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AN EVALUATION OF TWO DATA SOURCES AND THEIR EFFECTIVENESS FOR VEGETATION MONITORING IN DEVELOPING COUNTRIES USING NORMALIZED DIFFERENCE VEGETATION INDICES (NDVI)

by

Vicki Gauthier ©

A Report submitted in partial fulfilment of the
requirements for the degree of Master of Forestry

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ABSTRACT

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Key Words: developing countries, Ghana, Landsat, NDVI, NOAA, remote sensing, satellite imagery, vegetation indices.

To prevent environmental degradation that is occurring globally in both developed and developing countries, an environmental monitoring program must be created and implemented. One method of monitoring vast geographical areas is to incorporate remote sensing and vegetation indices.

This report examines areas of vegetation monitoring and explains some of the technology used to carry out vegetation monitoring in developed and developing countries.

A comprehensive literature review examines the importance of the earth's vegetation with respect to losses of vegetation and the consequences of these losses to the earth's systems, remote sensing and satellite systems and monitoring vegetation using remote sensing.

Normalized Difference Vegetation Index (NDVI) was derived from two different sources of remotely sensed data using satellite imagery acquired in 1991 over northern Ghana; Landsat Thematic Mapper (TM) and National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR). The mean NDVI calculated from the Landsat TM data was 0.11 and the mean NDVI calculated from the NOAA AVHRR was 0.10. The results are said to be the same because of the difference in ground cover imaged and data resolution of the two data sources.

Critical values were established to determine whether a value of NDVI obtained during the dry season in northern Ghana, for example, was low for that time of year possibly indicating increased environmental degradation. A monitoring system that watches the areas of non vegetation according to the critical value for that region sets the lower limits of NDVI values for a region that are more meaningful to that region. By setting the critical value at 0.10 for northern Ghana, any NDVI value above 0.10 was said to be vegetated. Continuing this critical value idea over many years can be used as an effective environmental monitoring program for northern Ghana and other countries experiencing environmental degradation problems.

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LIST OF ACRONYMS

NDVI - Normalized Difference Vegetation Index

NOAA - National Oceanic and Atmospheric Administration

AVHRR - Advanced Very High Resolution Radiometer

Landsat TM - Landsat Thematic Mapper

Landsat MSS - Landsat Multispectral Scanner

SPOT - Systeme Pour l'Observation de la Terre

ERTS - Earth Resources Technology Satellites

UNCED - United Nations Conferece on Environment and Development

UNEP - United Nations Environment Program

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SECTION 1

1.0 INTRODUCTION

As the global environment continues to deteriorate, methods of monitoring this deterioration need to be established. Incorporating remote sensing and vegetation indices is one way to monitor vast geographical areas and determine where resources and efforts can be efficiently concentrated. The purpose of this report is to explore the many subject areas of vegetation monitoring and explain some of the technology used to carry out vegetation monitoring in both developed and developing countries.

1.1 OBJECTIVES

This report covers two main objectives. Within each objective there are subdivisions which are explained at the beginning of each section.

The first objective of this report was to complete a comprehensive literature review of global vegetation monitoring. The review examines the importance of vegetation to the earth, remote sensing and satellite systems, and monitoring vegetation using remote sensing.

The second objective was to illustrate two main concepts using satellite imagery for vegetation monitoring. The first concept was to show that a common vegetation index derived from different sources of remotely sensed data can be normalized to yield the same information. Landsat Thematic Mapper (TM) and National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) data are used as examples. The second concept explains and describes how this Normalized Difference Vegetation Index (NDVI) from Landsat TM for an area in Northern Ghana can be used at the local level for monitoring vegetation and that NDVI from NOAA AVHRR can be used at the regional level for monitoring vegetation. The idea of establishing critical values of

NDVI to improve vegetation monitoring at both the local and regional levels is discussed here as well.

1.2 REPORT LAYOUT

The report is divided into four main sections. This first section introduces the report and explains the divisions within the report.

Section II covers the first objective of the report which is a review of literature covering three main topics: global vegetation, remote sensing, and remote sensing and vegetation.

Section III accomplishes the second objective of this report by including two projects; Project 1 and Project 2. Project 1 explores the first concept of normalizing a vegetation index and applying it to two different data sources: Landsat TM and NOAA AVHRR. Project 2 demonstrates how NDVI can be used at the local and regional levels for vegetation monitoring. Section III is divided into introduction, methodology, results and discussion and conclusion sections.

Section IV discusses how vegetation monitoring and the concept of critical values can be used to address the problem of land degradation in Ghana and includes recommendations for further study.

