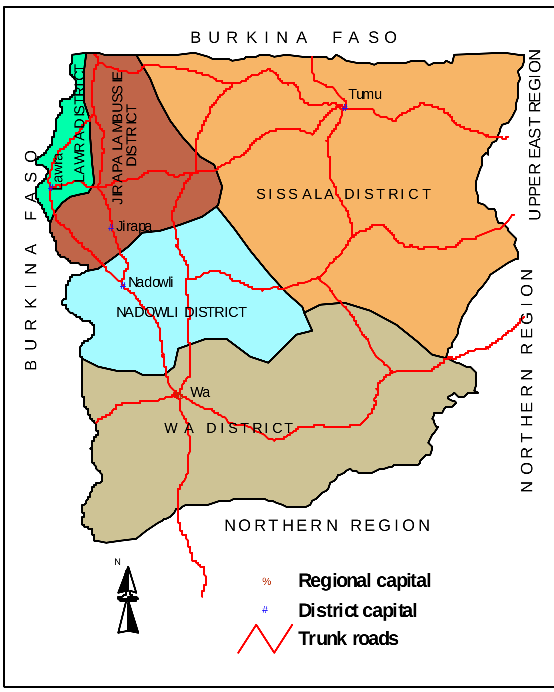


Figure 3.2: Districts of the Upper West Region and their capital towns

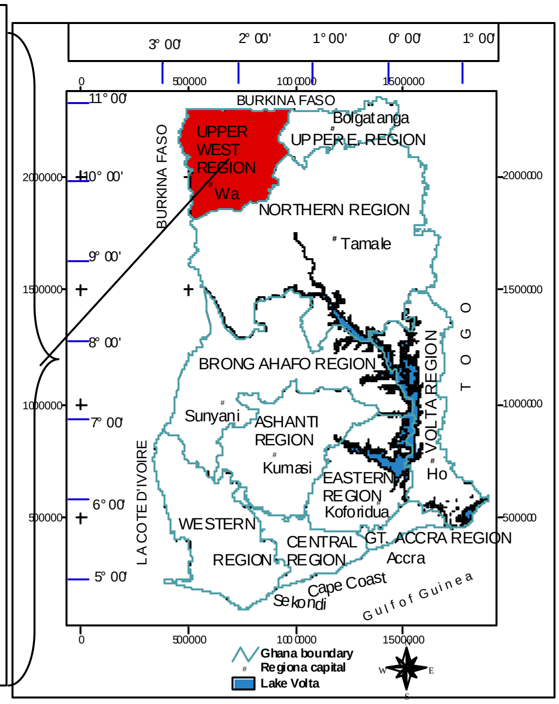


Figure 3.1: Location of the Upper West Region in Ghana.

Situated in the northwestern corner of Ghana, it is bordered in the west by the Republic of Burkina Faso, along the Black Volta River. In the north, it is bordered again by Burkina Faso along the Latitude 11^0 N parallel. In the south, it is bordered by the Northern Region and in the east by the Northern and Upper East Regions. The location of the region (shaded) in relation to the rest of the country is shown in Figure 3.1. The Region is divided into five administrative districts, namely the Jirapa-Lambussie, Lawra, Nadowli, Sissala and Wa districts (Figure 3.2).

Ghana occupies a total area of about 239,000 km^2 and is located in West Africa, approximately between latitudes 4^0 44'and 11^0 11'N and longitudes 3^0 W and 1^0 E. The country, which is made up of ten administrative regions, is bordered in the west by La Côte d'Ivoire and Burkina Faso, in the north by Burkina Faso, in the east by Togo and in the south by the Gulf of Guinea (Fig 3.1).

3.1.2 Climate

The Upper West Region falls into the Tropical Continental or Interior Savannah type of climate (Walker, 1962 and Dickson and Benneh, 1988), which is a semi-arid type of climate (Walker 1962). It is characterized by pronounced alternating wet and dry seasons, which result from the influence of two air masses that alternatively oscillate across the country (Walker, 1962 and Dickson and Benneh, 1988). The dry air mass is the tropical continental (cT) air mass and the moist one is the tropical maritime (mT) air mass (Dickson and Benneh, 1988 and Walker 1962). A third air mass, the Equatorial Easterly (E) also exits in Ghana (Dickson and Benneh, 1988). The *cT* air mass originates from the heart of the hot Sahara-Arabian desert and blows towards the sea (i.e., from north to south) across the whole of northern Ghana in the dry season (Walker, 1962 and Dickson and Benneh, 1988). The *mT* air mass, which originates in the south Atlantic Ocean and blows across the whole country during the wet season, is moisture-laden and brings rain to the country (Walker, 1962, Dickson and Benneh, 1988). The effects of the *mT* air mass decrease northwards (Walker, 1962 and Dickson and Benneh, 1988). The E air mass brings rainfall, which can be very heavy with a high intensity (Walker, 1962 and Dickson and Benneh, 1988).

The average rainfall and temperature of the region can be represented by the climatic data for Wa, which are shown in Figure 3.3. The region receives between 1,000 and 1,150 mm per annum from April/May to October. The period from November to the end of March/April is dry (Dickson and Benneh, 1988). Considerable variations exist in the rainfall pattern, in terms of distribution, onset and amount from year to year. These fluctuations, which cannot be predicted, affect crop production in the region since agriculture is mostly rain-fed (Dickson and Benneh, 1988). The mean monthly temperatures range from 30°C in March to about 27°C in August (Figure 3.3). There is an occurrence of clouds during the wet season, which makes the acquisition of quality images during that period of the year difficult, thereby restricting vegetation studies to the dry season. Air humidity during the wet season is high in the night and early

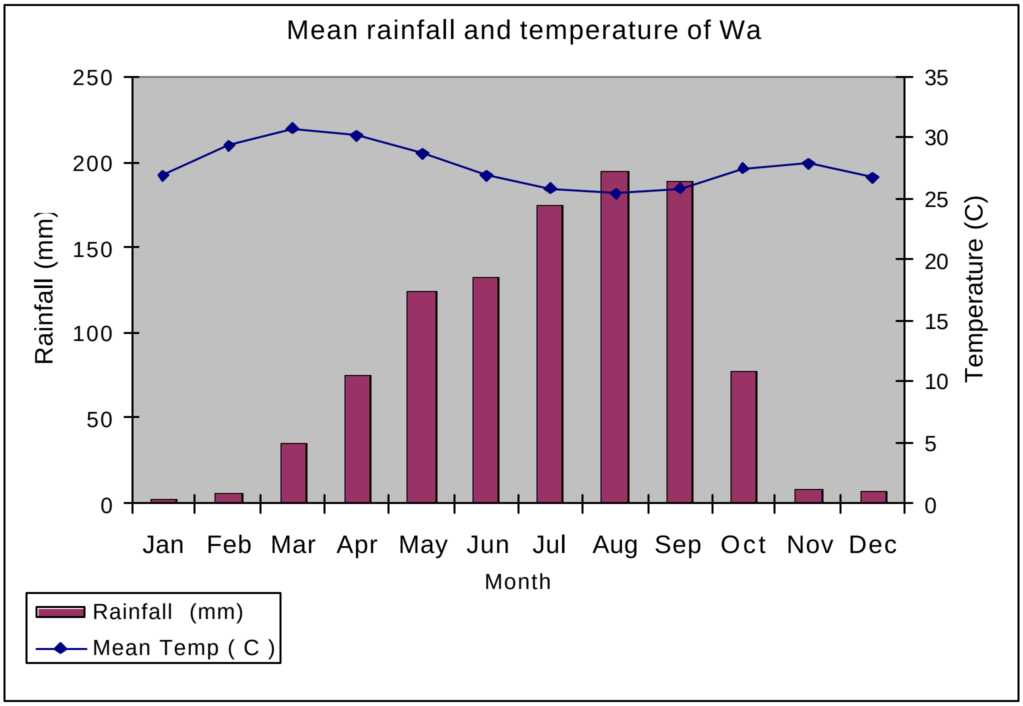


Figure 3.3: Mean monthly rainfall and temperature of Wa (*Source:Agyepong et al., 1999*)

morning (70-90%), while January, the driest month, has a relative humidity as low as 20% (Dickson and Benneh, 1988). The low humidity and high temperatures in the absence of rains during the dry season are conducive to the quick drying and easy burning of the vegetation. The resultant fire scars constitute one of the problems encountered in defining training samples for supervised classification of images acquired during that period.

Growing periods, as determined by the Soil Research Institute (SRI) of Ghana, generally range from 120 to 150 days, but can be between 150 and 180 days in valley bottoms, where moisture is retained for longer periods (SRI, 1999).

3.1.3 Geology and physiography

The greater part of the Upper West Region is underlain by granite, Birrimian formations and Basic Intrusives (Bates, 1962) (Figure 3.4). Birrimian rocks are the oldest material

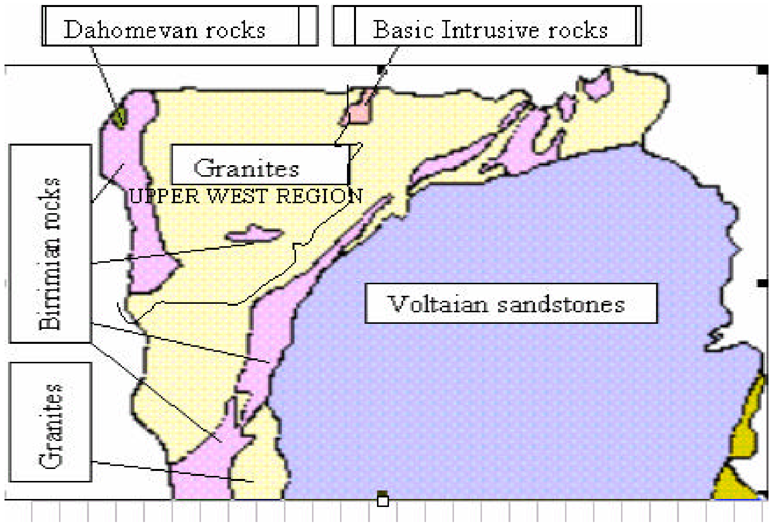


Figure 3.4: Geology of Northern Ghana, including the Upper West Region (*created from Geological map of Ghana*)

in northern Ghana and consists of "metamorphosed volcanic and pyroclastic rocks" (UNDP/FAO 1967). Due to long periods of sheet erosion, the topography of the region is, in general, flat to gently undulating, with most slopes having a gradient of 0-4% (Figure 3.5) (Dickson and Benneh, 1988). The general terrain consists of a series of

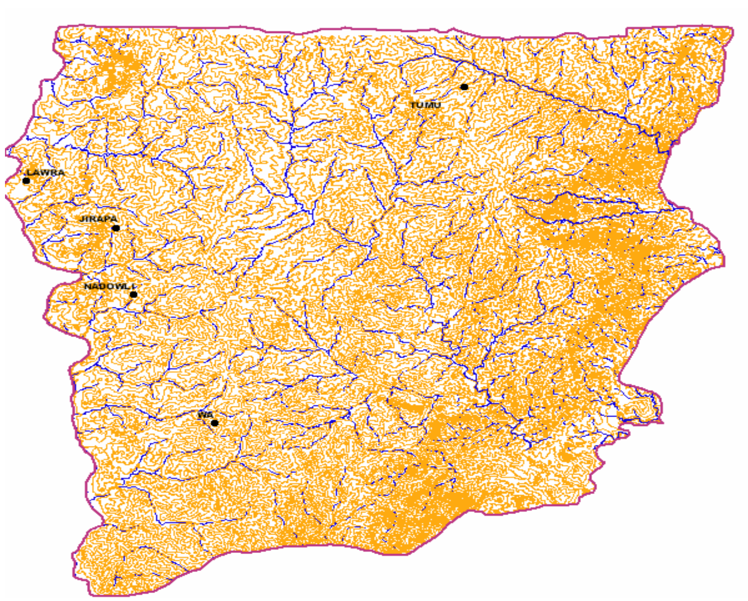


Figure 3.5: Relief of the Upper West Region, showing contours (created from Survey Department of Ghana data). *(High contour density depicts highlands. The rest of the region is relatively flat with valleybottoms, which contain the drainage channels)*

dissected plateaux, which average between 180 and 300 meters above sea level with higher sporadic hills or inselbergs of Birrimian rocks or granites at few locations (Dickson and Benneh, 1988).

The Upper West Region is drained by the Black Volta, Sissili and Kulpawn river systems (Dickson and Benneh, 1988). Apart from the Black Volta, the rivers and streams are intermittent, hence the sinking of hand-pumped wells (called bore-holes) in the villages in the region (Dickson and Benneh, 1988). Most valley-bottom areas are inundated during the wet season and some remain moist or wet during part (or the whole) of the dry season; some are used for the production of crops, mostly rice and vegetables.

3.1.4 Vegetation

Vegetation forms an important part of the physical environment of the Upper West Region and helps greatly in defining its resources and character. It provides the inhabitants with materials for shelter, food, clothing, and other numerous necessities of life (Dickson and Benneh, 1988) such as medicine (herbal), fuel wood, cash from the sale of wild products and by-products, e.g., sheanut (for sheanut butter), honey and game.

Vegetation is a function of rainfall, edaphic factors, geomorphology, fire occurrence rates and differential grazing pressures (Milich and Weiss (2000). So in the Upper West Region, the characteristics of the vegetation have been determined by its rainfall, soil and the influence of the people (Lane, 1962).

Rainfall is the most important factor that influences vegetation in West Africa, since it is the only climatic element, that varies widely in quantity, space and time (Ahn, 1970). In Ghana, it is the determinant of the boundaries between the various agro-ecological zones (e.g., between high forest and the Guinea savannah zones) and also determines the type of crops (and their varieties) grown there (Lawson, 1985) and when they are grown. In particular, the length of the dry season is a very important factor that limits the development of vegetation (Lawson, 1985) and the cultivation of crops. The long dry season (i.e., short rainy season) leads to the development of poorer vegetation in the region, compared to the high forest zone in the south of the country (Baker, 1962). Gallery or riparian forest is present along some sections of the rivers and streams in spite of the generally prevailing dry conditions in the region.

Soil properties such as moisture, nutrients and depth have been considered to be major factors that affect the distribution of savannahs alongside climatic and biotic factors (Cole, 1986, Lawson, 1985 and Hopkins, 1981). Many of the soils of the Upper West Region are so shallow and/or concretionary that they cannot store much water. Some also have low moisture-retention properties. A common phenomenon is the caking of some of the soils during the long dry season so that the first rains do not get the opportunity to infiltrate but run off (Lane, 1962). Such soils often support only stunted grasses and shrubs.

Cultivation and other human activities have resulted in the degradation of vegetation in the region, especially in the more densely populated western part (Agyepong *et al.*, 1999). However, the vegetation in the eastern part has been generally less disturbed than that of the other parts (Agyepong et al., 1999). Annual bush fires contribute to the present state of the vegetation.

3.1.4.1 Vegetation type

Figure 3.6 depicts the vegetation of Ghana. The vegetation of the Upper West Region is mainly mid-dry savannah, with only small isolated areas being wet savannah and dry savannah (Menz and Bethke, 2000). The mid-dry savannah and wet savannah correspond to Guinea savannah, as shown in Figure 3.7 (Taylor, 1952; Baker, 1962; Hopkins, 1981 and Lawson 1985). Guinea savannah occurs in areas where rainfall is between 900 and 1500 mm per year, with nearly all the rains falling over 5 to 6 months and the rest of the year being dry (Lawson, 1985, Hopkins; 1981 and Lane, 1962). Sudan savannah occurs in areas where the rainfall is between 600 and 900 mm per year and falls over 5 to 6 months. Mean rainfall values of more than 1300 mm per annum with a short dry season favour the development of high forests (Lawson, 1985). The Upper West Region receives, on average, between 900 and 1150 mm of rainfall annually and experiences a dry season of 5-6 months and is therefore classified as Guinea savannah (Figure 3.7). The northern fringe of the region along the border of Burkina Faso is transitory to the Sudan Savannah Zone (Lawson, 1985), since it receives an average of 800 to 900 mm of rain per year.

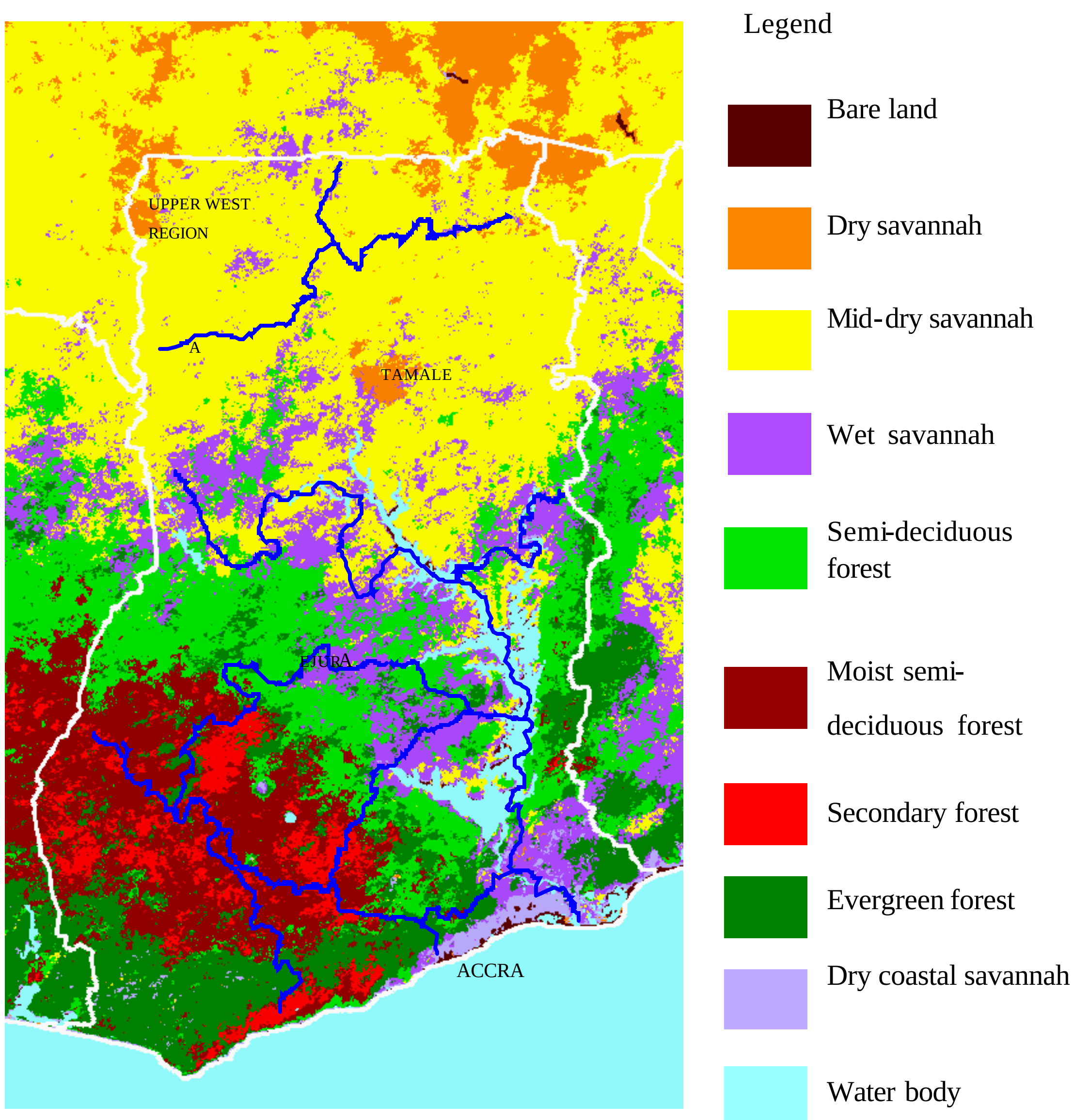


Figure 3.6: Vegetation map of Ghana (*Source: Menz and Bethke, 2000*)

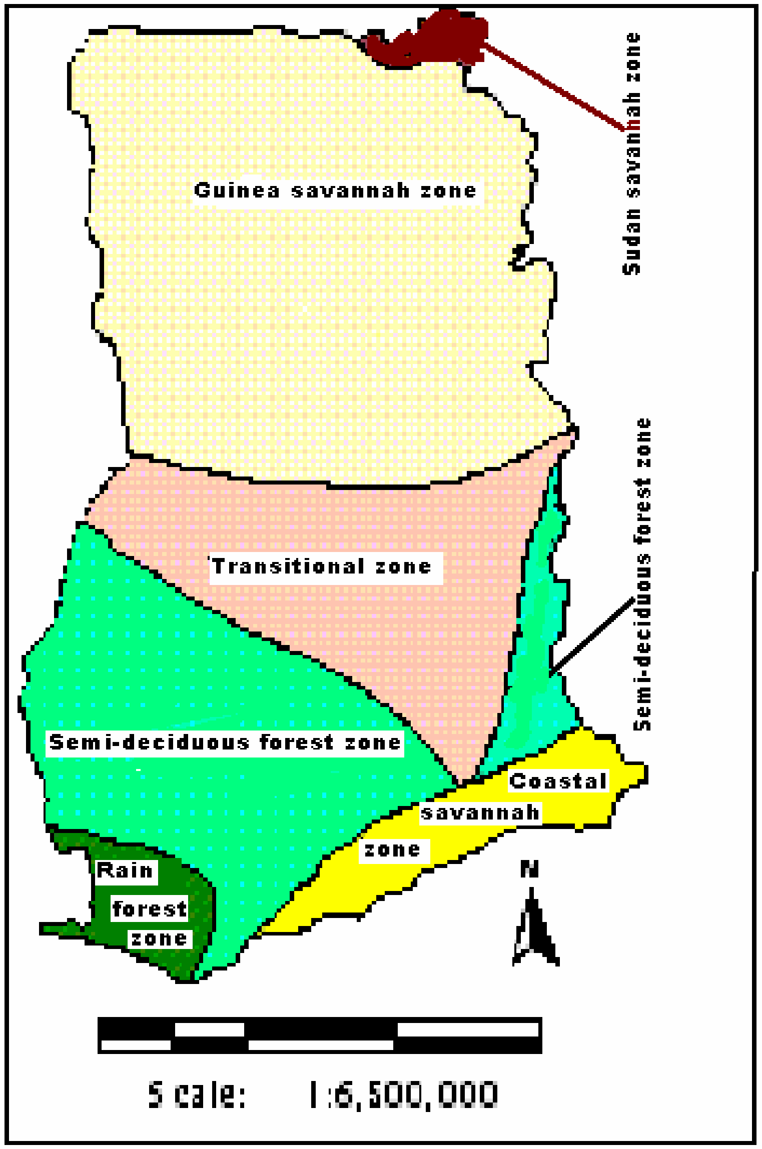


Figure 3.7: Ecological zones of Ghana (*Source: Taylor, 1952*)

3.1.4.2 General description of the vegetation

Lawson (1985), Dickson and Benneh (1988) and Wills (1962) have described the vegetation of the Guinea savannah zone as grassland with smaller or shorter deciduous fire-resistant widely spaced branching trees. Cole (1986) and Stout (1991) have defined savannah as a tropical physiognomic vegetation type that consists of a continuous grass stratum usually with a discontinuous stratum of either trees or shrubs. Observation in the field, however, indicates that there is actually no pure grassland in the Upper West Region. What pertains can be described as a mixture of grasses and shrubs. However, there are isolated areas of grass cover, which are mostly fallowed or degraded areas and woodlands with varying tree density. Typically, many of the trees are less than 16 meters tall and scattered without a closed canopy in many places, enabling sufficient light to reach the ground for the growth of grass and shrubs as long as there is soil moisture (Lawson, (1985).

Some grass species may reach a height of about 3 meters (Lane 1962), while the shrubs are of variable heights depending upon species and age. The grasses characteristically grow in tussocks, which are spaced out (Hopkins 1962). The riparian or fringing forests along the edges of the rivers and streams, as well as the low-lying areas, tend to have a different type, or at least a more luxuriant form, of vegetation from those of the higher lands (Lawson, 1985). In some areas such as in forest reserves and uninhabited areas, the tree population is relatively dense (Adu, 1995). On poor shallow soils underlain by iron pan, a more open and stunted vegetation occurs with shorter grasses (Lane, 1962).

The tree species have developed thick barks and the ability to reproduce from dormant buds or through root suckers (Lawson, 1985). These constitute an adaptation against frequent bushfires. In many parts of the region, especially the western and central parts, the landscape is characterized by a mosaic of cultivated land and secondary regrowth at different stages. During the dry season, most of the savannah trees lose their leaves, which is a mechanism to conserve systemic water that would otherwise be lost through transpiration. The grasses, on the other hand, become patched and are often burned so that towards the end of the dry season, the savannah appears rather stark blackened, which makes remotely sensed images difficult to interpret. The vegetation is made up of different species, which are difficult to differentiate by remote sensing due to image resolution, as well as to the complexity and heterogeneity of the landscape.

3.1.4.3 Tree species

The Guinea savannah trees are generally broad-leaved species, which are, on average, about 12-16 meters high. In places where the vegetation has not been disturbed or slightly cultivated, they form an almost closed canopy of branches (Lawson, 1985). The commonest trees include *Lophira lanceolata, Afzelia africana, Anogeissus leiocarpus, Borassus aethiopum, Butyrospermum paradoxum, Parkia clappertoniana, Daniellia oliveri, Adansonia digitata, Acacia albida, Hymernocardia acida, Parinari plyandra*

Pterocarpus erinaceus, Terminalia glaucescens, Vitex doniana, Isoberlinia tomentosa, Terminalia avicennoides, Terminalia macroptera, Monotes kerstingii, Uapaca toensis and *Isoberlinia doka.* On poorly drained sites, the common trees include *Mitragyna inermis, Combretum species, Lannea species, Gardenia species and Pseudocedrala species.*

Trees of economic importance are left on farmlands. These include *Afzelia africana* (mahogany bean), *Butyrospermun paradoxum* (shea tree), *Daniellia oliveri* (Africa copaiba balsam), *Parkia clappertoniana* (African locust bean) and *Vitex doniana* (black plum) (Hopkins, 1981). These trees, especially the shea species, may become so numerous in some places as to give an unrepresentative picture of the normal vegetation (Lawson, 1985). Weeds and sucker regrowth are removed by hoeing during cultivation. When the land is left to fallow they are left unchecked and regrow. *Butyrospermun paradoxum* (shea tree), *Daniellia oliveri* and *Lophira lanceolata* are particularly important species in this respect. A distinct continuous and uniform sucker regrowth stratum indicates previous cultivation. A prolonged sequence of alternating farming periods and bush fallows leads to a considerable decrease in the number of trees and those that do remain are confined to the useful species. If, however, the area is not re-farmed, the vegetation gradually changes into mature secondary savannah woodland, which may take about 50 years. (Hopkins, 1981).

3.1.4.4 Grasses

The ground vegetation cover is composed of different species of grass and shrubs of varying heights. The heights of the grasses generally range between 1.5 and 3m. Asiamah and Senaya (1988) identified *Andropogon gayanus var. bisqumulatus* and *Andropogon var. bisquanulatum sub. Var. argyrophues* as the main species in the tall-grass association. These may attain heights of 2.4 – 3 m and are often seen on the deep well-drain soils. On fallow lands, these grasses are grazed by cattle **(**Titriku, 1982). The short *Andropogon pseudapricus* may reach 15 to 60 cm high. Other grass types include *Diectomis fastgiat, Loudetia togoensis, Pennisetum pedicellatum, Pennisetum polystachyon, Hyparrhenia* species and *Heteropogon contortus*. The short grasses are commonly found on eroded low-lying nearly level ironpan sites. *Cymbopogon giganteus, Hyparrhenia rufa, Schizachyrium semiberbe, Sporobulus species, Aristida kerstingii, Chloris species* and *Imperata cylindrical* are also common.

Shrubs may include small offshoots of the bigger tress, such as *Butyrospermum species*, *Afzelia africana, Daniellia olivera*, and *Vitex doniana*. The common shrubs include *Deterium senegalensis, Gardenia erubeescens and Ximenia americana*.

3.1.4.5 Categorization of the vegetation

Physiognomically, the Guinea savannah and the Sudan savannah are characterized as (1) savannah woodland, when the trees and shrubs form a canopy, which is generally light, (2) tree savannah, when the trees and shrubs are scattered, (3) shrub savannah, when trees are absent and (4) grass savannah, when both trees and shrubs are absent (Hopkins, 1981). Lawson (1985) has described Guinea savannah as parkland savannah, when the trees are in clumps, and as orchard savannah when there are small evenly spaced trees.

However, for the purpose of mapping by visual interpretation of remotely sensed data, Agyepong et al. (1999) categorized non-cultivated areas in the savannah into (1) closed savannah woodland, when the tree population density is more than 150 trees per hectare, (2) open savannah woodland, when the tree population density is between 75 and 150 per hectare, (3) widely open savannah woodland, when there are 10 to 75 trees per hectare, (4) savannah grassland with scattered trees, when the landscape is composed predominantly of grasses interspersed with scattered trees up to 10 trees per hectare and (5) riverine vegetation, when the vegetation is found along rivers or streams.

In this study, the categorization of Agyepong *et al.* (1999) has been revised to facilitate supervised classification of remotely sensed data. The revised categories are (1) closed savannah woodland (Figure 3.8), (2) riparian vegetation (Figure 3.9), (3) open

Figure 3.8: Closed savannah woodland

Figure 3.9: Riparian (riverine) vegetation

Figure 3.10: Open savannah woodland

Figure 3.11: Mixture of grasses and shrubs with scattered trees

savannah woodland with shrubs and grasses (Figure 3.10) and (4) mixture of grasses and shrubs with scattered trees (Figure 3.11). The in-depth description of these classes is given under "Classification Schemes" in Chapter 4.

3.1.5 Soils

The soils of the region are closely related to its underlying geology, which is made up largely of granite, and in isolated places, of Birrimian rocks and sandstone. The granites are known to produce loamy sand or sandy loam or sandy clay loam on weathering

(Senaya et al., 1998). The Birrimian rocks are phyllites, greywackes and quartz sericite schist, which weather to produce sandy clay to clay soils with common to many quartz gravels and stones occurring in the surface layer (Senaya et al., 1998). Areas with sandstones also produce sandy soils. The soils are, therefore, generally sandy loams, sandy clays, loamy sands, or sandy clay loams. In many places they are shallow and underlain by iron pans and can also be concretionary. Differences in soil-hydrological conditions along slopes lead to the development of different but related soils from the summit to the bottom or valley, which is referred to as soil catena (Ahn, 1970). The upland soils are generally very sandy. The clay content of the soil increases down slope. The valley bottom soils have very high clay content and may be difficult to till.

3.1.5.1 Soil types

Figure 3.12 shows the major soils of the region, as mapped by Adu (1995). These include Dystric Leptosols, Calcic Vertisols, (1) Varempere *series* (Ghana) or Ferric Lixisols (FAO) or Typic Kandiustalf (USDA), (2) *Puga series* (Ghana) or Eutric Plinthisol (FAO) or Typic Plinthustalf (USDA), (3) *Tafali series* (Ghana) or Gleyic Lixisol (FAO) or Aeric Enduaqualf (USDA), (4) *Kolingu series* (Ghana) or Ferric Luvisol (FAO), (5) *Wenchi series* (Ghana) or Lithic Leptosol (FAO), (6) *Hilum series* (Ghana) or Lithic Leptosol (FAO), (7) *Pusiga series* (Ghana) or Eutric Leptosol (FAO), (8) *Kupela series* (Ghana) or Eutric Gleysol (FAO) or Typic Etropaqueft (USDA), (9) *Bianya series* (Ghana) or Gleyic Luvisol (FAO) or Albic Natraqulf (USDA), (10) *Bianya series* (Ghana) or Gleyic Luvisol (FAO) or Albic Natraqulf (USDA) and *Dorimon series* (Ghana). The spatial distribution of the major soils of the region is shown in Figure 3.12. north of the country were not developed. This is the main reason why northern Ghana is so far behind the rest of the country in terms of economic development (Dickson and Benneh, 1988).

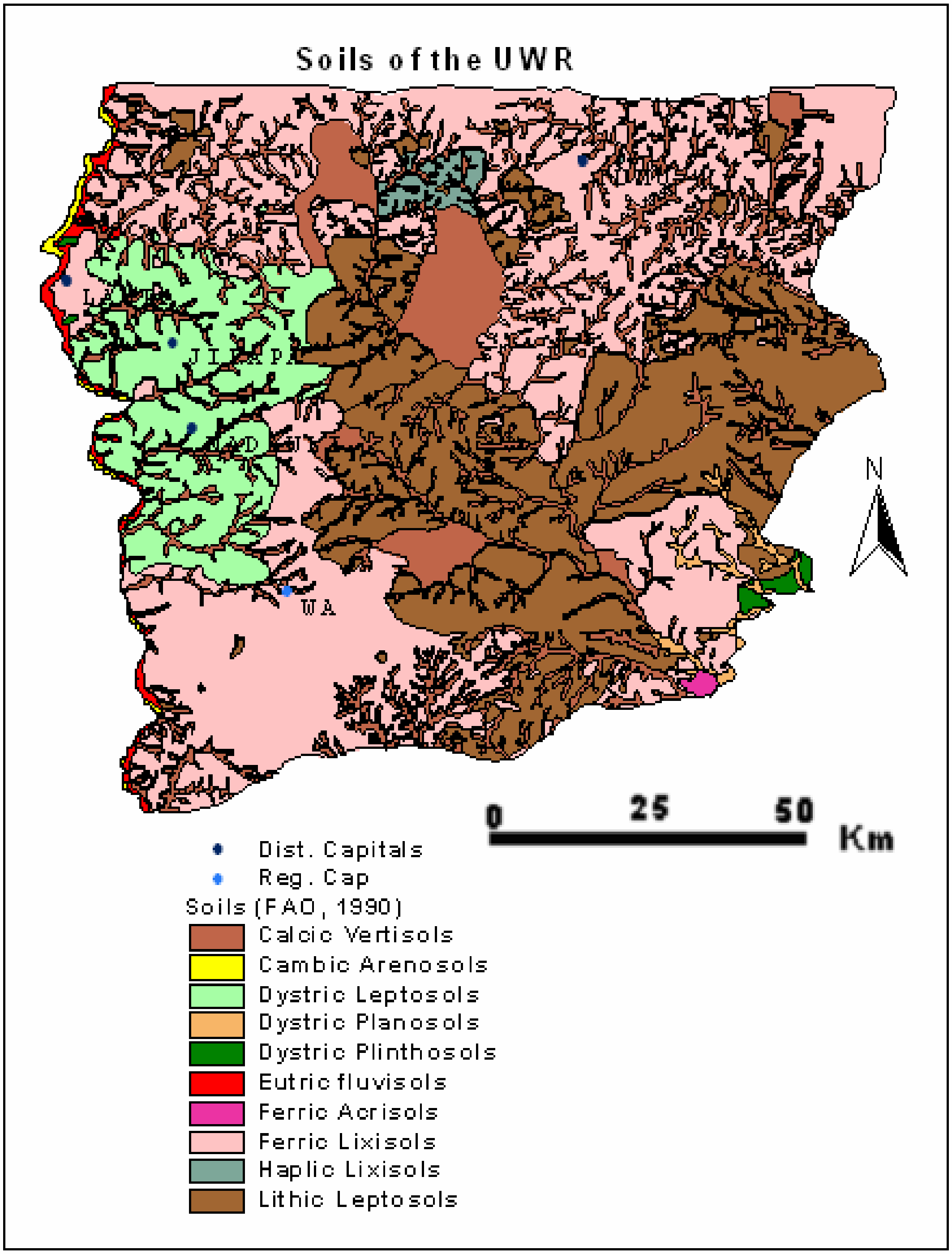


Figure 3.12: Distribution of major soils of the Upper West Region (UWR)
(*extracted from the Soil map of Ghana (SRI, 1999*)

3.2.2 Population

The total population of the Upper West Region, according to the 2000 Census, is 576,583, which is only about 3.14 % of the country's population of 18,357,382, making it the region with lowest population (Table 3.1 and Figure 3.13) (GSS, 2000). The population density is 31.2 inhabitants km^{-2} compared with the national density of 93 km^{-2}. The region is, thus, the second most sparsely populated region in Ghana after the Northern Region, which has a population density of 25.9 km^{-2} (Table 3.1 and Figure 3.13).

Table 3.1: Regional population distribution of Ghana (2000) (*Source: GSS, 2002*)

Region	Total population	Sex		Rural	Urban	% National	% Urban	Density	Males/100 Females	% Increase	Growth Rate
		Male	Female								
W.R	1,924,577	978,176	946,401	1,226,159	698,418	10.2	36.3	80.5	103.4	66.2	3.2
C.R.	1,593,823	760,221	833,603	995,418	598,405	8.4	37.5	16“	91.2	39.5	2.1
GA	2,905,726	1,436,135	1,469,591	358,042	2,547,684	15.4	87.7	89&	97.7	103	4.4
VR	1,635,421	790,886	844,535	1,194,337	441,084	8.6	27.0	79.5	93.6	34.9	1.9
ER	2,106,696	1,036,371	1,070,325	1,38,782	27,914	11.1	34.6	109	96.8	25.3	1.4
AR	3,612,950	1,818,216	1,794,734	1,759,885	1,853,065	19.1	51.3	148	101	72.9	3.4
BA	1,815,408	911,263	904,145	1,136,628	678,780	9.6	37.4	45.9	101	50.4	2.5
NR	1,820,806	907,177	913,629	1,33,016	483,790	9.6	26.6	25.9	99.3	56.3	2.8
UE	920,089	442,492	477,597	775,807	144,282	4.9	15.7	104	92.6	19.0	1.1
UW	**576,583**	**276,445**	**300,138**	**475,735**	**100,848**	**3.0**	**17.5**	**31.2**	**92.1**	**31.6**	**1.7**
Ghana	18357382	9357382	9554697	10637809	8,274,270	100	43.8	9.3	97.9	53.8	2.7

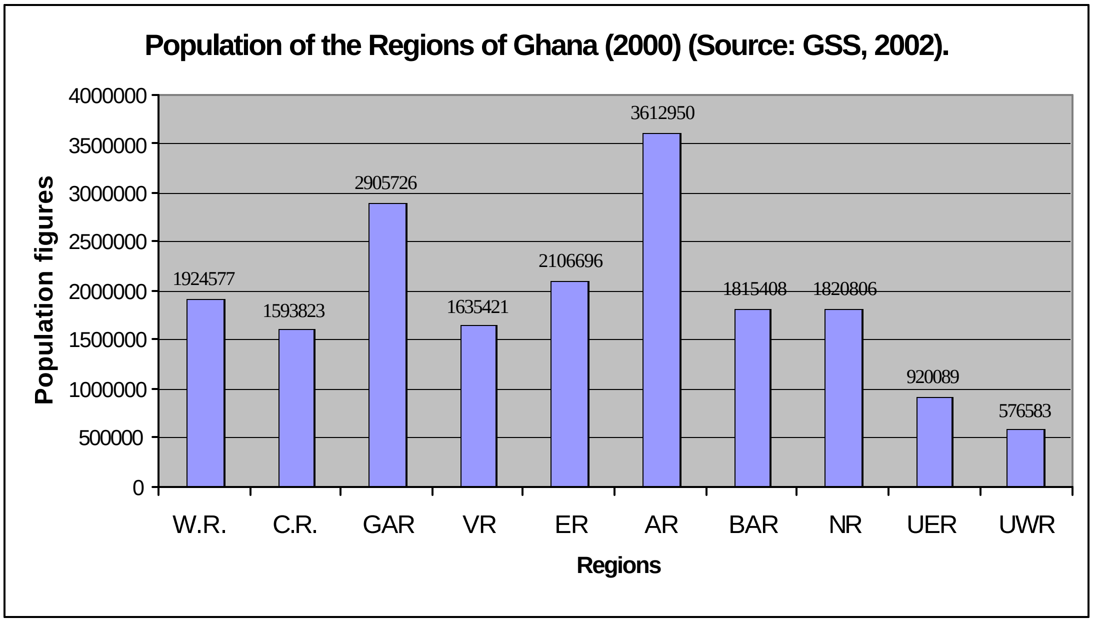


Figure 3.13: Population of the Regions of Ghana (2000) (Source: GSS, 2002)

Figure 3.14 shows the comparison of the population figures of the region for 2000 (576,683) and 1984 (438,000). It shows an increase of about 31.6% within 16 years at a

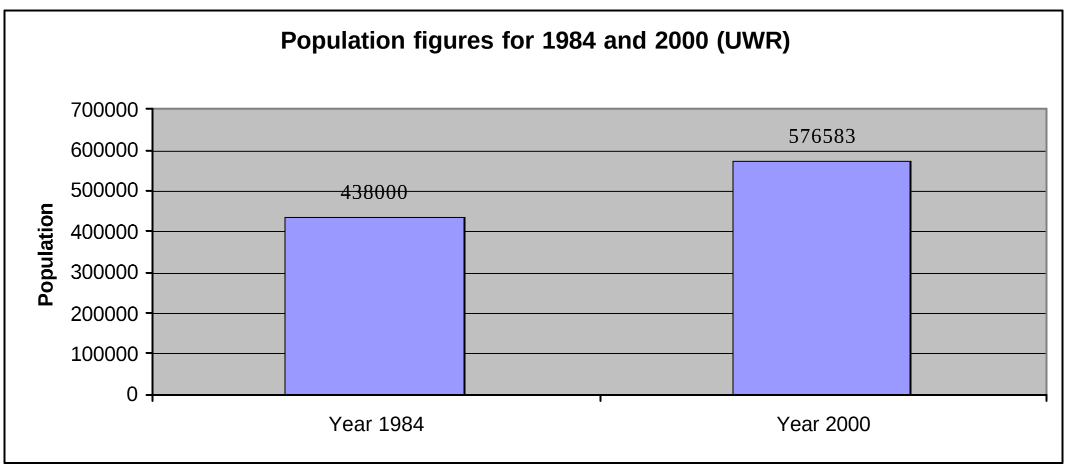


Figure 3.14: Comparison of the population of the Upper West Region (1984 and 2000) (*created from GSS data: GSS,2002*)

growth-rate of 1.7% against the national rate of 2.7%. Projection in 1984 indicated a population increase to about 632,850 by 2000. This means that the actual population fell short of the projected value by about 9.8%.

3.2.2.1 Population distribution

The population is largely rural (475,735), with only 100,848 people living in urban areas. Figure 3.15 compares the rural-urban population distribution and density for

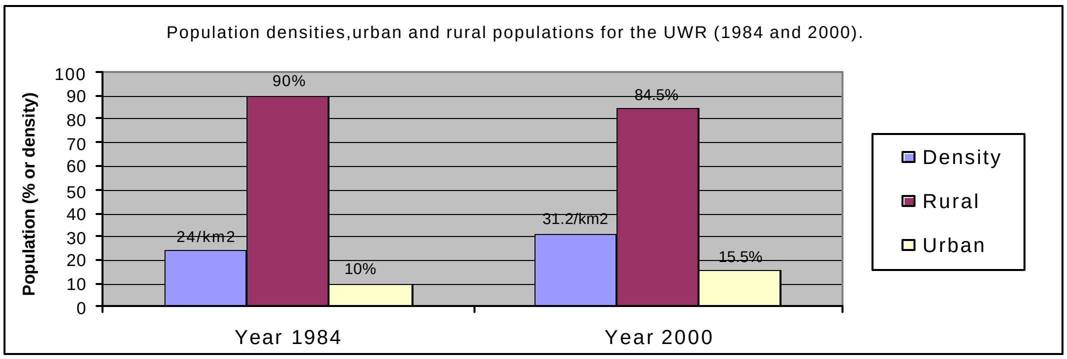


Figure 3.15: Population densities, urban and rural populations (UWR, 1984 and 2000) (created from GSS data: GSS, 2002)

1984 and 2000 (GSS, 2000 and 1984). It shows that in 1984, 90% of the population was rural and 10% urban, while in 2000 the corresponding figures were 84.5% and 15.5% respectively. The overall regional population density was 24 inhabitants km^{-2} for 1984 against the 2000 figure of 31.2 km^{-2}. Table 3.2 and Figure 3.16 show the population

Table 3.2: Population (2000) by districts of the Upper West Region (GSS, 2002)

District	Total populatio	Males	Females	Rural populatio	Urban populatio	Usual Res. pop	%Total pop.	Total populatio	Males/100 Females
Wa	224,066	109,627	114,439	157,422	66,644	233,166	38.9	29.7	95.8
Nadowli	82,716	39,35	43,341	82,716	-	100,019	14.3	-	90.8
Sissala	85,442	41,141	44,301	76,584	8,858	89,114	14.8	10.4	92.9
J.Lamb.	96,834	45,500	51,334	83,529	13,305	104,783	16.8	13.7	88.6
Lawra	8,525	40,802	46,723	5,484	12,041	95,080	15.2	13.8	87.3
Region	**576583**	**276445**	**300138**	**475735**	**100848**	**622162**	**100**	**17.5**	**92.1**

distribution in the region by districts. Appendices 9.3-9.8 show the distribution within the districts and major settlements of the region.

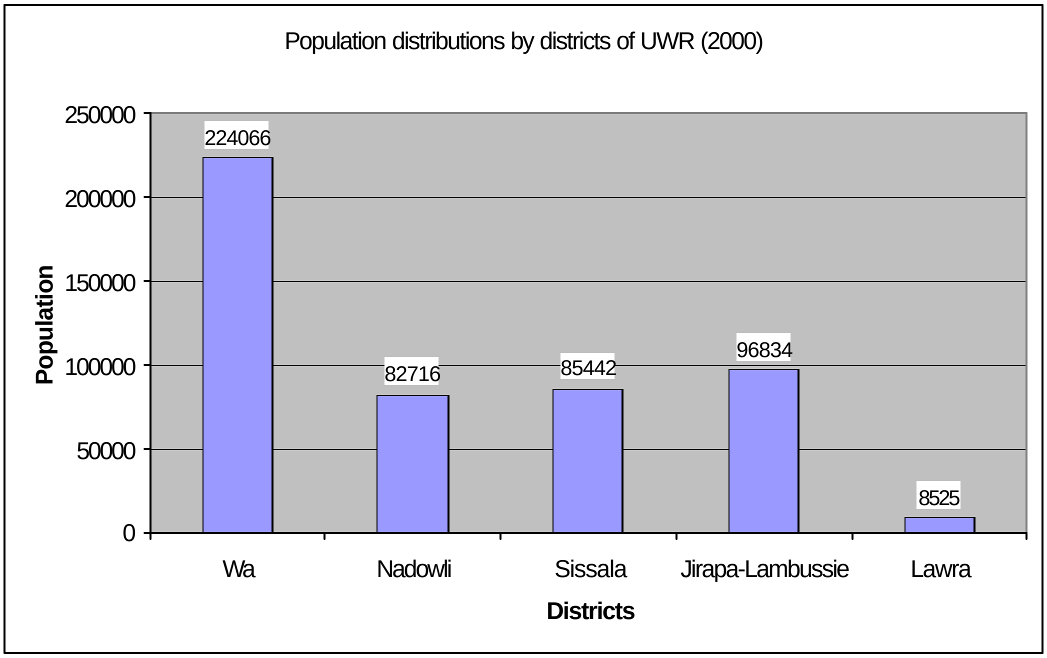


Figure 3.16: Comparison of the populations of the districts of the Upper West Region (2000)

The population density figures given can be said to be rough, because within the region population density varies from one locality to another, and even though the region is known to be generally sparsely populated, there are areas where the population density may be close to 50 persons km^{-2} as against the average population density of 31.2 km^{-2}. The Lawra and Jirapa-Lambusie Districts (in the northwest) and some localities of the Wa District have moderately high population densities (generally about 50 or more persons km^{2}). The Sissala District has a low population density of less than 9 persons km^{-2} (GSS, 2000). The basic reasons for the concentration of population in the northwest corner of the region are historical. In historical times, this area was militarily strong and relatively stable and could therefore resist invasions. Therefore, many refugees from neighbouring weaker tribes migrated there for protection (Dickson and Benneh, 1988). This has now resulted in over-population of the northwest resulting in considerable pressure on the land, which is causing soil degradation (Benneh and

Agyepong, 1990 and Asiamah and Senaya, 1988). Some of the farmers have, therefore, started moving eastward, where land is more fertile and readily available.

According to Dickson and Benneh (1988), the low population in the Sissala District and the eastern part of the region is due to depopulation in historical times as a result of wars, slave raids and the presence of the simulium and tsetse flies. The tsetsefly, which causes diseases to both human and livestock, has now been controlled (Dic kson and Benneh, 1988) and farmers have started moving there.

3.2.2.2 Population and economic activities

The industries of the region are rural or cottage industries. There are no large industrial manufacturing plants there. Table 3.3 and Figure 3.17 (GSS, 2002) show the main

Table 3.3: Occupation of economically active population (7+ years) (GSS, 2000)

	Econ. active (7yrs+)	**%**	**Male**	**Female**
Agriculture, hunting/forestry	225,688	75,37	118979	106709
Fishing	1,465	0,49	678	787
Mining and quarrying	2963	0,99	1343	1620
Manufacturing	23834	7,96	5622	18212
Electricity, gas and water	640	0,21	340	300
Construction	4047	1,35	2934	1113
Trading (wholesale and retail)	12505	4,18	4471	8034
Hotels and restaurants	2459	0,82	504	1955
Transport/storage/ commerce	3870	1,29	2617	1253
Financial intermediation	815	0,27	482	333
Real estate / business activity	876	0,29	507	369
Public administration	1794	0,6	1331	463
Education	6523	2,18	3953	2570
Health and social work	1936	0,65	928	1008
Other community services	4920	1,64	2010	2910
Private households	4866	1,63	1308	3558
Extra-territorial organizations	233	0,08	99	134
TOTAL	**299,434**	**100**	**148106**	**151328**

economic activities in the region. The most prominent economic activity is agriculture (mainly rain-fed and only few irrigated areas), which, together with hunting and forestry, engages a little over 75% of the economically active population. The large proportion of the population in agriculture has important implications for the vegetation as cultivation and grazing by cattle involves its removal or degradation. Cottage manufacturing industries, such as the manufacture of traditional goods (clothes, baskets, bags, furniture, pots, etc.) and trading (wholesale and retail) engage nearly 8% and some 4% of the economically active population respectively. About 2.18% of the population is engaged in various educational activities. Each of the other socio-economic activities, except education, engages around 2% or less of the economically active the population.

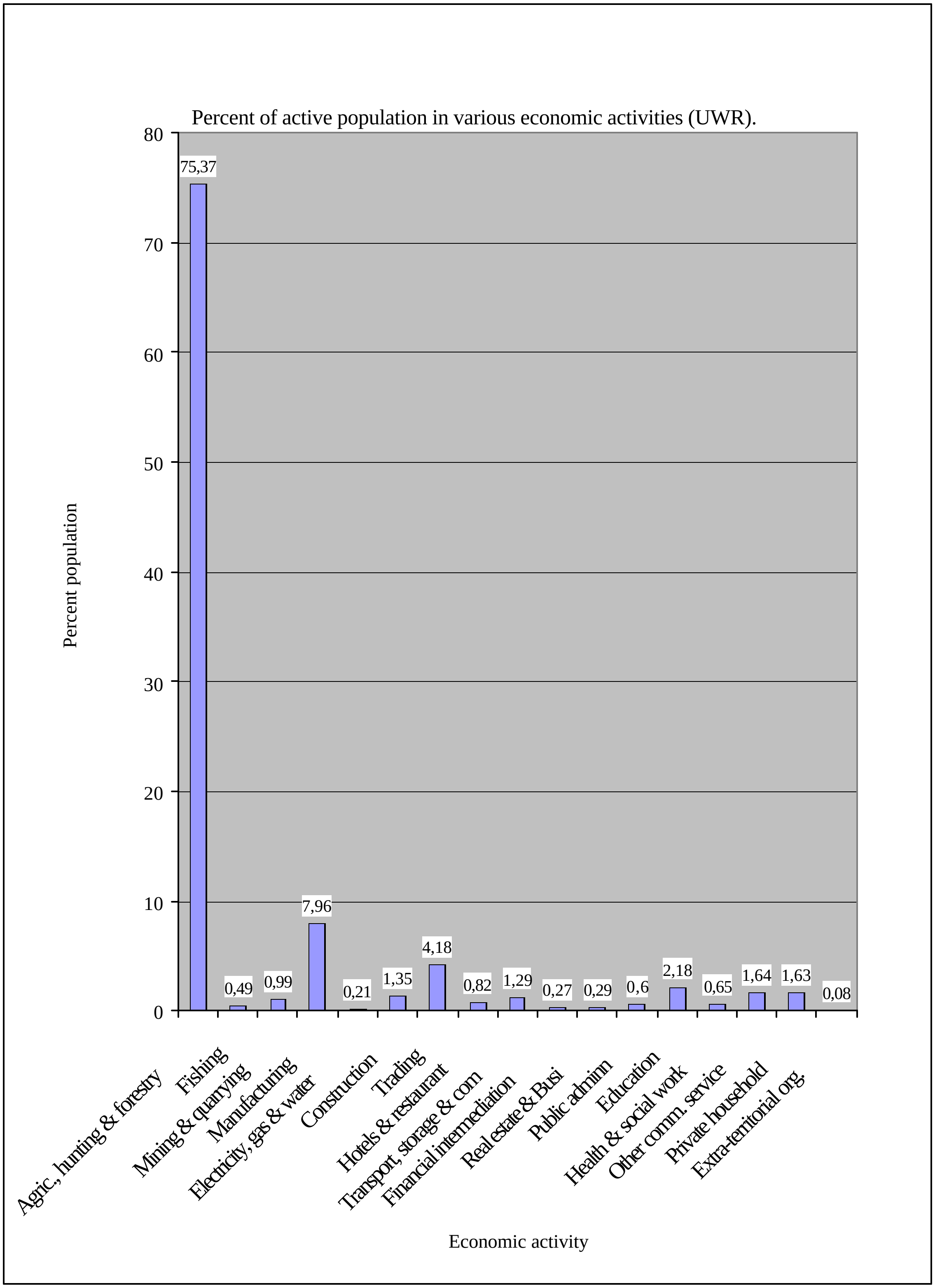


Figure 3.17: Proportion of active population in various economic activities (UWR)
(*Created from data from GSS, 2002*)

3.2.3 Land use and farming systems

The major land use in the region is agriculture, which comprises the cultivation of staple grains (cereals and legumes), vegetables, root and tuber crops, as well as the rearing of livestock (cattle, sheep, goats, pigs and donkeys) and poultry (chicken, guinea fowls, turkeys and ducks) (Benneh and Agyepong, 1990). Except under irrigation, the crops cultivated in the region are determined by the quantity and distribution of rainfall (Wills, 1962 and Dickson and Benneh, 1988). Because the region has marked wet and dry seasons, only crops that are able to complete their life cycles during the rainy season, can be cultivated without irrigation. This explains why farmers in the Upper West Region and the rest of northern Ghana, where the rainy season lasts for about 5 to 6 months of the year, do not cultivate the traditional tree crops, such as cocoa, coffee, rubber, kola, citrus, oil palm, plantain/banana, etc. that are grown in the high forest zone in the south. The crops grown in the region are therefore annual crops (SRI, 1999).

The cereals include millet, maize, sorghum (guinea corn) and rice, while the legumes include cowpeas, groundnuts and bambara beans. The root and tuber crops are cassava and yams. The crops are mostly produced on a subsistence level. In years of good harvests, peasant farmers may sell yields in excess of the need of their households. There is, however, a small percentage of the farmers that grows crops on a commercial scale. Almost all the crops produced in the region are consumed there. Sometimes, especially when crops fail or do not perform well due to rainfall unreliability or inadequacy, food has to be imported into the region from other parts of the country.

Herds of livestock (usually cattle) are kept free-range and only housed during the night. Goats, sheep and pigs are produced for both domestic and commercial purposes. Cattle production is more commercial- than subsistence-based. After the farming season in November, herds of animals, mainly cattle, are let loose to graze the crop residues and stubble of the crops. These animals wander afar into the fallow lands to graze and to the rivers and ponds to drink. In some localities, the animals cater for themselves in this way until the next cropping season, when they are again confined to their kraals (Titriku, (1982). Most of the country's livestock is reared in the savannah areas, including the Upper West Region (Benneh and Agyepong, 1990). The virtual elimination of tsetse flies in the region has also led to increased livestock rearing as a major occupation in the north. During the long dry period, there is usually an influx of Fulani herdsmen to the area from Mali, Niger and Burkina Faso to graze their cattle

(Asiamah and Senaya, 1988). The presence of the large herds puts a great deal of stress on the environment as the herdsmen tend to set fire to the dry old vegetation in order to facilitate the growth of succulent young vegetation for the animals. There are a few big commercial poultry farms. It is a common practice for each household to keep a few birds for subsistence purposes and occasionally for the market.

Soil fertility has declined in many areas of the region, especially in the west (Titriku, 1982, Asiamah and Senaya, 1988). This has serious implications for the production of crops. Field observation and interaction with farmers have revealed that, as a result of the decline in soil fertility of the soils in the western part of the region, cultivation is now shifting to the eastern part. The number of herdsmen is also increasing in the area. This is leading to the clearing and degradation of the primary woodland.

3.2.3.1 Farming systems

The farms are largely smallholdings of approximately one hectare or more (sometimes less) and are usually mixed cropping or monocropping systems. The type of crops grown in the Upper West Region are the same throughout the region, but the land is often rotated, in that a farmer cultivates a given plot of land for a couple of years and then abandons it under the traditional bush fallow system for a new one (Wills, 1962). The farm landscape is thus a mosaic of cultivated land, fallow regrowth (at various stages of growth) and natural vegetation (Sakyi-Dawson, 2000).

Field observations and reports by Titriku (982) indicate that in many places, the crops are planted on mounds or ridges so as to raise their rooting zone above stagnant water during the peak of the wet season. This is done because in many places the nearly-flat topography and the underlying lateritic subsoil layers, which impede percolation of water, cause flooding to occur during heavy rains (Titriku, (1982). The practice of preparing mounds and ridges tends to promote accelerated erosion while control measures are practically nonexistent (Titriku, 1982). Continual raising of mounds and ridges on the same plot year after year and re-earthing of the crop during the growth period increase the loss of the top soil and expose subsoil plinthite to the atmosphere. The subsoil then hardens irreversibly into ironpan, thereby degrading the soil and causing its fertility to decline (Titriku, (1982).

3.2.3.1.1 Bush fallow cropping

The bush fallow farming system is common in the Upper West Region, where availability of land for farming is not a problem. In this farming system, the farmer relies on natural regrowth fallow to restore the fertility of the soil (Wills, 1962 and Nye, 1960). He cultivates a piece of land for a few years and abandons it for another piece of land when he notices a decline in the fertility of the soil. The length of the fallow period (i.e., the period it takes the farmer to return to cultivate the fallowed land again) depends on the availability of land. The degree of fertility restoration is dependent on the length of the fallow and its composition (Wills, 1962). The bush fallow farming system also controls certain difficult types of weed such as lalang or spear grass (*Imperata cylindrical*) (Wills, 1962 and Nye, 1960). Agyepong *et al.* (1999) mapped the spatial distribution of bush fallow farming systems of the Upper West Region as at 1990 (Figure 2.2 in Chapter 2). These systems included the short bush fallow farming system, long bush fallow system, and the compound farming system.

3.2.3.1.2 Intensity of cultivation

The susceptibility of the land to degradation is influenced not only by the farming practices, but also by the intensity of cultivation, which is indicated by the length of the fallow period. Nye and Greenland (1960) and Ruthenberg (1980) have suggested that adequate fallow periods in the savannah ecological areas should be 15 years. Agyepong *et al.* (1999) used 3 years as the cut-off between short and long fallows, with those up to 3 years referred to as *short fallow* and those more than three years *long fallow*.

Land rotation or bush fallow farms are usually located some distance away from the settlements (Sakyi-Dawson, 2000). At any particular site, the farms of an individual may be interspersed with those of other farmers, giving rise to a mosaic pattern of land ownership with no characteristic shape of fields (Sakyi-Dawson, 2000). Fallow periods, which used to range between 6 and 10 years, have been shortened over the past two decades to 2-3 years in relatively dense population areas, such as the Lawra, Nandom and Jirapa areas, leading to a decline and deterioration of the cultivated soils and hence poor yields (Sakyi-Dawson, 2000). The practice of burning of litter, which is associated with the bush fallow system, exposes the soil to the sun and torrential rains until the first crop forms an effective protective cover. This hastens soil degradation.

3.2.3.1.3 Compound farming

This is another important farming system in the region (Wills, 1962). This land use system consists of the permanent cultivation by each family of the land immediately surrounding a homestead to its boundary with the adjoining homesteads (Wills, 1962). The settlements are dispersed and farming is continuous, with the use of household manures and animal droppings to maintain soil fertility (Wills, 1962). The crop sequence includes a deliberate inclusion of legumes like groundnut, cowpeas and bambara beans to help increase the nutrient status of the soil (Sakyi-Dawson). Compound farming areas are most common in the extreme northwest of the region (Lawra and Jirapa-Lambussie districts).

3.2.3.1.4 Mixed cropping and mixed farming

Mixed cropping is the cultivation of more than one type of crop on the same piece of land at the same time, usually in a seemingly haphazard mixture. Mixed farming is characterized by the combination of cultivation and animal husbandary. This farming practice is common throughout the region. It is a form of farming security, because the crops and animals have different levels of resistance to adverse conditions. For example, during periods of mild or short drought, which cannot be withstood by certain crops such as maize, sorghum is likely to be unaffected. In the same way, when all the crops fail, the animals may survive. It also has the advantage that the animals can be used for ploughing, carting and planting. The livestock and poultry droppings are also used to manure the soils (Ruthenberg, 1980 and Wills, 1962).

3.2.3.2 Land reservation

The traditional bush fallow system has been a powerful agent in the destruction of the vegetation (Thenkabail, 1999). In order to preserve some of the remaining vegetation, water resources and wildlife, reserves have been established (Figure 3.18). Reserved areas are those that have been set aside, gazetted and designated as areas with restriction on use. Those areas that are not subject to entry restrictions and the exploitation of products and resources by members of the community, are referred to as “open-access” land (Agyepong *et al.,* 1999).

Reserved areas are usually forest but may also include areas of savannah woodland, scrubland or grassland. The reserves serve many purposes including the

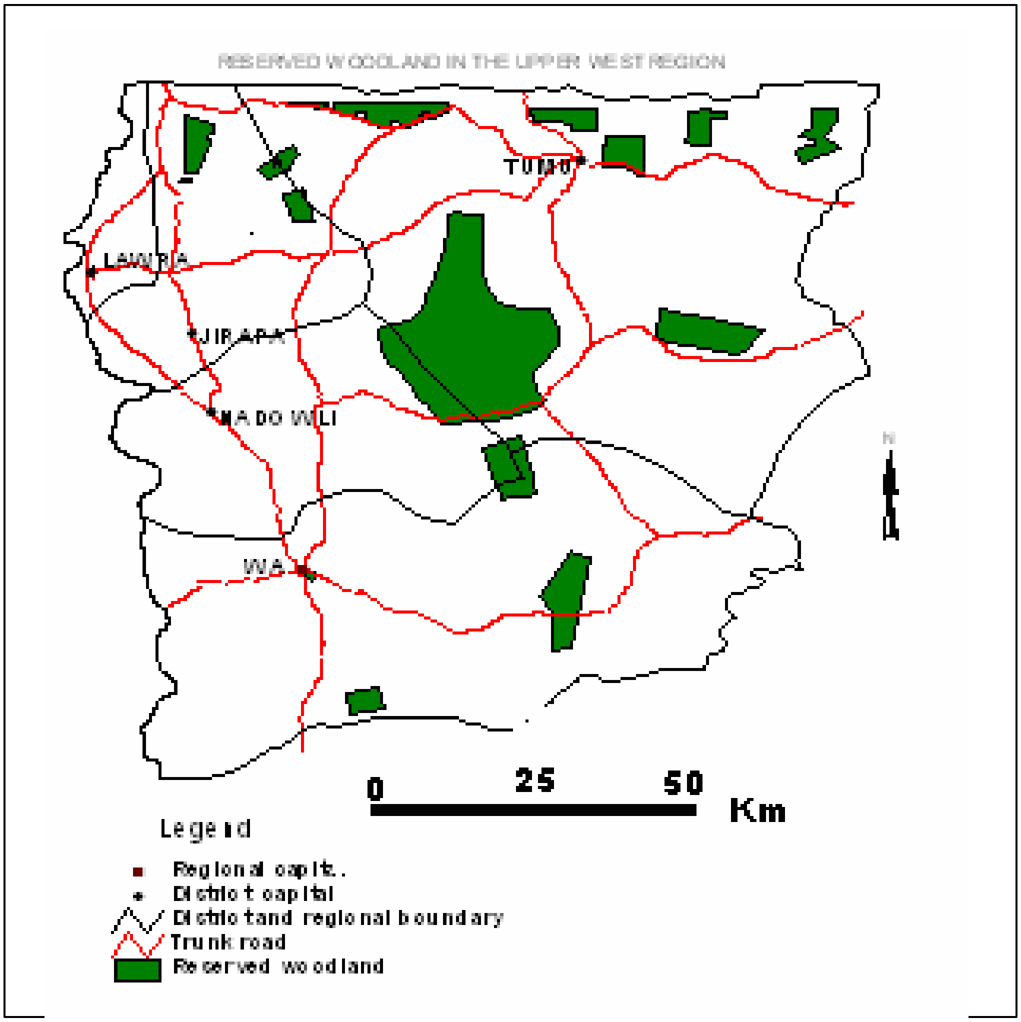


Figure 3.18: Reserved savannah woodlands, Upper West Region

protection of headwaters of rivers, checking of soil erosion and stopping of the advance of savannah vegetation (in case of forest regions) or desertification (in the case of savannah regions) and preservation of useful species of trees for future use as well as for biodiversity. Apart from these functions, some of the reserves, for e.g., the Gbele Reserve in the Upper West Region, have been designated hunting grounds during certain times of the year (Sakyi-Dawson, 2000). Only a few of the reserves in the Upper West Region, e.g., the Nuale Reserve near Yerebieyere, show clearly on LANDSAT images.

3.2.3.3 Gathering

Gathering is a common land use activity in Ghana (Wills, 1962) and is included in the Ghana land use and cover mapping scheme of Agyepong *et al.* (1999). It is important in the Upper West Region, and involves the collection of a wide variety of wild produce and wildlife from forests, savannah wetlands and water bodies, often for subsistence use, but increasingly for commercial purposes. The products include fruits (shea nuts, *dawadawa* and others), fuelwood and wood for construction, honey, medicinal herbs, fodder, thatch and game. Gathering is done in both the "open-access" and "reserved" areas. The practice of gathering cannot be directly interpreted from remotely-sensed data; it can only be inferred.

3.2.4 Settlements and infrastructure

A settlement with a population of 5000 or over is regarded as being urban and those with fewer persons, rural (GSS, 2000). Figure 3.19 shows the urban and some of the rural settlements connected by a network of roads. The main roads in the western and central parts of the region run north-south, while in the north they run west-east, providing a link with the Upper East Region. The Upper West Region is predominantly rural with only a few towns. These include Wa (the regional and district capital of the Wa District), Nadowli, Lawra, Jirapa and Tumu (district capital towns), Nandom, Lambusie and Hamile. Elsewhere, tracks join rural settlements to the main roads. The main road linking the southern part of the country has been tarred to Sawla in the Northern Region. The other tarred roads are the Wa-Nadowli-Lawra, Nadowli-Jirapa and the Wa-Han roads. The rest of the roads have only been gravelled.

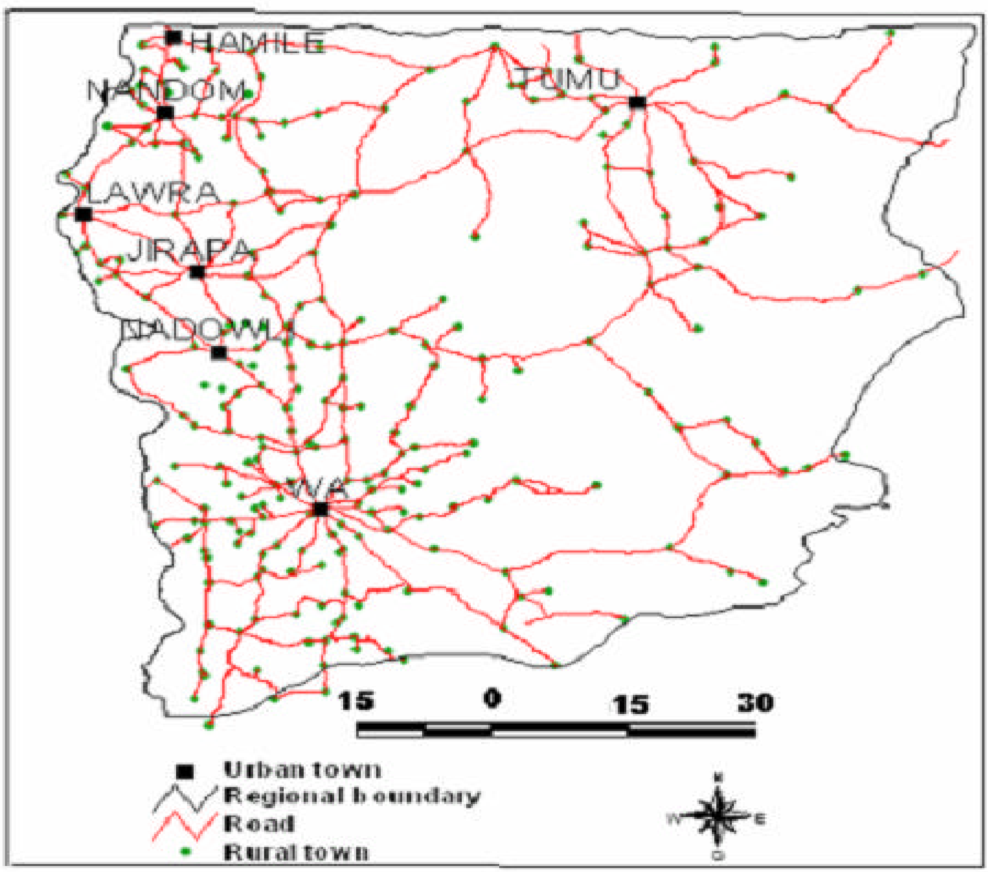


Figure3.19: Urban and rural settlements of the Upper West Region and their connecting roads (*created from Ghana Survey Dept. data*)

4 LAND USE AND LAND COVER CLASSIFICATION (Methods and Results)

This chapter describes the identification and selection of data types (images and ancillary data) that were used in the study, their pre-processing steps and classification results. It is therefore organized under three sub-headings, namely: (1) materials, (2) methods and (3) results.

4.1 Materials

4.1.1 Data type

The principal data sets used in the study were those of the LANDSAT Thematic Mapper (TM). This data type has been used for detailed land use and vegetation studies including change detection in different parts of the tropics by researchers such as Tucker and Townshend (2000), Foody and Hill (1996), Prakash and Gupta (1998) Purevdor *et al*. (1998) and Thenkabail (1999). Duadze *et al*. (1999) used LANDSAT TM data to manually classify the land use and land cover of Ghana. Other data sets used included (a) the *Ghana Land Use and Land Cover Classification Scheme*, (b) topographic maps at the scales of 1:50,000 and 1:250,000, (c) a geological map of Ghana, (d) climatic (rainfall) data and (d) a forest reserve and wildlife map of Ghana at a scale of 1:500,000. The equipment used included computers, digital cameras, global positioning systems (GPS) and plotters. The main image-processing programme used was ERDAS IMAGINE (1999).

The selection of LANDSAT TM data was based on the project implementation document of the GLOWA Volta Project. The decision by the GLOWA Volta Project to use LANDSAT images was guided by the use of the data type in a previous land use and land cover mapping of Ghana by the Remote Sensing Applications Unit (RSAU), now the Centre for Remote Sensing and Geographic Information Services (CERSGIS), Legon, Ghana, for the Ghana Environmental Resource Management Project (GERMP) during the period from 1996 to 1999. The RSAU's choice of LANDSAT TM images was based on the working document of the GERMP, which required that the lowest-costing high-resolution image per unit area be used. Supply bids submitted to the Environmental Protection Agency (EPA) (EPA, 1993), indicated that the lowest bid cost was $0.34 and $0.50 per square kilometer for LANDSAT TM and SPOT images respectively. Therefore, LANDSAT TM was selected (Duadze *et al*., 1999).

4.1.2 Seasonality of images

Landscape appearance, which influences the spectral response of features, varies from season to season due to variations in the growing cycle of plants and crops. This influences the accuracy of the classification of both agricultural and semi-natural cover features (Wright and Morrice, 1997). Thus, the choice of the appropriate season for the acquisition of images is important for distinguishing between the various vegetation classes in an image of a given area. Images of the same season of different years (anniversary images) minimize the changes in reflectance of a feature due to season (Yang and Prince, 2000 and Munyati, 2000). The use of dry-season images for mapping in savannah areas of Ghana enables clear discrimination of agricultural fields, constructed surfaces and bare land, which stand out clearly from the surrounding grassy, shrubby or woody areas or from burnt areas (Duadze *et al.*, 1999). Therefore, in this study, near-anniversary and dry-season (December to February) images were used. These were LANDSAT TM scenes of Path 195 and Rows 53 and 52 acquired on January 18, 1986; January 8, 1991 and January 12, 2000.

4.1.3 Classification scheme

The classification scheme used was an adaptation of the *Ghana Land Use and Land Cover Classification Scheme* designed by Agyepong *et al.* (1996), which was modelled on that of Anderson *et al*. (1976). It was designed for the visual interpretation of remotely sensed data. It does not completely suit supervised classification, e.g., by the use of the maximum likelihood algorithm. For example, most individual cultivated fields are too small and have diffuse boundaries to be delineated visually. Therefore, in visual classification, such cultivated fields and their adjoining fallow lands are mapped together and the intensity of cultivation is used to distinguish between short bush fallow cropping (high intensity of cultivation) and long bush fallow cropping (low intensity of cultivation) (Figure 4.2). It is not possible for supervised classification algorithms, e.g., maximum likelihood classifier, to make these deductions.

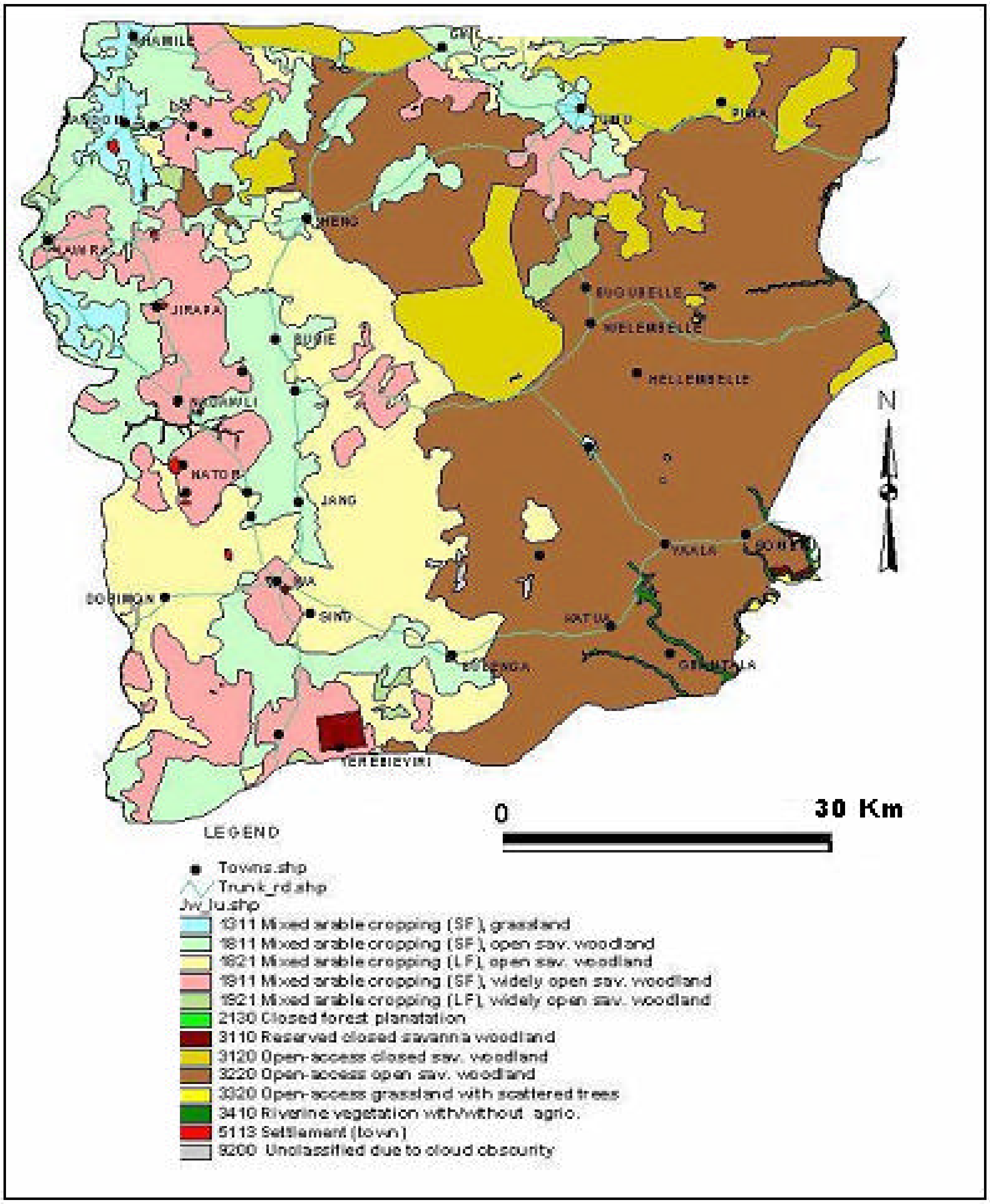


Figure 4.2: Land use and land cover (1991) of the Upper West Region (Ghana) produced by manual or visual classification (on-screen digitizing) (SF= short fallow; LF = long fallow)

The scheme was modified by the merging of some of the units. This facilitated consistent and repeatable reclassifications as recommended by Dai and Khorram (1998). For example, recently cultivated land, bare land and constructed surfaces, which could be delineated separately by visual classification (if large enough to be delineated), could not be discriminated by the maximum likelihood algorithm and were consequently mapped into one class designated *Farmland/bare land or constructed surfaces*. Similarly, closed savannah woodland and riparian vegetation (the closed and/or dense types) were placed into one category called *Closed savannah woodland/riparian vegetation*. Water bodies, which are mappable by visual interpretation into various sub-categories as rivers, lakes and reservoirs have been mapped collectively as *Water body* because it was difficult to separate them into the various sub-categories by the maximum likelihood classification procedure.

In addition, some of the classes in the *Ghana Land Use and Land Cover Classification Scheme* were revised in order to reflect better the landscape conditions. For example, *Open savannah woodland* has been re-designated. *Open woodland with grasses and shrubs*. Similarly, the category *Savannah grassland with or without scattered trees* has been modified to *Mixture of grasses and shrubs with scattered trees*.

4.1.3.1 Description of land use and land cover classes

Following the revision of the *Ghana Land Use and Land Cover Classification Scheme*, six broad land use and land cover classes were identified and mapped in the Upper West Region, using the maximum likelihood algorithm. These include:

1. Farmland/bare land or constructed surface
2. Closed savannah woodland/riparian vegetation
3. Open savannah woodland with shrubs and grasses
4. Mixture of grasses and shrubs with scattered trees
5. Reserved woodland
6. Water body

The classes are described as follows:

Farmland/bare land or constructed surface (code 100)

Farmland includes all pieces of land that are currently under crop cover, land that has been recently cultivated (within the past three years) or land that has been cultivated a longer time ago but has not yet regenerated into climax vegetation and shows traces of cultivation. Bare land is any part of the landscape that is not currently or has not been recently cultivated but is significantly devoid of vegetative cover to the extent that more than 50% of the soil surface is exposed. These are normally eroded surfaces but may also include expansive rock outcrop areas or quarries. Constructed surfaces include those portions of the landscape that have been used for the construction of cultural features such as roads, settlements and their component buildings, airstrips, etc.

Closed savannah woodland/riparian vegetation (coded 200)

This is made up of closed savannah woodland, which has more than 150 savannah trees per hectare, the trees being at least 5m tall. Riparian vegetation is usually made up of vegetation that grows along water bodies or in valley bottoms which are moist for a considerable period of the year. These include gallery forests and a mixture of shrubs and grasses with or without savannah trees.

Open savannah woodland with shrubs and grasses (coded 300)

This consists of savannah woodland with trees (about 75–150 per hectare) that are at least 5m tall with shrubs and grasses.

Mixture of shrubs and grasses with scattered trees (coded 400)

This class is made up of a mixture of shrubs and grasses interspersed with trees (about 0-75 per hectare) that are at least 5m tall.

Reserved woodland (coded 500)

Reserved areas are those that have been set aside, gazetted and designated as areas with restriction on use. Reserved areas are usually forest or woodland but may also include areas of scrubland or grassland.

Water body (coded 600)

Water bodies include any continuous collection of water such as a river or a pool of water, e.g. a reservoir (dam), or discontinuous pools of water as pertain in seasonal rivers or streams during the dry season.

4.2 Methods

The steps of the methodology used in image preprocessing, classification as well as the other aspects of the over-all study are given in Fig . 4.1.

Figure 4.1: Schematic diagram of key steps in the methodology

4.2.1 Band combinations for displaying TM Data

The spectral band combination for displaying images often varies with different applications (Trotter, 1998). This was necessary for the selection of training data for the subsequent classification of the images. A band combination of red, blue and green (RGB) is often used to display images in standard colour composites for land use and vegetation mapping (Trotter, 1998). In this study, the LANDSAT TM images were displayed in a band combination of 4, 3 and 2 (red, blue and green), which is standard for visual interpretation of vegetation mapping in the tropics (Prakash and Gupta, 1998 and Trotter, 1998). In the 4, 3 and 2 (RGB) band combination, (1) vegetated areas appeared in shades of red and sparsely vegetated areas in faint red (A in Figure 4.3), (2) water bodies and burnt areas appeared black, (3) roads (untarred), bare land and wastelands appeared in shades of dirty white and grey (C in Figure 4.3), while (5) settlements (B in Figure 4.3) appeared in shades of grey, bluish-grey, steel grey, etc. (B and C in Figure 4.3) (Prakash and Gupta, 1998). The discrimination of particular feature types necessitated the experimentation with other band combinations. For example, the band combinations 5, 4 and 2 (RGB) were used to discriminate between fire-scars and water bodies. The combination of bands 7, 5 and 3 (RGB) also provided useful information, especially with respect to the vigour of vegetation (Figure 4.4).