SECTION 2

2.0 INTRODUCTION

On a global scale, the quality of the environment is becoming an increasingly important issue. Environmental quality is no longer regarded as a luxury that only industrialized nations can afford. It has often been assumed that residents of the poorer, non-industrialized nations have been too preoccupied with economic and physical survival to be concerned about environmental problems (Dunlap *et al.* 1993). However, enthusiastic participation of such nations in the 1992 United Nations Conference on Environment and Development (UNCED) Earth Summit in Rio de Janeiro and the gradual emergence of environmental activism in many non-industrialized nations is proving this assumption wrong (Dunlap *et al.* 1993). Unfortunately, at the 1997 follow-up conference, Rio+5, the Chairman of the Earth Council Maurice Strong reported that "...despite progress made on many environmental fronts, the world community has still not made the transition to a development pathway that will provide the human community with a sustainable and secure future. Environmental deterioration continues and the forces which drive it persist" (Strong 1997). Both industrialized and non-industrialized nations have contributed to global environmental damage including desertification; deforestation; soil, air, and water pollution; soil degradation and erosion; and ozone depletion and they must work together to decrease environmental damage.

One of the most important environmental problems facing the global community is the decrease in the amount of vegetation covering the earth. Terrestrial vegetation influences the earth's atmosphere and energy budget. Vegetation affects the concentration of gases in the atmosphere, either directly or indirectly, contributing to the greenhouse effect (Botkin *et al.* 1984; CSIRO 1995b).

Vast removals of vegetation causes many problems. Two of these are an increase in the surface temperature of the earth caused by the loss in evaporative cooling capability (provided by trees) and a loss of surface soil due to all forms of soil erosion especially on sloped surfaces (Botkin *et al.* 1984). Without vegetation to prevent surface temperature increases and soil erosion these problems are perpetuated and the ability to re-establish vegetation on already damaged soils becomes increasingly difficult.

A common problem in developing countries is the inadequacy of information on current land cover and land use and available natural resource base. Without accurate information, policy-makers often fail to make decisions or make incorrect decisions. Sound decisions depend on accurate information, but developing countries have competing demands for the financial and human commitments necessary to meet the policy-making requirements (Botkin *et al.* 1984; ERDAS 1992; Lillesand and Kiefer 1994; Haack 1996).

The frequent inadequacy of land cover and resource information may be due to difficulties in accessing some regions because of limited or failed infrastructure; lack of trained personnel, equipment, or funds to collect information properly; or rapid changes in the resource base not detectable by traditional data collection methods. Spaceborne remote sensing can often provide this information for developing countries (Haack 1996).

The continent of Africa, especially the sub-Sahara region, is a region of great variety and rapid change. Many changes are due to rapid population growth and severe land degradation. There is an urgent need for accurate, timely information on renewable resources, land use, and land ownership patterns in this region (Falloux 1989). Remote sensing offers geographically referenced information using a single consistent method over a large area with uniform, reliable accuracies and repeated measurements over time to detect change

(Falloux 1989; Haack 1996). Valuable information that can be derived from remotely sensed data are vegetation indices.

Vegetation indices are generally derived from some subset of spectral bands of remotely sensed data on a pixel-by-pixel basis. The reflectance of the specific bands at various pixels are combined and correlated with vegetation parameters such as green leaf biomass or green leaf area. A commonly used vegetation index is the NDVI. This index takes advantage of the difference between reflectance of green plants in the red and near infrared spectral bands (CSIRO 1995b; Okin 1996a).

Sustainable development of a country must include sound environmental management of a country's natural resources (Asare 1992). Ghana is one African country that is trying to take responsibility and action to halt the degradation of its environment. The population of this country will double within twenty-five years and the government of Ghana realizes its natural resources are not inexhaustible (Otoo 1989). In a developing country like Ghana, the rural conditions deteriorate when forests are used for energy supplies and deforested land is used for farming. Severe climate and rugged physical topography have accelerated forest depletion and overall environmental degradation in this part of the continent (Otoo 1989). Sustainable development proposes balanced economic development to meet basic needs of the people without causing severe damage to the environment on which the resources are based (Otoo 1989). Monitoring the natural resources of Ghana using remote sensing techniques and vegetation indices can provide some of the necessary information to make responsible decisions and help this country begin to achieve sustainable development by its own means.

2.1 OBJECTIVES

The objective of Section II is to complete a comprehensive literature review of global vegetation monitoring. The review is divided into three main topics of global vegetation monitoring.

The first of these topics examines the importance of vegetation to the earth and the consequences of its removal including disturbance and land degradation. The second topic discusses remote sensing, satellite imagery and three main satellites used for monitoring vegetation; Landsat, SPOT and NOAA. This section also includes Normalized Difference Vegetation Index and vegetation monitoring. The third, and final part of Section II examines remote sensing and vegetation including monitoring vegetation and the applications of Landsat and NOAA AVHRR data for vegetation monitoring.