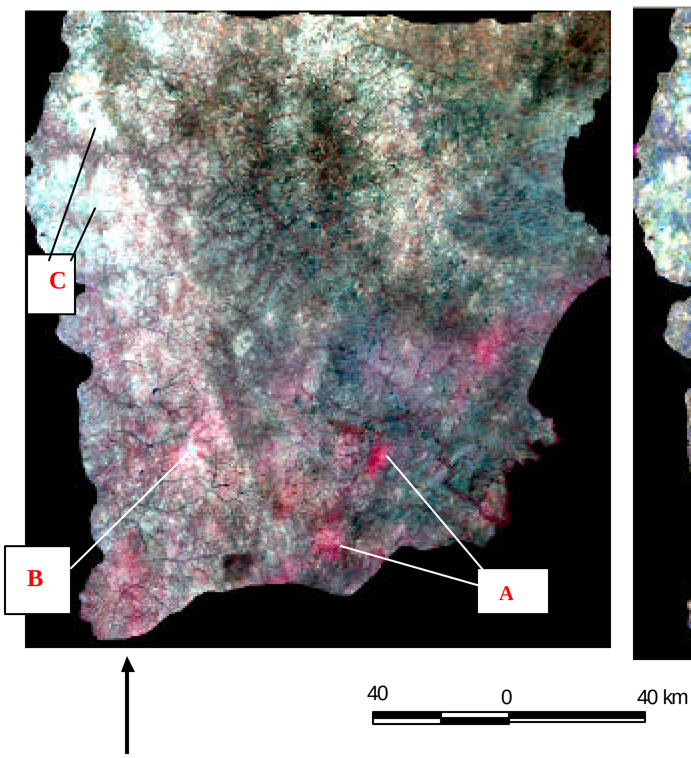


Figure 4.3: Landsat 7 image displayed in bandcombination of 4, 3 and 2 (RGB)

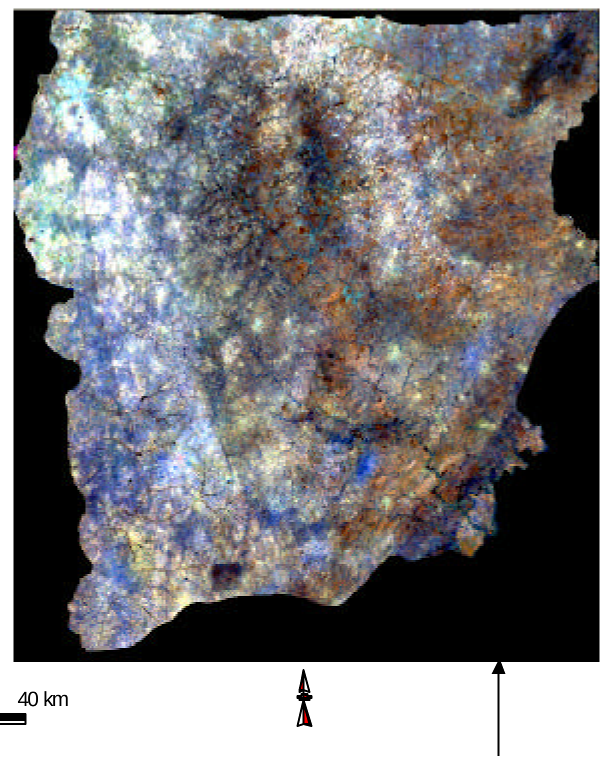


Figure 4.4: Image of the Upper West Region displayed in a band combination of 7, 5 and 3 (RGB)

4.2.2 Geometric correction

Geometric correction was performed on the images. This was done by image-to-image registration, in which the 1991 image was used as the master image and the 1986 and 2000 ones as the slave images. The 1991 image had already been geometrically corrected to the Transverse Mercator (TM) projection system by the Centre for Remote Sensing and Geographic Information Services (CERSGIS) at the University of Ghana, Legon, using the 1:50,000 and 1:250,000 topographic data as well as global positioning system (GPS) data collected from the field.

Pixel distortion for LANDSAT images and other high spatial resolution satellite data is known to be small or minimal due to the relatively stable satellite orbits and a small scan angle (<6°) (Bingfang and Haiyan, 1997 and Lillesand and Kiefer, 1994). Such images are assumed to have regular pixels and can consequently be geometrically corrected using the non-parametric method of selecting ground control points (GCPs) and using polynomial transformation (Sunar and Musaogilu, 1998; Roy *et al.*, 1997; Sunar and Kaya, 1997 and Bingfang and Haiyan, 1997).

According to Richards (1995), the location of points in the master image (i.e. 1991 image) can be defined by a coordinate system (**x**, **y**) and those in the slave images (i.e.,1986 and 2000 images) also by another coordinate system represented by (m,n). These two coordinate systems can supposedly be related via a pair of mapping functions ¦ and **g** so that

$$m = f(x, y) \qquad n = g(x, y) \qquad \text{Equations 4.1}$$

The explicit form of the mapping functions of Equation 4.1 can be chosen as a simple polynomial. In this study, a second-degree (or -order) polynomial was chosen and is given as follows:

$$m = a_0 + a_1 x + a_2 y + a_3 xy + a_4 x^2 + a_5 y^2 \qquad n = b_0 + b_1 x + b_2 y + b_3 xy + b_4 x^2 + b_5 y^2 \qquad \text{Equations 4.2}$$

According to Richards (1995), if the coefficients a_1 and b_1 in equation 4.2 are known, then the mapping polynomials can be used to relate any point in the master image to its corresponding point in the slave images (or the reverse). A set of corresponding distinct point-like features called ground control points (GCPs) common to the master (1991) image and the slave (1986 and 2000) images were identified and substituted in Equation 4.2 to estimate the polynomial coefficients. The spatial relationships between the corresponding GCPs (coefficients) were assumed to be representative of the distortion on the images, so they were used to calculate the mapping functions between the slave and master images, as used by Wright and Morrice (1997). Most of the ground control points were the confluences of narrow drainage channels, as used by Turner and Congalton (1998), bridges, intersections or junctions of roads (gravelled and tarred) and other well-marked features.

After determining the mapping polynomials (transformation coefficients), corresponding points on the master and slave images were related by using the nearest-neighbour resampling (interpolation) algorithm (Lillesand and Kiefer, 1999). This was done to avoid the modification of the radiometric values (i.e., to maintain the radiometric properties) of the original data (Wright and Morrice, 1997; Lillesand and Kiefer, 1999 and Yang and Prince, 2000).

The minimum number of GCPs required for second-order polynomials mapping is six (Richards, 1995). Forty control points were digitized for the 1986 image and 45 for the 2000, but these were progressively edited and the less accurate ones deleted until an acceptable root mean square (RMS) error was attained. An example of the records of the GCPs for the 1986 image is shown in Appendix 9.9.

According to the USDA (1995), terrain correction is recommended if precise location is required and if the relief differences between the lowest and highest points of the study area are greater than 500 ft (about 150m). Topographically, the Upper West Region varies in height from 180 to 300m above sea level. It is largely a plateau and can be considered homogeneous in height in many places. Furthermore, this study was concerned with the assessment and comparison of general spatial patterns. Therefore, exact pixel-to-pixel spatial agreement was not mandatory (Weishampel *et al.*, 1998), though that was the aim of the geometric correction. Notwithstanding, the images were registered to within one pixel (RMS <1). The accuracy of the registration was evaluated on checkpoints on the image (Appendix 9.9). Control points with large residuals were iteratively deleted until the RMS values associated with each registration were less than one pixel (0.59 pixels for the 1986 image and 0.67 pixels for the 2000 image). The geometric correction information for the 1986 image is shown in Appendix 9.9.

4.2.3 Atmospheric correction or normalization of images

Images are often corrected for atmospheric effects so that a direct comparison of the grey values of pixels can give an indication of an actual or 'true' change (Prakash and Gupta, 1998; Trotter, 1998; Schmidt and Gitelson, 2000 and Roy, 1997). Atmospheric correction may not be necessary when no direct multi-temporal spectral (i.e., pixel-to-pixel) comparisons are to be made prior to any application (Wright and Morrice, 1997). Furthermore, atmospheric correction is not necessary for a relatively flat area that is covered by only one LANDSAT scene (Todd *et al.*, 1998 and Prakash and Gupta, 1998). Effectively, the Upper West Region covers an area that is less than that of one complete image scene and is relatively flat. If tropical images are of the same season, the atmospheric, phenological and seasonal factors can be assumed to be quite comparable (Prakash and Gupta, 1998), especially in West Africa, in which case, atmospheric corrections may not have any significant effect (Mansor *et al.*, 1994 and Owen *et al.*, 1998). The images used in this study were of the dry season and were sufficiently clear for the visual identification of training samples.

For the above reasons, the atmospheric correction process was not necessary in this study. This is especially so, as the method of land use and land cover change detection used involved only a general comparison of the statistics of the various land use and land cover categories, and not pixel-to-pixel comparison. The geo-registered image of 2000 was printed and used in a reconnaissance field survey.

4.2.4 Field reconnaissance visit

An effective interpretation of images using supervised procedures requires *a priori* knowledge of the scene (Sunar, 1998). This knowledge was derived from ground truth data, global positioning system (GPS) points and topographic maps. Training pixels were selected on the 2000 image (the most recent) and located in the field. The field campaign also provided first-hand observation, the acquisition of accurate locational data and the interviewing of farmers and experts as done by Campbell and Browder (1995). As far as possible, ground truthing was done on homogeneous stretches of land cover types, which were marked on the image and the corresponding topographic maps. This was done in the dry season so as to more correctly correlate spectral responses on the image with features on the ground, since the images were acquired in dry seasons. After the field campaign, the images were stratified before being classified.

4.2.5 Image stratification

In this study, the images were first subsetted into distinctive components (strata) based on visual interpretation of patterns in them (textural and tonal indicators) and the sub-strata were then classified separately by digital classification techniques (Thenkabail, 1999). Figure 4.5 shows the lines along which an image was stratified. The stratification

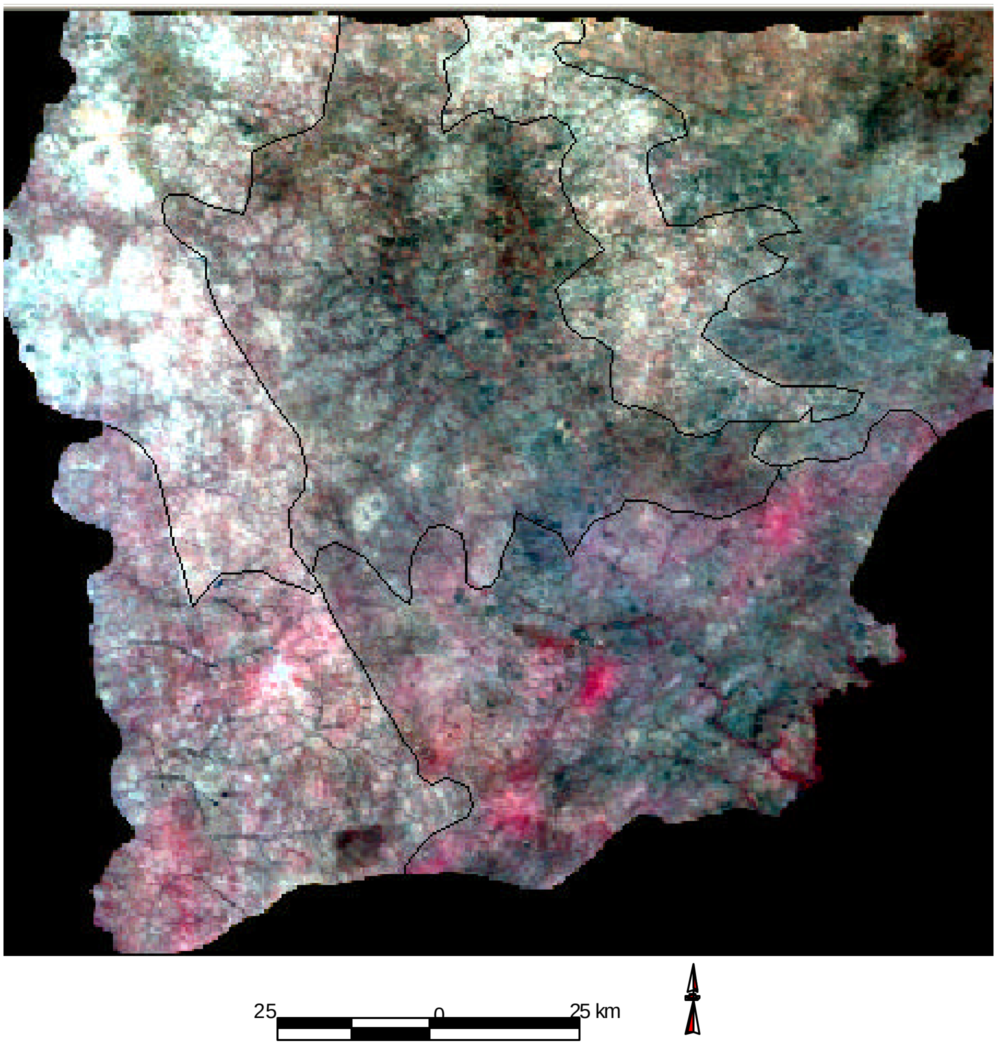


Figure 4.5: LANDSAT (ETM+) Image of the Upper West Region, showing lines along which it was stratified

was also guided by ground-truth information as well as topographic, soil and geological data of the study area, as well as image interpretation techniques (Sannier *et al.*, 1998). Finally, all the classified component strata were mosaicked to form one classified image. Following the work of Harris and Ventura (1995), further subsets were delineated in areas where confusion still existed. Very problematic classes, such as the reserved lands, were masked off and later overlayed on the classification during post-classification procedures.

4.2.6 Classification

The images were classified digitally because digital (spectrally-oriented) classification is commonly used these days and has been found to give better results than visual classification for vegetation mapping (Bottomley, 1999). It allows the interpretation of smaller and complex mapping units, and thus offers greater detail compared to the visual technique, where the mapping units are generalized (Viovy, 2000).

The objective of the classification is to generate quantitative information. Therefore, supervised classification was used because, according to Trung (2002), it is the procedure most often used for quantitative analysis of remotely sensed images. However, one of the major problems of supervised classification of land use and land cover is the ability to correctly identify and digitize representative training samples visually for all the categories on the displayed images. In this study, it was not easy to visually differentiate between land cover categories that were nearly similar in spectral responses (e.g., dry *Open woodland with shrubs and grasses* and *Mixture of grasses and shrubs with scattered trees*). This is due to the heterogeneity or complexity of the landscape features, which the human eye cannot clearly discriminate on the image. Furthermore, field data collection, which formed the basis for the identification of training samples, was undertaken almost two years after the study area had been imaged. This affected the results of the classification. Therefore, it was thought that digital classification, which does not rely solely on the visual digitization of training samples could give better results.

Supervised classification involves three major steps, namely (1) selection or generation of training areas, (2) evaluation of training signature statistics and spectral pattern and (3) classification of the images (Lillesand and Kiefer, 1994 and Trotter, 1998). Vinas and Baulies (1995) observed that unsupervised classification is useful for areas of extreme heterogeneity. Therefore, a test-unsupervised classification was carried out. However, it could not discriminate between water body and some closed savannah woodland units, e.g., fire-scorched closed savannah woodland, and wet or dark dry riverbeds. Trotter (1998) and Thomson *et al.* (1998) have separately reported that unsupervised classification of differently vegetated surfaces with similar reflectance produce inconsistent results, with the differentiation between woodland and other semi-natural vegetation types, between urban and arable, and between water and shaded woodland being very poor. This rendered the use of unsupervised classification ineffective for this study since these features constituted the bulk of the landscape. Thus, an unsupervised classification was not used in this study as a sole procedure. However, following the work of Garcia and Alvarez (1994) and Sunar (1998), a combination of unsupervised and supervised classification was used. In this approach, unsupervised clustering was used to generate training samples, which were used together with those collected in the field for a subsequent supervised classification.

4.2.6.1 Collection of training samples

Trotter (1998), observing that the higher the spectral classes selected, the better, performed ISODATA unsupervised clustering and selected 50, 80 and 110 spectral classes, which were visually interpreted by comparing them with reference information before merging them into a few major classes. Therefore, in this study, each image stratum was first classified by ISODATA clustering into 50 spectral classes. The large number of clusters chosen was also meant to see whether all classes could separate. The resulting spectral classes were matched with the corresponding spectral responses on the image and similar classes were merged. Then training samples were extracted from spectral classes that corresponded to a class in the classification scheme. The field records (GPS data) were used as aids to identify patterns on the images prior to the on-screen digitization of further training samples, especially for features that could not be clearly resolved by unsupervised clustering. The training areas of each land use or land cover class were selected throughout the study area in order to obtain good representatives (Lillesand and Kiefer 1994 and Trotter, 1998). The training samples (statistics) were then evaluated and similar ones merged to form composite training samples for the land cover classes before they were applied to a supervised maximum likelihood classification (Sunar, 1998). Fig 4.6 shows some of the locations where training samples were identified. The list of other locations of the various land cover types, from which the training samples were extracted, are listed in Tables 4.2.1, 4.2, 4.3 and 4.4.

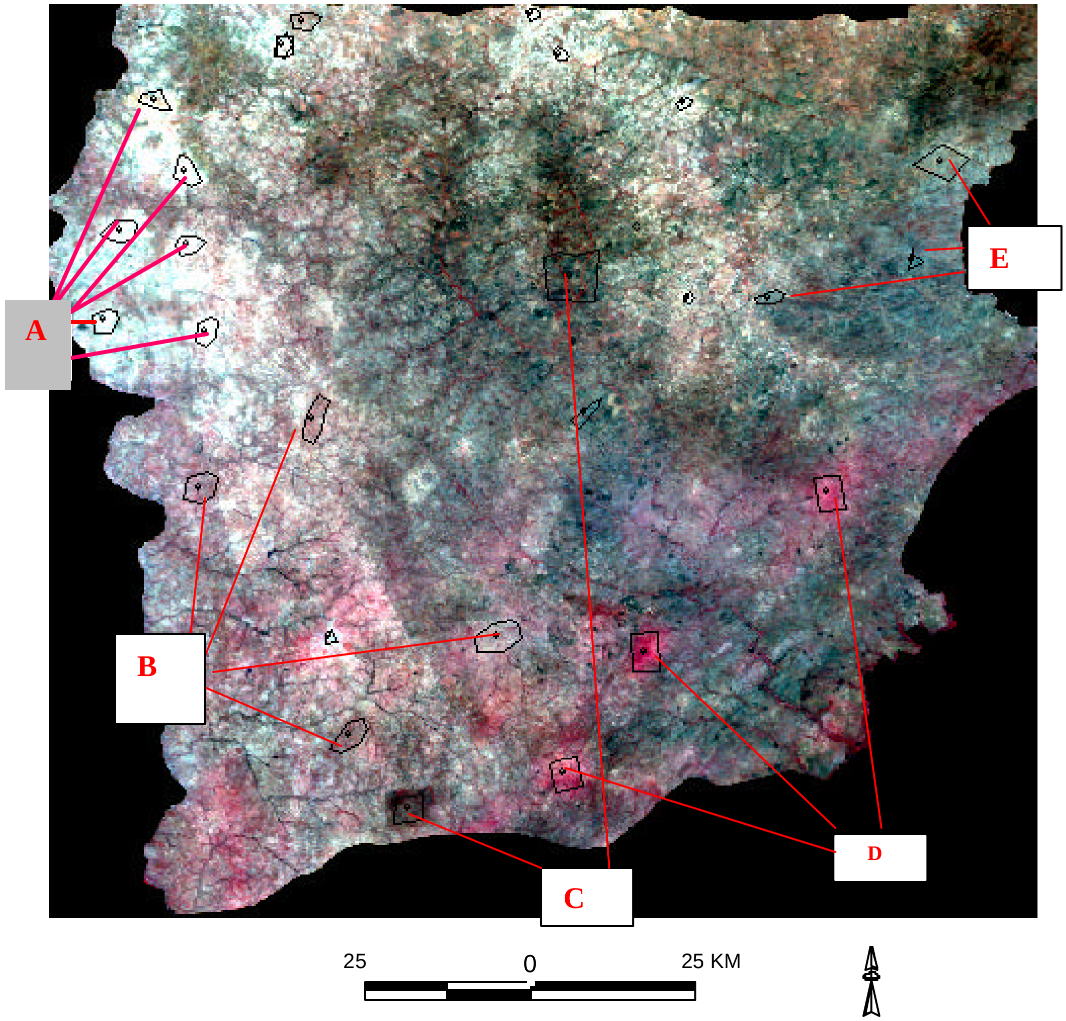


Figure 4.6: Field locations of selected training samples

Table 4.1: Training samples from *Closed woodland*

Geographic location		Locality	Land use and land cover
Latitude	**Longitude**		
09 58 19 N	01 59 14 W	East of Bulenga	Closed woodland
09 57 58 N	01 58 41 W	Ambalara Resreve	Closed woodland
10 05 57 N	02 01 03 W	mining area road	Closed woodland
10 09 15 N	01 55 13 W	Yala	Closed woodland
10 05 35 N	01 54 26 W	Kulung (bet Yala & River	Closed woodland (primary)
10 04 59 N	01 53 24 W	After River towards Katua	Closed woodland (primary)
10 58 39 N	02 26 55 W	Kulpawn Headwaters Res	Reserved woodland (primary)
10 49 27 N	02 08 29 W	Jeffisi (Tumu-Han rd)	Closed woodland
10 40 38 N	02 26 52 W		Closed woodland (primary)
09 57 11 N	02 07 33 W	East of Bulenga	Closed woodland

Table 4.2: Training samples from *Open woodland cover*

Geographic location		**Locality**	**Land use and land cover**
Latitude	**Longitude**		
10 47 41 N	02 44 12 W	Northwest of Dorimon	Open woodland
09 55 24 N	02 10 20 W	West of Boti	Open woodland
09 56 53 N	02 07 46 W	Mining area road	Open woodland
10 11 21 N	02 28 54 W	Fian, near Welembelle Jn	Open woodland
10 05 15 N	02 36 11 W	West of Ullo	Open woodland
10 39 18 N	02 29 41 W	9 km south of Fian	Open woodland
10 40 09 N	02 4720 W	West of Dorimon	Open woodland
10 45 31 N	02 29 44 W	N. of Jang near Jangbosi	Open woodland

Table 4.3: Training samples from *Mixture of grasses and shrubs cover*

Geographic location		**Locality**	**Land use/land cover**
Latitude	**Longitude**		
10 47 41 N	2 02 11 W	Kong Tumu-Wellembele rd	Fallow (5-6 years old)
09 55 24 N	2 27 16 W	Near Tanina	Fallow (4 years old)
09 56 53 N	2 44 23 W	South of Dorimon	Fallow (5 yrs)
10 11 21 N	2 38 43 W	Near Sankama	Fallow (5 years old)
10 05 15 N	2 30 02 W	North of Wa	Fallow (4-5 years old)
10 39 18 N	2 46 15 W	Near Eremon	5-year-old fallow (shallow soil)
10 45 31 N	2 14 13 W	Near Jeffisi	6-year-old fallow
10 51 40 N	2 00 30 W	Tumu outskirt (Han rd	Fallow (4 years old)
10 22 05 N	2 06 59 W	East of Kojo Pere	Mixture of grasses and shrubs

Table 4.4: Training samples from *Farmland* (recently cultivated fields)

Geographic location		**Locality**	**Land use/land cover**
Latitude	**Longitude**		
10 17 01 N	02 15 42 W	Near Fian	Fallow (2 yrs)
09 46 39 N	02 30 48 W	Samanbo near Ga	Cultivated previous year
10 38 05 N	02 41 31 W	North of Nadowli	Cultivated previous year
10 33 29 N	02 42 46 W	Near Jirapa	Cultivated previous year
10 44 14 N	02 49 11 W	Eremon area	Intensively farmed
10 45 42 N	02 50 12 W	Near Kamba	Fallow (2 yrs)
10 51 25 N	02 47 50 W	Danko near Nandom	Cultivated previous year
10 59 51 N	02 41 42 W	outskirt of E. Hamile	Cultivated previous year
10 59 17 N	02 35 27 W	Near Fielmon	Fallow (2 yrs)
10 00 19 N	02 22 22 W	East of Busa	Fallow (2 yrs old)
10 01 21 N	02 21 03 W	Wa-Ga road	Fallow (2 yrs old)
10 02 19 N	02 40 59 W	Northwest Dorimon	Almost bare

4.2.6.2 Evaluation of training signature statistics and spectral pattern

Following the procedure used by Ringrose *et al.* (1997), the statistics of the spectral signatures were evaluated and revised until a reasonable degree of separability of the resultant ellipses was apparent throughout the available feature space before they were applied to supervised classification. The procedures used for the evaluation included feature space plotting and using *Transformed Distance* separability listing for band pairs) (Tables 4.5, 4.6 and 4.7). Feature space plots of red against infrared bands showed vegetated surfaces with high infrared reflectance compared to red, and were therefore separated from unvegetated surfaces that had a red-infrared ratio closer to unity, as reported by Thomson *et al.*, 1998. According to Trotter (1998), pairs of only four bands (1, 3, 4 and 5) normally show separability for vegetation types.

The maximum likelihood classifier requires a multivariate normal distribution of the pixel values of each class (Su, 2000; Wright and Morrice, 1997; Sannier *et al.*, 1998 and Rogers *et al.*, 1997). Therefore, the training signatures were edited to give a digital value distribution of each class to approximate a normal (unimodal) grey-level distribution of pixel values. However, it was difficult to get samples that were truly unimodal in pixel value distribution. This is considered a disadvantage for the use of maximum likelihood classification for an image of the savannah in Ghana. According to Mather (1993), it is difficult to get land cover samples that are truly unimodal in pixel value distribution.

4.2.6.3 Computation of signature separability and distance

Signature separability and distance were computed on the training samples, using the ERDAS IMAGINE programme. Signature separability is a statistical measure of the distance between two signatures. It can be calculated for any combination of bands that is used in the classification, and thus enables the ruling out of any bands that are not useful in the result of the classification (ERDAS, 1999). Four methods of computing signature separability and distance between training samples are listed in ERDAS (1999). These are the (1) Euclidean distance, (2) Divergence, (3) Transformed Divergence and (4) Jefferies-Matusita Distance. The Transformed Divergence was used in this study because, according to ERDAS (1999), it is the most efficient method of the four techniques.

4.2.6.4 Transformed Divergence

The formula for computing Transformed Divergence (***TD***) is as follows:

$$D_{ij} = \frac{1}{2} tr\left(\left(C_i - C_j\right)\left(C_i^{-1} - C_j^{-1}\right)\right) + \frac{1}{2} tr\left(\left(Ci^{-1} - C_j^{-1}\right)\left(m_i - m_j\right)\left(m_i - m_j\right)^T\right)$$

$$TD = 2000\left(1 - \exp\left(\frac{-D_{ij}}{8}\right)\right)$$

Where

D = Divergence

i and j = the two signatures (clases) being compared

C = the covariance matrix of signature i

μ = the mean vector of the signature i

tr = the trace function (matrix algebra)

T = the transportation function

Source: Swain and Davis (1978)

The computations for the TD and separability of the signatures are shown in Tables 4.5 and 4.6.

Table 4.5: Transformed divergence separability distance computation values

Class	1	2	3	4	5
1.Closed sav. woodland/riparian vegetation	0	2000	2000	2000	1781
2. Mixture of grasses and shrubs	2000	0	2000	1996	1680
3. Water body	2000	2000	0	2000	2000
4. Farmland/bare land or constructed surface	2000	1996	2000	0	1973
5. Open savannah woodland	1781	1680	2000	1973	0

Table 4.6: Separability of training samples

Class	Normalized probability
1. Closed savannah woodland/riparian vegetation	0.2000
2. Mixture of grasses and shrubs with scattered trees	0.2000
3. Water body	0.2000
4. Farmland/bare land or constructed surface	0.2000
5. Open savannah woodland with shrubs and grasses	0.2000

According to Jensen (1996), the scale of the divergence values can range from 0 to 2,000. As a general rule, if the value is greater than 1,900, then the classes can be separated. When it is between 1,700 and 1,900, the separation is fairly good. Below 1,700, the separation is poor. The computation (Table 4.5) shows that apart from *Mixture of grasses and shrubs with scattered trees* and *Open savannah woodland with shrubs and grasses* where the separability value was 1680, all the other ones equal or were very close to 2000 (2000 or 1995.87). *Closed savannah woodland/riparian vegetation* and *Water body* gave 1780.88. Thus the classes were well separable. The normalized probability for the classes was 0.2 (Table 4.6). The separability for the band pairs are shown in Table 4.7, which shows that the band pairs are mostly well separated. After the evaluation of the signatures, a maximum likelihood supervised classification was performed.

Table 4.7: Minimum and average separability

Best minimum separability												
Bands	AVE	MIN	Class Pairs: 1: 2	1: 3	1: 4	1: 5	2: 3	2: 4	2: 5	3: 4	3: 5	4: 5
1 2 3 4 5 6	1943	1680	2000	2000	2000	1781	2000	1996	1680	2000	2000	1973
Best average separability												
Bands	AVE	MIN	Class Pairs: 1: 2	1: 3	1: 4	1: 5	2: 3	2: 4	2: 5	3: 4	3: 5	4: 5
1 2 3 4 5 6	1943	1680	2000	2000	2000	1781	2000	1996	1680	2000	2000	1973

4.2.6.5 Maximum likelihood classifier

The maximum likelihood classifier was selected because it is a primary algorithm for supervised classification of image data and offers the best results (Bresci, 1992, and Stemmler and Su, 1993). It is the most commonly applied classification technique because of its well-developed theoretical base and its successful application with different data types and classification schemes (Bolstad, 1991). It has the benefit of assigning every pixel to a class, since the parametric decision space is continuous (Kloer, 1994). It is parametric, because it uses a decision rule based upon statistical parameters (mean and standard deviation) and assumes probability distribution functions of each class to establish decision boundaries between them (Swain and Davis, 1978). It gives consistent results. In this way it is better than than object-based and Neural Network classifiers. Its requirement of a normal distribution of the values of the pixels of the training samples is, however, difficult, because training samples from a complex and heterogeneous landscape such as the Upper West Region are hardly normally distributed (Mather, (1993).

4.2.7 Post-classification enhancement

Su (2000), Trotter (1998) and Ringrose *et al.* (1997) performed post-classification filtering enhancement of the final result of their classifications, using a 3 x 3-kernel majority filter to reduce the "salt-and-pepper" effects in (i.e., smoothening) the classified image. This procedure was not carried out in this study, because it tended to generalize the classification to the extent that some mapping units, e.g., water body (dug-out dams or water reservoirs), small farm plots and settlements disappeared. Su (2000) made a similar observation. The statistics of the various classes were generated using the ERDAS IMAGINE programme. Finally, maps were composed, using the ARCVIEW (3.2 version) programme and the 2000 map was validated in the field to assess its accuracy and hence the accuracy for the other maps.

4.2.8 Accuracy assessment

The accuracy of the classification was assessed directly in the field to define how close the classification agreed with the real world. It also offered more knowledge about errors in the data for the improvement of the mapping procedure and also allowing future users of the classification to assess the data's suitability for particular applications.

The procedure used was that of Cogalton (1991), which has been used in several studies, e.g., the NPS/NBS Vegetation Mapping Project (2002). It involved the selection of samples of identified locations on the map, which were then checked directly in the field. The results were then tabulated in the form of an error or misclassification matrix (also referred to as a contingency or confusion matrix) (Congalton 1991). The columns of the table defined the classes in the reference data, and the rows defined the classified classes. The values in the cells of the table indicate how well the classified data agrees with the reference data. The diagonal elements of the matrix indicated correct classifications. The overall accuracy, which is the percentages of correctly classified cases lying along the diagonal, was determined as follows:

$$Overall\ \ Accuracy = \frac{\sum(correctly\ classified\ classes\ along\ diagonal)}{\sum(Row\,total\ or\ Column\ total)}$$

The producers' accuracy (errors of omission) of each class was computed by dividing the number of samples that were classified correctly by its total number of reference samples as follows:

$$\Pr oducers'\,accuracy = \frac{Number\,of\ correctly\,classified\,class\,in\ a\ column}{Total\,number\,of\ items\ verified\,in\ that\,column}$$

The users' accuracy (errors of omission) of each class was computed by dividing the number of correctly classified samples of that class by its total number of samples that were verified as belonging to the class as follows:

$$Users'\,accuracy = \frac{Number\,of\ correctly\,classified\,item\,in\ a\ row}{Total\,number\,of\ items\ verified\,in\,that\,row}$$

4.3 Results and discussion

4.3.1 Classification results

The image of the Upper West Region for 1986 is shown in Figure 4.7 and its land use and land cover classification in Figure 4.8.

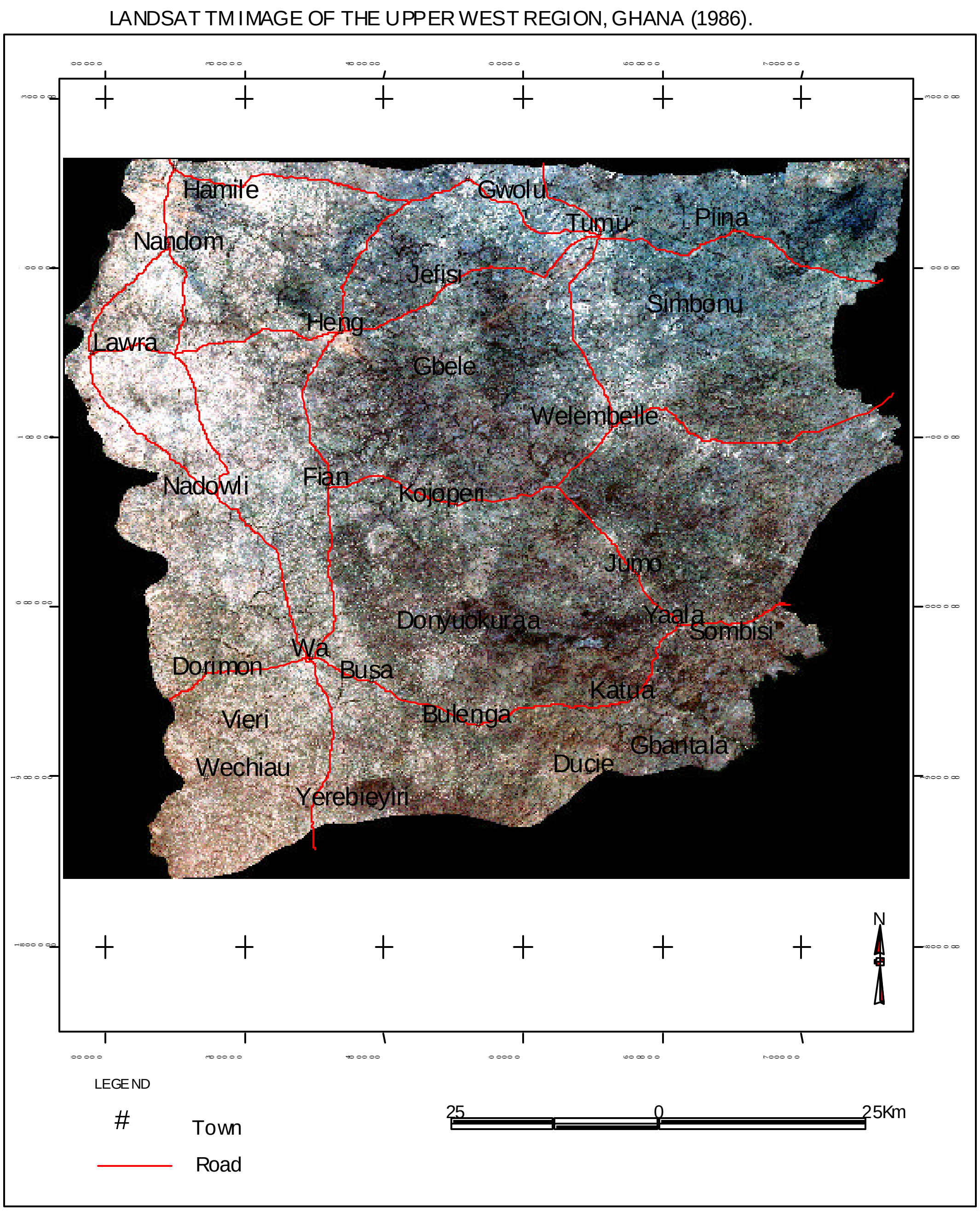


Figure 4.7: LANDSAT (TM) image of the Upper West Region (Ghana) (January 18, 1986), displayed in a band combination of 4,3,2 (RGB)

LAND USE AND LAND COVER MAP OF THE UPPER WEST REGION, GHANA (JANUARY 18, 1986)

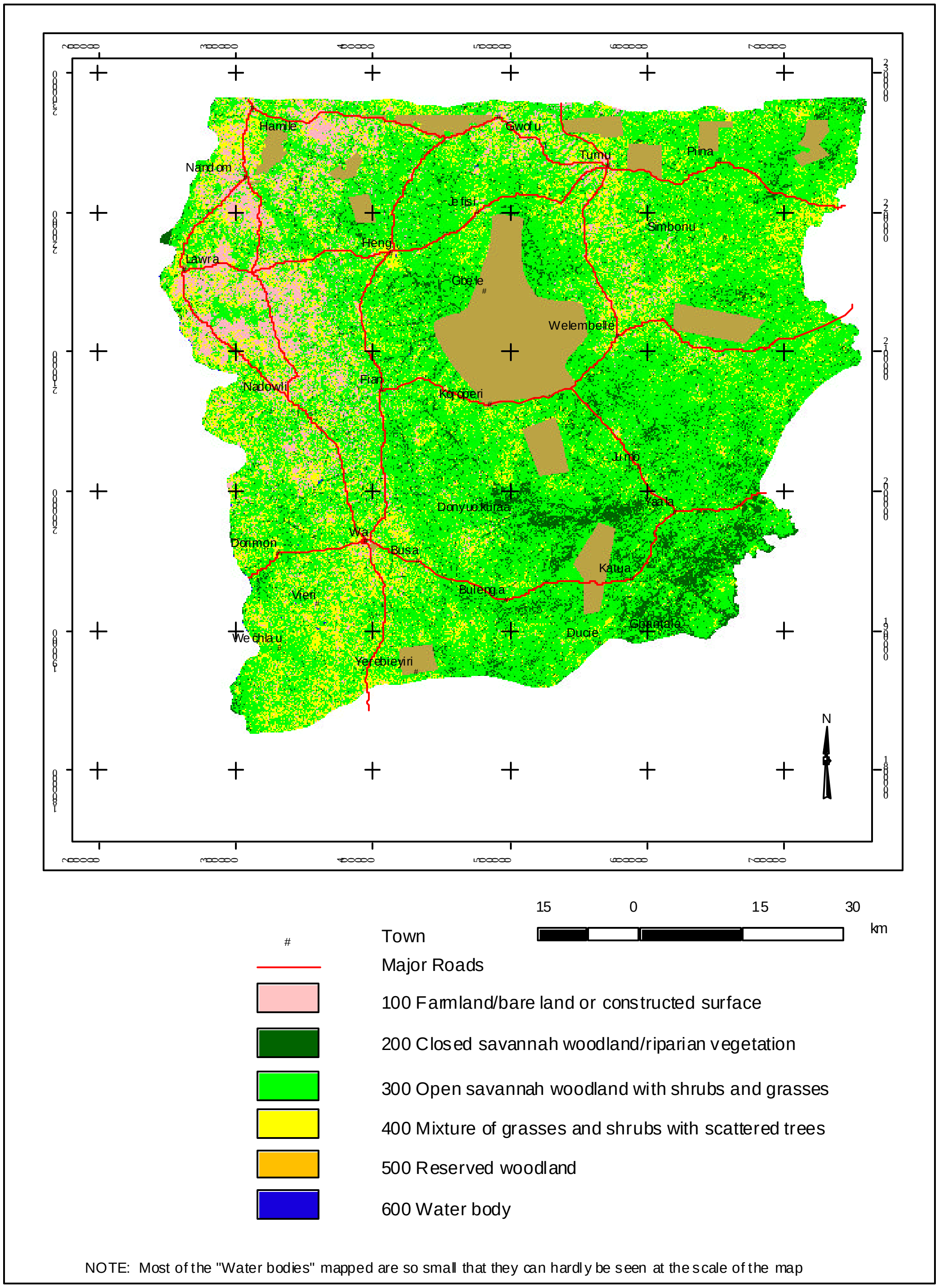


Figure 4.8: Land use and land cover map of the Upper West Region, Ghana (January 18, 1986)

The LANDSAT image of the region and its land use and land cover classification for 1991 are also shown respectively in Figure 4.9 and Figure 4.10.

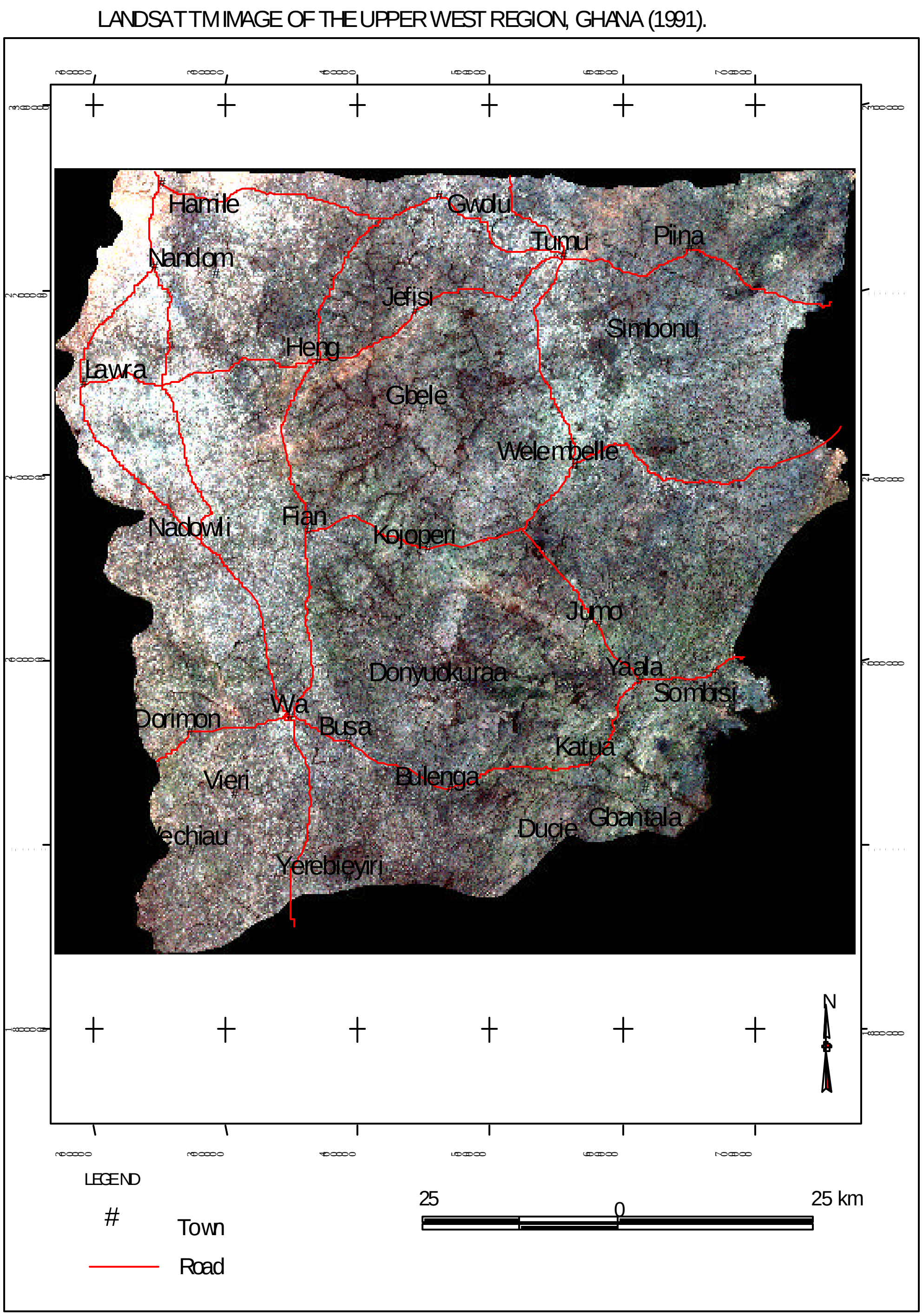


Figure 4.9: LANDSAT (TM) image of the Upper West Region (Ghana) (January 8, 1991), displayed in a band combination of 4,3,2 (RGB)

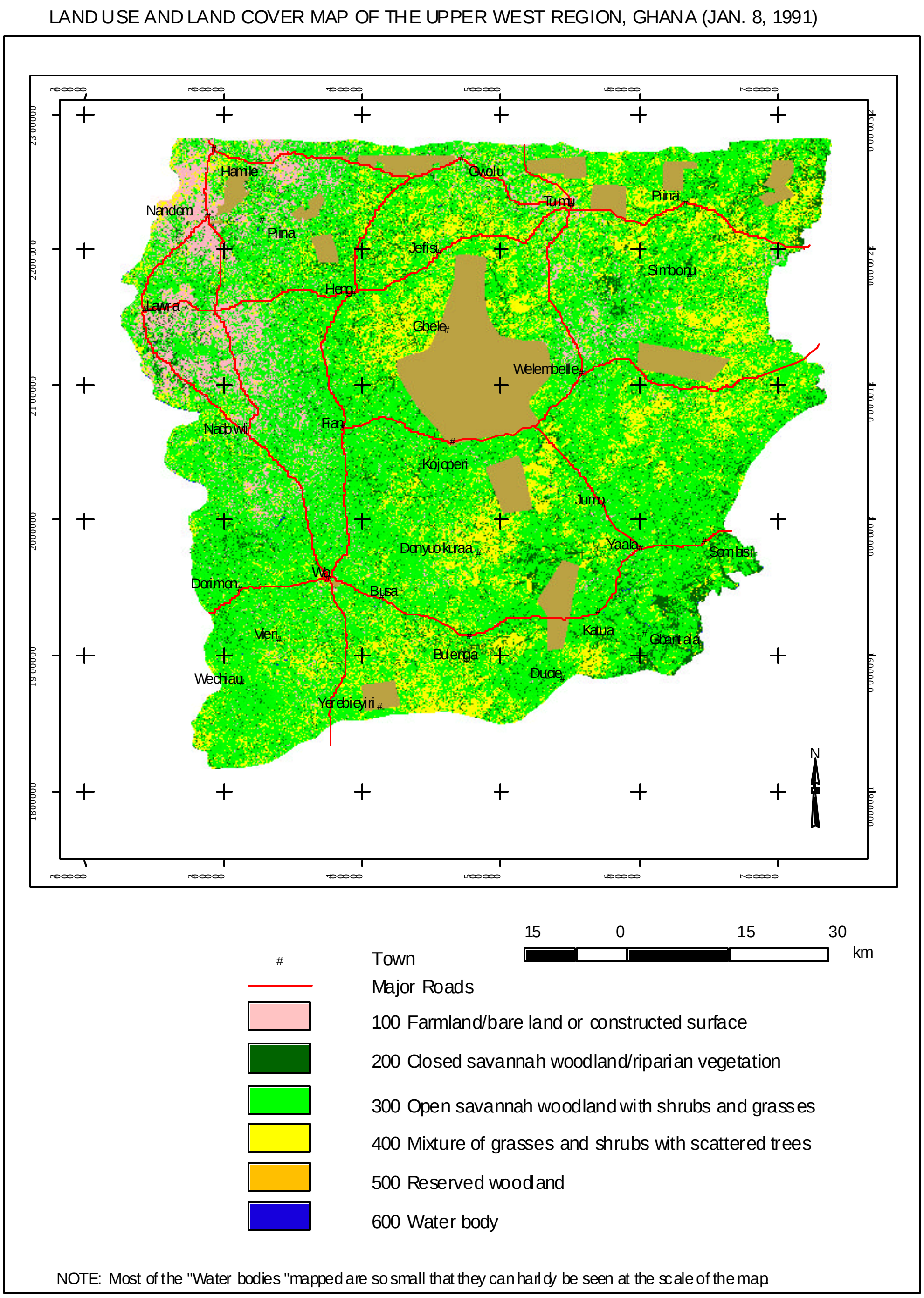


Figure 4.10: Land use and land cover map of the Upper West Region, Ghana (January 8, 1991).

The image of the region for 2000 and its land use and land cover classification are also given in Figures 4.11 and 4.12, respectively.

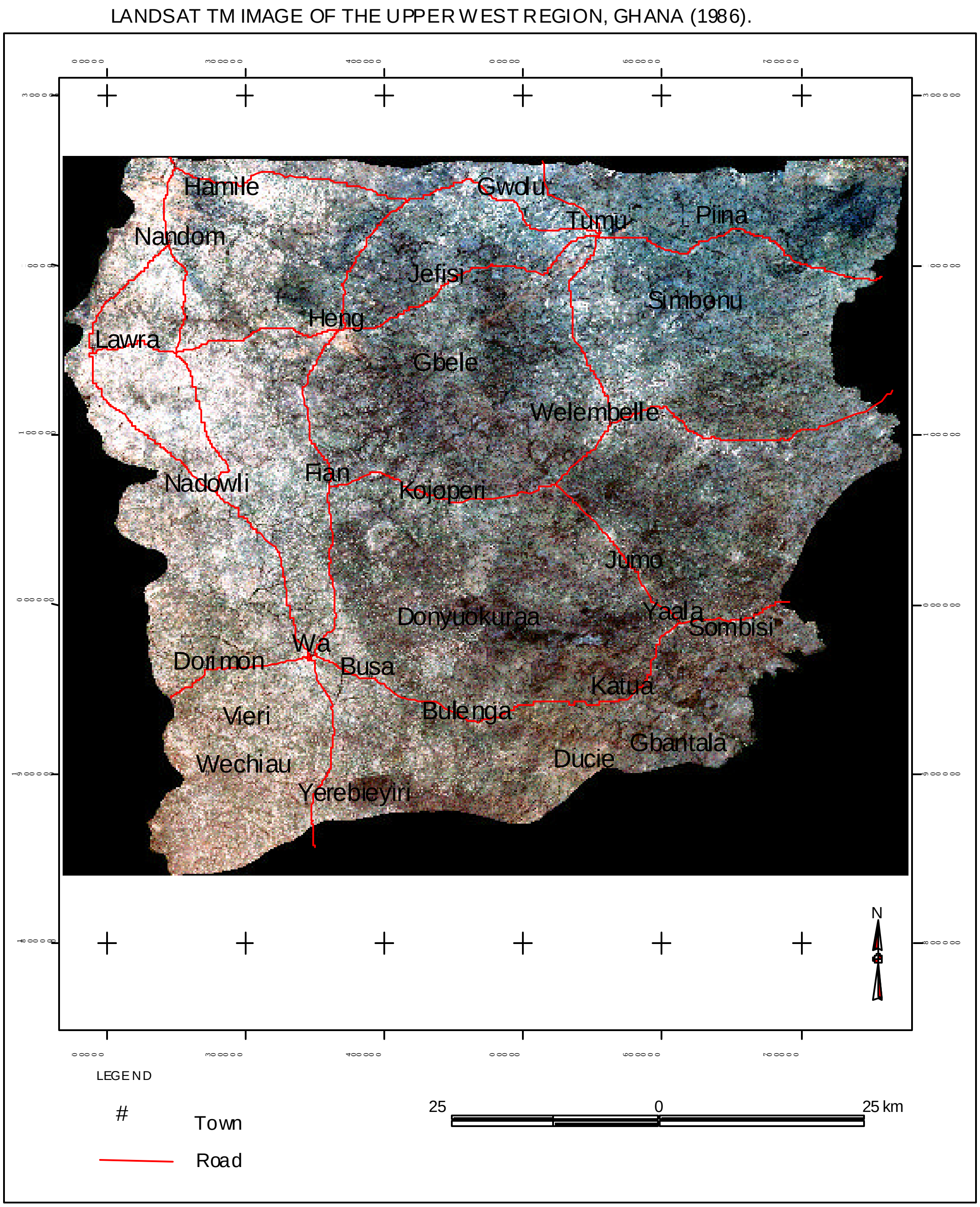


Figure 4.11: LANDSAT 7 (+ETM) image of the Upper West Region (Ghana) (January 12, 2000), in a band combination of 4,3,2 (RGB)

LAND USE AND LAND COVER MAP OF THE UPPER WEST REGION, GHANA (JANUARY 12, 2000)

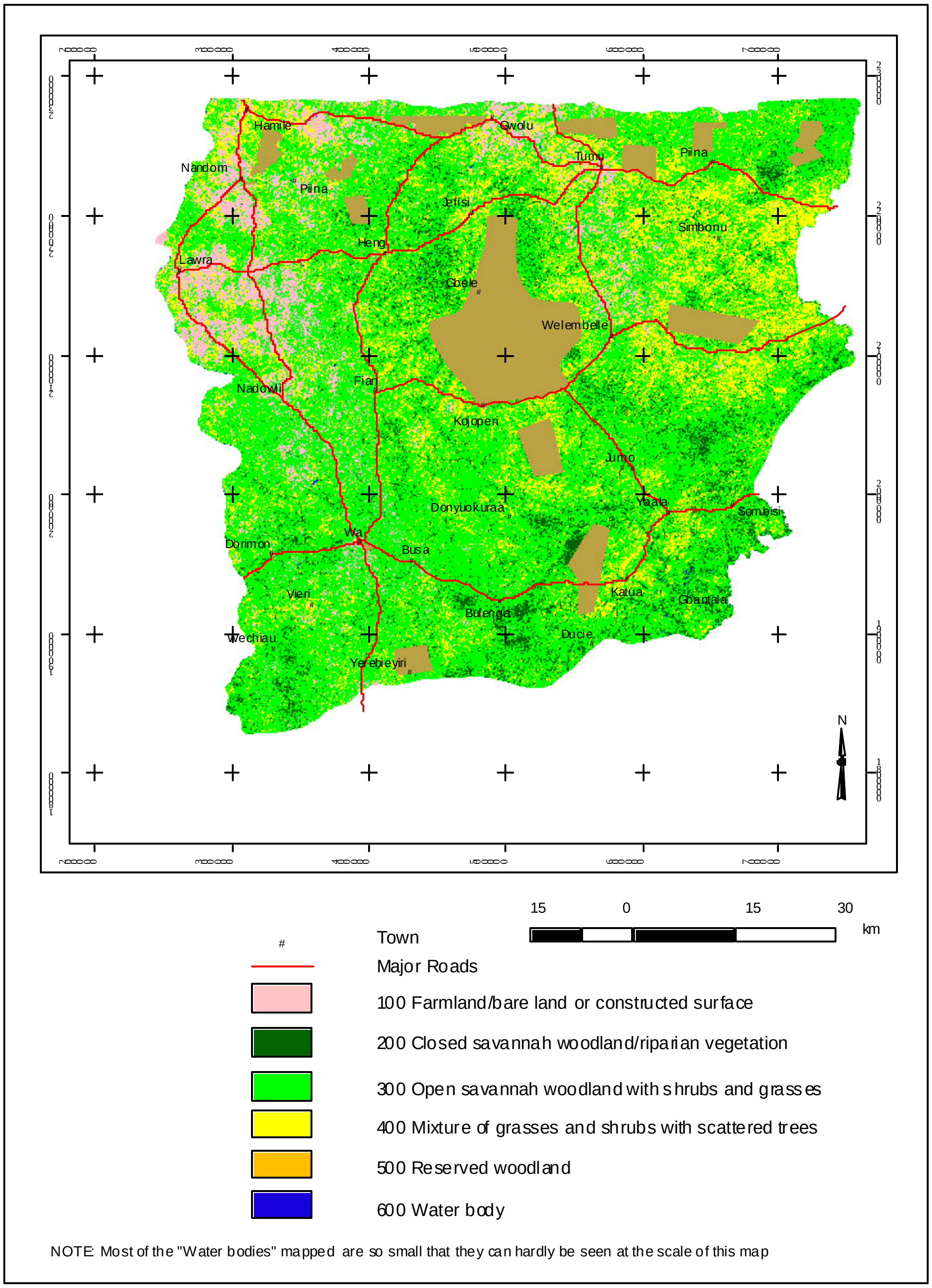


Figure 4.12: Land use and land cover map of the Upper West Region, Ghana (Jan. 12, 2000).

In all, six broad land use andland cover classes were mapped. These were:

- Farmland/bare land or constructed surface
- Closed savannah woodland or riparian vegetation
- Open savannah woodland with shrubs and grasses
- Mixture of grasses and shrubs with scattered trees
- Reserved woodland
- Water body

These classes were deduced from the ***Ghana Land Use and Land Cover Classification Scheme for Visual Classification of Remotely Sensed Data ,*** which was designed by Agyepong *et al.* (1999). The mapped classes are broad because the supervised classification method (maximum likelihood classification) could not discriminate the image features into more detailed classes.

The extents of the mapped land use and land cover classes of the region are shown in Table 4.8 and Figure 4.13 shows their graphical representation.

Table 4.8: Land use and land cover classes of the UWR as in 1986, 1991 and 2000

LAND COVER CLASS	Jan. 18, 1986		Jan. 8, 1991		Jan. 12, 2000	
	Area (Ha)	*% Region*	Area (Ha)	*% Region*	Area (Ha)	*% Region*
Farmland/bare land or constructed surface	132,197	*6.98*	136,802	*7.22*	143,716	*7.59*
Closed savannah woodland/riparian vegetation	138,870	*7.33*	138,728	*7.32*	119,350	*6.30*
Open savannah woodland with shrubs and grasses	1,136,371	*60.00*	1,114,590	*58.84*	1,101,091	*58.13*
Mixture of grasses and shrubs with scattered trees	317,602	*16.77*	334,538	*17.66*	360,260	*19.02*
Reserved woodland	168,752	*8.91*	168,752	*8.91*	168,752	*8.91*
Water body	406	*0.021*	887	*0.047*	1,029	*0.054*
TOTAL	1,894,198	*100*	1,894,198	*100*	1,894,198	*100*

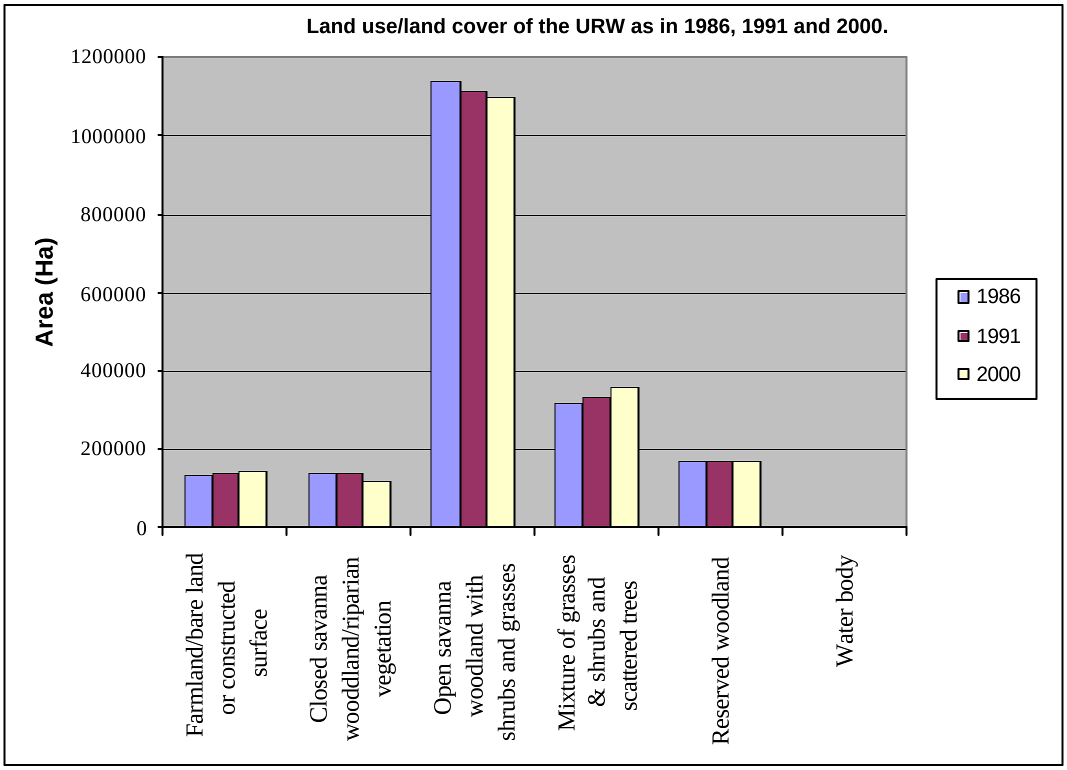


Figure 4.13: Land use and land cover of the Upper West Region as in 1986, 1991 and 2000.

4.3.2 Extent of land use and land cover classes

4.3.2.1 Extent of land use and land cover classes in 1986

As shown in Table 4.8 and Figure 4.13, the most extensive land cover category of the Upper West Region, as at January 8, 1986, was *Open savannah woodland with shrubs and grasses*, which covered about 1,136,371 hectares (60%) of the region. The second most extensive land cover category was *Mixture of grasses and shrubs with scattered trees*, which covered about 317, 602 hectares (about 17%). *Reserved woodland* covered about 168,752 hectares (about 9%), being the third most extensive land cover of the region. This is followed by *Closed savannah woodland/riparian vegetation*, covering an area of approximately 138,870 hectares (about 7.33%) and *Farmland/bare land or constructed surface*, which also covered 132,197 hectares (6.98%). The least extensive land cover was *Water body*, which covered only 406 hectares, about 0.021% of the regional land surface.

4.3.2.2 Extent of land use and land cover classes in 1991

As shown in Table 4.8, the order of magnitude of the spatial extent of the land cover categories of the region in 1991 was the same as that in 1986, with the most extensive land cover again being *Open savannah woodland with shrubs and grasses*. It covered 1,114,590 hectares representing about 58.84% of the land surface of the region. It was followed again by *Mixture of grasses and shrubs and scattered trees*, which covered about 334,538 hectares (some 18%). The third most extensive land cover was again *Reserved woodland*, which covered about 168,653 hectares (about 8.91%) of the land surface. *Closed savannah woodland/riparian vegetation* was again the fourth most extensive land cover and covered 138,728 hectares (about 7.32 %). *Farmland/bare land or constructed surface* also covered 136,802 hectares (7.22%) of the region, while *Water body* covered some 887 hectares, which was about 0.047% of the total land surface.

4.3.2.3 Extent of the land use and land cover classes in 2000

The order of the magnitude of the extent of coverage of the land surface of the region by the various land cover classes changed slightly in 2000. *Open savannah woodland with shrubs and grasses* was still the most extensive land cover, occupying some 1,101,091 hectares (about 58.13%) of the region. It was followed by *Mixture of grasses and shrubs and scattered trees*, which covered about 360,260 hectares (about 19.02%). The next most extensive land cover was *Reserved woodland*, which covered about 168,752 hectares, (8.9%) of the region, followed by *Farmland/bare land or constructed surface*, covering 143,716 hectares (7.59%). *Closed savannah woodland/riparian vegetation*, covered 119,350 (6.30%) of the land. Water body increased in extent in 2000, covering about 1,029 hectares, which represented about 0.054% of the land surface of the region.

As shown later, *Closed savannah woodland/riparian vegetation* and *Open savannah woodland with shrubs and grasses* decreased in extent from 1986 to 2000, while *Mixture of grasses and shrubs with scattered trees*, *Farmland/bare land or constructed surface* and *Water body* land cover categories increased in extent over the same period. These changes are further discussed in Chapter 5.

4.3.3 Accuracy of the classification: 2000

The result of the assessment of the classification accuracy, which is shown in Table 4.9, yielded an overall accuracy of 92%. The producer and user's accuracies for the various land cover categories are shown below.

Table 4.9: Assessment of classification accuracy of 2000 image

		Reference Data (from field work)						
LAND COVER CLASSES		Farmland/ bare land or constr. Surf.	Closed sav. wld/rip. veg.	Open sav. wld + shrub & grasses	Mix. grasses & shrubs	Water body	ROW TOTAL	Row Total (%)
Classified Data	Farmland/bare land or constr. Surf.	***96.96***	1	0.63	1.47	0.00	6863	100.06
	Closed sav. Woodland/ rip. veg	0.00	***91.28***	6.69	0.00	0.00	3788	97.97
	Open sav. w'land + shrubs & gasses	2.25	8.69	***82.99***	5.56	0.99	14171	100.61
	Mix. of grasses & shrubs	0.00	0.00	9.68	***92.98***	0.00	3986	102.66
	Water body	0.00	0.00	0.00	0.00	***99.01***	399	99.01
COLUMN TOTAL		932	2947	16405	2520	03	29207	503.96

Overall accuracy= (96.96+91.28+82.99+92.98+99.01)/503.96 = 91.92%

4.3.3.1 Producer's accuracy

Farmland/bare land or constructed surface= 96.96/(2.25 + 95.96) =97.93%

Closed savannah woodland/riparian vegetation = 91.28/ (1+91.28 +8.69) = 90.40%

Open savannah woodland with shrubs & grasses=82.99/(0.63+6.69+82.99+9.68) = 83%

Mixture of grasses and shrubs with scattered trees = 92.98/(1.47+5.56+92.98) = 92.97%
Water body = 99.01/(0.99+99.01) = 99.01%

4.3.3.2 User's accuracy

Farmland/bare/bare land or constructed surface= 96.96/(96.96+1+0.63+1.47) = 96.90%
Closed savannah woodland/riparian vegetation = 91.28/(91.28+6.69) = 93.17%
Open sav. woodland (shrubs & grasses)=82.99/(2.25+8.69+82.99+5.56+0.99) = 82.59%
Mixture of grasses and shrubs with scattered trees = 92.98/(9.68+92.98) = 90.57%
Water body = 99.01(99.01 = 100%

The producer's accuracies for *Farmland/bare land or constructed surface*, *Open savannah woodland with shrubs and grasses* and *Mixture of grasses and shrubs with scattered trees* were higher than their corresponding user's accuracies. However, for *Closed savannah woodland/riparian vegetation* and *Water body*, the producer's accuracies were lower.

The over-all accuracy of 92% seems to be high. However, given that the land use and land cover classes are broad, it is reasonable to have such a high level of accuracy. In reality, however, the high level of accuracy cannot be so high for the *Open savannah woodland with shrubs and grasses*, which had an over-all accuracy of about 83%, which was the lowest, though. This can be explained by the fact that the farming system in the region consists of the growing of crops in the open savannah areas. In such cultivated fields, the farmers intentionally leave economic trees such as *Butyrospermum paradoxum* (shea), *Parkia clappertoniana* (dawadawa), *Daniellia oliveri* (black berry), etc., on their plots, the fruits of which they collect for sale or domestic use. This means that some of the *Farmland/bare land or constructed surface* (agricultural fields) are likely to have been underestimated since some might have been mapped as *Open savannah woodland with shrubs and grasses*, which was possibly over-estimated. Again, since the mapping was carried out some two years after the 2000 image had been acquired, it was likely that some of the areas mapped on that image as *Farmland/bare land or constructed surface* had become fallow regrowth and were therefore mapped as *Mixture of grasses and shrubs and scattered trees*.

The most accurately classified land cover was *Water body*, with 99% (producer's accuracy) and 100% (user's accuracy). This was followed by

Farmland/bare land or constructed surface, which had an accuracy of about 98% (producer's accuracy) and 97% (user's accuracy). *Mixture of grasses and shrubs with scattered trees* was classified at 93% (producer's accuracy) and 91% (user's accuracy), while *Closed savannah woodland /riparian vegetation*, was classified at 91%. *Open savannah woodland with shrubs and grasses* was classified at 83% (producer's and user's accuracies).

4.3.4 Distribution of land use/land cover categories

4.3.4.1 Farmland/bare land or constructed surface

The images of the three dates (Figues 4.7, 4.9 and 4.11) and their respective classifications (Figure 4.8, 4.10 and 4.12) show that the *Farmland/bare land or constructed surface* category was more concentrated in the western part of the region than in the east. A study of the three images and their corresponding maps shows that cultivation is, however, extending gradually towards the east. According to Dickson and Benneh (1988), the eastern part of the region is sparsely populated because of wars and slave raids in the past, as well as the infestation of black flies (*Simulium spp*) and tsetse flies (*Glossina spp*), which cause "river blindness" and "sleeping sickness" (trypanosomiasis) respectively. These pushed settlements to the western part of the region; hence the higher intensity of cultivation in the west. Furthermore, the soils of the western part of the region have been reported to be originally more fertile than those of the east (van der Geest, 2002). Wars and slave raids have ceased a couple of centuries ago and the black flies and tsetse flies have been controlled, and with the decreasing availability of agricultural land and declining soil fertility in the west, cultivation is gradually shifting to the east, where land is more available and fertile.

4.3.4.2 Closed savannah woodland/riparian vegetation

Apart from reserved woodlands and forest plantations, which have been mapped as closed savannah woodland, the *Closed savannah woodland/riparian vegetation* category is found mostly in the eastern and southeastern part of the region (Figures 4.7 and 4.8). The woodlands in the northwest, midwest and mid-north of the region have been more intensively degraded because of the higher population densities in these areas. This agrees with the observation of Contreras-Hermosilla (2000) and Schroth and Sinclair (2003), that population growth contributes to the degradation of forests and woodlands because of the increased clearing of land for farming and exploitation of wood for construction and fuel wood. Fuel wood collection is, particularly, known to degrade forests and woodlands around settlements (Contreras-Hermosilla, 2000).

4.3.4.3 Open savannah woodland with shrubs and grasses

Open savannah woodland is the most common or expansive vegetation type in the region and found almost everywhere. It is found mostly in areas that have been farmed for a long time and where the economic trees have been left on the land. It is also found in areas that, though not cultivated, could not develop closed savannah woodland probably due to various edaphic and other human factors.

4.3.4.4 Mixture of grasses and shrubs with scattered trees

This vegetation category develops when closed or open savannah woodland areas have been cleared, cultivated and left to fallow. It is, thus often found in association with farmlands. Edaphic factors may also have contributed to its formation. It is currently found more in the eastern part of the region than the west, because these areas are now experiencing increased expansion of cultivation. With the availability of land, there is enough room for shifting cultivation, which results in the abundance of fallow farmlands and hence the large area *of Mixture of grasses and shrubs and scattered trees*. Patches of this land cover type are also found in the central and southeastern part of the region.

4.3.4.5 Reserved woodland

The reserved areas of the region are shown in Figures 4.8, 4.10 and 4.12. They are concentrated mostly along the border with Burkina Faso and in the central part of the region, with only a few in the east and south. The west does not have reserves, except the northwest. It appears that at the time that the reserves were created, most of the woodland in the west had already been cleared so that there was no true large tract of primary woodland to be set aside as a reserve. This is probably the reason why those in the west are so small and relatively degraded. On the contrary, there were large areas of undisturbed or slightly disturbed natural woodland in the central and northern areas to be set-aside as reserves. Therefore, there are many reserves in those areas. The biggest reserved woodland is the Gbele Reserve, which is situated between Gbele, Kojoperi and

Welembelle. It is noted as a hunting ground (Sakyi-Dawson, 2000). The Nuale Reserve in the extreme south of the region is the most conspicuous reserve on the image with clear boundaries (Figure 4.7, 4.9 and 4.11).

4.3.4.6 Water body

The mapped water bodies are mostly water reservoirs or dams. Most of them were difficult to map because they are too small to be mapped with a 30-metre-resolution image. In a study of water reservoirs in the adjoining Upper East Region, Liebe (2003) found out that the number of small reservoirs can be higher than that of large ones. In this study, it was observed that some of the small ones dry up or have significantly reduced volumes during the peak of the dry season. The assessment of water usually involves the estimation of volume instead of area, so that the use of area in this study does not depict the quantity of water on the ground. Even, most of those that have been mapped are not visually outstanding on the maps. Water volumes change in response to changes in climatic factors, so that the area mapped as *Water body* cannot be taken to represent the situation on the ground at the time of image acquisition. This is especially the case when the dates of data acquisition and ground truthing are different (Liebe, 2003). Thus, even if the two dates are anniversary, the mapped areas can still differ from reality because climatic elements, especially rainfall, in the case of the Upper West Region, vary from year to year (inter-annual variations) and even within years (intra-annual variations).

The reservoirs are concentrated more in the western part than in the east. This is because they are associated with settlements, as these reservoirs provide water for domestic use as well as for livestock. According to Liebe (2003), the number of reservoirs can be determined by the density of the population of the area, with densely populated areas having more than areas with lower population density.

There are also rivers and streams, which form three drainage basins. These are the Black Volta, Sissili and Kulpawn Basins. The Black Volta River forms the western border of the region, and is the largest continuous water body in the region. The Sissili and the Kulpawn Rivers, which form the region's eastern boundary with the Upper East and Northern Regions, have continuous water only during the wet season and only pools of water during the dry season. Since the Black Volta, Sissili and Kulpawn rivers form boundaries, they have not been completely represented on the maps.

5 LAND USE AND LAND COVER CHANGE ASSESSMENT (Methods and results)

This chapter describes the assessment of land use and land cover changes of the Upper West Region during the periods between 1986 and 1991, 1991 and 2000 and 1986 and 2000. The relationship between this chapter and the rest of the study can be seen in Figure 4.1 (Chapter 4), which shows all the key steps in the methodology used for the over-all study.

5.1 Change detection methods

The commonly used change detection procedures, namely, (i) image overlay, (ii) image differencing, (iii) principal component analysis, (iv) classification comparisons, (v) image ratioing, (vi) change vector analysis and (vii) the differencing of normalized difference vegetation index (NDVI) have been discussed in Chapter 2. The procedure used in this study was that of classification comparison of land use and land cover statistics. The reasons why the other methods were not considered have also been discussed in that chapter. The classification comparison method was chosen because the study sought to find out the quantitative changes in the areas of the various land cover categories.

Using the post-classification procedure, the area statistics for each of the land use and land cover classes was derived from the classifications of the images for each date (1986, 1991 and 2000) separately, using functions in the ERDAS Imagine programme (1999). The areas covered by each land use and land cover type for the various periods were compared by using the Microsoft Excel programme to determine the magnitude of the differences between the dates. Then the directions of the changes (positive or negative) in each land cover type between 1986 and 1991, 1991 and 2000 and 1986 and 2000 were determined (Table 5.1 and Figures 5.1 - 5.11). Information collected from farmers and agricultural experts on the land use system in the region was then used to construct a general land cover change dynamics (Figure 5.12).

5.2 Results and discussion

Table 5.1 shows the changes in the various land use and land cover categories (in hectares and percentage) during the periods between 1986 and 1991, 1991 and 2000 and 1986 and 2000. Figure 5.1 represents the changes graphically.

Table 5.1: Land use and land cover changes of the Upper West Region during various periods (1986-1991, 1991-2000 and 1986-2000)

	1986-1991		1991-2000		1986-2000	
Land cover type	Change (Ha)	% Change	Change (Ha)	% Change	Change (Ha)	% Change
Farmland/bare land or constructed surface	+ 4605	*3.48*	+ 6914	*+5.05*	+11519	*+8.71*
Closed sav. Woodland/riparian vegetation	-142	*-0.102*	-19378	*-13.97*	-19520	*-14.06*
Open savannah woodland with shrubs and grasses	-21881	*-1.92*	-13499	*-1.21*	-35280	*-3.10*
Mixture of grasses and shrubs with scattered trees	+16936	*+5.33*	+25821	*+7.69*	+42658	*+13.43*
Reserved woodland	--	--	--	--	--	--
Water body	+481	+118.50	+142	*16.01*	+623	*153.45*

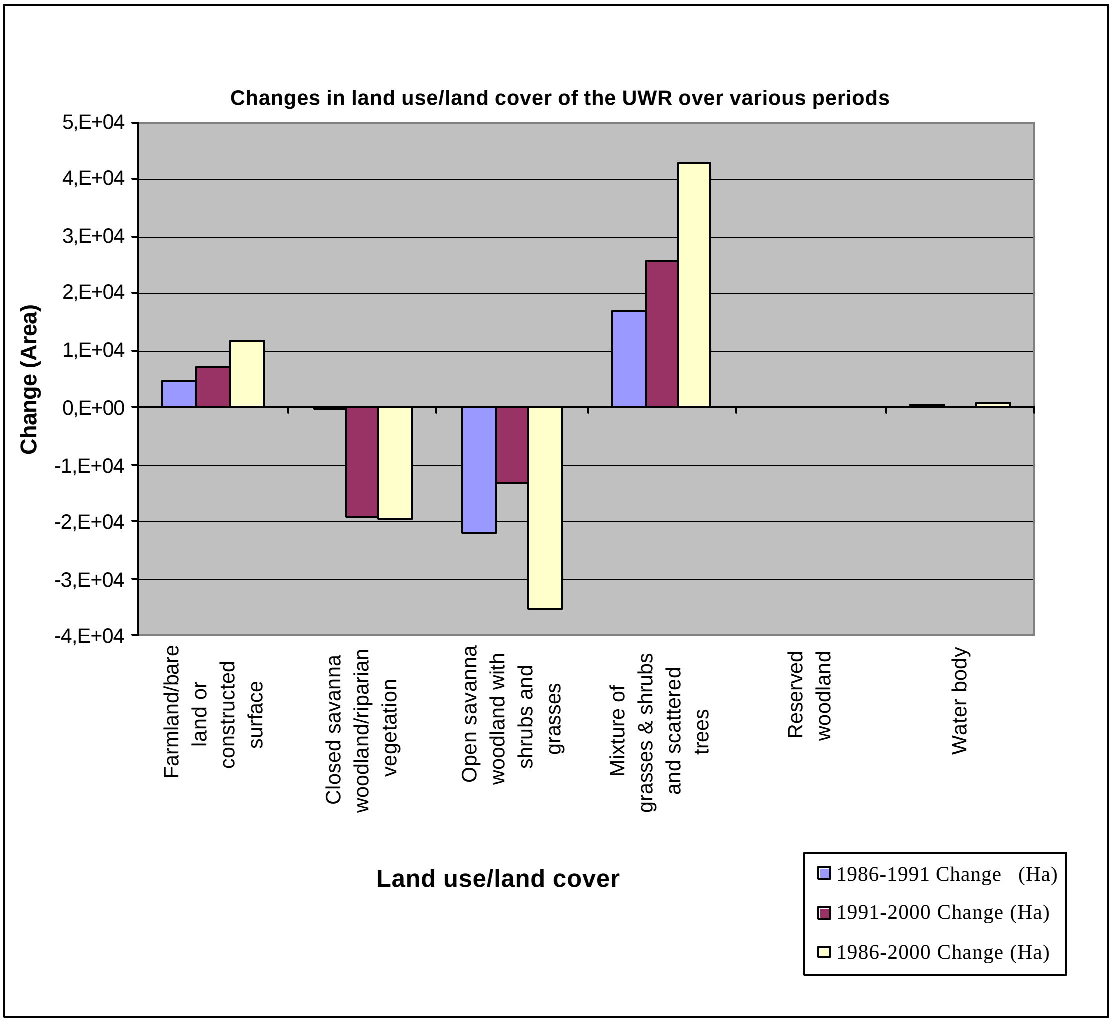


Figure 5.1: Changes in land use and land cover of the Upper West Region over various periods

While *Farmland/bare land or constructed surface*, *Mixture of grasses and shrubs with scattered trees* and *Water body* increased spatially, *Closed savannah woodland/riparian vegetation* and *Open savannah woodland with shrubs and grasses* decreased in extent. The boundaries of *Reserved savannah woodland* were assumed not to have changed spatially, though subtle changes do occur within them. The changes in each of the land use and land cover categories are discussed separately as follows:

5.2.1 Farmland/bare land or constructed surface

As shown in Figures 5.2 and 5.3, *Farmland/bare land or constructed surface* increased spatially from 132,197 hectares in 1986 to 136,802 hectares in 1991, which was an increase of 4,605 hectares (3.48%). It increased further to 143,716 hectares in 2000, which was an additional increase of 6,914 hectares (5.05%). Over all, the increase from 1986 to 2000 was 11,519 (143,716 - 132,197) hectares, which was 8.71% of the region.

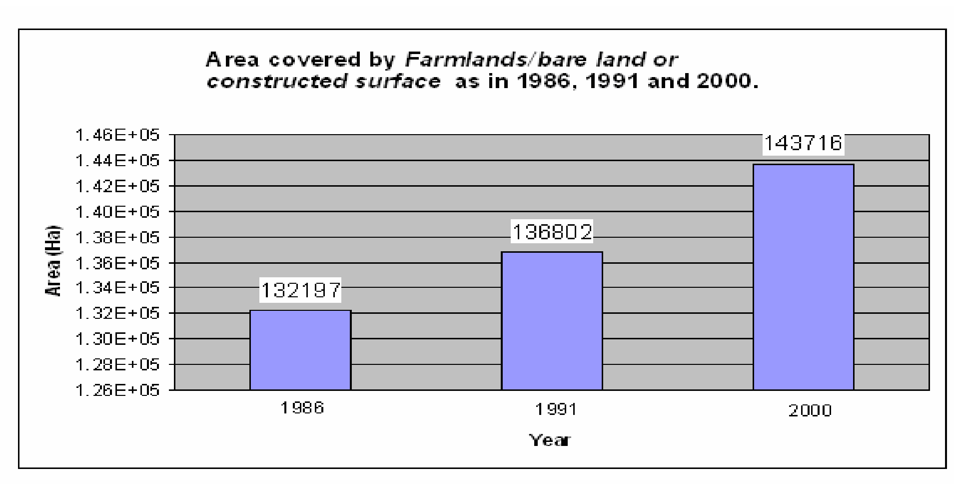


Figure 5.2: Area covered by *Farmlands/bare land or constructed surface* as in Jan. 1986, 1991 and 2000. *NB: Time spans are different for the periods (5 yrs and 10 yrs)*

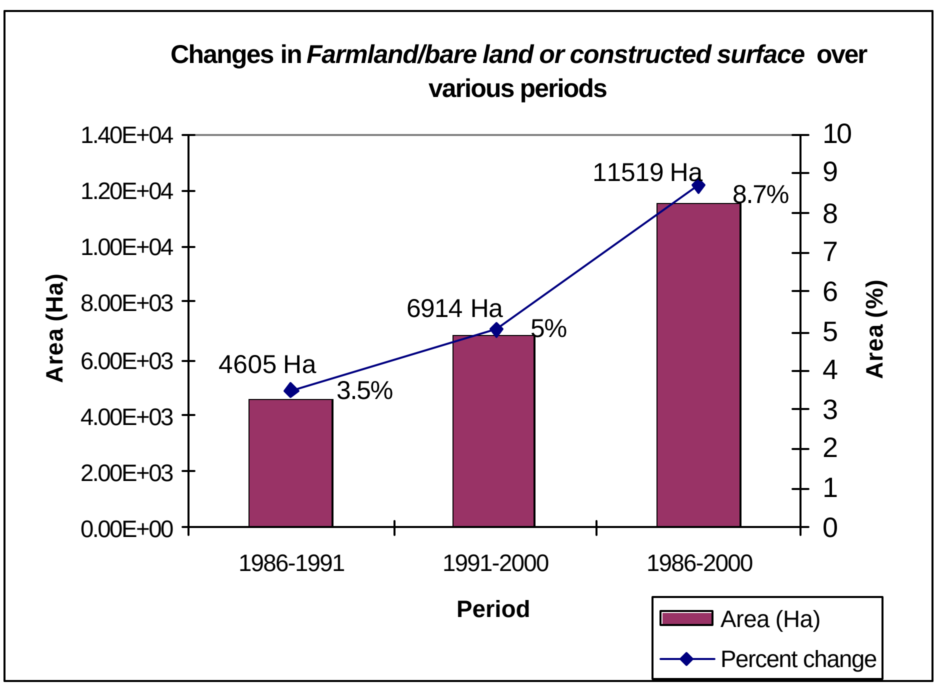


Figure 5.3: Changes in *Farmland/bare land or constructed surface*. (***NB: Time spans are different for the periods (5 years and 10 years)***

5.2.2 Closed woodland/riparian vegetation

The changes in *Closed savannah woodland/riparian vegetation* are shown in Figures 5.4 and 5.5. This land cover class decreased in area from 138,870 hectares (7.33%)

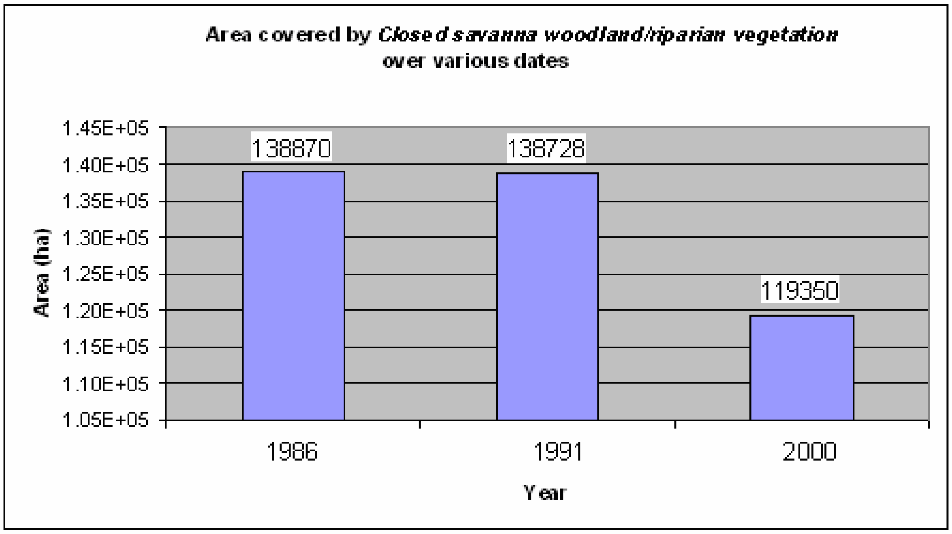


Figure 5.4: Area covered by *Closed savannah woodland/riparian vegetation* over various periods

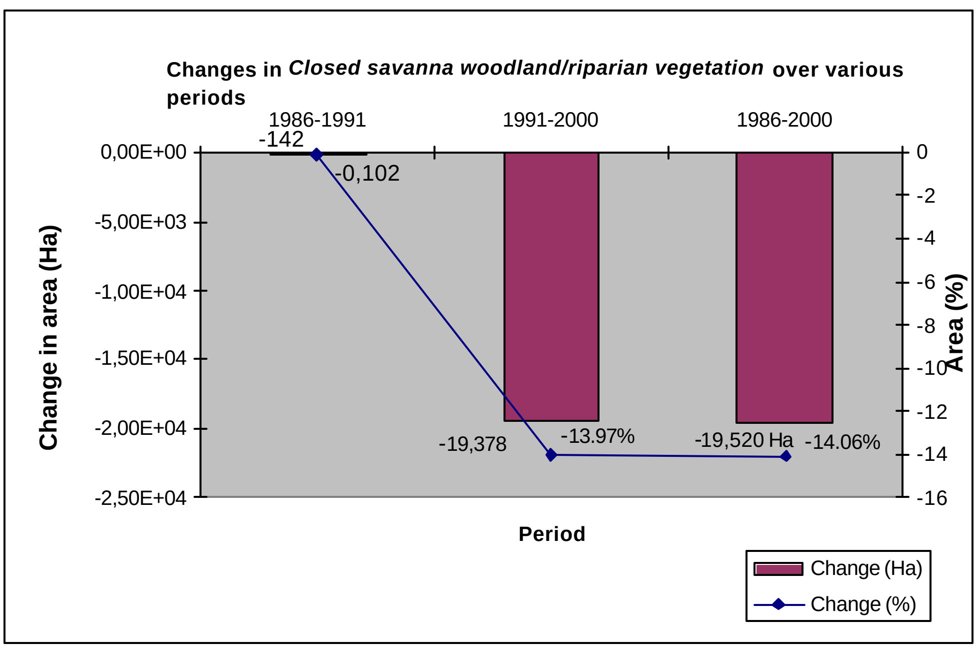


Figure 5.5: Changes in *Closed savannah woodland/riparian vegetation* over various periods (*NB: Time spans are different for the periods (5 years and 10* ***years)***

in 1986 to 138,728 hectares (7.32%) in 1991 and further to 119,350 hectares (6.30%)of the Region) in 2000.