2.2 LITERATURE REVIEW

2.2.1 IMPORTANCE OF THE EARTH'S VEGETATION

2.2.1.1 Why Vegetation Is Important

The earth's terrestrial vegetation is a dominant component of the biosphere which includes everything from grasses to shrubs to trees. Terrestrial vegetation, especially higher plant forms like shrubs and trees, is dynamic and plays an important role in the following:

- forming an effective shield against land degradation,
- influencing local climate,
- providing the shade that is important to maintain the moisture and biological activity in the soil,
- reducing rapid evapotranspiration and surface runoff,
- ensuring that larger amounts of rainfall can infiltrate the soil,
- regulating water flow and helping to replenish underground resources,
- and generating and protecting humus which is important for plant growth and soil erosion protection (Zaimeche 1994).

Removing large areas of vegetation by clear cut logging, or natural disaster such as forest fires, affects the concentration of gases in the atmosphere and increases the surface temperature of the earth because of the loss of evaporative cooling. Such drastic and sometimes catastrophic changes could cause other adverse effects including decreases in the regional transfer of water from the land to the atmosphere; decreases in the amount of energy lost from the land to the atmosphere by the latent heat of evapotranspiration; increases in the earth's surface temperature; and increase in runoff, soil erosion and sediment transport to rivers, lakes and oceans (Botkin *et al.* 1984; Korem 1985). Terrestrial vegetation and soils have long-term effects on the atmosphere because they act as reservoirs for carbon and other life-sustaining elements.

Although only 29 percent of the earth's surface is terrestrial, and of this, a maximum of 20 percent is actually vegetated, the total surface area of leaf material in contact with the atmosphere is far greater than the total surface area of the entire planet (Belward 1991). Vegetation accounts for 99 percent of the earth's biomass. This value is important where the global environment is concerned because vegetative cover is a major source of global energy and moisture for the atmosphere. Changes in vegetation types and rates of growth and development directly lead to changes in energy, water, and material transport within an ecosystem which, in turn leads to environmental change. For example, deforestation, conversion of natural vegetation to agricultural land, and biomass burning are all responsible for increasing the concentration of atmospheric CO_2 and for changing the equilibrium temperature of the earth (Park *et al.* 1983; Belward 1991).

The vegetation canopy itself is a good indicator of ecosystem condition because it readily responds to both climate and human activity. Vegetation is dynamic in responding and adapting to environmental conditions. This can include changes in the distribution of vegetation type and changes in plant growth and development. Monitoring these changes requires repeated observation and measurement (Belward 1991).

The study of vegetation dynamics on regional and global scales is concerned with the community, ecosystem and biome levels of organization, not the individual plants or populations. Vegetation monitoring is an integral part of natural resource surveys such as tropical deforestation assessment, agricultural production forecasting, forest fire monitoring and environmental degradation monitoring (Belward 1991).

2.2.1.2 Factors Influencing Vegetation Type and Structure

The vegetation on the earth today is the result of a long developmental process influenced by past and present environmental factors. The structure of vegetation in an area is determined primarily by climate and soil. The climate exerts a direct influence on the vegetation as well as an indirect influence through the soil (Walker 1975).

There are five basic ecological factors that influence vegetation.

1. Regional climate determines water and energy availability and can be the dominant influence on the general structure of vegetation.

2. Topography modifies the moisture available to vegetation by influencing local climate and water movement over the landscape.

3. Soil or substrate may also affect moisture supplies and is the major factor in the chemical relationships linking plants and their environments.

4. Biotic influences include both plant-animal and plant-plant interactions.

5. Disturbance events, such as fires, alter the local climate, substrate characteristics and biotic interactions.

The removal of trees, shrubs, herbs and grasses exposes the soil, leading to erosion and water runoff. Erosion leads to the removal of the thin upper layers of soil and reduces the organic matter content and the potential for new vegetative growth. When soils in arid regions lose this organic matter, they can no longer retain moisture in periods between the rainy seasons. Even with an increase in precipitation, the soils remain unproductive. Any vegetation regeneration is impeded by the loss of soil moisture and increased erosion (Korem 1985; Zaimeche 1994).

An example of the magnitude of soil loss to erosion can be observed in the temperate climate of Western Europe. Here soil loss is between 0.33 - 0.66 m^3/ha/year. At the other end of the scale, the semiarid regions of North Africa have shallow soils where nutrients are concentrated in the thin top layer and climatic conditions are very extreme. Soil losses are extreme, in some places upwards as high as 48 m^3/ha/year with subsoil losses of up to 0.5 cm/year (Zaimeche 1994).

Together these factors influence the structure of the earth's vegetation, including both the arrangement of plant mass vertically and horizontally and the physical characteristics associated with the plant mass. In addition, the species composition of the vegetation is determined by the same ecological factors. These five environmental influences combine with human impacts to create the "natural" vegetation that exists over the earth's landscapes (Vale 1982).

2.2.1.3 Disturbance As A Vegetation Factor

Disturbance may be defined as having two characteristics. First, it is an environmental change or event that makes plant resources available (such as water or light) that were formerly fully utilized by pre-disturbance vegetation. Second, as a result of the resources being freed, vegetative change is initiated.

Many types of environmental change are clear examples of this such as fire creating an opening, resulting in increased sunlight reaching the forest floor, windstorms creating blow-downs, or landslides exposing mineral soil. Other types of change are not so clearly defined. For example, an increase in browsing animals consuming and eliminating a plant species from the forest may lead to replacement by a less-favoured species because of the available moisture and light. The role of disturbance and how it is described is important when discussing the nature of vegetation and vegetation change (Vale 1982).

On this subject of disturbance and vegetation change, Vale (1982) discussed that prior to 1950, an ecologist, F.E. Clements, described disturbance as a deviation from a vegetation equilibrium that results from environmental factors. Clements was describing succession, the predictable sequence of change (disturbance) of vegetation leading to the return to predisturbance conditions. The equilibrium which ended succession was termed the climax, a stable, undisturbed state of vegetation.

Vale also presented, contrasting Clements view, that others decided that post-disturbance vegetation does not revert back to predisturbance condition, but instead becomes a new grouping of species and vegetation structure. Vale found the ideas of F.E. Egler who argued that the condition of the vegetation at the time of the disturbance was the most important factor influencing subsequent vegetation development. Also, this condition varied from place to place and from time to time allowing the formation of a new equilibrium (Vale 1982).

Vegetation is always changing. During relatively short time periods, twigs elongate with spring growth, deciduous forests drop leaves as winter arrives, a fire-consumed woodland may be replaced by a field of flowers and grasses, an open meadow fills with shrubs and a forest protected from fire may shift from fire-dependent pines to fire-sensitive maples. Over even longer time scales, other factors may contribute to constantly changing plant cover: migration of plant species, changes in climate, evolutionary change in the genetics of a species, or progressive changes in soil characteristics (Kellogg and Schneider 1977; Vale 1982). Besides the natural processes affecting changes in vegetation there are various human activities that affect plant communities. Human disturbances include changing fire regimes, grazing, logging, trampling, polluting air, constructing roads, introducing or removing plant and animal species, developing agricultural land (including water course manipulation), and manipulating other environmental factors (Kellogg and Schneider 1977; Vale 1982).

The earth and its ecological systems are dynamic when relatively long time-scales are considered. Major continental ice caps and species extinctions are not difficult to understand. There is a general understanding that over millions of years, the earth has been an extremely dynamic planet.

What is not so easily understood are the observations of shorter time-scales, relatively rapid changes in atmospheric and surface features of the earth and the strong evidence that some of these changes are caused by human activity. Humans are producing measurable changes in major earth systems with relatively little knowledge of how these systems work or what the future impacts might be. This insufficient knowledge has produced an international research program (the International Geosphere-Biosphere Program - IGBP) which was chartered by the International Council of Scientific Unions in 1986,

> "to describe and understand the interactive physical, chemical, and biological processes that regulate the total earth system, the unique environment it provides for life, the changes that are occurring in this system, and the manner in which they are influenced by human activities" (Shugart 1993).

Even though two thirds of the earth is covered by oceans, it is the continental surfaces that provide most of the spatial and temporal variability making up the weather and climate. Since vegetation is the main influence on the physical characteristics of the earth, it also influences the climate of the earth (Martin 1993).

Local vegetation affects surface hydrology since the vegetation controls transpiration, determines interception losses, and affects infiltration in the soil, thus vegetation greatly influences surface runoff. The physiological responses and physical characteristics of the vegetation determine how much of the sun's heat and energy reach the surface of the earth, which in turn affects atmospheric winds and the water balance. Therefore, the control that vegetation has on the evaporative cooling process is of interest to atmospheric scientists, hydrologists, plant physiologists and ecologists all over the world (Martin 1993).

2.2.1.4 Land Degradation

Land degradation, defined by Critchley *et al.* (1992) as the loss of the productive capacity of the land to sustain life, is a condition that is prevalent throughout sub-Sahara Africa. The factors that contribute to this process include physical factors relating to the rise in human population and the associated demands on the environment. The two main components of this definition are as follows:

> "Soil degradation is a reduction in the soil fertility caused by soil erosion and exploitative cropping. Low soil fertility is often the major constraint for production, both for crops and for natural vegetation."