The change between 1986 and 1991 was a loss of 142 hectares of closed savannah woodland, which was less than 1% (Figure 5.5). Between 1991 and 2000, the change was a further loss of an area of 19,378 hectares of the land cover category, which also represented a loss of just under 14%. The total loss in closed savannah woodland over the period between 1986 and 2000 was close to 20,000 hectares, which was a little over 14%. The trend showed that from 1991 the rate of loss of savannah woodland slackened a little compared with the preceding period.

5.2.3 Open savannah woodland with shrubs and grasses

As shown in Figures 5.6 and 5.7, this land cover category decreased in area from 1,136,371 hectares (60%) in 1986 to 1,114,590 hectares (59 %) in 1991 and further to 1,101,091 hectares (58%) of the region in 2000. The analysis showed that all the changes in this land cover were negative, meaning that the region experienced losses of the land cover during the periods in question. The loss in area during the 1986-1991 period was close to 22,000 hectares (representing about 2%), while that for the period 1991-2000 was about 13,500 hectares (1.21%) of the area under the land cover.

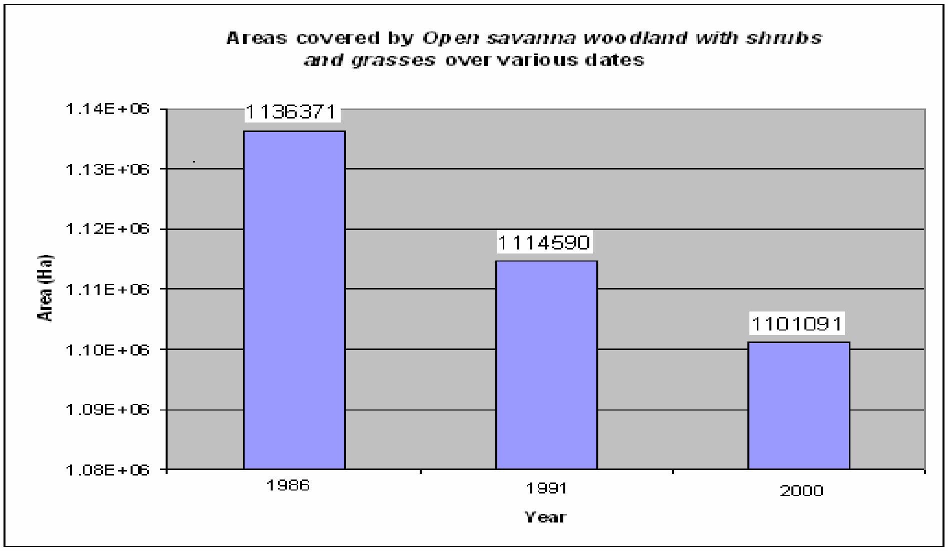


Figure 5.6: Area covered by *Open savannah woodland with shrubs and grasses* over various periods. *NB: Time spans are different for the periods (5 years and 10 years)*

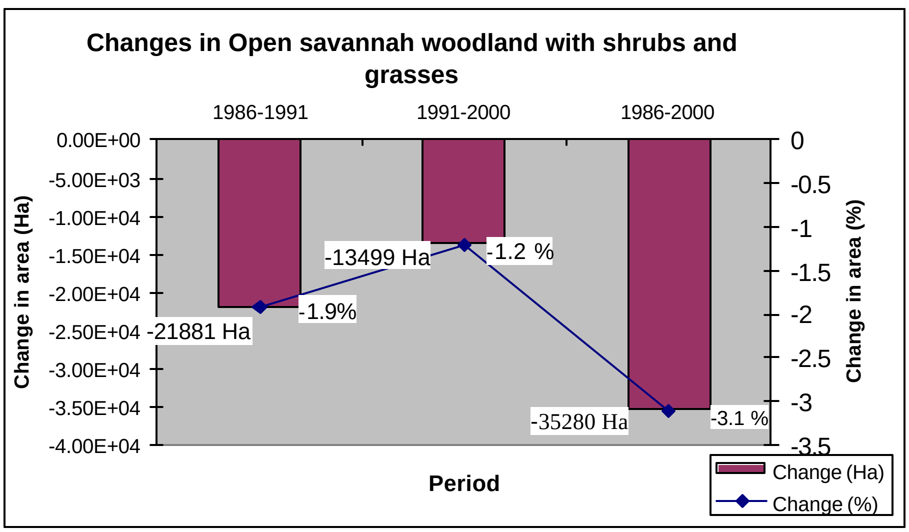


Figure 5.7: Changes in *Open savannah woodland with shrubs and grasses.*
NB: Time spans are different for the periods (5 years and 10 years)

5.2.4 Mixture of grasses and shrubs and scattered trees

The changes in this land cover category are shown in Figures 5.8 and 5.9. This land cover category increased from 317,602 hectares (18.8% of the region) in 1986 to

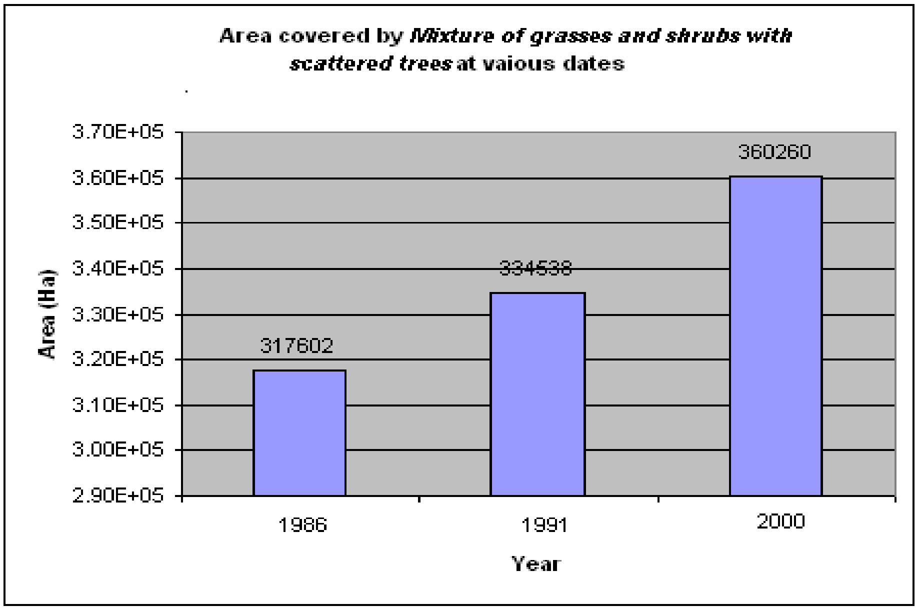


Figure 5.8: Area covered by *Mixture of grasses and shrubs with scattered trees* at various dates. NB: Time spans are different for the periods (5 years and 10 years)

334,538 hectares (about 18%) in 1991 and further to 360,260 hectares (a little over 19%) of the region in 2000. The changes depict increases during all the periods. During the 1986-1991 period, the increase was 16,936 hectares, which represented 5.3%. Between 1991 and 2000, it rose to 25,722 hectares, which was close to 7% of gain. On the whole, the increase between 1986 and 2000 was 13.4%, which represented 42,658 hectares of land.

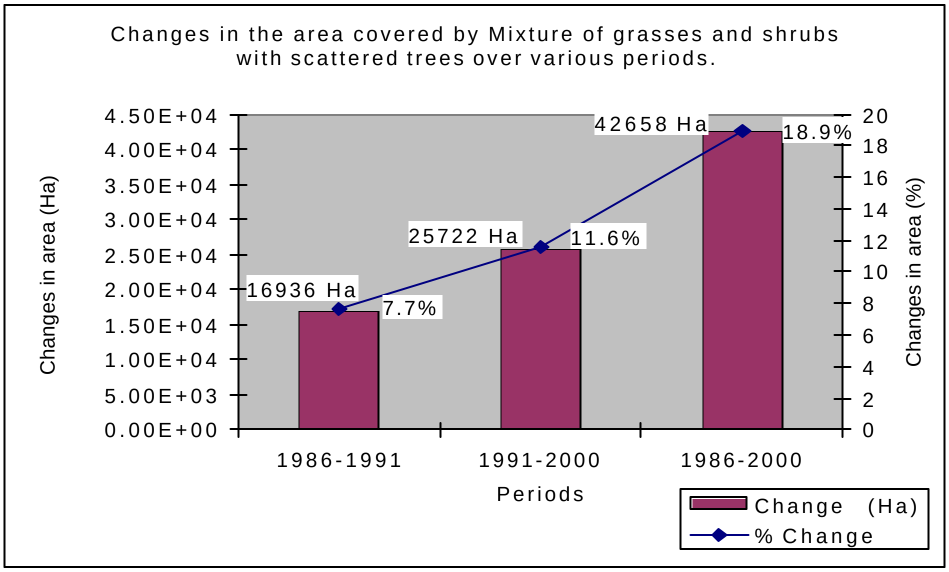


Figure 5.9: Changes in the area covered by *Mixture of grasses and shrubs with scattered trees* over various periods. *NB: Time spans are different for the periods (5 years and 10 years)*

5.2.5 Water body

The analysis shows that from 1986 to 1991, the land surface of the Upper West Region covered by water increased from 406 hectares (0.021 % of the region) to 887 hectares (0.047 %). This further increased to 1029 hectares in 2000, which represents some 0.54% of the region (Figures 5.10 and 5.11). The changes in the area of water may indicate an increase in the number of dams or reservoirs, but since water bodies do change in response to climatic conditions in a given year, it is difficult to discuss the changes recorded here.

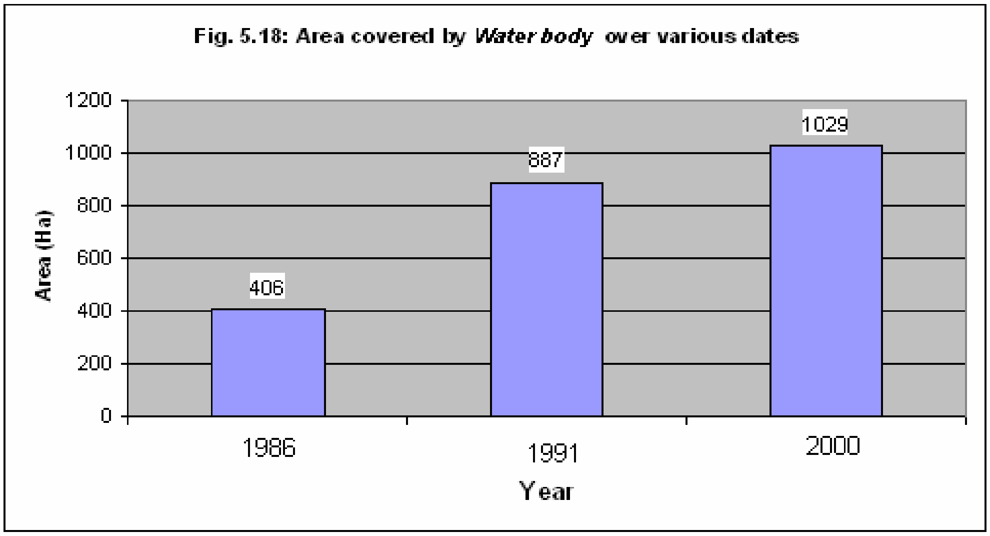


Figure 5.10: Area covered by *Water body* at various dates NB: Time spans are different for the periods (5 years and 10 years)

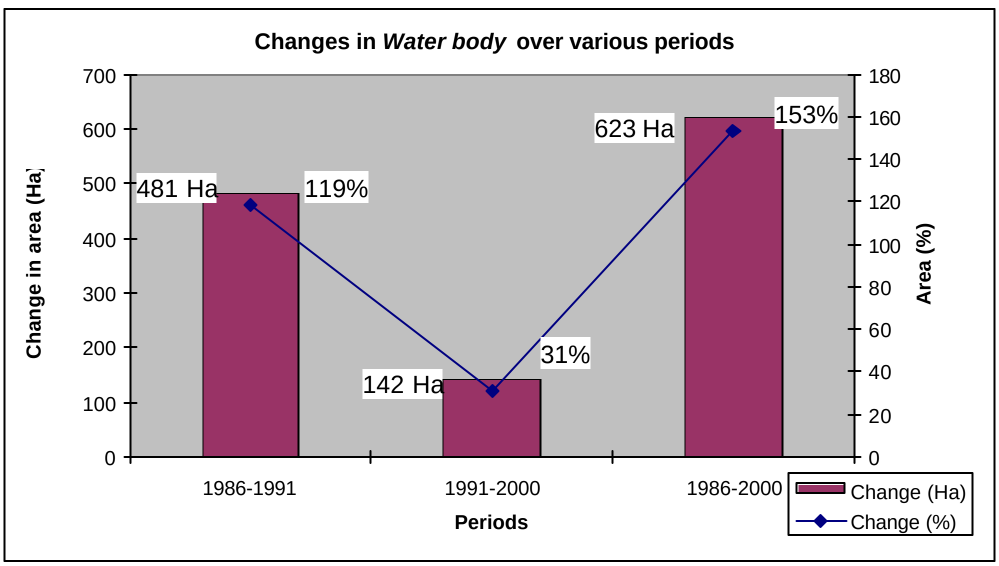


Figure 5.11: Changes in *Water body* over various periods. *NB: Time spans are different for the periods (5 years and 10 years)*

The changes in land use and land cover described above are dynamic and consist of the conversion and interconversion of the land use or land cover classes. It is important to understand the dynamics of the conversions and inter-conversions of the land cover classes, as they show the nature of the conversions in question.

5.3 Dynamics of land use and land cover change

The dynamics of land cover conversions and inter-conversions in the Upper West Region and, for that matter, other parts of the *Guinea* and *Sudan Savannah Ecological Zones* of Ghana are depicted schematically in Figure 5.12. More often than not, the uncultivated primary or virgin vegetation is either closed or open savannah woodland. In the scheme of intervention, the farmers move in to clear the primary or

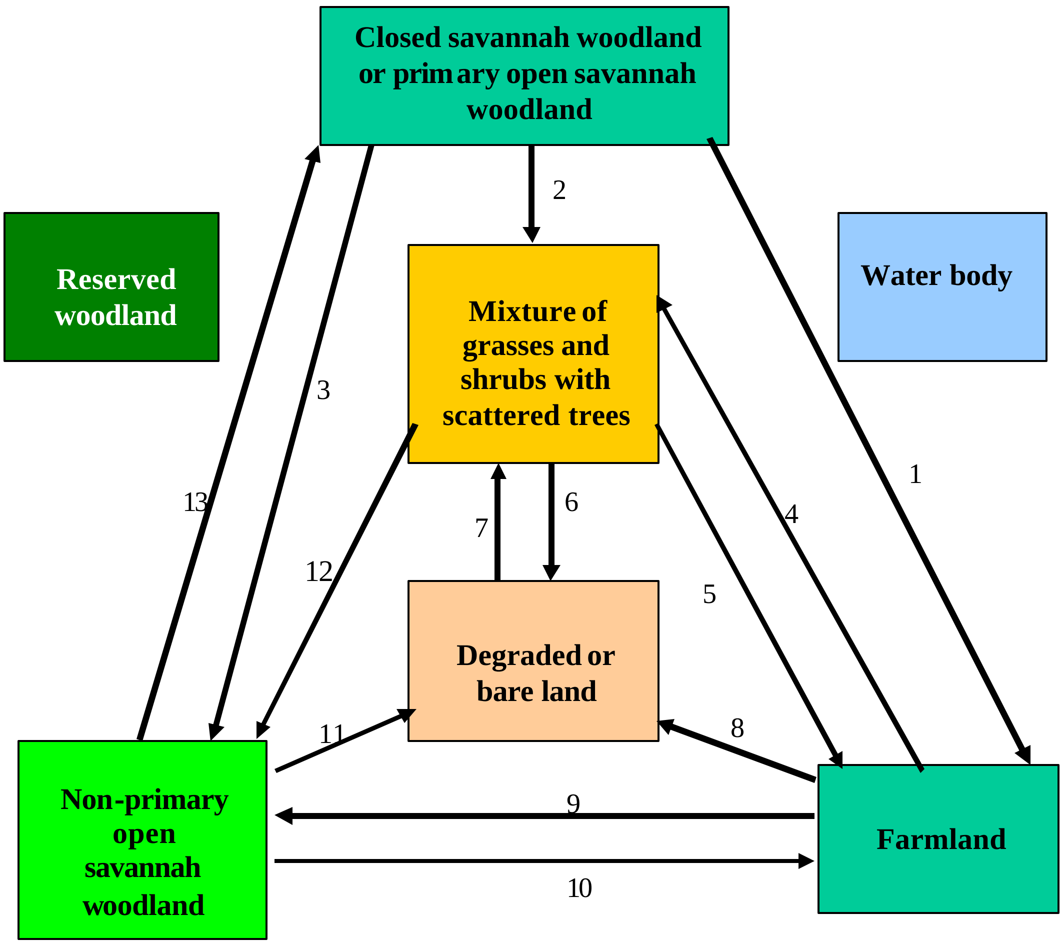


Figure 5.12: Land cover dynamics in the Upper West Region of Ghana *(Numbers refer to land cover change processes descibed in the text. Water body and Reserved woodland have been observed to be not involved in the inter-cover change relationship).*

virgin woodland for cultivation, thereby converting it into *Farmland* (1), which comprises cropland or newly fallowed land. Sometimes, due to other events than cultivation, such as incessant bushfires or other forms of human intervention, for example surface mining, etc., the primary savannah woodland may convert to *Mixture* *of grasses and shrubs with scattered trees* (2). According to Garrity *et al*. (1997), woody regrowth may be prevented by recurrent fires as in grasslands. Again primary *closed savannah woodland,* either due to exploitation such as for timber or fuel wood or other products or incessant fires, may also turn directly into *Open savannah woodland* (3). The cultivated plots when left to fallow turn into *Mixture of grasses and shrubs with scattered trees* (4). *Mixture of grasses and shrubs with scattered trees* can also be cultivated and become *Farmland* (5). When *Mixture of grasses and shrubs with scattered trees* is cultivated continuously without fallows or with shortened fallow periods without any effective land management, the land may degrade and become *barren or bare land* (6). Similarly, when *Farmland* is over-cultivated or over-grazed without any land management practice, it may become degraded (8). The bare land may regain vegetation and become *Mixture of grasses and shrubs with scattered trees* (7). Continuous farming of a particular piece of land for a long time and where economic trees are left standing (i.e. not cut), the land may turn into non-primary *open savanna woodland* (9) (Boffa, 1999). Non-primary *open savannah woodland*, especially the fallowed ones may be farmed (10). Non-primary *open savannah woodland* may become degraded through over-use and mismanagement and consequently become degraded (11). *Mixture of grasses and shrubs with scattered trees* can change into *Open savannah woodland*, if left unexploited for a number of years (12). Finally, non-primary *Open savannah woodland*, if left undisturbed, may revert to *Closed savannah woodland* again (13) after 15-20 year (Lawson, 1987 and Yang, 2000).

Following the classification of the various land use and land cover classes in the Upper West Region and the determination of the levels of changes they have undergone, it is important to determine the likely factors that are responsible for those changes. The factors were therefore studied and described in Chapter 6.

6 ASSESSMENT OF CAUSES OF LAND USE AND LAND COVER CHANGE (Methods and Results)

Many scientists, such as Schroth and Sinclair (2003), Dechert and Veldkamp (2002), von Uexküll and Mutert (1995), Lawson (1985), Boserup (1996), Contreras-Hermosilla (2000) and Shoshany *et al.*, (1995), have reported that rainfall, soils and population growth are important determinants of land use changes and vegetation patterns in savannah ecosystems. Rainfall exerts a strong influence on the condition of vegetation cover and there are varying correlations between them in semi-arid environments (Damizadeh *et al*., 2001; Penauelas *et al.*, 1997; Thompson, 2002 and Sternberg *et al.*, 1999). The fertility levels of soils in tropical savannah ecosystems determine land use and indirectly influence deforestation or loss of woodland (Schroth and Sinclair, 2003 and Dechert and Veldkamp, 2002). Therefore, the rainfall pattern of the Upper West Region was studied to see whether its regime over the period between 1980 and 2000 was suitable for the performance of the crops. The general fertility of the soils of the region was also assessed to see the extent to which they are suitable for the production of the traditional crops being grown there. The population of the region was also studied to see whether its growth over the period under study are related to changes in the areas of farmland and closed savannah woodland.

This chapter, therefore, covers soil sampling and analysis, the analysis of the rainfall of the region during the period betweeen 1980 and 2000, the evaluation of soil fertility and rainfall data for the key crops grown in the region and the analysis of population growth and its comparison with changes in farmland and closed savannah woodlands during the 1986-2000 period. The relatonship of the methodologies used in this chapter to the entire study has been shown in Figure 4.1 (Chapter 4).

6.1 Methods

6.1.1 Soil sampling and analysis

Soil samples were taken from all the land cover types and analysed to see whether their fertility levels were capable of supporting economic cultivation of crops, given that all other conditions for crop production are optimum. In particular, the soil fertility survey was to assess whether there are significant differences between the soils under the various land cover types including those of agricultural fields that have been cultivated continually over the years.

Judgement rather than random point soil samples were taken from the top 30 cm, using a soil auger or a chisel. The geographic locations, locality and land cover types of each bulk sample sites are shown in Tables 6.1, 6.2, 6.3 and 6.4.

Table 6.1: Locations of samples from *Closed savannah woodland*

	Geographic location		Locality	Land use and land cover
#	**Latitude**	**Longitude**		
5	9 58 36N	2 3 50W	East of Bulenga	Closed woodland
15	9 58 19 N	1 59 14 W	East of Bulenga	Closed woodland
16	9 57 58 N	1 58 41 W	Ambalara Resreve	Closed woodland
17	10 05 57N	2 01 03W	mining area road	Closed woodland
18	10 09 15N	1 55 13W	Yala	Closed woodland
20	10 05 35N	1 54 26W	Kulung (bet Yala & River	Closed woodland (primary)
21	10 04 59N	1 53 24W	After River Katua rd	Closed savannah (primary)
32	10 58 39N	2 26 55W	Kulpawn Headwaters	Reserved woodland
33	10 49 27N	2 08 29W	Near Jeffisi	Closed woodland
34	10 40 38N	2 26 52W		Closed savannah (primary)
54	9 55 00N	2 15 00 W	Bulenga	Closed woodland
79	9 57 11N	2 07 33W	East of Bulenga	Closed woodland

The top 30 cm of the soil was sampled because it can be considered to be the rooting zone of most of the arable crops grown in the region. Within a given land cover area, point samples were taken from various locations with relatively uniform slopes

Table 6.2: Locations of samples from *Open woodland* cover

	Geographic location		Locality	Land use and land cover
#	**Latitude**	**Longitude**		
80	10 04 41 N	02 44 12 W	Northwest of Dorimon	Open woodland
71	10 50 23N	2 10 20W	West of Boti	Open woodland
22	10 03 09N	2 07 46W	Mining area road	Open woodland
26	10 22 27N		Fian, near Welembelle	Open woodland
35	10 01 39N	1 55 32W		Open woodland
53	10 41 39N	2 36 11W	West of Ullo	Open woodland
56	10 27 46N	2 32 47W	Near Busie	Open woodland
78			On Tumu-Chana road	Open woodland
25	10 12 04N	2 29 41W	9 km south of Fian	Open woodland
3	10 00 36	2 47 20	West of Dorimon	Open woodland
24	10 11 34N	2 29 44W	Near Jangbosi	Open woodland

and/or under similar management. These were bulked and mixed thoroughly to form a composite sample, a portion of which was then taken for laboratory analysis. Bulk samples were taken from different areas of (i) cultivated land and young fallowed lands, (ii) mixture of grasses and shrubs, (ii) uncultivated open woodlands and (iv) uncultivated closed woodlands. Care was taken not to sample soils from recently fertilized fields. For every composite soil sample site, the agricultural land use and/or vegetation (and for fallows, the possible age), were determined. In all 87 composite samples were taken throughout the region. The soils were analyzed for nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) magnesium (Mg) and organic carbon. Cation exchange capacity (CEC), base saturation (BS), pH and organic matter were also determined. The nutrient levels of the soil samples were evaluated in terms of the fertility requirements of the common crops grown in the region, using the guidelines of Landon (1991) and Sys (1985).

Table 6.3: Locations of soil samples from *Mixture of grasses and shrubs*

	Geographic location			
#	**Latitude**	**Longitude**	**Locality**	**Land use and land cover**
76	10 47 41N	2 02 11W	Kong, Tumu	Fallow (5-6 years old)
2	10 02 18 N	2 45 25W		Fallow (3 to 4 yr)
37	9 55 24N	2 27 16W	Near Tanina	Fallow (4 years old)
6	10 06 49 N	2 46 41W		Fallow (3 yrs old)
10	9 45 42 N	2 40 16W	S. Dorimon	Fallow (3-4 yrs old)
11	9 53 28 N	2 35 44W	S.E. Dorimon	Fallow (2-3 yrs old)
12	9 58 47 N	2 31 25W	South of Wa	Fallow (2-3 yrs old)
13	10 00 30 N	2 24 52W	East of Wa	Fallow (3-4 yrs old)
8	9 56 53 N	2 44 23W	S. Dorimon	Fallow (4-5 yrs)
40	10 11 21N	2 38 43W	Sankama	Fallow (5 years old)
23	10 05 15N	2 30 02W	North of Wa	Fallow (4-5 years old)
52	10 40 36N	2 36 03W	W. Karni	Fallow (4 years old)
48	10 39 18N	2 46 15W	Eremon	Fallow (5 years)
77	10 40 09N	2 00 09W	Near Sakolo	Fallow (4 years old)
75	10 45 31N	2 14 13W	Near Jeffisi	Fallow (6 yrs) shallow
72		2 00 30W	Tumu	Fallow (4 years old)
29	2 06 59W	2 06 59W	Kojo Pere, E.	Mixture of grasses/shrubs
30	1 59 16W	1 59 16W		
31	1 50 43W	1 50 43W		Mixture of grasses and shrubs

Table 6.4: Locations of soil samples from *Farmland* (recently cultivated fields)

#	Geographic location			Land use and land cover
	Latitude	Longitude	Locality	
7	10 07 42N	2 45 55 W	Dorimon (NW)	Cultivated previous yea
9	9 52 07 N	2 40 38 W	South Dorimon	Fallow (grasses & shrubs)
1	10 01 23N	02 41 09W		Cultivated previous year
19	9 58 24N	1 57 41 W		Fallow
27	10 17 01N	2 15 42W	Near Fian	Fallow (2 yrs)
28	10 21 49N	2 14 07	Kojo Pere	Fallow
38	9 46 39N	2 30 48W	Samanbo near Ga	Cultivated previous year
39	10 09 55N	2 31 07W	S of Kaleo	Cultivated previous year
41	10 12 20N	2 39 22W	Gyili, near Takpo	Fallow (2 yrs)
42	10 14 52N	2 43 13 W		Cultivated previous year
43	10 14 28N	2 34 49W	Near Banko	Fallow (2 yrs)
44	10 20 46N	2 36 26W	North of Sombo	Old fallow
45	10 38 05N	2 41 31W	North of Nadowli	Cultivated previous year
46	10 33 29N	2 42 46W	Near Jirapa	Cultivated previous year
47	10 37 20N	2 42 46W	Jirapa-Eremon rd	Cultivated previous year
49	10 44 14N	2 49 11W	Eremon area	Intensively farmed
50	10 37 53N	2 56 39W	Dikpe near Lawra	Cultivated previous year
51	10 39 41N	2 40 16W	E of Eremon	Fallow (2 yrs)
55	10, 28 28N	2 30 53W	Near Busali	Fallow (2 yrs)
57	10 27 01N	2 30 45W		Cultivated previous year
58	10 25 36N	2 33 42W	Near Dafiama	Cultivated previous year
59	10 22 40N	2 40 43W	Nadowli (Lawra Rd)	Fallow (2 yrs)
60	10 28 35N	2 47 10W		cultivated soil
61	10 39 40N	2 55 38W	North of Lawra	Farmland (stony)
62	10 45 42N	2 50 12W	Near Kamba	Fallow (2 yrs)
63	10 51 25N	2 47 50W	Danko near Nandom	Cultivated previous year
64	10 54 13N	2 44 24W	North or Nandom	Fallow (2 yrs)
65	10 59 51N	2 41 42W	Outskirt of Hamile	Cultivated previous year
66	10 59 17N	2 35 27W	Near Fielmon	Fallow (2 yrs)
68	10 58 04N	2 17 13W	Gbal on Gwollu rd	Cultivated previous year
69	10 57 10N	2 11 05W	Outskirt of Gwollu	Shallow soil
71	10 50 12N	2 01 12W	5 km W. Gwollu	Concretionary soil
14	10 00 19N	2 22 22W	East of Busa	Fallow (2 yrs old)
36	10 01 21N	2 21 03W	Wa-Ga road	Fallow (2 yrs old)
73	10 48 47N	2 03 09W	Tumu-Han road	Fallow (3yrs)
4	10 02 19N	2 40 59 W	Northwest Dorimon	Almost bare

6.2 Results of soil fertility assessment

The results of chemical analyses of the soil samples for the assessment of the general fertility of the soils of the Upper West Region are presented in Tables 6.5, 6.6, 6.7 and 6.8. These tables show, respectively, the results for soils under the four main land cover categories, namely, (i) *Closed savannah woodland* (which includes reserved savannah woodland), (ii) *Open savannah woodland with shrubs and grasses*, (iii) *Mixture of* *grasses and shrubs with scattered trees* and (iv) *Farmland* (recently cultivated land). The results of the analyses of the soils are discussed for each of the land cover types, according to the rating of Landon (1991) as given in Table 6.5.

Table 6.5: Soil chemical analyses and their interpretations (after Landon, 1991)

Par	Method	Unit	Range	Rating	General interpretation
pH	1:2.5 soil:water suspension		>8.5	Very high	Alkaline soils: Ca and Mg may be unavailable; Na may be high; possible B toxicity
			7.0-8.5	High	Decreasing P and B availability; Above pH 7.0, deficiency of Co, Fe, Mn and Zn
			5.5.-7.0	Medium	Preferred range for most crops; lower end may be acidic to some crops
			<5.5	low	Acid soils: Possible Al toxicity; excess Co, Cu, Fe, Mn & Zn; Deficiency of Ca, K, Mg, N, P, S and <pH 5, B
CEC	(a) Unbuffered 1M KCl at pH of soil (b) Na or Nh_4 Acetate (pH 8.2	Cmol(+) kg^{-1}	>40	Very high	Normally good agricultural soils: only small quantities of lime and K fertilizers required
			25-40	High	
			15-25	Medium	Normally satisfactory for agric., given fertilizers
			5-15	Low	Marginal for irrigation (FAO, 1979a quoted low is 8-10 me/100g soil)
			<4	Very low	Few nutrient reserves. Usually unsuitable for irrigation, except rice.
	Tot. ex. bases /CEC	%	>60	High	Generally fertile soils
			20-60	Medium	Generally less fertile soils
			<20	low	
Ca	As for CEC		>10	High	Response to Ca fertilizer expected at levels <0.2 me/100 g soil. If high Na levels, response occurs with higher Ca levels.
			<4	low	
Mg	As for CEC	Cmol(+) kg^{-1}	>4.0	High	Mg deficiency more likely on coarse, acid soils. With high Ca, Mg is less plant-available.
			<0.5	low	
	As for CEC		>0.6	high	Response to K fertilizer unlikely. High K effects often similar to high Na; depends on soil type, e.g., texture
			<0.2	Low	Response to K fertilizer likely
Org.	Micro-Kjeldahl	% by weight	>0.5	High	Interpretation depends on soil and location
			0.2-0.5	Medium	
			<0.2	Low	
P	Bray	ppm			
OC	Walkey-Black	% by weight	>10	Very High	Interpretation depends on soil and location
			4-10	High	
			4	medium	
			2-4	low	
			<2	Very low	
OM	OC x 1.72	-	0.5-1.0	Low	
			<0.5	Very low	

6.2.1 Soil chemical properties: Closed savannah woodland

As shown in Table 6.6, the pH of the soils under *Closed savannah woodland* ranged from 5.5 to 6.5, giving an average of pH 5.8. This falls within the medium rating level (pH 5.5 – 7.0), which is the preferred range for most crops, though the lower end of it may be too acidic for some of them. The cation exchange capacity (CEC) of the soils ranged generally from 4.54 to 15.84, which averaged 11.78

Table 6.6: Soil chemical analytical results: soils under *Closed savannah woodland*

Sample	pH	Extractable Bases: Cmol(+)/kg					CEC Cmol (+)/kg	BSP	Avail. P	Tot. P	OC	OM	N
#	1:1	Ca	Mg	Na	K	Sum		%	ppm	ppm	%	%	%
7	5.6	1.64	0.34	0.26	0.05	2.29	8.91	25.7	4.80	107	0.70	1.21	0.03
18	5.6	3.68	1.04	0.23	0.08	5.03	12.70	39.6	8.38	141	1.89	3.27	0.05
20	5.6	2.56	0.54	0.24	0.05	3.39	10.8	31.5	1.68	63.6	0.81	1.40	0.03
21	5.5	8.22	3.32	0.26	0.07	11.9	38.80	30.6	3.77	85.8	2.40	4.13	0.07
32	6.0	3.38	0.70	0.21	0.04	4.33	7.80	55.5	9.00	148	0.97	1.68	0.04
33	6.1	5.94	0.84	0.21	0.05	7.04	7.80	90.3	9.81	54.2	1.71	2.94	0.06
34	5.8	4.74	0.84	0.21	0.05	5.84	9.31	62.7	5.36	159	1.68	2.89	0.05
67	5.7	1.20	0.24	0.11	0.02	1.57	4.54	24.8	0.95	102	0.43	0.74	0.02
74	6.5	2.12	0.56	0.15	0.03	2.86	6.25	46.2	1.32	144	0.88	1.51	0.03
54	5.8	2.46	0.92	0.13	0.04	3.55	5.38	66	0.73	121	2.00	3.44	0.05
15	6.1	6.80	1.50	0.26	0.09	8.65	15.8	54.6	3.66	149	2.63	4.53	0.08
16	5.4	3.44	0.96	0.28	0.09	4.77	13.3	36	1.91	141	0.98	1.69	0.04
Ave	5.8	3.85	0.98	0.21	0.06	4.73	11.78	47	4.28	118	1.42	2.45	0.05

Legend: Ca: Calcium; Mg: Magnesium; Na: Sodium; K: Potasium; CEC: Cation exchange capacity; BSP: Base saturation; Avail. P: Available phosphorus; OC: Organic carbon; OM: Organic matter; N: Nitrogen

Cmol(+) kg^{-1}, though there was an exceptional value of 38.8 Cmol(+) kg^{-1} for one of the soils. On average, the CEC of the soils is low (5 – 15 Cmol(+) kg^{-1}), which means a low nutrient reserve. The base saturation percentage (BSP) falls within the range of 25.7 to 62% (average of 36%), with one being 90%. This generally indicates a medium BSP rating (20 – 60%) for the soils under closed savannah woodland. The calcium content ranged from 1.64 to 8.22 (average of 3.85) Cmol(+) kg^{-1}, which, is low (<4 Cmol(+) kg^{-1}). The magnesium (Mg) levels of the soils were from 0.24 to 3.32 Cmol kg^{-1} soil, indicating that the soils are low (<0.5 Cmol(+) kg^{-1}) to medium (0.5 – 4.0 Cmol(+) kg^{-1}) in the nutrient element. The potassium (K) content of the soils was estimated to be

0.02 - 0.09 (average of 0.06) Cmol(+) kg^{-1}, which was low and an indication of a requirement for fertilizer application.

A soil nitrogen (N) content of less than 0.2% (Kjeldahl method) is low. The soils under closed savannah woodland had nitrogen levels ranging from 0.02 to 0.08%, with an average of 0.05%, indicating a low level of the plant nutrient and responses to nitrogenous fertilizers could be expected. The available phosphorus (P) content of the soils varied from 0.73 to 9.81 (average of 4.28) ppm. For soils cultivated to cereals and legumes, cotton, grass and vegetables, which is the case for the Upper West Region, a phosphorus level of 8 ppm or more is considered adequate, while a level less than 4 ppm is deficient. Thus, the soils are, on average, low to marginally adequate, meaning that some areas are grossly deficient. Phosphorus fertilizer application is required for optimum yield. The organic carbon (OC) level of the soils ranged from 0.43 to 2.63% (average of 1.42%), which is considered low (<4%), and which also meant that the organic matter content of the soils are also low.

6.2.2 Soil chemical properties: Open savannah woodland

Table 6.7 shows that the pH levels of the soils sampled under *Open savannah woodland* ranged from 4.8 to 6.3 (with an average of about 5.5), which can be considered low

Table 6.7: Soil chemical analytical results: soils under *Open savannah woodland*

Sample	pH	Extractable bases Cmol(+)/kg^{-1}					CEC	BSP	Avail P	Organic	OM	N
#	1:1	Ca	Mg	Na	K	Sum		%	ppm	%		
5	5.1	3.20	2.78	0.28	0.06	6.32	15.4	41.1	0.74	1.44	2.48	0.05
70	6.3	2.26	0.70	0.13	0.05	3.14	8.78	36.6	1.76	0.83	1.43	0.03
22	5.3	2.24	0.96	0.24	0.05	3.49	11.2	31.1	5.29	0.78	1.35	0.03
26	4.9	1.92	0.48	0.22	0.05	2.67	5.30	50.4	2.18	0.70	0.70	0.03
35	6.0	4.24	0.64	0.22	0.09	5.19	7.25	71.58	1.08	1.04	1.79	0.04
53	5.3	2.06	0.76	0.13	0.04	2.99	4.85	61.49	1.04	1.32	2.27	0.05
56	5.8	1.36	0.42	0.13	0.02	1.93	6.08	31.74	1.04	0.65	1.13	0.03
78	5.8	1.24	0.26	0.13	0.02	1.65	4.83	34.2	2.58	0.8	1.38	0.02
25	4.8	1.88	0.72	0.23	0.05	2.88	8.49	33.9	1.00	1.04	1.80	0.03
3	5.2	3.44	1.96	0.26	0.07	5.73	14.2	40.46	1.91	0.78	1.34	0.03
31	5.1	4.94	2.32	0.22	0.05	7.53	13.1	57.5	12.70	1.39	2.40	0.04
Tot:	59.6	29	9.7	2.2	0.6	43.5	99	490	31.3	11	18	0.38
Ave.	5.5	2.62	0.88	0.2	0.05	4.0	9.04	44.54	2.85	0.98	1.65	0.03

(<5.5) and acidic, with possible aluminum toxicity and excess of Co, Cu, Fe, Mn, Zn and deficiency of Ca, K, N, Mg, Mo, P and S,accordingto the rating of Landon (1991). The cation exchange capacity (CEC) of the soils under the open savannah woodland cover ranged from 4.83 to 15.37 Cmol (+) kg^{-1}, which averaged to about 9.04) Cmol (+) kg^{-1}. This indicated that the CEC levels, according to the rating of Landon (1991), were very low (<5) to low (5 –15), meaning that the nutrient reserves were low. The base saturation percentage (BSP) varied between 22.59 and 71.58% (average of 44.54%). These levels are medium (20-60%). The calcium (Ca) content of the soils were between 1.24 and 4.24 Cmol(+) kg^{-1} with an average of 2.62 Cmol(+) kg^{-1}, which is low (<4 Cmol(+) kg^{-1}). However, since the soils are acidic and since the calcium (Ca) level is above 0.2 Cmol(+) kg^{-1}, a response to the application of calcium fertilizer may not be significant (Landon, 1991). The magnesium level ranged from 0. 26 to 2.78 (average of 0.88) Cmol(+) kg^{-1}, which is a low level (<0.5) (Landon, 1991). The soil potassium (K) content ranged from 0.02 to 0.07 (average of 0.05) Cmol(+) kg^{-1}, which was low (<0.2), according to Landon (1991), indicating a likelihood of a response to K fertilizer.