> "Impoverishment of the vegetative cover is a reduction in the available biomass caused by climatic factors, over utilization of vegetation and reduced soil fertility. Immediate implications for sub-Sahara Africa are lower and less reliable crop yields, reduced grazing and browsing for livestock, decreased availability of fuelwood and declining dry season water flows needed for small scale irrigation" (Critchley *et al.* 1992).

Land degradation is also caused by ignorance, mismanagement and inappropriate land use. The driving forces here are population increase, lack of economic opportunities and alternatives and land tenure restrictions. This in turn leads to land degradation manifest in the cultivating of steep slopes, overgrazing, and extending land cultivation into marginal areas (Critchely *et al.* 1992).

By 1983, an estimated 17 percent of the world's arid, semi-arid and subhumid regions had suffered some loss of land productivity. Land degradation, reduction in species diversity and reduced production potential are the common problems in these regions. Although the social and economic reasons for these problems are complex, specific causes, such as increased pressure from livestock grazing, deforestation for charcoal production, and inadequate agricultural practices have contributed to the degradation of the landscape (Solbrig 1992).

Preliminary land degradation assessments of Africa indicate that unless conservation measures are introduced on all cultivable land, 544 million hectares (1986 figure) of potentially productive crop land could be lost due to agricultural use or over-use by the year 2000. Almost 50 percent more food will have to be grown in the year 2000, if only to meet present inadequate levels (Howard and Odenyo 1986).

In most of the literature, the terms "land degradation" and "desertification" are used interchangeably when the semi-arid lands of sub-Sahara Africa are discussed. However, in this region of Africa, Critchley *et al.* (1992) argue that land degradation is not so much a problem on the fringes of the desert, but is more of a problem in the relatively heavily populated zones. Rain-fed cropping is possible on these fringes of the desert, but it is an unreliable method of agriculture. Desertification will be discussed separately from land degradation.

Desertification and Human Activities

Desertification is an often misused term, but it must be included in the discussion of the earth's vegetation. Crtichley *et al.* (1992) proposed a concise definition of desertification, formulated from those of many authors:

> "Desertification is the process of continued land degradation in drylands caused at least partially by man. The productive potential of the land is greatly reduced and the process is only reversed slowly and with considerable input."

In 1991 the United Nations Environment Program (UNEP) defined desertification as "land degradation in arid, semi-arid and dry sub-humid areas (drylands) resulting mainly from adverse human impact." In this context, land includes soil and water resources, land surface, vegetation and crops. One year later, the United Nations Conference on the Environment (UNCED) adopted the definition of "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors including *climatic variations* and human activities" (Hellden 1991; Hulme and Kelly 1993; Biswas 1994). Even though *climatic variations* was added to the definition, human activities are an important component of any definition of the process of desertification (Hellden 1991; Crtichley *et al.* 1992; Hulme and Kelly 1993; Biswas 1994). Over the past two decades, recurrent drought and inappropriate management of natural resources - especially in Africa - have threatened millions of dryland inhabitants. In many developing countries it is these drylands that are the basis of agricultural production (Biswas 1994).

Desertification has also been defined as a process leading to reduced biological productivity with consequent reduction in plant biomass, in the land's carrying capacity for livestock, in crop yields, and in human well being. This also leads to the intensification or extension of desert conditions (Hellden 1991; Hulme and Kelly 1993).

The expansion of deserts along their edges is due mostly to human action; to the permanent and increasing pressure of man and his animals to produce more food, fodder and fuel to meet the demands of the growing population on fragile and unstable ecosystems and to the misuse of natural resources through careless management (or lack of management) (LeHouerou 1977; Prasad *et al.* 1990; Biswas 1994).

At present time, desertification affects directly or marginally one quarter of the global land surface and impacts on almost one fifth of the world population. As recently stated by the Governing Council of UNEP, it is one of the major environmental problems of our time (Hellden 1991). Reliable warnings of impending drought would help identify the areas most severely affected by the unusual aridity and encourage better use of land resources during post-drought recovery (Mohler *et al.* 1986). Desertification on the African continent is spreading on the south and north sides of the Sahara Desert, in the African Horn and around the Kalahari desert in the south of Africa. In the Sahel region, the damages caused by desertification on agriculture and stock-farming are serious (Yoshinaga *et al.* 1988).

Causes for desertification include mainly climatological changes, deforestation, excessive cultivation (agriculture), overgrazing and bush fires. Prevention and control of desertification requires the prevention of overgrazing, protection of forests, proper management of water resources, soil erosion prevention, soil improvement practices, adequate land use policy and agricultural development (Glanz 1977; Yoshingaga *et al.* 1988).

Deforestation

Deforestation can be simply defined as the removal of trees from the land, which may result from human activity or natural disturbances. By human intervention, land may be cleared for logging purposes, homesteading, agriculture, or animal grazing (Agatsiva *et al.* 1989). Land can also be cleared by forest fires, insect and disease infestations, and the general deterioration of tree health in an area. Whatever the cause, deforestation has detrimental effects on the environment (Korem 1985; Prah 1988; Defourny 1990).

In many developing countries tropical deforestation, as a specific example, is continuing at an accelerated rate. This is continuing in spite of international attention to the deforestation problem. It has been estimated that in 1980 the loss of open and closed tropical forests was about 11 million ha/year. Ten years later, in 1990, this rate had increased to 17 million ha/year. It is not clear whether deforestation actually increased by this amount or the surveys to detect deforestation became more accurate. Even though the specific causes of tropical deforestation are not easily identified, to a great extent it is driven by the demand for increasing food production for growing populations in tropical regions.

It is easily understood that as population growth increases the demands for arable lands, fuel wood and timber increase, thus leading to a decline in tree stocks and forested regions (Anderson 1986; Agatsiva *et al.* 1989). Also resulting from the population explosion, there will be major changes in patterns of land use with increasing threats to agriculture and food production caused by deforestation, soil erosion, declining soil fertility, and in some regions, increased desertification (Howard and Odenyo 1986). The clearance of land for agriculture, commercial logging and the removal of tree stocks for fuel wood and fodder are sources of large and increasing losses each year in forests, woodlands, watersheds and on farmlands in Africa. The concern is that the losses are accompanied by readily visible and largely avoidable ecological damage and economic costs. These costs can be measured in terms of a threat to the carrying capacity of the fertility of soils over large areas (Anderson 1986; Prah 1988).

There are five consequences commonly associated with deforestation which were presented by Anderson (1986):

- gully erosion and loss of topsoil to winds and rains;
- greater surface evaporation and reduced soil moisture content as surface wind velocities increase;
- greater surface run-off and adverse changes in water tables (which also place the remaining trees under increased stress);
- a general reduction in the recycling of nutrients; and
- in some regions, the consumption of soil nutrients (animal dung and crop residues) as fuel when fuel wood becomes scarce.

The last of these events is usually the terminal stage of the desertification process, and can set in very quickly once fuel becomes scarce (Anderson 1986; Prior and Cutler 1992).

Deforestation in Ghana

A number of authors concentrate and report on various environmental issues in Ghana (UNDP 1968; Dei 1987; Allotey 1988; Panin 1988; Prah 1988; WCMC 1988; Amomoo-Otchere 1990; Asare 1992; Pitkanen and Paivinen 1992; IIED 1992; Wagner and Cobbinah 1993; FAO 1994). Ghanaian soils are susceptible to all forms of erosion. It has been observed that most of the soil nutrients are found in the top 15-20 cm of soil and that the organic matter and plant nutrient content decreases sharply just below the topsoil. These topsoils have a light texture and fragile consistency which causes them to erode quickly and easily. There are indications that the removal of protective vegetation cover for fuel wood utilization and farming has contributed to the high incidence of erosion in some areas of Ghana (Asare 1992).

With populations sometimes doubling in 25 years, as is the case of Kenya, Ghana, and Nigeria, many governments have realized that their natural resources will not last indefinitely. As rural conditions deteriorate, attention is given to the use of forests for energy supply and the deforested land for farming. This, in conjunction with severe climatic and physical conditions, has accelerated forest depletion in many parts of continental Africa (Otoo 1989).

Rates of deforestation in West Africa are among the highest in the world. The deforestation rate in Ghana for 1981-85 was estimated at 1.3 percent annually (Wagner and Cobbinah 1993) and has increased to 2 percent annually since 1985 (Anon. 1998). There is also an estimation that over 70 percent of the original 8.2 million ha of closed forest in Ghana have been destroyed, reducing the amount to about 1.7 million ha by 1987. Deforestation is not yet monitored in Ghana and figures on current rates are only estimates (Otoo 1989; IIED 1992; Wagner and Cobbinah 1993).

Forests in Ghana are generally cleared for agriculture (both commercial and small-scale), logging, and fuelwood (IIED 1992). Other sources of deforestation in Ghana are shifting cultivation and the accompanying bush fires, cocoa farming, timber exploitation, food farming, and industrialization. The problem of deforestation in Ghana is serious because timber is the second most important export item, cocoa being the first major export of this country. Cocoa cannot be successfully cultivated outside the forest because of its need for partial shade and high humidity provided by the forests (Korem 1985; Wagner and Cobbinah 1993). However, these forests are usually reserves set aside by the government. Cocoa farms often have small forested patches on slopes or along streams that serve as islands for tropical tree species.