The available phosphorus content ranged between 0.74 and 12.70 (average of 2.85) ppm, which was an indication of deficiency of the element (<4 ppm) for the production of cereals, legumes, tomatoes, potatoes, onion , sweet corn, cotton and grass (Cooke,1967). The nitrogen levels of the soils were between 0.02 and 0.05%, giving an average of 0.03%, which is low (<0.2%.). The organic carbon content of the soils was from 0.7 to 1.44 (average of 0.98), which indicated a low level (<4%). Consequently, organic matter was assessed to be low.

6.2.3 Soil chemical properties: mixture of grasses and shrubs

Table 6.8 shows that the pH of the soils under *the Mixture of grasses and shrubs* land cover generally ranged from 5.4 to 6.0 (average of 5.4), which can be considered low (<5.5). Thus, aluminium toxicity and excess of Co, Cu, Fe, Mn and Zn are possible in some of these soils, while Ca, K, Mg, Mo, P, S and B may be deficient in those with pH <5. The cation exchange capacity (CEC) was between 3.77–14.41 (average of 8.63) Cmol(+)/kg. This means that the cation exchange capacity was very low to low, because levels less than 5 Cmol(+)/kg are considered to be very low and those between 5 and 15 Cmol(+)/kg low. The base saturation percentage levels were between 13.92 and

Table 6.8: Soil chemical analytical results: soils under *Mixture of grasses and shrubs*

Sample	pH	Extractable bases					CEC	BSP	Avail able P	Organic C	Organic Matter	N
		Cmol(+)/kg^{-1}										
	1.1	Ca	Mg	Na	K	Sum		%	ppm	%		
24	5.3	1.54	0.50	0.23	0.06	2.33	10.3	22.59	1.92	0.49	0.84	0.03
76	5.6	0.82	0.28	0.14	0.03	1.27	6.33	20.06	1.34	0.48	0.83	0.02
2	5.0	0.96	0.5	0.23	0.05	1.74	8.78	19.81	1.66	0.29	0.50	0.02
37	5.0	2.78	0.52	0.15	0.03	3.48	6.10	57.05	1.29	0.80	1.37	0.03
6	5.0	1.28	0.70	0.27	0.05	2.30	9.80	23.46	1.32	0.32	0.56	0.03
10	5.3	1.14	0.34	0.26	0.05	1.79	10.1	17.79	1.68	0.52	0.90	0.02
11	5.6	3.1	0.88	0.27	0.06	4.31	12.2	28.25	1.60	1.14	1.97	0.03
12	5.6	2.32	0.92	0.26	0.05	3.55	14.4	24.77	1.91	1.01	1.74	0.03
13	5.4	2.1	0.42	0.27	0.05	2.84	10.9	25.91	1.06	0.42	0.73	0.02
8	5.5	2.54	0.76	0.25	0.06	3.61	12.70	28.42	2.22	1.08	1.86	0.04
40	5.6	0.86	0.24	0.11	0.02	1.23	8.82	13.92	13.42	0.46	0.80	0.02
23	6.0	1.34	0.32	0.23	0.04	1.93	8.30	23.25	2.16	0.24	0.42	0.05
52	5.8	1.80	0.80	0.20	0.03	2.83	5.19	25.77	1.08	0.94	1.62	0.02
48	5.3	1.06	0.20	0.12	0.03	1.41	3.77	37.4	0.82	0.65	1.13	0.03
77	5.6	1.80	0.46	0.12	0.03	2.41	5.16	46.70	1.09	0.77	1.32	0.03
75	5.3	1.42	0.30	0.13	0.02	1.87	8.45	30.40	1.78	0.57	0.99	0.02
72	5.1	0.82	0.24	0.13	0.03	1.22	5.74	25.15	1.21	1.00	1.72	0.02
29	5.3	2.60	0.80	0.23	0.04	3.67	7.28	50.41	2.28	0.72	1.24	0.03
30	5.4	4.42	1.64	0.26	0.06	6.38	9.75	65.54	17.80	0.72	1.24	0.02
Tot	1037	34.7	10.8	3.86	0.79	42.00	164	586.65	57.64	12.62	21.78	0.51
Av	5.4	1.83	0.57	0.20	0.04	2.21	8.63	30.88	3.03	0.66	1.15	0.03

Legend: Ca: Calcium; Mg: Magnesium; Na: Sodium; K: Potasium; CEC: Cation exchange capacity; BS: Base saturation; Avail. P: Available phosphorus; OC: Organic carbon; OM: Organic matter; N: Nitrogen

65.54% (average of 30.88%), which were medium (20–60%). The available phosphorus (P) content was also low, ranging from 0.82-17.80 ppm (average of 3.03 ppm). Soil available P levels lower than 4 ppm are low. Thus, these soils are deficient in available P. The nitrogen content of the soils ranged from 0.02-0.5% (average of 0.03%), which is low (<0.2%). The organic carbon content varied from 0.24 to 1.14 % (average of 0.66%), which was low (< 4%). Consequently, the organic matter content was also low.

6.2.4 Soil chemical properties: Farmland

As shown in Table 6.9, the pH of the farmland or recently cultivated soils ranged from 4.4 to 6.0 (average of 5.4), which can be considered low (<5.5). The cation exchange

Table 6.9: Soil chemical analytical results: soils under Farmlands (recently cultivated fields)

#	pH	Extractable bases					CEC	BSP	Available P	Total P	Organic C	Org. Matter	Nitrogen
		Cmol(+)/kg^{-1}											
	1:1	Ca	Mg	Na	K	Sum		%	ppm		%		
7	4.7	1.26	0.38	0.26	0.05	1.95	9.13	21.36	2.04	133.3	0.31	0.53	0.03
9	4.8	3.00	0.48	0.27	0.04	3.79	11.3	33.62	1.01	124.3	0.36	0.61	0.03
1	4.9	1.66	0.82	0.23	0.05	2.76	11.20	24.64	1.59	68.5	0.57	0.98	0.03
19	5.7	1.62	0.36	0.23	0.06	2.27	8.35	26.94	4.51	45.7	0.54	0.93	0.03
27	5.4	1.32	1.62	0.26	0.06	3.26	10.3	31.71	9.69	136.3	1.60	2.76	0.04
28	4.4	1.36	0.28	0.26	0.04	1.94	5.55	35.31	1.73	47.9	0.94	1.62	0.03
38	5.4	2.04	0.38	0.11	0.02	2.55	4.90	52.04	2.56	100.3	0.80	1.37	0.02
39	5.8	0.96	0.32	0.12	0.02	1.42	5.21	27.25	5.80	151.1	0.40	0.69	0.02
41	5.6	1.60	0.20	0.13	0.02	1.95	4.36	44.72	1.72	161.3	0.37	0.64	0.02
42	5.1	1.32	0.24	0.13	0.03	1.72	5.16	33.33	1.48	152.8	0.96	1.65	0.02
43	5.2	2.28	0.44	0.14	0.02	2.88	8.28	34.78	1.75	135.4	0.72	1.24	0.02
44	5.3	1.00	0.30	0.11	0.02	1.43	6.30	22.69	1.33	48.7	0.49	0.85	0.03
45	5.0	0.62	0.18	0.10	0.02	0.92	4.47	20.58	0.94	46.9	0.48	0.82	0.02
46	4.5	0.66	0.12	0.10	0.02	0.90	4.91	18.33	1.04	132.2	0.41	0.72	0.02
47	4.7	0.48	0.12	0.10	0.02	0.72	5.00	14.40	1.06	103.9	0.30	0.52	0.02
49	7.6	1.06	0.44	0.10	0.03	1.63	7.22	22.57	1.53	68.4	0.64	1.10	0.02
50	5.3	1.98	0.36	0.12	0.03	2.49	12.3	20.24	5.90	172.1	1.08	1.87	0.04
51	5.7	0.60	0.18	0.12	0.02	0.92	11	8.37	2.11	122.4	0.45	0.77	0.02
55	5.3	0.98	0.32	0.13	0.02	1.45	6.89	21.04	1.48	166.9	0.89	1.54	0.04
57	5.9	1.76	1.86	0.12	0.02	3.76	5.11	73.58	1.05	139.2	0.64	1.10	0.03
58	5.7	1.00	0.30	0.13	0.02	1.45	9.54	15.19	2.01	155.9	0.59	1.06	0.03
59	5.8	1.04	0.20	0.13	0.05	1.42	7.92	17.92	1.68	148.7	0.37	0.63	0.02
60	5.6	1.52	0.20	0.15	0.06	1.93	7.52	25.59	1.47	133.0	1.02	1.76	0.04
61	6.0	6.62	4.20	0.13	0.06	11.0	14.4	76.67	3.03	160.1	0.97	1.68	0.04
62	5.4	1.94	0.38	0.12	0.03	2.47	6.72	36.75	3.84	170.2	0.59	1.02	0.03
63	5.0	1.72	0.88	0.13	0.02	2.75	5.16	53.29	1.06	153.4	0.73	1.26	0.05
64	5.5	4.64	1.84	0.12	0.06	6.66	8.69	76.63	1.00	96.9	1.68	2.90	0.05
65	5.8	4.40	2.58	0.12	0.04	7.14	9.13	78.20	1.06	180.2	1.71	2.94	0.04
66	5.5	0.5	0.14	0.13	0.02	0.80	6.42	11.22	1.31	83.5	0.45	0.77	0.02
68	5.6	0.76	0.24	0.14	0.02	1.16	5.72	24.88	1.21	127.2	0.49	0.85	0.02
69	5.5	1.16	0.42	0.15	0.03	1.76	8.59	30.42	1.71	149.6	0.8	1.37	0.03
71	5.1	0.62	1.60	0.12	0.02	2.36	4.77	27.33	1.02	65.7	0.41	0.72	0.02
14	5.4	2.64	0.58	0.26	0.05	3.53	11.3	31.35	2.59	137.6	0.62	1.07	0.06
36	4.9	2.16	0.50	0.18	0.02	2.86	5.10	56.07	2.41	65.0	0.49	0.85	0.02
73	4.4	0.64	0.12	0.13	0.02	0.91	6.13	16.02	1.39	101.4	0.73	1.27	0.03
4	5.3	2.16	0.44	0.24	0.04	2.88	13.4	21.22	1.91	71.3	0.75	1.29	0.04
	193	61.1	24.0	5.52	1.17	77.4	277	1186.3	79.02	4257.0	25.35	43.75	1.07
	5.4	1.70	0.67	0.15	0.03	2.15	7.70	32.95	2.20	118.3	0.70	1.22	0.03

Legend: Ca: Calcium; Mg: Magnesium; Na: Sodium; K: Potassium; CEC: Cation exchange capacity; BS: Base saturation; Avail. P: Available phosphorus; OC: Organic carbon; OM: Organic matter; N: Nitrogen

capacity (CEC) ranged from 4.36 to 13.30 (average of 7.70) Cmol(+)/kg soil. Levels lower than 5 Cmol(+)/kg soil are considered to be very low and 5-15 Cmol(+)/kg soil low. This means the cation exchange capacity of the soil is very low to low, indicating that the nutrient reserves of the soils are low. The base saturation percent of the soils were found to be between 8.37 and 78.2%, giving an average of 32.95%, which is medium (20 – 60). The soil nitrogen content was between 0.02 and 0.06 % (average of 0.03)%, which was low (< 0.2%).The available phosphorus (P) content was also found to be low in these soils. It ranged between 0.94 and 5.80 ppm (average of 2.2) ppm, against the limit of 4 ppm (lower limit). This also means that the soils are, on average, deficient in available phoshorus for the production of crops. The organic carbon (OC) varied from 0.30 to 1.71 % (average of 0.70%), which is lower than the low limit of <4 of Landon, 1991). Consequently, organic matter will also be low.

6.3 Comparison of the soils under the different land cover types

Table 6.10 shows the result of an analysis of variance (ANOVA) between and within the soils under the four land cover categories. It shows that the differences are significant for pH, calcium (Ca), sodium (Na), potassium (K), base saturation percentage (BSP), organic carbon (OC), organic matter (OM) and nitrogen (N) at 95% confidence level. It means that for these chemical soil parameters, there are significant differences between the soils under the various land cover types. There are, however, no differences between cation exchange capacity (CEC), magnesium (Mg), available phosphorus (P) and total phosphorus at 95% confidence level ($p<0.05$).

Table 6.10: Analysis of variance (ANOVA) of soil analytical results

Parameter	Differences	Sum of Squares	Df	Mean Square	F	Sig.
pH	Between Groups	1.910	3	0.637	2.893	0.041
	Within Groups	16.284	74	0.220		
	Total	18.194	77			
Ca	Between Groups	46.275	3	15.425	8.191	0.000
	Within Groups	139.362	74	1.883		
	Total	185.637	77			
Mg	Between Groups	2.797	3	.932	1.663	0.182
	Within Groups	41.486	74	.561		
	Total	44.284	77			
Na	Between Groups	0.052	3	0.017	5.307	0.002
	Within Groups	0.244	74	0.003		
	Total	0.296	77			
K	Between Groups	0.006	3	00.002	6.786	0.000
	Within Groups	0.021	74	.000		
	Total	0.027	77			
Sum of bases	Between Groups	70.623	3	23.541	5.705	0.001
	Within Groups	305.367	74	4.127		
	Total	375.990	77			
CEC	Between Groups	150.755	3	50.252	2.513	0.065
	Within Groups	1479.717	74	19.996		
	Total	1630.472	77			
BSP	Between Groups	3068.950	3	1022.983	3.381	0.023
	Within Groups	22391.928	74	302.594		
	Total	25460.878	77			
Avail. P	Between Groups	40.542	3	13.514	1.395	0.251
	Within Groups	717.121	74	9.691		
	Total	757.663	77			
OC	Between Groups	5.546	3	1.849	10.963	0.000
	Within Groups	12.479	74	.169		
	Total	18.025	77			
OM	Between Groups	16.204	3	5.401	10.608	0.000
	Within Groups	37.681	74	.509		
	Total	53.885	77			
N	Between Groups	0.003	3	.001	7.962	0.000
	Within Groups	0.009	74	.000		
	Total	0.013	77			

Table 6.11 shows the average soil chemical levels for some key parameters under the four main land cover types. The average pH of the soils under *Closed*

Table 6.11: Average soil chemical levels for soils under various land cover types

Land cover	pH 1:1	Ca	Mg	K	CEC	BSP	Avail. P	%N	% OC	% OM
		Cmol(+) kg^{-1}				%	(ppm)	%	%	%
Closed woodland	5.8***a***	3.8***a***	0.98	0.06***a***	11.8***a***	47.0***a***	4.28	0.05***a***	1.42***a***	2.45***a***
Open w'ld + shrubs, grasses	5.4***b***	2.6***b***	1.1	0.05***ab***	9.04***ab***	44.5***ab***	2.85	0.03***b***	0.96***b***	1.65***b***
Mixture of grasses and shrubs	5.4***b***	1.8***b***	0.57	0.04***bc***	8.63***ab***	30.9***bc***	3.03	0.03***b***	0.87b	1.15***b***
Farmland	5.3***b***	1.7***b***	0.67	0.03***c***	7.70***b***	33.0***ab***	2.0	0.03***b***	0.70***b***	1.22***b***

Note: Values with same letters in a column are not significantly different at $p < 0.05$

savannah woodland (5.8) was higher (less acidic) than those under *Open savannah woodland*, *Mixture of grasses and shrubs* and of *Farmland*, which respectively had pH values of 5.4, 5.4 and 5.3. Thus, the O*pen woodland* soils were, on average, as acidic as those under *Mixture of grasses/shrubs* and less acidic than *Farmland* soils. At 95% confidence level ($p < 0.05$), there were, however, no significant differences between the pH values of *Open woodland, Mixture of grasses and shrubs and Farmland*. But that of *Closed savannah woodland* was significantly different from the others. The calcium (Ca) level was also highest in the *Closed woodland* soils (3.8 Cmol (+) kg^{-1}), followed by the *Open woodland* soils (2.6 Cmol ($^{+}$) kg^{-1}), *Mixture of grasses and shrubs* soils (1.8 Cmol (+) kg^{-1}) and *Farmland* soils (1.7 Cmol ($^{+}$) kg^{-1}). At $p < 0.05$, there were no significant differences between the calcium content of the soils under *Open woodland, Mixture of grasses and shrubs and Farmland.* However, these soils were significantly different from those under *Closed savannah woodland.* Magnesium (Mg) was also highest in the *Closed woodland* soils (1.1 Cmol (+) kg^{-1}), followed by the O*pen woodland* ones (0.88 Cmol (+) kg^{-1}), *Farmland* soils (0.67 Cmol (+) kg^{-1}) and *Mixture of grasses and shrubs* soils (0. 57 Cmol (+) kg^{-1}). There were no significant differences between them at $p < 0.05$. The average exchangeable potassium (K) level was 0.06 Cmol (+) kg^{-1} for the soils under *Closed savannah woodland*, which was the highest, followed by those under *Open savannah woodland* (0.05 Cmol (+) kg^{-1}), then those under *Mixture of grasses and shrubs* and *Farmland*, which were 0.04 and 0.03 Cmol (+) kg^{-1}) respectively. At $p < 0.05$, there were no differences between the soils under *Closed savannah woodland* and those under *Open savannah woodland*, *Open woodland, Mixture of grasses and shrubs* and the *Farmland* soils.

The cation exchange capacity (CEC) of the soils under *Closed savannah woo* dland was higher (11.8 Cmol(+) kg^{-1}) than it was in the soils under *Open savannah woodland* (9 Cmol(+) kg^{-1}), which in turn, was higher than those under *Mixture of grasses and shrubs* (8.63 Cmol(+) kg^{-1}). The CEC of the soils of the *Farmland* was 7.7 Cmol(+) kg^{-1}). There were no significant differences between the soils under *Closed savannah woodland, Open savannah woodland* and *Mixture of grasses and shrubs*. But there was a significant difference between the soils under *Closed savannah woodland* and the *Farmland* soils at $p < 0.05$.

The base saturation percentage (BSP) was also highest in the *Closed woodland* soils (47%). It was 44.5% in the *Open savannah woodland* soils, 33% in the *Farmland* soils and 30.9% in the soils under *Mixture of grasses and shrubs*. At $p < 0.05$, the differences between the soils under *Closed savannah woodland* and those under *Open savannah woodland* were not significant. But the differences between the *Closed savannah woodland* soils and those under *Mixture of grasses and shrubs* and *Farmland* were significant. There were, however, no significant differences between the soils under *Open savannah woodland*, *Mixture of grasses and shrubs* and those of *Farmland*.

Available phosphorus was also highest in the *Closed woodland* soils (4.28 ppm) and lowest in the *Farmland* soils (2.0 ppm). It was 3.03 and 2.85 ppm in the soils under *Mixture of grasses and shrubs* and *Open savannah woodland* respectively. These values were significantly different. Nitrogen was higher for the *Closed woodland* soils (0.05%) than for the soils under the three other land cover types (0.03 for all). At $p < 0.05$, there were significant differences between the *Closed savannah* soils and these other soils, which were not significantly different from each other. Organic matter decreased from the *Closed woodland* soils (2.45%) to the soils under *Mixture of grasses and shrubs* (1.15%). While there were no significant differences between the levels in the soils under *Open savannah woodland, Mixture of grasses and shrubs* and those of *Farmlan*. For organic carbon, the soils under *Closed savannah woodland*, which had a level of 1.42%, was significantly different from the other soils. There was no significant difference between the organic carbon (OC) content of the soils under *Open savannah woodland, Mixture of grasses and shrubs* and of *Farmland*, while those under *Closed savannah woodland* was significantly different from the these others. The trends for organic matter were the same.

Generally speaking, the soils under *Closed savannah woodland* were more fertile than those under *Open savannah woodland*, which, in turn, had a higher fertility status than the soils under *Mixture of grasses and shrubs*. The soils of the *Farmlands* (recently cultivated) fields were found to be the lowest in fertility. However, while the differences between the fertility of the soils under *Closed savannah woodland* were almost always significantly different from those under the other land cover types, the differences within these other soils were sometimes not significant.

6.4 General fertility status of the soils

As shown in Tables 6.12 and 6.13, the soils of the Upper West Region are generally low

Table 6.12: Rating of the fertility of soils under closed and open woodland (Upper West Region) according to Landon (1991)

Land cover	Parameter	Method	Unit	Range	Average	Rating (Landon, 1991)
Closed savannah woodland	pH	1:1 soil:H_2O	--	5.4 -6.5	5.8	medium
	Ca	NH_4 Acetate	Cmol (+) kg^{-1}	1.20 – 6.80	3.85	low
	Mg			0.34 – 3.32	0.98	medium
	Na			0.24 – 3.32	0.21	low
	K			0.02 – 0.09	0.06	low
	CEC			4.54 – 38.80	11.78	low
	BSP	Calculation	%	24.76– 90.25	46.95	medium
	Avail P	Bray 1		0.73 – 9.00	4.28	
	Tot. P			54.2 – 159.4	117.95	
	N	Kjeldahl	%	0.02 – 0.08	0.05	Low
	OC	W-Black		0.43 – 2.63	1.42	Low
	OM	OC x 1.72		0.74 – 4.53	2.45	Low
Open savannah woodland	pH	1:1 soil:H_2O		4.8 – 6.3	5.5	medium
	Ca	Ammonium acetate	Cmol (+) kg^{-1}	1.24 – 4.24	2.62	low
	Mg			0.26 – 2.78	0.88	medium
	Na			0.13 – 0.28	0.2	low
	K			0.02 – 0.09	0.05	low
	CEC			4.83 – 15.37	9.04	low
	BSP	Calculation	%	22.59– 71.58	44.54	medium
	Avail P	Bray 1	ppm	0.74–5.29	2.85	
	Tot. P			30.2 – 166.0	101.13	
	N	Kjeldahl	%	0.02 – 0.05	0.03	low
	OC	W-Black		0.49 -1.44	0.98	low
	OM	OC x 1.72		0.70 – 2.48	1.65	low

in fertility, when compared with the rating for tropical and subtropical soils by Landon (1991). Titriku (1982) and Senaya *et al.* (1998) also observed the generally low fertility of the soils of the region. This is not unusual, because infertile soils are said to be common in the tropics (Pieri, 1989) and African savannah soils, in particular, are generally known to be inherently low in fertility because most of them have been derived from granitic rocks and are therefore, mostly sandy (Ker, 1995). The geology of the Upper West Region is predominantly made up of granite. Compared with the rating of Landon (1991), the soils are low in cation exchange capacity and have limited nutrient contents. According to Titriku and Senaya *et al.* (1998), the soils are also often shallow over ironstone, gravel or plinthite and subject to erosion. Sanchez (1976) made

Table 6.13: Rating of the of the fertility of soils under soils Mixture of grasses & shrubs and Farmland (Upper West Region) according to Landon (1991)

Land cover	Par.	Method	Unit	Range	Average	Rating (Landon, 1991)
Mixture of grasses and shrubs (mostly fallow land)	pH	1:1 soil:water	---	5.0 – 6.0	5.4	low
	Ca	Ammonium acetate	Cmol (+) kg^{-1}	0.82 – 4.94	1.83	low
	Mg			0.20 – 2.32	0.57	medium
	Na			0.11 - 0.27	0.20	low
	K			0.02 - 06	0.04	low
	CEC			3.77 – 14.41	8.63	low
	BSP	Calculation	%	13.92– 65.54	30.88	medium
	Avail. P		ppm	0.82 – 17.80	3.03	
	Total P	Bray 1		39.6 – 156.4	111.8	
	N	Kjeldahl	%	0.02 – 0.05	0.03	
	Org. C	Walkley-Black		0.24 – 1.39	0.66	low
	OM	OC x 1.72		0.50 – 2.40	1.15	low
Farmland	pH	1:1 soil:water		4.4 – 6.0	5.4	low
	Ca	Ammonium acetate	Cmol (+) kg^{-1}	0.48 –6.62	1.70	low
	Mg			0.12 – 4.20	0.67	medium
	Na			0.10 - 0.27	0.15	low
	K			0.02 – 0.06	0.03	low
	CEC			4.36 – 14.36	7.70	low
	BSP	Calculation	%	8.37 – 78.20	32.95	medium
	Avail. P	Bray 1	ppm	0.94 - 9.69	2.20	
	Tot. P			45.7 – 180.2	118.3	
	N	Kjeldahl	%	0.02 – 0.06	0.03	Low
	Org. C	Walkley-Black		0.31 – 1.71	0.70	low
	OM	OC x 1.72		0.53 – 2.94	1.22	low

a similar statement about African savannah soils, and stated that many of them have characteristically low effective cation exchange (CEC), often below 4 Cmol(+) kg^{-1}; and this is closely related to their organic matter and clay contents, with many of them having variable charges. The generally low pH of the soils of the Upper West Region agrees with the observation of Ker (1995) that many savannah soils are acid (low in pH), particularly in the more humid areas, and that in such soils aluminium toxicity is a major limiting factor for the growth of susceptible crops, such as leguminous crops (e.g., groundnut and soybean). Maize, sorghum and many other crops are also susceptible to varying extents, while cassava can tolerate a certain degree of acidity. Ker (1995) stated that the CEC of most savannah soils limits the amount of exchangeable calcium or magnesium to about 0.3-3.0 Cmol(+)/kg^{-1}.

The generally low organic matter content of the soils of the region confirms the statement of Lal (1983) that savannah soils are typically low in this property. Organic matter may be quite high under a thick cover of natural vegetation, such as forest (including closed woodland) but declines rapidly when the land is cleared and cultivated (Lal, 1983),. Thus, the organic matter content of the soils under the *Closed woodland* and the *Open woodland* was found to be higher than it was in the *Farmland* (cultivated fields and young fallows) soils and those under *Mixture of grasses and shrubs*. The low nitrogen status of the soils of the Upper West Region confirms the report of Sanchez (1976) that nitrogen deficiency is widespread in savannah farming systems and is often a limiting factor for crop growth. According to Sanchez (1976), the nitrogen status of the soils is closely associated with the soil organic matter content, which is itself low.

The phosphorus content of the Upper West Region soils is also generally low. This lends credence to the finding of Zapata (1991) and Kowal and Kassam (1978) that deficiencies of the nutrient are widespread in savannah soils, and many authorities consider the lack of phosphorus to be the primary nutrient limiting crop production in the savannah ecosystems.

Savannah soils are also comparatively low in potassium (Nye and Greenland, 1960 and Ruthenberg, 1980) and this study has confirmed this observation for the Upper West Region. As is the case for the other nutrient elements, this is normally due to continuous and/or heavy cropping and removal of crop residues (Ker, 1995 and Schroth and Sinclair, 2003).

On the whole, the low fertility of the soils under *Farmland* (cultivated) was most probably due to net nutrient losses resulting from human-induced land degradation, which consists of 'soil mining' (the removal and storage of mineral nutrients by crops in their harvestable parts), poor soil management practices that lead to increased runoff, soil erosion and gaseous losses. According to Pieri (1989), de Koning *et al.* (1997) and Van der Pol (1992), these phenomena are common in Sub-Saharan Africa and are leading to decreasing soil fertility in many farmed fields of the savannah areas. Most farmers are not able to match these losses by fertilizer application (de Koning et al., 1997). Furthermore, soil fertility management is hampered by the low or moderate nutrient-retention capacity of the soils (Van der Pol, 1992). This results in negative nutrient budgets, which are specially threatening for sustainable food production in the African savannah areas (von Uexküll and Mutert, 1995).

Apart from soil quality (including fertility), crop yields are determined by climatic conditions, farming practices and technology, incidence of disease and pests ,among many other factors. Apart from rainfall, many of the factors do not vary from year to year in the Upper West Region. Rainfall has therefore become the most important climatic factor influencing inter-annual crop performance in the tropics, including the Upper West Region (van der Geest, 2002). The amount and distribution of rainfall partly determine the crops that are grown. Therefore, having assessed the fertility status of the soils of the region for the traditional crops being grown there, the rainfall of the region is similarly assessed.

6.5 Analysis of the rainfall of the Upper West Region

Specific crops grow under specific range of climatic and edaphic conditions. Where soil and all other climatic conditions are optimum, a significant change in the rainfall regime (quantity and distribution) may lead to some crops failing or performing below average. In this study the rainfall quantities were studied to ascertain whether there had been a change over the period under considration to affect the growth of crops. Annual rainfall figures and those of the farming season from 1980 to 2000 were plotted to assess any change trend (Tables 6.14 and 6.15 and Figures 6.1 and 6.2). The rainfall figures were then evaluated in terms of the soil moisture requirements of the traditional crops grown in the region, using the guidelines of Sys (1985).

The annual rainfall data for three locations in the Upper West Region for the period between 1980 and 2000 are shown in Tables 6.13, and Figure 6.1. These are Wa (in the south), Lawra (in the west) and Tumu (in the north) of the region. There is no

Table 6.14: Mean annual rainfall (mm) of the Upper West Region (1980-2000) (Data from the Ghana Meteorological Services Dept).

Year	Wa	Lawra	Tumu
1980	1186	627	1201
1981	756	456	815
1982	1027	514	798
1983	674	462	958
1984	937	888	957
1985	1060	879	917
1986	524	884	933
1987	777	1075	238
1988	931	474	637
1989	1042	885	1233
1990	906	591	780
1991	1008	660	1365
1992	863	714	860
1993	1130	605	1019
1994	1000	239	1106
1995	1244	1242	1336
1996	1135	677	934
1997	1358	337	688
1998	767	938	825
1999	1290	359	882
2000	1141	412	649
Lowest	**524**	**412**	**238**
Highest	**1290**	**1242**	**1335**

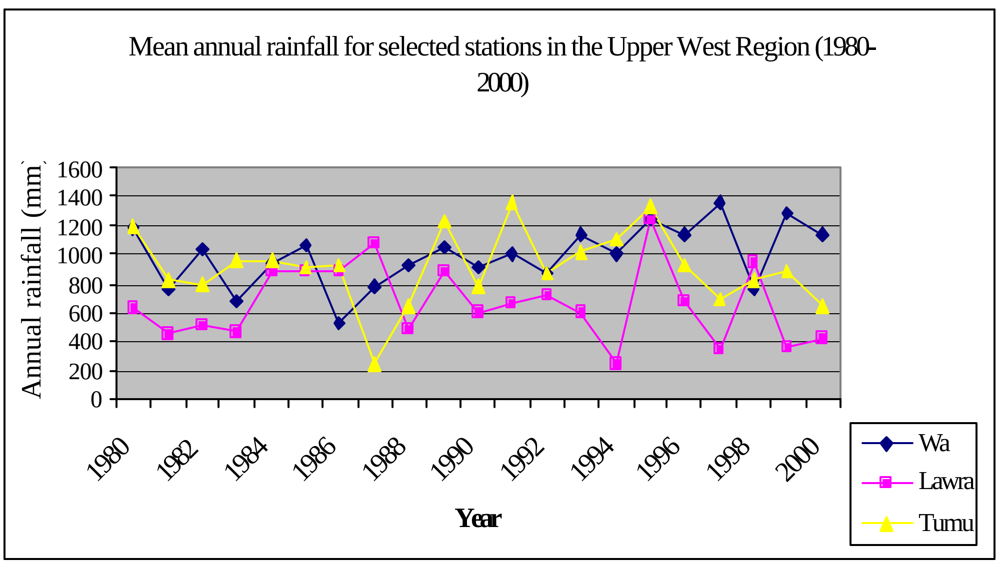


Figure 6.1: Mean annual rainfall for the Upper West Region (1980-2000)

meteorological station in the eastern part of the region. Generally speaking, the rainfall regime in the Upper West Region (Figure 6.1) can be said to be erratic. While some years have enough rainfall for farming, others have too little and in other years, there can be too much rain. Even within a particular year, some months may have too little rain for the growth and yield of crops, while others may have enough and still others too much. Too little rainfall causes crop failure. This has led Higgins *et al*. (1982) to state that the occurrence of drought in the savannah zone is a common phenomenon, making it to be widely considered to be the zone at the greatest risk of declining agricultural production, with parts of it being severely affected by food shortages in recent years. Too much rainfall in some years causes flooding and the destruction of crops and infrastructure (e.g., bridges and gravelled roads), especially in the low-lying areas.

For the cultivation of crops, the total amount of rainfall during the growing season and its distribution is more important than the total annual rainfall. A year with low rainfall can be a good one agriculturally, if the rains start at the right time and spread evenly over the cropping period and end about the expected end of the season. Conversely, a wet year can be a bad agricultural year, if the rains do not start on time or are interrupted by a dry spell. Moreover, too much rain in a short time can be detrimental to crop performance.

The rainfall distribution pattern during the farming season over the 1980-2000 period is shown in Table 6.15 and Figure 6.2. While it could be said that the total amount of rainfall during the farming seasons are enough for the crops grown in the region, its distribution is not always favourable. The erratic nature of rainfall in the region does cause mid-season drought or dry-spells during some growing seasons. This reduces yield or sometimes causes total crop failure. Some months of the farming season do have too little or too much rainfall, while some others seem to have enough. Apart from even distribution of rainfall during the farming season, its intensity is also important. Heavy rains falling within a short period are known to sometimes cause flooding, erosion and crop damage in the Upper West Region and other parts of the savannah of the Volta Basin.

Having determined the soil fertility levels of the soils and the pattern of rainfall in the region, it is necessary to evaluate these factors in terms of the requirements of the various crops grown in the region.

Table 6.15: Mean rainfall during (mm) farming-season (April-October), Upper West Region (1980-2000) (Data from the Ghana Meteorological Services Dept)

Year	Wa	Lawra	Tumu
1980	1102	621	1179
1981	665	417	782
1982	947	479	773
1983	640	404	945
1984	894	845	912
1985	968	879	917
1986	511	878	921
1987	758	1075	1080
1988	922	433	975
1989	962	861	949
1990	885	570	803
1991	984	647	1220
1992	841	562	860
1993	1108	585	996
1994	979	1120	1036
1995	1208	1199	1149
1996	1108	983	927
1997	1300	982	633
1998	756	889	808
1999	1175	1179	853
2000	1071	807	642
Lowest	**511**	**404**	**633**
Highest	**1207**	**1199**	**1220**

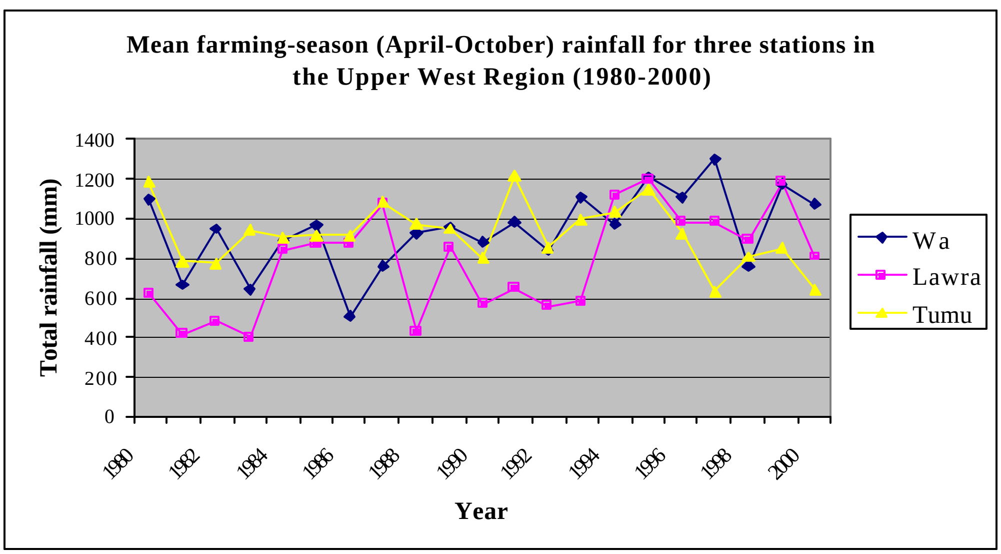


Figure 6.2: Mean farming-season (April-October) rainfall of the Upper West Region (1980-2000)

6.6 Rainfall and soil fertility evaluation for crops grown in the Upper West Region (Sys, 1985)

Table 6.16 presents the rainfall and soil fertility evaluation for the common crops grown in the Upper West Region according to the procedure of Sys (1985). An alternative land evaluation procedure that could have been used is that of the FAO (1983). The FAO land evaluation procedure (called the Framework, 1983) is used in FAO and UNDP projects, and by many national agencies, with modifications and simplifications made to suit local conditions (van Diepen *et al.,* 1991). According to van Diepen *et al.* (1991), the FAO Framework has many weaknesses when applied, and therefore functions only as a background philosophy from an operational point of view. Further points raised on the FAO Framework by Diepen *et al.* (1991) are presented as follows (personal comments in relation to the study have been added in some of the points raised):

1. Land suitability is assessed and classified with respect to *specified* kinds of uses (as opposed to a single scale of 'goodness' of land). That is, there is not one scale of 'goodness' of land from 'excellent' to 'poor'; instead one must speak of *very suitable* through *unsuitable* land for a specific use.
2. The suitability classes are defined by *economic* and *social* criteria (as opposed to purely physical criteria. In practice, this has rarely been followed. In this study, economic factors are not considered in the evaluation process.
3. *Multidisciplinary* approach is required (not just soil information). This study requires only soil fertility and rainfall evaluation and therefore does not need a multidisciplinary approach other than rainfall, soil fertility and population.
4. Evaluations should take into account the physical, economic, social and political context of the area concerned. This study does not need all these contexts.
5. Suitability refers to land use on a *sustained* basis (i.e., the environmental impact of the evaluation should be such that it cannot deplete the resource base). In practice this is rarely the case. Such a requirement is beyond the scope of this study, because much more detailed information is needed to deduce the sustainability of the recommended use.
6. Evaluation involves comparison of two or more *alternative* kinds of use; this seems redundant to point 1.
7. Assessment of suitability should be in relation to management and conservation requirements. Crop requirements are not completely independent of

management. If the land utilization types vary widely, for example, traditional smallholder and large-scale mechanized production systems, crop requirements will have to be assessed separately. There are many examples of perfectly suited land areas for one use, which are extremely unsuited for another. For example, intensive semi-mechanized irrigated rice versus areas for urban expansion.

8. Some aspects of the combination of land qualities involve subjective combination of factors. This could vary with different evaluators.

The above-stated points make a direct application of the FAO Framework (1983) difficult. The scope of this study does not require modifications and simplifications, required by the FAO Framework. Furthermore, the FAO Framework involves specific evaluation exercises, which have been designed separately for each problem and area by the local land evaluator, e.g., the Papua New Guinea Land Evaluation System (Venema and Daink, 1992). There is no such a design for the Upper West Region and for, that matter, Ghana.

The system of Sys (1985), on the other hand, has a direct and simple application and does not involve some of the complex considerations listed above. Unlike the FAO Framework (1983), it does not need such modifications and simplifications to suit local areas. Therefore the procedure of Sys (1985) was used in this study. Table 6.16 presents rainfall and soil fertility evaluations for the common crops grown in the Upper West Region. The symbols, S1, S2 and S3, are respective ratings for suitable, moderately suitable and marginally suitable classes for the crops (Sys, 1985). In terms of rainfall, the region is suitable (S1) for the cultivation of millet, sorghum and groundnut. It is moderately suitable (S2) for maize and cotton. The soils are marginally suitable (S3) to suitable (S2) for the crops. The soils under the *closed savannah woodlands* are suitable. The *open savannah woodland* soils are moderately to marginally suitable, while those under *Mixture of grasses/shrubs* and the *Farmlands* (recently cultivated fields) soils are moderately or marginally suitable. The cation exchange capacity (CEC) and therefore the base saturation percentage (BSP) are the major problems, which means that the soils will need to be fertilized to achieve economic yields. The CEC of the acid soils can be increased by liming or by increasing their organic matter content. Thus, even though the soils of the region are inherently not fertile, they are being used for cultivation. However, the choice of crops is restricted to those that can thrive in soil of such low fertility rating and under such erratic rainfall regime.

Table 6.16: Rainfall and soil fertility evaluation for common crops grown in the Upper West Region of Ghana according to procedure of Sys (1985)

Crop	Rainfall/Soil fertility characteristics	Ave. range (UWR)	Level	Suitability
Millet	Annual rainfall (mm)	900-1000	750-900	S1
	Length of growing season (days)	150	90-120	S1
	Rainfall: growing season (mm)	600-900		S1
	CEC (Cmol(+)kg^{-1}	8-12	<16	S3
	Base saturation (%) Organic matter (%C, 0-15 cm)	30-47 0.7-1.5	15-35, 35-50 <0.8, 0.8-1.5	S2, S1 S2-s1
Sorghum	Annual rainfall (mm)	900-1100	600-1200	S1
	Length of growing season (days)	150	120-240	S1
	Rainfall: growing season (mm)	600-900	---	S1
	CEC (Cmol(+)kg^{-1}	8-12	<16 (+)	S3
	Base saturation (%)	30-47	<15, 15-35, 35-50	S3, S2, S1
	Organic matter (%) (0-15 cm)	1.15-2.45	0.8-1.5, <1.5	S2, S1
Maize	Annual rainfall	900-1200	750-1600	S1
	Length of growing season	150 days	130-270 days	S1
	Rainfall: growing season	600-1100	600-1800	S2
	CEC (Cmol(+)kg^{-1}	8-12	<16(+)	S3
	Base saturation (%)	30-47	20-35, 35-50	S2, S1
	Organic matter (%) (0-15 cm)	1.15-2.45	0.8-1.2, 1.2->2	S2, S1
Groundnut	Length of growing season (days)	150 d	120-150	S1
	Rainfall during growing season (mm)	600-1000	120-230	S1
	CEC (Cmol(+)kg^{-1}	8-12	<16(+)	S3
	Base saturation (%)	30-47	<35, 35-50	S2, S1
	Organic matter (%)	1.15-2.45		S2, S1
Cotton	Length of growing season	150 days	135-250	S1
	Rainfall: growing season (mm)	600-1100	625-1600	S2
	Rainfall during ripening season	<50	<50	S1
	CEC (Cmol (+) kg^{1})	8-12	<16(+)	S3
	BSP	30-47	35-50	S3- S2
	Organic matter (%C, 0 -15 cm)	1.15-2.45		S2-S1

Human beings have been modifying the environments, and in so doing, change its suitability for many utilization types, particulary the cultivation of crops, through land degradation. Therefore popupulation dynamics has become an important factor in the study of environmental degradation issues. The results of the analysis of the population of the region over the periods under study is therefore also presented below.