A second important source of forest islands are "sacred groves." These small patches, located throughout the country, serve as burial grounds and sites for a variety of religious purposes. Both these island types of forests tend to be very small, which may limit their long-term value, but they contain many tropical species and may be an important source of biological diversity (Wagner and Cobbinah 1993).

Agriculture

With increasing population there is a progressive creeping of cultivation into pastoral areas. The unproductive and highly risky cropping situations evolving in newly desertified lands results in the destruction of native fodder species. These are then replaced by either annual weeds which have little forage value or by species that are altogether unpalatable (Glanz 1977).

As cultivable land area is significantly reduced, fallow is reduced, soil fertility is no longer restored, and yields eventually decrease. As well, soil left barren after cropping or after a crop failure is subject to wind erosion (Glanz 1977; Defoumy 1988).

The population increase, in combination with extensive agricultural techniques, bring almost all arable land into cultivation. This means farming has taken on characteristics of a destructive use of ground cover. Many of the farmers cannot and do not meet the fallowing requirements of traditional farming systems on their small farming plots which means the soils are deteriorating (Defoumy 1990).

Expanding agriculture also has the effect of reducing local forested areas. While clearing ground for cultivation, farmers cut all but the largest trees and then set fire to the brush killing most of the younger seedlings. The sedentary population also uses large amounts of wood for fuel and construction. This leads to a steady demand for wood and wood products used in cooking, heating, storage construction, tools and fencing, which increasingly depletes the wood stock (Thomson 1977; Defourny 1988).

Some of the marginal land that is cleared for cultivation is later abandoned because of low crop yields and is subsequently left open to wind erosion and desiccation (Katz and Glanz 1977).

In Ghana, agriculture is the dominant economic activity which supports 70 percent of the population, contributes more than 50 percent of the national revenue, and occupies 65 percent of the available land base. For the past three decades serious, sometimes irreparable, damage has been documented from the effects of deforestation due to agricultural practices and bush fires (Allotey 1988).

Grazing

The ranching of livestock is widespread around the globe. These animals have serious impacts on the lands that they graze, but the type and degree of the impact is dependent on the type of land which they are allowed to graze. In arid landscapes, for example, the impact is much more serious and evident than in lusher landscapes (Okin 1996b).

Globally, the cattle industry is a major economic player. There are currently over 1.28 billion cattle world-wide, and over 200 million people globally who depend on cattle for their livelihoods (Okin 1996a). Cattle are able to graze lands that are otherwise uncultivable, thus increasing the economic value of these lands. For example, cattle are able to graze in regions where the topography is unfavourable for farming. While for the most part cattle do not graze in these areas, but instead graze on lands that could be beneficial for other purposes, this is a practical way of making use of otherwise unusable lands (Okin 1996a). The result of this is a progressive reduction in vegetation cover and increased wind erosion, trampling, increased runoff, higher water tables and salinity - all mechanisms that feed the desertification process (Glanz 1977; Zaimeche 1994).

Fast-rising livestock populations have reduced grazing capacities of lands that were previously used for this purpose. Moving livestock herds from depleted areas to new grazing areas prevents effective plant regeneration and results in deforestation, soil erosion, sedimentation, and flooding (Biswas 1994; Zaimeche 1994).

Grazing by livestock influences wild vegetation directly through the removal of foliage and indirectly by trampling of both plants and soils. Grazing may influence the amount of energy available to plants by reducing the photosynthetic area of the leaves. The vigour and reproduction of the affected plants can be reduced if the grazing is heavy and occurs at a time when plants may be stressed from other factors like drought or nutrient deficiency (Glanz 1977; Vale 1982).

Bush Fires

Biomass burning is one of the key factors affecting global processes. During combustion, amounts of trace gasses are released which strongly affect atmospheric chemistry. Frequently, fire results in a partial or complete destruction of vegetation cover which in turn modifies the radiation balance by increasing the surface radiation reflection, influencing the hydrological cycle and increasing rates of soil erosion (Chuvieco and Martin 1994).

On a local scale, biomass burning also has strong effects on the landscape and ecology, especially in semi-arid lands. In tropical areas, recurrent use of fire as a soil fertilizer, or as a means of pasture improvement, involves soil and grass degradation in many areas as fire cycles are shortened. Fires also modify the hydrological cycle by increasing the runoff into water sources (Chuvieco and Martin 1994).