6.7 Population and land use and land cover of the Upper West Region

Population growth is widely recognized as a key driving force behind environmental change, especially in developing countries (Boserup, 1996). The increases in total population and population density in the region from 1984 to 2000 are shown in Figures 3.14 and 3.15 respectively (Chapter 3). The population of the region in 2000 was 576,683 compared to 438,000 in 1984. This represents an increase of about 32% (within 16 years) at the growth-rate of 1.7% against the national rate of 2.7% (Table 3.1, Chapter 3). In 1984, 90% of the population was rural and 10% urban, while in 2000 the corresponding figures were 84.5% and 15.5% respectively (Figure 3.15, Chapter 3). The overall regional population density was 24 inhabitants km^{-2} for 1984 against the 2000 figure of 31.2 inhabitants km^{2} (Figure 3.15, Chapter 3). The most prominent economic activity is agriculture, which, together with hunting, engages a little over 75% of the economically active population (Table 3.3, Chapter 3). The large proportion of the population in agriculture has important implications for the degradation and disappearance of woodland through cultivation and grazing by cattle. Agriculture is the major cause of the decline of the woodlands of the region. This is because the soils of the woodlands are more fertile than those of cultivated fields and are therefore the first choice for farmers.

Figures 6.3-6.7 compare population with area of farmland in the various districts of the region as in 1986, 1991 and 2000 and Figures 6.8-6.12 compare population to areas of closed savannah woodland at the same dates. Figure 6.3 shows that in the Sissala District, both population and area of farmland increased during the 1986-1991 and 1991-2000 periods. Image analyses have also shown that cultivation has been extending into the district from adjoining districts. Interview of farmers in the adjoining district (Lawra, Jirapa-Lambussie and Nadowli districts) revealed that they have been shifting cultivation into the Sissala District, where there are larger tract of virgin or pr imary woodland than the adjoining districts.

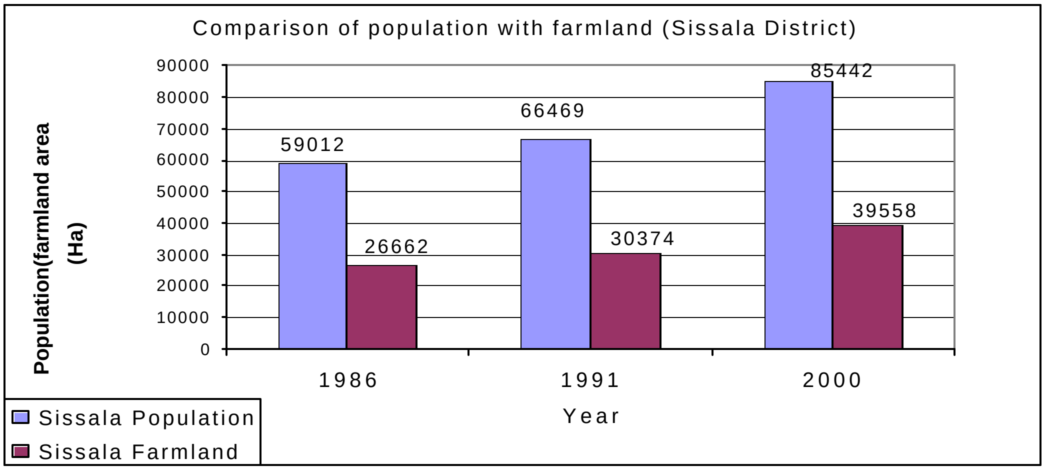


Figure 6.3: Comparison of population and area of farmland in the Sissala District

As shown in Figure 6.4, the population increase in the Wa District from 1986 to 2000 was large (from 68,966 to 224,066). The large increase was due to the creation

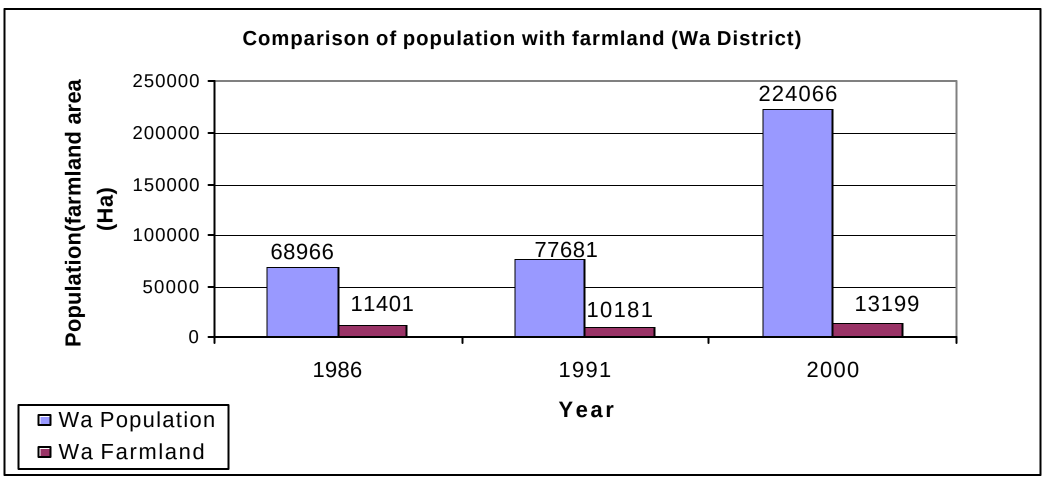


Figure 6.4: Comparison of population and area of farmland in the Wa District

of the Upper West Region in 1984. Wa, which is the capital town of the region, as well as for the Wa District, is experiencing increased commercial and civil activities, which is leading to a fast population growth. The population growth is not being matched by a corresponding fast spatial increase in farmland in the district. This can be explained by the fact that the bulk of the population of the district is found in the Wa township, where many of the people are engaged in economic activities other than farming, e.g., trading, civil service jobs and small-scale industries, etc., and depend on food produced in the rural areas of the Wa and other districts

The population of the Nadowli District also increased steadily over the periods (Figure 6.5). However, the area of farmland decreased over the period. As explained above, this district has been settled and cultivated over many years and is experiencing declining soil fertility. This compels some of its farmers to move out to the eastern part of the region.

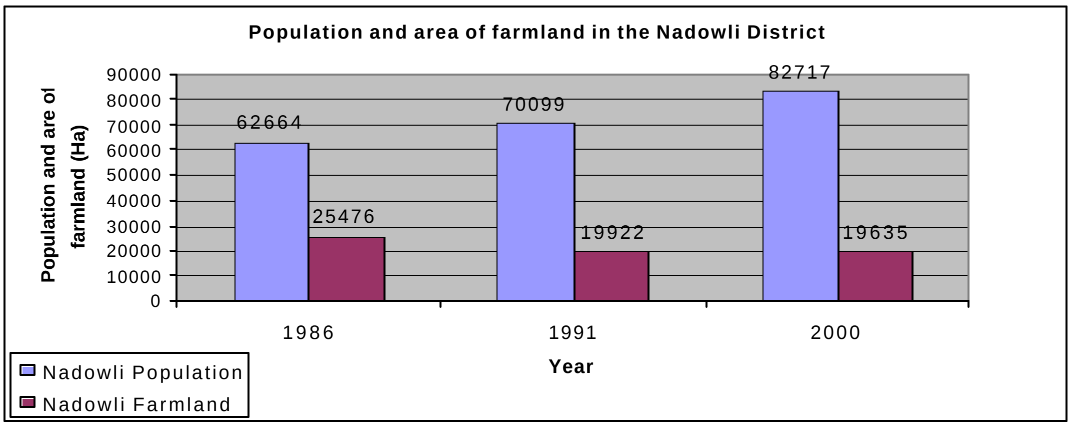


Figure 6.5: Comparison of population and area of farmland in the Nadowli District

The Population of the Jirapa-Lambussie District also increased over the periods; however, these increase did not reflect in the area of farmland (Figure 6.6). The area of farmland in the Jirapa-Lambussie District over the period appeared to be more or less

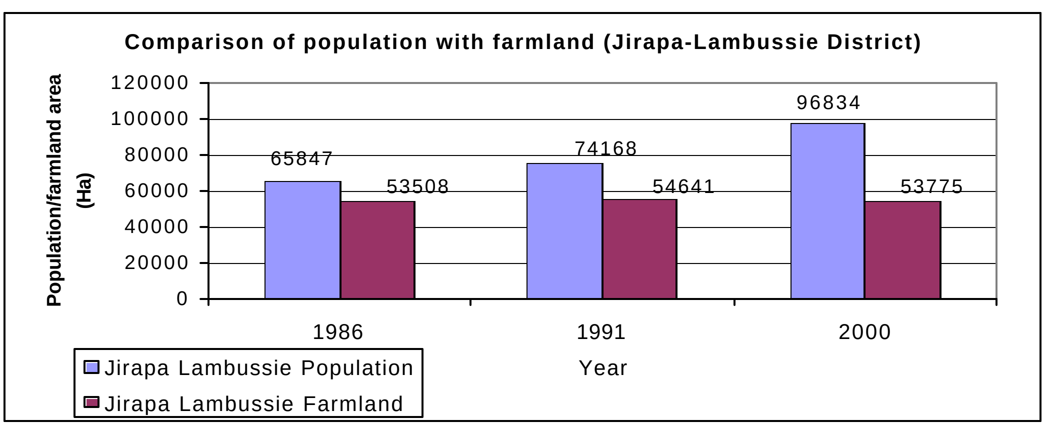


Figure 6.6: Comparison of population and area of farmland in the Jirapa-Lambussie Dist.

constanct. Since this district has also been settled and cultivated for many years, the soils have also become degraded, making some of the farmers to also shift cultivation to the eastern part of the region where the soils are less degraded. Furthermore, expansion of farmland in the district is constrained by unavailability of fertile land, as almost every part of the district has come under cultivation at one time or the other.

The population of the Lawra District also increased over the period, while the area of farmland increased only slightly in 1991, but decreased in 2000 (Figure 6.7). This district has also been settled and cultivated over many years and therefore experiencing soil degradation, which is causing some of the farmers to shift cultivation to the Sissala District in the east. Availability of fertile land for the expansion of cultivation is a problem in this district also.

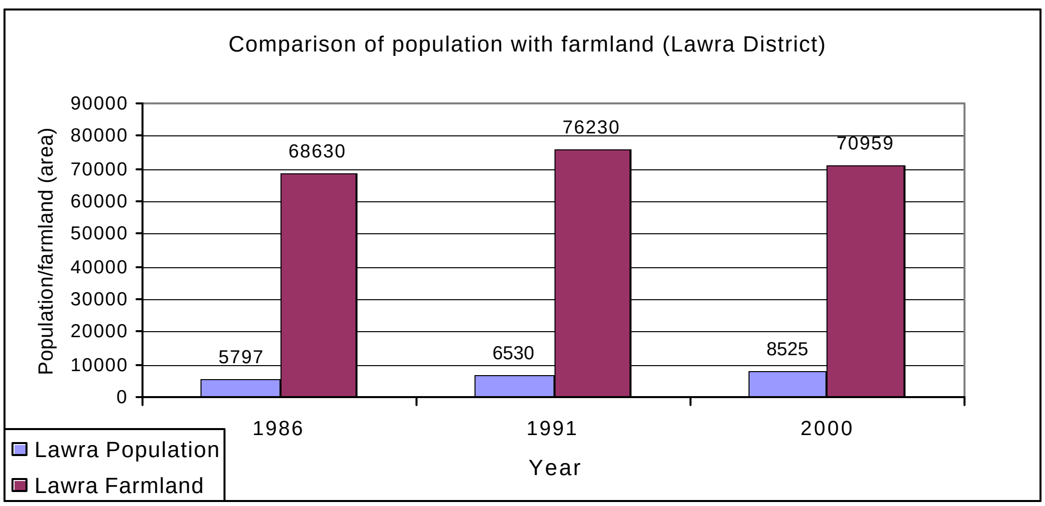


Figure 6.7 Comparison of population and area of farmland in the Lawra District

The changes in the area of closed savannah woodland in relation to population growth are shown in Figures 6.8-6.12. In all these districts, population growth corresponded with decreases in the area of closed savannah woodland. This was the case even in those districts where farmland did not increase appreciably in area in response to population increase. This means that cultivation is not the only cause of degradation or decline of closed woodland, especially in high population density areas. Exploitation of wood for fuelwood and construction is also important for the loss or degradation of woodland in such districts. The grazing by cattle could also be important, though no study has been conducted in that direction.

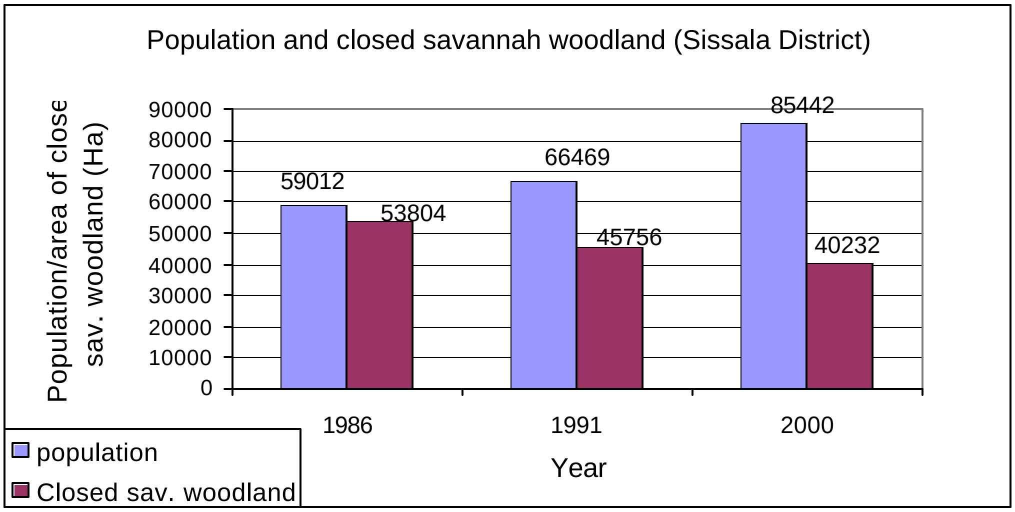


Figure 6.8 Comparison of population and area of closed savannah woodland (Sissala Dist.)

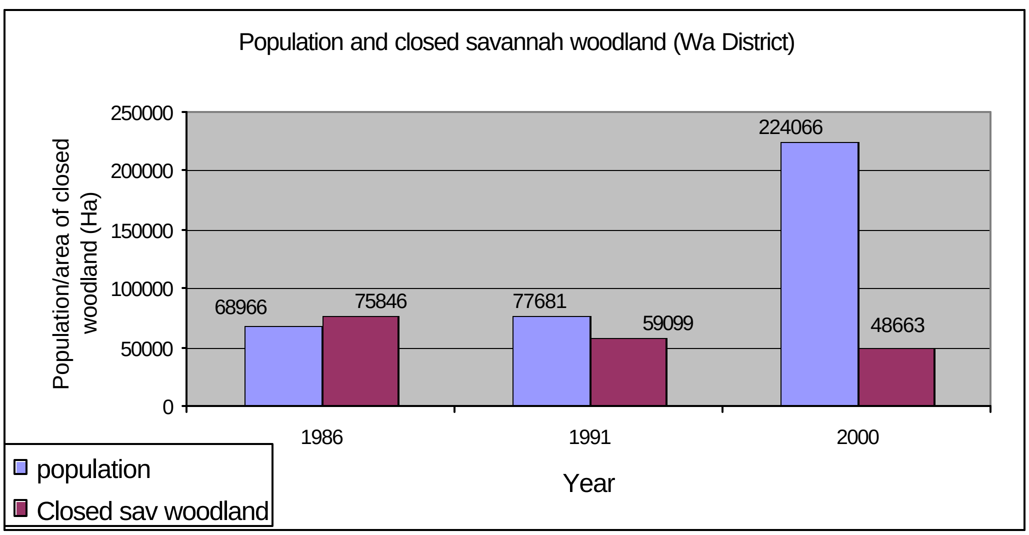
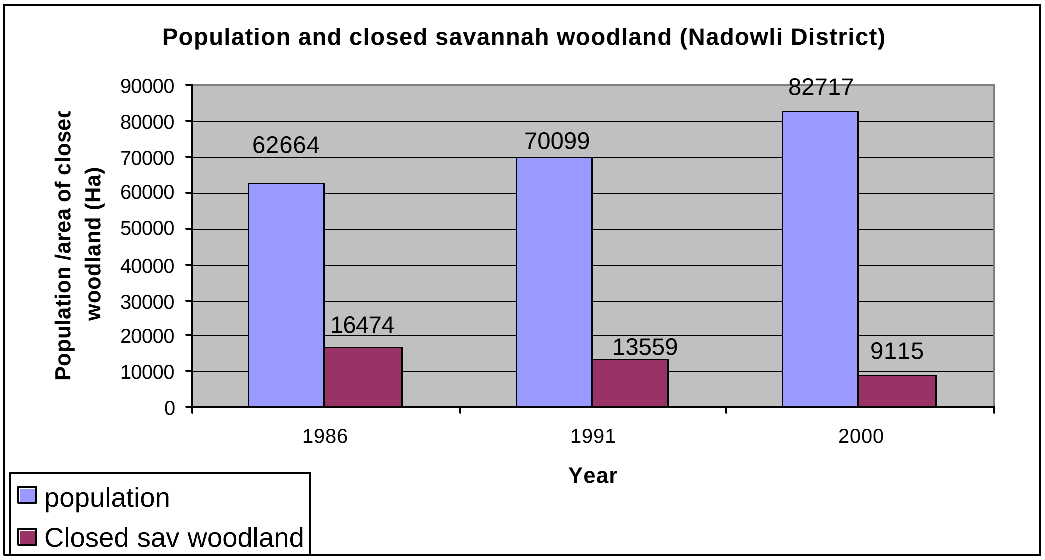


Figure 6.9 Comparison of population and area of closed savannah woodland in the Wa Dist.



6.10: Comparison of population and area of closed savannah woodland in the Nadowli District

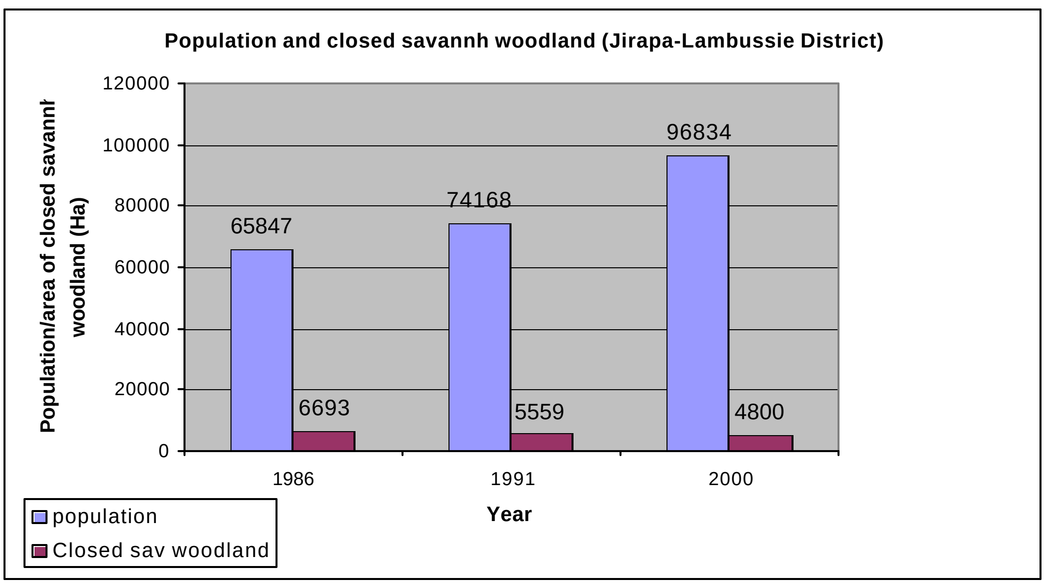


Figure 6.11: Comparison of population and area of closed savannah woodland (Jirapa-Lambussie District)

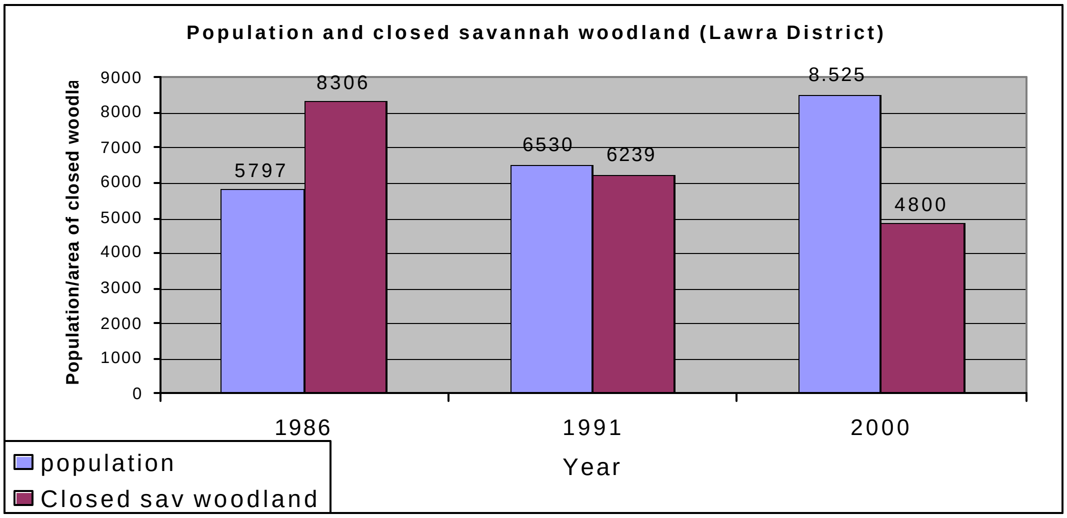


Figure 6.12: Comparison of population and area of closed savannah woodland (Lawra District)

Generally, the analyses showed that population growth resulted in increases in the area of farmland and decreases in the area of closed savanna woodland. Regression analyses were not performed because the population and land use and land cover data were too few.

The changes in the extent of the various land cover categories have been determined in Chapter 5. Of particular importance is the progressive decrease in the area of *Closed savannah woodland/riparian vegetation* and *Open savannah woodland with shrubs and grasses* in favour of *Farmland* and *Mixture of grasses and shrubs with scattered trees,* which increased in extent. Following the analysis of the general fertility levels of the soils under these land cover categories and the trend of population growth in relation to the decreases in woodland, it is now possible to discuss how these two factors combine to drive the decline of savannah woodland under rainfall variability in the Upper West Region.

6.8 Causes of decline of savannah woodland

Land use, population and climate change are drivers for deforestation or degradation of woodland. In the Upper West Region of Ghana, land use is largely rain-fed agriculture, which is controlled mainly by soil fertility, rainfall regime and population. Under the prevailing rainfall regime in the region, the climax vegetation that can be expected is closed savannah woodland. The erratic pattern of rainfall distribution cannot directly cause a decrease in the area of woodland. This is because differences in rainfall between years do not affect vegetation dynamics to a great extent (Richard and Poccard, 1998). Furthermore, woody vegetation does not respond immediately to such inter-annual fluctuations of rainfall totals (Kutiel *et al.,* 2000). However, if there is a long-term change (several decades) in the rainfall regime of an area, it can be assumed that the vegetation may change (Richard and Poccard, 1998). There are, however, some short-term responses of vegetation to rainfall, and these depend on a large number of climatic variables that define moisture availability to plants rather than on the total rainfall (Richard and Poccard, 1998).

The water content of plants decreases during the dry season (Myers *et al.,* 1997). Therefore, plants that are native to arid regions, such as the Guinea savannah ecosystem of the Volta Basin, have various physiological and anatomical characteristics by which they survive dry spells (Kutiel, 2000). Most crops do not have such adaptations. This puts a restriction on the types of crops that can be grown in arid environments. Therefore, the year-to-year variability in rainfall tends to affect agriculture more than the vegetation of the region.

In spite of the erratic rainfall pattern and the inherent low fertility of the soils of the Upper West Region, the cultivation of a limited range of arable crops has been going on there since time immemorial, even though occasional crop failures due to drought or abnormal distribution of rainfall do occur. In particular, the north-western and mid-western parts of the region were the first areas to be permanently settled and cultivated (Dickson and Benneh, 1988). According to van der Geest (2002), the soils of the north-western part used to be relatively fertile and the area was therefore first settled. However, it became densely populated and the high population density led to the overuse of the area (overgrazing and over cultivation), leading to its degradation (van der Geest, 2002). Thus, many of the soils in these areas, which are inherently low in fertility, have become more infertile or degraded as a result of long periods of cultivation without adequate or appropriate soil conservation practices.

The farming system in these areas, like other parts of the region, is “shifting” or “slash-and-burn” cultivation (Nye and Greenland, 1960). In such a system, according to Ker (1995), the farmers naturally choose the most fertile land to grow their crops (so the north-western and western parts were first settled and cultivated). According to

Rose-Innes (1963) and Hall and Swaine (1976), the interior savannah of Ghana (into which the Upper West Region falls), in its present state, is thought to be made up of degraded forms of woody formations. This is because, farmers clear the woodland and grow their crops for a few years, and when the soil fertility declines, move to another fertile land. Besides "shifting" cultivation, there is also the compound farming system, which involves the cultivation of the land immediately surrounding the homesteads (Wills, 1962 and Nye and Greenland, 1960). This farming system is permanent as long as the homesteads are inhabited. The compound farming system is sustainable because the sizes of the plots are small, usually a couple of hectares or less than a hectare, and the plots receive high inputs of organic manure from household refuse and animal droppings. This is not the case for the "shifting" cultivation system, which is practised on plots far away from the homesteads.

As the farmers continue to farm a given area within the shifting cultivation system without adequate or no soil conservation practices or regular input of adequate fertilizers, the soils, which are inherently low in fertility (Tritriku, 1982 and Senaya *et al*., 1998) become further infertile. Interview of farmers in the region revealed their awareness of the fact that the soils of frequently cultivated fields are less fertile than those of compound farms and primary woodland. According to Smaling *et al.* (1997) many farmers in savannah ecosystems recognize low soil fertility in cultivated fields as a major constraint to crop production. Smaling (1998), Schroth and Sinclair (2003) and Mokwunye and Vlek (1985) noted that the decline in soil fertility during cultivation is due to the loss of soil organic matter and nutrients in the topsoil through erosion and "nutrient mining". The slash-and-burn practice of preparing land for cropping also contributes to declining soil fertility (Lal, 1987, 1986). Pieri (1989) observed that chemical and physical soil degradation due to cultivation is common and widespread in the savannahs of Africa. The conversion of the woodlands of the Upper West Region into cropland leads to the decline in soil fertility. This is corroborated by the results of soil analyses in this study, which showed that the *Farmland* (cultivated fields) soils were the lowest in fertility, while those under *Closed savannah woodland* were the most fertile.

Interview of farmers also revealed that as one moves away from settlements, land becomes more available (decreasing pressure on land), and the chances of finding a relatively fertile woodland (i.e., increasing soil fertility and decreasing soil degradation) become higher (Figure 6.3). This trend can be said to be due to the fact that when a

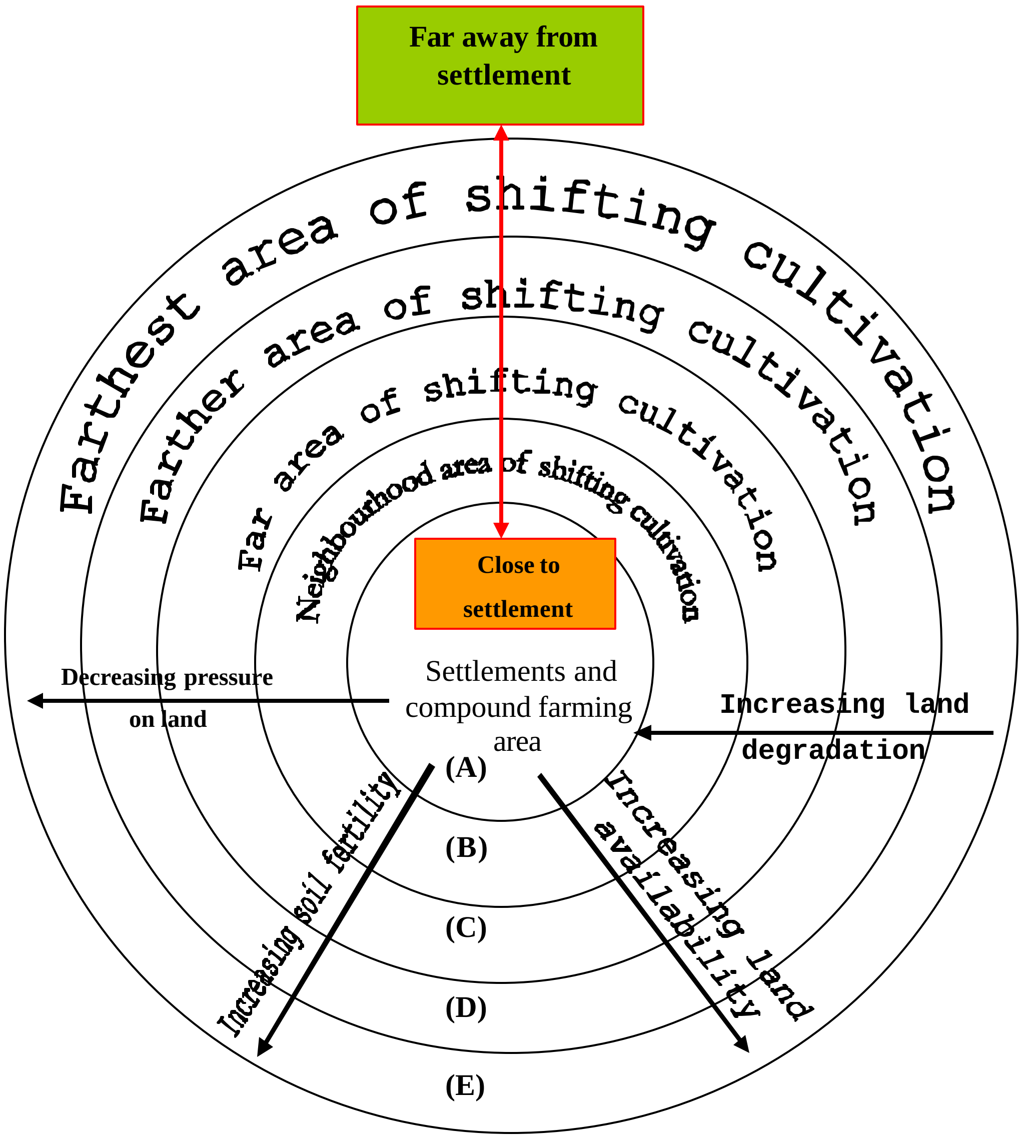


Figure 6.3: Trend of soil fertility decline, land availability, land degradation and pressure on land within the shifting cultivation system

settlement is built, shifting cultivation is initially confined only to its immediate neighbourhood just beyond the compound farming area (B in Figure 6.3), because the population is low and there is enough land for each farmer to practice shifting cultivation in addition to the compound farming around his homestead. However, as the soils degrade and population increases, putting pressure on land, cultivation is shifted farther away from the settlements to a more fertile land (C in Figure 6.3). The greater the density of settlements (i.e., the higher the population), the greater is this occurrence.

Interviews of farmers of the region, especially those from the north-western and mid-western parts, revealed that in the distant past the farmlands were more fertile than they are now, and the farmers were able to feed their households by cultivating smaller areas than they do now, because yields per unit area were higher in those days. Similar interviews conducted by van der Geest (2002) gave the same information.

The growth of the population of the Upper West Region by about 32% within 16 years (1984-2000), with 75% of the people being farmers has implication for land use and land cover. Population growth is known to be the most important factor that causes a large increase in the demand for food (Boserup, 1996). It has been shown in this study that as population increased, the area of farmland increased at the expense of closed woodland, which, thus, decreased in area. Even though the population density of the region is relatively sparse (31 km^2), the generally low fertility of the soils necessitates the cultivation of a large area to obtain enough yield to feed the growing population.

Figure 6.4 illustrates the effect of increasing population and declining soil fertility on the loss of savannah woodland in the Upper West Region. As the population of a settlement increases, putting pressure on the land in its neighbourhood, and with declining soil fertility, yield per hectare decreases. The farmers respond to this situation by expanding the area of land they cultivate per season so that they can get enough food (more than previously) to feed the increased population of their households. Since there is a large proportion (75%) of the population in agriculture, and the population is concentrated in these intensively cultivated areas (the north-western and mid-western part of the region), the fertile land at the disposal of each farmer becomes limited.

Therefore, in order to expand his farm, he must shorten the fallow periods. Interview of farmers showed that fallow periods in the densely populated north-western and western parts of the region have become shorter as a result of increased demand for land for farming. This consequently leads to further decline in soil fertility because the land has not been allowed to "rest" or fallow sufficiently enough for the soil to regain some of the fertility it lost during previous periods of cultivation. It also leads to the degradation of the vegetative cover on the soil surface, thereby allowing erosion to accelerate so that soil fertility further declines progressively and erosion damage increases. Eventually, the soil productivity may decline to so low a level that the farmer has to react in a way to ensure that he gets the needed food for his household and also surplus to sell to earn income for other necessities.

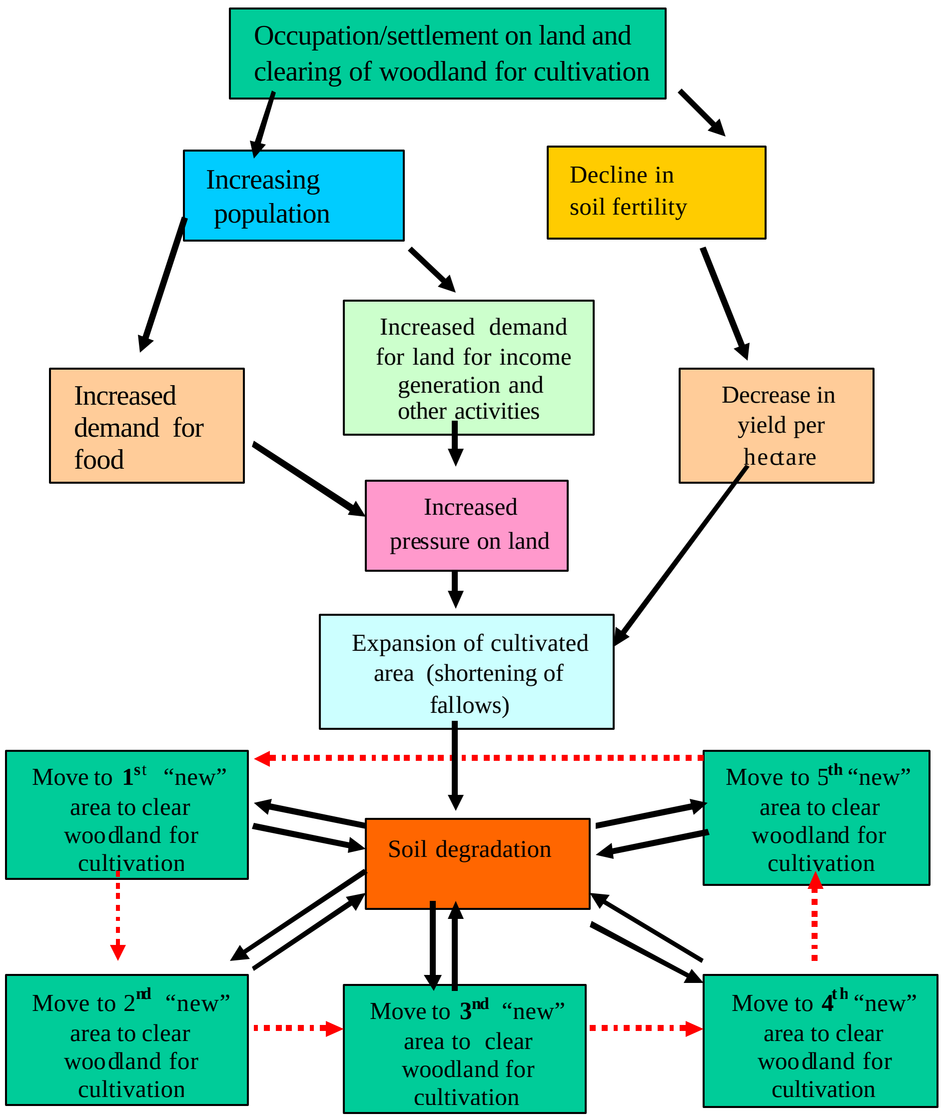


Figure 6.4: Illustration of the effect of population increase and declining soil fertility on the decline of woodland/forest. (*Dotted red arrows show direction of shifting cultivation)*

According to Ker (1995), there are three ways in which a farmer can respond to such a situation. He may change the cropping system and cultivate other crops that tolerate low soil fertility (e.g., cassava). However, in the Upper West Region, the rainfall regime imposes a restriction on the choice of crops. The next option for him is to intensify the farming practices by increasing the use of manures and fertilizers alongside practising simple soil conservation techniques that conserve and build up soil fertility, and/or develop an irrigation system. Boserup (1996) and Turner *et al.* (1993) observed that increasing population density often leads to the intensification of agriculture because intensification of cultivation has been identified with increasing crop yields. In the Upper West Region, most farmers have neither enough manure at their disposal nor the money to buy artificial fertilizer, which is expensive, for a large field for intensification of cultivation. The third option is to move to a more fertile land, if it is available.

Most farmers in the Upper West Region respond to declining soil fertility in their cultivated fields by adopting this third option. Thus, where a more fertile land (usually, primary woodland) is available, the farmer moves (far away from his settlement) to clear it (Figure 6.3). When the fertility of the soil declines in this "new" area also, and where land is still available, he moves again (farther away) to clear another "new" piece of primary woodland, which he will cultivate until its fertility also falls below the capacity to support economic crop yields. Then he moves again still farther away to clear another piece of woodland, when soil fertility falls again. This continues as long as relatively fertile land is available.

This practice results in the progressive decrease in the area of woodland, because the "new" fertile lands are usually primary closed or open savannah woodland. Thus, the degradation of the savannah woodland is generally caused indirectly by decreasing soil fertility in cultivated fields and increasing population. As a result of this phenomenon, *Closed savannah woodland* and *Open savannah woodland* have been decreasing in area, while *Farmland* and *Mixture of grasses and shrubswith scattered trees* increase in extent. Dechert and Veldkamp (2003) made a similar observation in Indonesia. The loss in the area of woodland, especially *Closed savannah woodland,* is a gain for *Farmland* and *Mixture of grasses and shrubswith scattered trees*.

Image analysis has shown that the western and north-western parts of the region, which were the first part to be settled and cultivated for a longer period, are more densely populated (and have a higher concentration of settlements) than the eastern part, and have consequently lost almost all their open-access closed woodland to farmland. The loss of the woodla nd in the region began in these more populous parts and now spreading progressively to the other parts, particularly the east. Though, the population density and rate of growth for the region seem to be low (32 km-2 and 1.7 respectively), they are much higher in the north-west and western parts), forcing some of the people to emigrate to the south of the country. Moreover, because the soils are inherently low in fertility, each farmer needs a relatively large tract of land to cultivate. This results in the expansion of cultivation as population grows. This expansion has not been possible in the westward direction, because the Black Volta River imposes a limit and the land at the other side of it (over bank) is in the Republic of Burkina Faso.

From the foregoing, it can be said that even though soil fertility is crucial for the growth and development of trees, its effect on the decrease in the area of woodland in the Upper West Region must be seen from the point of view of extensification or "shifting" of cultivation, which is conditioned by the synergy of declining soil fertility of the old cultivated fields and increasing population pressure on land. This is more pronounced in the western part of the region than in the east. In response to this, farmers are extending cultivation to the east and this is leading to a progressive decrease in the area of closed and open savannah woodland, which, when left unchecked, can result in the total loss of all open-access primary savannah woodland.

7 SUMMARY, CONCLUSION AND RECOMMENDATIONS

7.1 Summary

This study is one of the components of the GLOWA-Volta Project, which is being implemented under the theme: "*Sustainable water use under changing land use, rainfall reliability and water demands in the Volta Basin*". The Project has been designed to generate various data sets for the development of a decision support system for the management of the biophysical and socio-economic attributes of the Basin. It is being executed through research clusters. This study falls into the "*Land Use and Land Cover Change*" cluster. The study sought to (i) adapt a suitable supervised classification method for land use and land cover classification in a savannah landscape of the Volta Basin, using remote sensing, (ii) produce historical and current land use and land cover information of the Basin, (iii) determine land use and land cover changes over a period of fifteen years (1986–2000) and (iv) assess the relationships, if any, between land use and land cover change on the one hand and rainfall, soil fertility and population on the other.

Land use and land cover information is important because, it constitutes a key environmental information for many scientific, resource management and policy purposes, as well as for a range of human activities. This information is currently not available for the Volta Basin, though it is currently undergoing rapid and wide-ranging changes in land use and vegetation due to the agricultural practice of "slash-and-burn" or "shifting cultivation".

Increasing population pressure and declining soil fertility of the cultivated fields in certain parts of the Basin are leading to intensive human over-utilization of the land and the shortening of fallow periods in order to obtain more food to feed the growing population. This is leading to the degradation of the land, and causing lower crop yields per unit area. Consequently, the farmers progressively shift to primary savannah woodland areas where the soils are more fertile. This results in rapid changes in the productivity, structure and composition of the vegetation of the Basin. It also has important implications for biogeochemical cycles, climate and biodiversity in a regional and global context and therefore needs to be studied. The study of such conversions necessitates the use of remotely sensed data for the production of maps as well as a classification scheme or system in which the various units are well defined and standardized to facilitate the comparison of maps of different dates and places.

Currently, there is a lack of systematic and reliable basin-wide land use and land cover information to address the concerns for a sustainable use of land in the countries of the Basin. For Ghana, the only nation-wide land use and land cover information ever produced by using remote sensing was the one produced by the Remote Sensing Applications Unit (RSAU), within the framework of the Ghana Environmental Resources Management Project (GERMP). The method used was that of visual (manual) interpretation (on-screen digitisation). Supervised classification of land use and land cover is known to give more accurate results than the visual or manual ones, yet it has not been successfully applied in Ghana for large areas such as the Upper Volta Region. Attempts at applying straightforward unsupervised or supervised classification of land use and land cover in Ghana, using remotely sensed data for a large area, have produced low-accuracy results.

One of the objectives of this study, therefore, was to adapt the maximum likelihood supervised classification method of land use and land cover mapping to the Volta Basin. In this regard, land use and land cover maps of the Upper West Region for 1986, 1991 and 2000 were produced using stratification and supervised maximum likelihood classification of remotely sensed data. The study also assessed the effectiveness of unsupervised classification of remotely sensed data for land use and land cover of the region. It also attempted to compare visual or manual classification methods with maximum likelihood supervised classification.

The general objectives of the study involved:

- the evaluation or comparison of visual, unsupervised, and supervised classification methods in the Upper West Region of the Volta Basin of Ghana.
- assessment of the land use and land cover change of the Upper West Region over a period of 15 years.
- evaluation of the fertility status of the soils under the various land cover categories for the production of the traditional crops grown in the region
- evaluation of the rainfall regime in relation to the production of the traditional crops grown in the region.

- assessment of population increases and their comparison with changes in farmland and closed savannah woodland in the region.

The specific objectives of the study were to:

- find a suitable unsupervised or supervised method for land use and land cover classification of the savannah of the Volta Basin of Ghana.
- assess whether there have been changes in land use and land cover of the Upper West Region over a period of fifteen years.
- determine the fertility of the soils under the various land cover categories, analyse the rainfallregime and population of the region over 15 years.
- deduce whether soil fertility and population under rainfall variability have effects on land use and land cover of the Upper West Region of Ghana.

The study sought to provide answers to the following research questions:

- Can supervised or unsupervised classification methods give a more accurate land use and land cover mapping than that produced by visual interpretation for the Volta Basin?
- Which digital land use and land cover mapping method can best be adopted for the Volta Basin?
- Have there been spatial changes in the primary woodland, arable land or other natural savannah land cover categories of the Upper West Region between 1986 and 2000?
- Are there any relationships between land use and land cover change on one the hand and soil fertility, rainfall and population on the other in the Upper West Region?

The Upper West Region has been selected for this study because it is undergoing rapid biophysical and socio-economic transformation. There is a rapid expansion of cultivation and grazing from the west to the east, resulting in a fast rate of disappearance and degradation of the primary woodland. The trend and intensity of the changes in the various categories of vegetation over a period of 15 years has been assessed in this study. The region is located in the north-western corner of Ghana and covers about 1,850km^2. It receives 1,000–1,150 mm annually, which occurs from May to October. The mean monthly temperatures range from about 27°C in August to about 30°C in March. The daily range of temperature varies between 5 and 20°C. The relative humidity varies between 20-90%, while the growing period ranges from 120 -180 days.

The general terrain consists of a series of dissected plateaux with a topography that is flat to gently undulating with most slopes having a gradient of 0-4%. The region is generally between 150 and 300 meters above sea level. It is drained by the Black Volta, Sissili and Kulpawn river systems. The geology of the region is made up mostly of granitic and *Birrimian* rocks. The soils of the region are closely related to its underlying geology and are low in fertility. The vegetation type is Guinea savannah. The total population of the Upper West Region has increased by 32% over the past 15 years (1984-2000) at the general growth-rate of 1.7%. The population is largely rural and agrarian.

Multitemporal images were pre-processed, stratified and classified using a classification scheme derived from the *Ghana Land Use and Land Cover Classification Scheme*. The component strata were then mosaicked and statistics generated and maps composed. The study also attempted to compare unsupervised classification with maximum likelihood classification. It also attempted to compare visual classification with unsupervised or supervised classification of land use and land cover, using remotely sensed data. The study showed that the results of visual or manual classification of land use and land cover, using the Ghana Land Use and Land Cover Classification Scheme cannot be compared with that obtained by supervised classification. Moreover, unsupervised classification of land use and land cover of the Upper West Region was not able to discriminate between certain land cover categories. Unsupervised clustering was used to generate training samples, which were then used together with those collected in the field for an ultimate supervised classification. Land use and land cover change detection was done by the determination and comparison of the area statistics of the various land cover classes over the various periods.

Six broad land use and land cover classes of the Upper West Region were mapped for 1986, 1991 and 2000. These were (i) *Farmland/bare land or constructed surface,* (ii) *Closed savannah woodland or riparian vegetation,* (iii) *Open savannah woodland with shrubs and grasses* (iv) *Mixture of grasses and shrubs with scattered trees,* (v) *Reserved woodland, and* (vi) *Water body*.

The over-all accuracy of the classification was assessed directly in the field at 92%. In 1986 and 1991, *Open savannah woodland with shrubs and grasses* was the most extensive land cover category, followed by *Mixture of grasses and shrubs with scattered trees, Reserved woodland, Closed savannah woodland/riparian vegetation, Farmland/bare land or constructed surface* and *Water body.* In 2000, the order was the same, except that *Farmland/bare land or constructed surface* became more extensive than *Closed savannah woodland/riparian vegetation*

While *Closed savannah woodland/riparian vegetation* and *Open savannah woodland with shrubs and grasses* decreased in extent over the period, *Farmland/bare land or constructed surface*, *Mixture of grasses and shrubs with scattered trees* and *Water body* increased spatially. *Reserved savannah woodland* was assumed to not have changed. The decreases in the area of *Closed savannah woodland/riparian vegetation* and *Open savannah woodland with shrubs and grasses* resulted in increases in the areas of *Farmland/bare land or constructed surface*, *Mixture of grasses and shrubs with scattered trees*. Soil fertility levels vary under the various land cover categories. The soils of the Upper West Region are generally low in fertility. The rainfall regime in the Upper West Region is erratic and this does reduce crop yield and/or cause total crop failure.

In terms of rainfall, the region is suitable (S1) for the cultivation of millet, sorghum and groundnut. It is moderately suitable (S2) for maize and cotton. The soils are marginally suitable (S3) to suitable for the crops. The suitability of the soils under the various land cover categories for crops varies with the land cover categories. Soil chemical analyses show that the soils are generally low in fertility and need to be fertilized to obtain economic yields. The greater proportion of the economically active population of the Upper West Region depends directly on the cultivation of the land for their living and most them live in the rural areas. The population increase from 1984 to 2000 was about 32%. The study showed that as population increased, farmland increased in areas, while closed savannah woodland decreased, suggesting that the loss of closed savannah woodland is due to the increase in the area of farmland.

Declining soil fertility and increasing population create a greater demand for land for the production of more food as well as for other economic activities. This, in turn, creates pressure on land and leads to the shortening of fallow periods, which, in the absence of sound land management practices, causes soil degradation. In response to this situation, the farmers progressively clear woodland areas, which are more fertile, to grow their crops. This phenomenon is continuing progressively as long as woodland is available, resulting in the progressive decrease in the area of woodland. Thus, the disappearance of the savannah woodland in the Upper West Region is generally caused indirectly by the decreasing soil fertility in cultivated fields and the increased demand for food to feed a growing population.

7.2 Conclusion

The study assessed visual, unsupervised and maximum likelihood supervised methods of classification of remotely sensed data for land use and land cover mapping in the savannah landscape of the Upper West Region of Ghana. It was observed that the results of visual interpretation cannot be compared with those of unsupervised and supervised classification, because some of the land use and land cover mapping units (e.g., cultivated land) are differently defined for the methods. In particular, visual interpretation is capable of mapping the different types of farming systems and the level of intensity of cultivation, which cannot be done with unsupervised (ISODATA) or supervised classification (maximum likelihood) under the present technology. The study also shows that unsupervised classification is unable to discriminate between water body, fire-scorched and shaded closed woodland and moist and dark valley bottoms. However, unsupervised classification can be used alongside field data to generate training samples for use in a supervised classification. Stratification of images prior to classification improves classification accuracy because area with similar features, having somehow different spectral responses, are classified separately. By this approach, it was demonstrated that maximum likelihood supervised classification is applicable to large areas in the savannah of the Volta Basin of Ghana, and can give better results than unsupervised and visual classification, since it is able to map small intricate features (e.g., small cultivated plots and fish-bone-like features), which visual classification is not able to do.

The rainfall of the Upper West Region is characterized by a high degree of variability and unreliability. However, it is able to support the cultivation of a few arable crops that are able to complete their life cycles during the raining season.

The study also showed that *Closed savannah woodland/riparian vegetation* and *Open savannah woodland with shrubs and grasses* decreased in area over the period between 1986 and 2000, while *Farmland* (cultivated fields) and *Mixture of grasses and shrubs with scattered trees* (fallowed land) increased in area. The lost woodland classes were converted to *Farmland/bare land or constructed surface* and *Mixture of grasses and shrubs with scattered trees.* Declining soil fertility and a growing population in the intensively cultivated north-western and midwestern parts of the region have caused the farmers to be moving towards the east, where there are more primary uncultivated woodlands and where population density is low. This phenomenon is leading to a progressive disappearance of the primary or virgin woodland of the region.

In conclusion, the following points are highlighted:

- Stratification of images prior to supervised maximum likelihood classification with training data generated through unsupervised classification and field data collection increased classification accuracy of savannah land use and land cover of the Volta Basin of Ghana.
- Supervised maximum likelihood classification of images can be applied to derive a more accurate land use and land cover map than visual classification in a savannah ecosystem of the Volta Basin of Ghana.
- Though classification of remotely sensed data has been done in Ghana, this is the first time that a supervised classification method has been used to classify the land use and land cover of a large area in the country.
- The high accuracy of classification can probably be ascribed to the fact that the land use and land cover categories are broad, though the stratification of the images prior to classification has been proved to contribute to the high accuracy of classification.
- Results of visual or manual classification of land use and land cover in Ghana cannot be compared with those of supervised maximum likelihood classification, because the mapping units are different.
- Land use and land cover of the Upper West Region has changed over the past 15 years.

- Changes in land use and land cover in the Upper West Region are related to declining soil fertility and population growth under rainfall variability.
- If no steps are taken to arrest the progressive decline in soil fertility and to check population growth in the densely populated north-western and mid-western part of the region, one may conclude that after some years, the primary woodland of the Upper West Region will completely be cleared. Marginal land will then be brought under cultivation. The soils may be further degraded and desertification may set in.

7.3 Recommendations

The following recommendations are made.

- The study should be extended to other areas of the Volta Basin and should cover both the dry and rainy seasons so that features that may not have been captured by dry-season images can be covered. In this case, the use of RADAR data may be useful, since rainy season images tend to be obscured by clouds.
- More detailed soil testing studies of cultivated fields should be undertaken to provide the basis for fertilizer recommendation.
- Further studies of land use and land cover changes as well as of the decline in soil fertility, increasing population and rainfall should be made in order to generate a model to predict different scenarios for the future.
- As much as possible, future studies should be done in the year of image acquisition, so that the result of the classification is not affected by the intra-annual and inter-annual dynamics of the land cover types.
- Campaign against the setting of bush fire should be intensified, since the burning or scorching of vegetation by fire makes image interpretation for such a complex environment more difficult.
- Extension education on land and water conservation to reduce soil erosion and fertility loss should be intensified. In this regard, more attention should be paid to the practices of:
    - clearing without burning, since this will increase the organic matter content of the soils of the farmlands
    - minimizing soil mining by leaving crop residues on the land

  - ploughing along contours instead of across contours to minimize soil erosion
  - green manuring to increase soil organic matter and soil nitrogen, using nitrogen-fixing plants (leguminous herbs).

- The degraded lands should be afforested. This may rejuvenate the soils after many years.
- Agroforestry should be practised. This will raise and maintain the fertility of the soils and at the same time provide fuel wood as well as forage for livestock during the dry season.
- Population growth rate should be lowered through education and facilitation.
- The Government should explore the possibilities of establishing other economic ventures for the region, e.g., mineral exploration, as there are small-scale mining in several areas in the region, to reduce the over dependence on agriculture. The small-scale rural industries in the region should also be supported and improved. This will reduce the over-dependence on farming as the principal source of livelihood and thereby reduce the proportion of the population (75%) that is currently in agriculture.
- There are a few irrigation facilities in the region, but these are not enough. More of such irrigation facilities should be provided in areas where water is available. This will minimize the incidence of crop failure due to unreliable rainfall regimes.

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9 APPENDICES

Appendix 9.1: List of most commonly used image types (Telsat Guide, June, 2002)

	Type of data		Reso. (m)	Price/image (€ or US$)	Price €/100km2	Image Size (km)	Data providers
ERS 1-2 AMI-SAR	Annoted Raw data		30	1000	10,00	100x100	Eurimage Spot Image
	Precision image			1200	12,00		
	Geocoded image			1400	14,00		
	Terrain Geocoded image			2300	23,00		
Ikonos	Archive images (Belgium)	Geo Pan	1	2178 $ (18 $/km²)	1908,84 (*)	11x11 (100km² minimum order)	GIM Eurosense Luciad
		Geo MS	4	2178 $ (18 $/km²)	1908,85 (*)		
		Geo Bundle	1	2831,40 $ (23,40 $/km²)	2481,49 (*)		
	New acquisition (Belgium)	Geo Pan	1	2722,50 $ (22,50 $/km²)	2386,05 (*)		
		Geo MS	4	2178 $ (18 $/km²)	1908,85 (*)		
		Geo bundle	1	3569,50 $ (29,25 $/km²)	3101,87 (*)		
QuickBird	New Acquisition Basic	Pan	0,7	6120 $	2535,18 (*)	16x16 (256km² minimum order)	GIM Eurimage
		MS	2.8	6800 $	2816,87 (*)		
		Bundle or Pansharpened	0.7/2.8	8160 $	3380,24 (*)		
	New Acquisition Standard	Pan	0.7	5760 $ (22,5 $/km²)	2386,05 (*)	16x16 (64km² minimum order)	
		MS	2.8	6400 $ (25 $/km²)	2651,17 (*)		
		Bundle or Pansharpened	0.7/2.8	7680 $ (30 $/km²)	3181,40		
	New Acquisition Orthorectified	Pan	0,7	23040 $ (90 $/km²)	9544,21 (*)	16x16 (150km² minimum order)	
		MS	2.8	25344 $ (99 $/km²)	10498,63(*)		
		Bundle or Pansharpened	0.7/2.8	29952 $ (117 $/km²)	12407,47(*)		

	Type of data		Reso. (m)	Price/image (€ or US$)	Price €/100km2	Image Size (km)	Data providers
LANDSAT 1-5 MSS	Archive from 1977 to 1993 (Pan-European)		80	200	0,63	183x173	Eurimage
LANDSAT 5 TM	New set and recent set (from 1/1/95)		30 MS 120 TIR	1500	4,74	183x173	urimage
	Historical set (<31/12/94)			1000	3,16		
	10-year-old set			425	1,34		
LANDSAT 7 ETM+	Basic Set	Standard level 0R	15 Pan 30 MS 60 TIR	475	1,50		
		Standard level 1R/1G		600	1,90		
		Float across 1R/1G		1000	3,16		
	Extended Set	Standard 0R/1R/1G		1500	4,74		
		Float across 0R/1R/1G		2000	6,32		
NOAA AVHRR	Level 1/2A/2B Table		1000	100 $	0,0024 (*)	3000x1500	Eurimage
Orbview 2 SeaWiFS	Level 1A/1B/2A		1100	500 $	0,0126 (*)	2800x1500	Orbimage
Radarsat SAR	Archive data (before 1/1/1999)		8-100	1500 $	0,64 - 63,63(*)	50x50 - 500x500	Radarsat Eurimage Spot Image
	Other			2750 - 3750 $	1,17 - 159,07(*)		
SPOT HRV/HRVIR P/Xs/Xi	Level 1A/1B/2A	SPOT View 1986 - 1998	10 P 20 Xs/Xi	1250	34,72	60x60	Spot Image
		SPOT View since 1999		2600	72,22		
		Programmed SPOT View		4000	111,11		
SPOT VGT	P		1000	120	0,0120	1000x1000 (ROI can be specified by user)	Vito EOWorks
	S1		1000	160	0,0160		
	S10		1000	260 (free 3-month-old data)	0,0260		

Appendix 9.2: Land use and land cover classification scheme for Ghana

LEVEL I	LEVEL II	LEVEL III	LEVEL IV
1000 Agricultural land	1100 Crop cover	1110 Tree crop plantation	1111 Cocoa 1112 Oil palm 1113 Coconut 1114 Citrus 1115 Shea 1116 Rubber 1117 Cashew 1118 Coffee
		1120 Non-tree (rain-fed) mono-cropping	1121 Pineapple 1122 Sugar cane 1123 Banana/plantain 1124 Cotton 1125 Tobacco 1126 Maize 1127 Rice
		1130 Irrigated cropping	1131 Rice 1132 Vegetables 1133 Pineapple 1134 Sugar cane 1135 Banana/plantain 1136 Mixed arable crops
		1140 Pasture	1141 Livestock
	1200 Shrubland and crop cover (<25 trees/ha)	1210 Mixed bush fallow cropping (short fallow)	1211 Mixed arable crops 1212 Mixed arable & tree crops
		1220 Mixed bush fallow cropping (long fallow)	1221 Mixed arable crops 1222 Mixed arable & tree crops
	1300 Grass/herb fallow & crop cover (<10 trees/ha).	1310 Mixed bush fallow cropping (short fallow)	1311 Mixed arable crops 1312 Mixed arable & tree crops 1313 Vegetables 1314 Mixed arable crop & pineapple
		1320. Mixed bush fallow cropping (long fallow)	1321 Mixed arable crops
		1330 Compound farming	1331 Mixed arable crops & livestock
	1400 Dense herb/bush/grass fallow & crop cover (10–50 tree/ha)	1410 Mixed bush fallow cropping (short fallow)	1411 Mixed arable crops 1412 Mixed arable & tree crops 1413 Mixed arable & tree crops (cocoa) 1414 Mixed arable & tree crops (oil palm) 1415 Mixed arable & tree crops (coconut)
		1420 Mixed bush fallow cropping (long fallow)	1421 Mixed arable crops

LEVEL I	LEVEL II	LEVEL III	LEVEL IV
1000 Agricultural land	1500 Herb/bush & crop cover with high density (>50) forest trees/ha	1510 Mixed bush fallow cropping (variable fallow	1511 Mixed arable & tree crops (cocoa) 1512 Mixed arable & tree crops (coffee) 1513 Mixed arable & tree crops (oil palm) 1514 Mixed arable & tree crops (coconut) 1515 Mixed arable crops 1516 Mixed arable & tree crops
		1520 Sub-canopy cropping	1521 Mixed arable & tree crops (cocoa) 1522 Mixed arable & tree crops (coffee)
	1600 Mosaic of thickets/grass and crop cover (<10 trees/ha)	1610 Mixed bush fallow cropping (short fallow)	1611 Mixed arable crops 1612 Mixed arable & tree crops
		1620 Mixed bush fallow cropping (long fallow)	1621 Mixed arable crops 1622 Mixed arable & tree crops
		1630 Mixed bush fallow cropping (long fallow) & grazing	1631 Mixed arable crops & livestock
	1700 Mixture of closed savannah woodland and crop cover (>150 trees/ha)	1710 Mixed bush fallow cropping (short fallow)	1711 Mixed arable crops
		1720 Mixed bush fallow cropping (long fallow)	1721 Mixed arable crops
	1800 Mixture of open savannah woodland and crop cover (75-150 trees/ha)	1810 Mixed bush fallow cropping (short fallow)	1811 Mixed arable crops
		1820 Mixed bush fallow cropping (long fallow)	1821 Mixed arable crops
	1900 Mixture of widely open savannah	1910 Mixed bush fallow cropping (short fallow)	1911 Mixed arable crops
	woodland & crop cover (10-75 trees/ha)	1920 Mixed bush fallow cropping (long fallow)	1921 Mixed arable crops

LEVEL I	LEVEL II	LEVEL III	LEVEL IV
2000 Forest	2100 Closed forest (>60% canopy covered)	2110 Reserved closed forest	2111 Timber 2112 Conservation 2113 Wildlife 2114 Traditional gro ve
		2120 Open-access closed forest	2121 Wild produce
		2130 Closed forest plantation	2131 Timber 2132 Conservation 2133 Fuel wood
	2200 Open forest (<60% canopy covered)	2210 Reserved open forest	2211 Timber 2212 Conservation
		2220 Open-access open forest	2221 Timber 2222 Conservation
		2230 Open forest plantation	2231 Timber 2232 Conservation 2233 Fuel wood
	2300 Riverine vegetation	2310 Riverine vegetation with/without scattered farms	
3000 Savannah	3100 Closed savannah woodland (>150 trees/ha)	3110 Reserved closed savannah woodland	3111 Wildlife 3112 Conservation 3113 Traditional grove
		3120 Open-access closed savannah woodland (with/without scattered farms/grazing)	3121 Livestock/wild produce 3122 Wild produce
	3200 Open savannah woodla nd (<150 trees/ha)	3210 Reserved open savan nah woodland (with/without scattered farms/grazing)	3211 Conservation 3212 Wildlife
		3220 Open-access open savannah woodland with/without scattered farms/grazing	3221 Livestock/wild produce 3222 Wild produce
	3300 Grassland with/without scattered trees (<10/ha)	3310 Reserved grassland with/without farms/grazing	3311 Conservation 3312 wildlife
		3320 Open-access gras sland with/without scattered farms/grazing	3321 Livestock 3322 Wild produce
	3400 Riverine vegetation	3410 Riverine vegetation +/- farming or grazing	

LEVEL I	LEVEL II	LEVEL III	LEVEL IV
4000 Shrub-thicket (Scrub)	4100 Shrub-thicket (<10 trees/ha)	4110 Reserved shrub-thicket	4111 Wildlife 4112 Traditional grove 4113 Conservation
		4120 Open-access shrub-thicket +/-scattered farms	4121 Wild produce
	4200 Mosaic of thickets & grassland	4210 Reserved mosaic of thicket and grassland	4211 Wildlife 4212 Traditional grove 4213 Conservation
		4220 Open-access mosaic of thickets & grassland +/-scattered farms/grazing	4221 wild produce 4222 Livestock
5000 Non-biotic constructed surfaces	5100 Settlement	5110 Urban settlement	5111 City nucleus 5112 Peri-urban 5113 Town
		5120 Rural settlement	5121 Village 5122 Cottage/hut
	5200 Transport	5210 Road	5211 Trunk road 5212 Feeder road 5213 Track
		5220 Railway	5221 Single track 5222 Double track
		5230 Aerodrome	5231 International airport 5232 Local airport 5233 Airstrip
6000 Bare land	6100 Rocky land	6110 Quarrying	6111 Stone 6112 sand
		6120 Mining	6121 Gold 6122 Diamond 6123 Bauxite 6124 Manganese
	6200 Eroded surface	6210 Eroded surface	6211 Eroded surface
	6300 Beach	6310 Beach	6311 Recreation 6312 Port / harbour
	6400 Salt flats	6410 Salt winning	6411 Salt
7000 Water body	7100 River	7110 Water supply	7111 Water
		7120 Fishing	71212 Fish
	7200 Reservoir	7210 Water supply	7211 Water
		7220 Fishing	7221 Fish
	7300 Lake	7310 Water supply	7311 Water
		7320 Fishing	7321 Fish
	7400 Lagoon	7410 Fishing	7411 Fish
		7420 Salt winning	7421 Salt
8000 Wetland		8110 Conservation	8111 Wildlife
		8120 Gathering	8121 Fuelwood, etc.
		8130 Fishing	8131 Fish
9000 Unclassified land	9100 Cloud/haze obscurity		
	9200 Fire scars		

9.2.1: Ghana land cover and land use classification scheme (Explanation)

The land cover and land use classification system for Ghana (Agyepong et al., 1996), was modelled on that of Anderson et al. (1976). It has a hierarchical structure in that it accommodates different levels of information starting with broad-level classes. It has been structured to allow further subdivision into more detailed sub-classes at higher levels. Four levels are recognized with, broadly speaking, the first two levels corresponding to land cover categories and third and fourth levels to land use categories, as defined as follows:

Level I: Principal vegetative and non-vegetative landscape cover.

Level II: Sub-categories of the principal vegetative and non-vegetative cover defined in terms of formation characteristics, of canopy closure, tree stand density and dominant life form.

Level III: Land use defined in terms of the major management systems.

Level IV: Land use categories defined in terms of products and services.

One of the important features of the classification scheme is the 4-figure coding system. The coding system reflects the hierarchical nature of the scheme and enhances the development of a land cover and land use database.

Nine Level I classes are coded as 1000, 2000, 3000, 4000, 5000, 6000, 7000, 8000 and 9000. Level II categories are coded by an open scale of 100 units resulting in such sub-category codes as 1100, 1200,1300, 1900, 2100, 2200, 3100, 3200, etc. At Level III the sub-classes are coded as 1110, 1120, 1130, 1910, 1920; 2110, 2120, 2210, 2220, etc., with a scale interval of 10 units. Level IV is the lowest level of the classification where the codes reflect the products and services of land use and are coded as for example; 1111, 1112, 1113, 2111, 2112, 2113, etc.

Explanation of terminology

The majority of terms used in the classification are self-explanatory. Below are explanations of some terms, which may not be so clear.

Bush fallow cropping

The system of farming in which the farmer relies on the natural regrowth fallow to restore the fertility of the soil including the control of weeds. The degree of restoration of fertility depends upon the length of the fallow period and the composition of the fallow. "Land rotation" and "recurrent cultivation" are other terms used to describe the system, while "shifting cultivation" is a variant of the system where the farmer moves to cultivate fresh areas and may not come back to the abandoned field (Dickson and Benneh, 1988).

The intensity of cultivation is indicated by the length of the period of the fallow. ***Short fallows*** have a cultivation factor of <33% while the ***long fallows*** have a factor of >33-66%, where the cultivation factor is calculated as the ratio of the years under cropping and the total length of the cropping and the fallow cycle (Ruthenberg, 1980). Nye and Greenland (1960) suggest that adequate fallow periods in the forest and savannah ecological areas should be 5 and 15 years respectively. For present purposes, however, a period of three (3) years has been used as the cut-off between short and long fallows. Thus, fallows of duration up to three years are considered to be short, while those of duration longer than three years are termed long fallow. Short fallows generally indicate pressure on the land.

Compound farming

This is the permanent cultivation of crops immediately around dwelling units known as "compounds". Cultivation is intensive, made possible by the use of household refuse for manure, particularly in the dispersed settlement areas of the northern parts of Ghana (Wills, 1962), and in much of the savannah areas of West Africa

Gathering

A common form of land use activity in Ghana, in which a wide variety of wild produce and wildlife are collected from forests, savannah s wetlands and water bodies, often for subsistence use but increasingly for commercial purposes. The products include fuel wood, honey, medicinal herbs, fodder, thatch and meat. Gathering is done primarily in the "open access" land cover areas that may be statutory reserved or traditionally designated and controlled areas.

Mixed cropping

The cultivation of more than one crop on the same piece of land, usually in a seemingly haphazard mixture and at the same time. Mixed cropping may involve arable crops, (cassava and vegetables) and tree crops (oil palm, citrus, mango). Some of these may be wild, but tended by the farmer, for instance, the fruit trees, or they may be ratoon crops such as sugar cane and plantain.

Open-access

Open-access describes areas that are not subject to restrictions as to entry and the exploitation of products and resources by members of the community. Resources exploited include wood for fuel and construction, wildlife, medicinal herbs, fodder, etc.

Reserved land

In contrast to open access these are areas that have been gazetted and designated reserves with restriction on use. They are usually forest but also include areas of savannah woodland and shrub thicket. Areas of reserved land that have had their cover removed have been mapped as that land cover and land use rather than intended cover.

Mosaic

Applies to a cover of shrub thicket and grassland where neither cover can be mapped separately at the scale of mapping.

Tree density and canopy cover

Field estimates of tree densities and canopy cover have been used for the identification of sub-categories for the vegetative classes. Broad density ranges used are fewer than 10; 10-75; 75-150 and greater than 150 trees per hectare.

Description of Level I categories:

Agricultural land (1000)

Land where over 50% of any defined area is used for agriculture. This may be currently cropped or in fallow and may include areas for grazing of livestock (in association with crop cultivation). Agricultural land is sub-divided at Level II according to the vegetative cover within which the agriculture takes place.

Forest (2000)

Continuous, multi-storied stand of trees at least 5m high with interlocking crowns, usually lacking a grass ground cover. Forest is sub-divided at Level II into closed (>60% canopy cover) and open (<60% canopy cover) and also riverine forest.

Savannah (3000)

An area of land comprising a mixture of woodland (single storied stand of trees less than 5m high), and/or bushes (woody plant with multiple stems, usually over 2m tall), and/or shrubs (woody plant with multiple stems, usually less than 2m tall), and/or grassland with or without scattered cultivation. Savannah is sub-divided at Level II into closed (>150 trees/ha) and open (<150 trees/ha) woodland, grassland and riverine vegetation.

Shrub thicket (4000)

Areas dominated by dense shrubs in association with grassland. This category does not occur in Upper West Region.

Non-biotic constructed surfaces (5000)

Areas that have an artificial cover modified by human activity. Sub-divided at lower levels into settlement and transport.

Bare land (6000)

Areas that are devoid of vegetative, cover either naturally (rock, sand) or through the results of human activity (erosion, mining). This category has not been mapped in Upper West Region.

Water bodies (7000)

These include rivers, reservoirs, lakes and lagoons. This category has not been mapped in the Upper West Region.

Wetland (8000)

Vegetated areas where the water table is at or near the surface for a significant part of most years. This category has not been mapped in the Upper West Region.

Unclassified (9000)

Areas that could not be classified due to cloud, cover or fire scars. Fire scars have been mapped in the Upper West Region.

Description of Levels II-IV categories

Grass/herb fallow with scattered trees (0-10 trees/ha) (1300)

This category describes primarily arable land within grassland cover and scattered trees. It is sub-divided at Level III into short and long fallow mixed bush fallow cropping and compound farming and mixed arable cropping at Level.

Open savannah woodland (75-150 trees/ha) (1800)

This category describes arable land occurring in association with open savannah woodland with a tree density of 75-150 trees per hectare. It is sub-divided at Level III into short and long fallow, mixed bush fallow cropping systems.

Widely open savannah woodland (10-75 trees/ha) (1900)

This category describes arable land occurring in association with widely open savannah woodland with a tree density of 10-75 trees per hectare. It is sub-divided at Level III into short and long fallow, mixed bush fallow cropping systems and at Level IV into cropping types, though only mixed food crops are recognized.

Closed forest (>60% canopy cover) (2100)

This category describes a forested area with greater than 60% canopy cover. At Level III it is sub-divided into reserve, open-access and plantation and at Level IV into its particular land use; timber, conservation, wildlife or traditional grove.

Open forest (<60% canopy cover) (2200)

This category describes a forested area with less than 60% canopy cover. At Level III it is sub-divided into reserve, open-access and plantation and at Level IV into its particular land use; wild produce, timber, conservation, or fuel wood.

Closed savannah woodland (3100) (>150 trees/ha)

This category describes savannah woodland with greater than 150 trees/ha. It is relatively extensive covering 179,600 ha or 9.7% of the total area. At Level III it is sub-divided into closed woodland reserve (3110), further subdivided at Level IV into its particular land use; wildlife, conservation or traditional grove; and open access woodland, which may contain some scattered farms (3120).

Open savannah woodland (3200) (75-150 trees/ha)

This category describes savannah woodland with fewer than 150 trees/ha and is the most extensive land cover in the region with 751,000 ha or almost 41% of the total area. At Level III it is sub-divided into open woodland reserve - 3210; and open access woodland, which may contain scattered farms - 3220. At Level IV these are subdivided according to land use as; conservation, wildlife, livestock and wild produce.

Savannah : Riverine vegetation (3400)

This category describes the mixture of woodland, grassland, shrubs and bushes with or without occasional farms or grazing, which occurs along water courses.

Settlement (5100)

This describes areas of settlement and is sub-divided at Level III into urban and rural settlement and at Level IV into specific settlement types.

Unclassified land: Fire scars (9200)

This category describes burnt areas. They are not sub-divided at lower levels in the classification.

Appendix 9.3: Population (2000) in the Wa District of the Upper West Region

Wa District	Population				
	2000			1984	1970
Locality	Total	Male	Female	Total	Total
Wa	66644	31974	34670	36067	13740
Funsi	2899	1366	1533	2038	1405
Busa	2611	1283	1328	669	417
Charia	2488	1209	1279	1918	1602
Bulenga	2392	1139	1253	1532	1091
Boli	2158	1125	1033	1792	1134
Gorripe	1997	948	1049	1304	907
Tanina	1922	935	987	1509	1010
Kpongu	1911	958	953	1354	1140
Mengwe	1803	1012	791	1257	869
Chaggu	1765	938	827	487	370
Kolipong	1689	866	823	1560	616
Nechau	1661	800	861	1014	607
Viera	1617	827	790	1234	1090
Metiaw	1487	702	785	345	705
Nyoli	1431	620	811	765	378
Kundungu	1359	648	711	1202	957
Kperisi	1339	719	620	739	294
Ga	1311	641	670	1073	720
Dusie	1302	660	642	2254	752

Appendix 9.4: Population (2000) in the Nadowli District of the Upper West

Nadowli District	Population 2000			1984	1970
Locality	Total	Male	Female	Total	Total
Kaleo	3037	1402	1635	-	-
Nadowli	2813	1402	1635	1254	1162
Bussie	2656	1233	1423	2735	664
Naro Narung	404	1130	1274	1971	1579
Takpo	2388	1159	1229	1110	157
Tabeasi	2359	1175	1184	1500	157
Fian	2270	1094	1176	1335	1182
Duong	2104	1002	1102	1834	1078
Sankana	2079	928	1151	2208	1425
Wogu	2048	936	1112	1822	2005
Daffiama	2011	954	1057	2543	1533
Sombo	1902	839	1063	329	2010
Kojoperi	1811	911	900	1758	258
Nator	1787	829	958	2041	1446
Issa	1782	865	917	1288	1446
Jang	1574	766	808	1377	850
Goli	1568	747	821	301	782
Owlo	1462	649	813	1504	269
Nanvilli	1153	510	643	1158	764
Serikperee	1141	505	636	968	741

Appendix 9.5: Population (2000) distribution in the Sissala District, Upper West

Locality	Total	Male	Female		
Sissala	Population				
	2000			1984	1970
Locality	Total	Male	Female		
Tumu	8858	4270	4588	6014	4366
Gwolu	4802	2359	2443	2408	1741
Walembelle	3397	1593	1804	2298	1568
Fiemon	2497	1226	1271	1923	1679
Jeffisi	2366	1104	1262	1675	1152
Challo	2073	1029	1044	483	-
Nabulo	1985	915	1070	453	333
Sakai	1926	921	1005	1461	1200
Bugubelle	1859	885	974	763	846
Buo	1712	67	945	821	589
Sorbelle	1551	77	774	1267	912
Pulima	1398	715	683	976	819
Lipilime	1382	655	727	-	-
Jawia	1341	632	709	1032	518
Nabugubelle	1339	640	699	960	739
Pieng	1336	697	639	777	510
Bawiesiboi	1301	661	640	960	770
Mwanduanu	1248	583	665	945	602
Kong	1206	592	614	785	610
Nyimeti	1196	585	611	614	321

Appendix 9.6: Population (2000) in the Jirapa Lambussie District, Upper West

Jirapa-Lambussie District Locality	Population				
	2000			1984	1970
	Total	Male	Female		
Jirapa	8060	3637	4423	5466	3520
Hamile	5245	2469	2776	4329	2526
Tizza	2298	1041	1257	2615	2026
Lambussie	2199	1043	1156	2694	1377
Billaw	2168	1047	1121	1590	1169
Karni	2066	905	1161	1582	1005
Samoa	1924	930	994	1664	917
Han	1902	906	996	1199	843
Sabuli	1784	852	932	1352	1097
Tapomo	1593	722	871	1223	1108
Nimbare	1592	742	850	132	131
Chapuri	1352	663	689	956	697
Suggo	1251	607	644	732	470
Piina	1171	555	616	899	688
Kuunkyeni	1150	552	598	735	597
Kunzokala	1050	502	548	945	648
Tampala	1047	459	588	1021	1026
Ullo	1009	514	495	658	972
Kogri	893	444	449	545	354
Kpari	881	426	455	815	578

Appendix 9.7: Population (2000) in the Lawra District of the Upper West Region

Lawra District	Population				
	2000			1984	1970
Locality	Total	Male	Female	Total	Total
Nandom	6526	2948	3578	4336	3236
Lawra	5763	2618	3145	4080	2709
Babile	3044	1420	1624	2147	1346
Boo	1770	902	868	1504	1486
Doweni	1584	717	867	1011	593
Bu	1192	505	687	821	589
Nabugangn	1054	519	535	729	554
Kunyukuo	1053	495	558	999	510
Puffien Baagangen	952	488	464	464	-
Brutu	905	413	492	731	534
Lissa Gondour	874	452	423	486	778
Eremon-Zinpen	808	398	410	303	-
Tantuo	718	308	410	595	521
Kogle	710	352	358	554	555
Naapaal	701	322	379	483	356
Eremon- Yagra	694	351	343	485	516
Tome Kokoduor	690	348	342	206	-
Kentuo	682	342	340	591	402
Munyopele	680	312	368	199	-
Eremon—Kuo-Ang	673	320	353	271	-

Appendix 9.8: Population (2000) of major settlements of the Upper West Region

Locality	**District**	**Population**				
		2000			**1984**	**1970**
		Total	**Male**	**Female**	**Total**	**Total**
Wa	Wa	66644	31974	34670	36067	13740
Tumu	Sissala	8858	4270	4588	6014	4366
Jirapa	Jirapa-Lambushie	8060	3637	4423	5466	3520
Nandom	Lawra	6526	2948	3578	4336	3236
Lawra	Lawra	5763	2618	3145	4080	2709
Hamile	Jirapa-Lambushie	5245	2469	2776	4349	2526
Gwolu	Sissala	4802	2359	2443	2408	1741
Walembelle	Sissala	3397	1593	1804	2298	1568
Babile	Lawra	3044	1420	1624	2147	1346
Kaleo	Nadowli	3037	1402	1635	-	-
Funsi	Wa	2899	1366	1533	2038	1405
Nadowli	Nadowli	2813	1269	1544	1254	1162
Bussie	Nadowli	2656	1233	1423	2735	664
Busa	Wa	2611	1283	1328		417
Fielmon	Sissala	2497	1226	1271	1923	1679
Charia	Wa	2488	1209	1279	1918	1602
Naro Norung	Nadowli	2404	1130	1274	1971	1579
Bulenga	Wa	2392	1139	1253	1532	1091
Takpo	Nadowli	2388	1159	1229	1110	157
Jeffisi	Sissala	2366	1104	1262	1675	1152

Appendix 9.9: Records of geocorrection of LANDSAT TM (January18, 1986).

GCP Tool : (Input : 1986_input_gcps.gcc) (Reference : 1986_ref_gcps.gcc)

File View Edit Help

Check Point Error: (X) 0.5157 (Y) 0.2833 (Total) 0.5884

Point #	Point ID	>	Color	X Input	Y Input	>	Color	X Ref.	Y Ref.	Type	X Residual	Y Residual	RMS Error	Contrib.	Match
1	GCP #1			2337.046	-4195.254			367403.289	1957807.723	Control					
2	GCP #2			2338.717	-4278.124			366360.695	1950032.948	Control					
3	GCP #7			2524.588	-4971.215			373986.528	1883455.847	Control					0.784
4	GCP #8			2508.355	-4764.044			375267.430	1902758.738	Control					0.697
5	GCP #6			2448.987	-5202.383			363798.891	1863110.362	Control					0.609
6	GCP #9			2486.710	-5591.954			361803.068	1826470.615	Control					0.831
7	GCP #13			2661.414	-5840.868			374428.562	1801082.790	Control					0.889
8	GCP #14			2454.243	-5818.451			355666.655	1805976.187	Control					0.574
9	GCP #15			2816.792	-6019.437			386289.142	1782502.919	Control					0.811
10	GCP #17			2884.045	-6114.520			391204.230	1772702.531	Control					0.871
11	GCP #20			2383.898	-4233.748			371126.840	1953607.557	Control					0.634
12	GCP #22			2191.414	-4073.732			355666.655	1971003.990	Control					0.673
13	GCP #23			2255.575	-4143.304			360551.954	1963676.040	Control					0.784
14	GCP #24			2149.671	-4093.830			351466.489	1969663.511	Control					0.252
15	GCP #26			2315.098	-4103.880			366624.368	1966561.371	Control					0.731
16	GCP #25			2030.625	-3774.571			344913.038	2000822.190	Control					0.388
17	GCP #21			3732.123	-2688.906			517358.155	2077825.235	Control					-0.401
18	GCP #27			2705.476	-2828.387			420516.027	2079016.771	Control					0.646
19	GCP #28			2850.805	-2888.683			433176.103	2071510.091	Control					0.653
20	GCP #43			2008.980	-4939.521			326703.309	1893452.109	Check	0.008	0.119	0.119	0.202	0.898
21	GCP #44			2205.329	-4225.245			354809.601	1956842.134	Check	-0.034	0.537	0.538	0.914	0.849
22	GCP #31			2723.256	-4346.610			400945.041	1938445.255	Check	-0.582	-0.004	0.582	0.989	0.916
23	GCP #29			2296.830	-4242.069			363024.392	1953965.018	Check	-0.047	-0.129	0.138	0.234	0.865
24	GCP #32			2242.816	-4172.198			359092.322	1961173.814	Check	0.881	0.048	0.883	1.500	0.843
25	GCP #30			2246.492	-4454.555			355398.559	1935019.588	Check	-0.187	-0.025	0.189	0.322	0.814
26	GCP #34			2247.845	-4377.531			356560.307	1942079.442	Check	-0.503	-0.553	0.747	1.270	0.769
27	GCP #33			2433.371	-5226.313			361867.622	1861079.547	Check	-0.791	-0.083	0.796	1.353	0.798
28	GCP #35			2795.920	-4355.886			407647.433	1936598.374	Check	0.601	0.296	0.670	1.138	0.705
29	GCP #36	>				>				Check					

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