In most areas of sub-Sahara Africa, bush fires are a major problem. Bush fires destroy litter on the forest floor, grasses and other plants, and decrease the organic matter content in the forest soils. A canopy of trees, shrubs, grasses, and other plants will reduce the impact of rainfall on the soil. When rain falls on vegetation first the velocity of the rain is reduced and less damage to the soil surface structure occurs. If the forest or grassland is protected against burning then litter is present and soil organic matter content is high. With higher organic matter content the soil has the ability to absorb greater quantities of rainfall in a very short time (Korem 1985).

Slash-and-burn agriculture is commonly considered a major cause of deforestation. This method of agriculture is still widely practised in Ghana, however, it is restricted to land outside of forest reserves that is already classified as deforested, and it is primarily practised on abandoned farmland rather than on natural forest (Wagner and Cobbinah 1993).

An example of how detrimental fire can be to both land and water resources is the study of a forest fire in Australia presented by Korem (1985). The streamflow and sediment load were assessed before and after a major fire. Following the fire, sheet erosion was observed immediately. The effect of the fire on flood flows is compared with two storms that occurred over a catchment area where one storm occurred before the fire and another storm occurred after a fire. During the first storm, a rainfall of 12 mm produced a peak flow of only 0.34 m^3/sec while the storm after the fire, with a rainfall of 8.5 mm caused a flood exceeding 9.5 m^3/sec (Korem 1985).

During the dry season in Ghana many of the farmers burn vast areas of bush and the land is left bare and fully exposed to the detrimental effects of the sun, rain and winds. When the soil is dried and baked this way the small soil particles and black ashes are easily blown away by winds. Most of the plant nutrients are lost from the soils by this method. Wind erosion is becoming increasingly serious in the Upper Region where many places are devoid of trees and grasses and are annually burnt. By the end of the dry season the soil is extremely dry and hard and water permeability is very low. When the first rains come, usually in the form of violent storms, the burnt soils are severely eroded (Korem 1985).

When crop residues from rice straw, Guinea corn stalks, or millet stalks are left on the field during the dry season they provide sufficient protection against wind erosion, excessive evapotranspiration and the sun. However, the farmers burn the residues directly on the field or collect them for fuel. If the crop residues were left unburned and in the field for even just the first one or two rainfalls, the soil would absorb some of the moisture and there would be less chance of severe erosion (Korem 1985).

2.3 REMOTE SENSING

Remote sensing is the study of objects and phenomena from a distance by systems that are not in contact with the object or phenomenon being investigated (Belward 1991; Lillesand and Kiefer 1994). Using various sensors, data is remotely collected and can be analyzed to obtain information about the objects, areas or phenomena being investigated.

In this report, remote sensing refers to electromagnetic energy sensors currently operating from airborne and spaceborne platforms that assist in inventorying, mapping, and monitoring earth resources (Lillesand and Kiefer 1994).

2.3.1 History of Satellite Imagery

The initial efforts to image the surface of the earth from space were incidental advancements with the development of meteorological satellites. In 1960, TIROS-1, an early weather satellite sent back coarse images of cloud patterns and virtually indistinct surface images of the earth. Eventually, as images improved, meteorologists began an intensive study of earth surfaces to collect data on water, snow, and ice features. During the manned space programs of the

1960s, photography of the earth evolved to nearly vertical, overlapping photos of the southwestern United States, Mexico, Africa and Asia which lead to discoveries in tectonics, volcanology, and geomorphology (Lillesand and Kiefer 1994).

In 1973, Skylab astronauts took over 35,000 images of the earth with the Earth Resources Experiment Package (EREP). This EREP included a six-camera multispectral array, a long focal length camera, a 13 channel multispectral scanner and two microwave systems, and was the first effort to show photography and electronic imaging from space (Lillesand and Kiefer 1994).

At the time of Landsat-1, there were many efforts at technology transfer of spaceborne remote sensing to developing countries. Those efforts were most abundant in the 1970s and 1980s and continue today. Many of the early efforts were by the United States government as an extension of the Landsat program and eventually included many international organizations such as Food and Agriculture Organization (FAO), United Nations Environment Program (UNEP), United Nations Development Program (UNDP), and the World Bank (Haack 1996).

2.3.2 Landsat Satellite Program

The National Aeronautics and Space Administration (NASA) and the United States Department of Interior began a series of satellites known as Earth Resources Technology Satellites (ERTS). The ERTS-1 was launched on July 23, 1972 and was operational until January 6, 1978. The ERTS-1 sensors were placed aboard a Nimbus weather satellite. It was the first unmanned satellite specifically designed to acquire data of earth resources on a systematically repetitive, medium resolution, multispectral basis. This system was only designed as an experiment to test the feasibility of collecting earth resource data from unmanned satellites. In many experiments, the ERTS-1 exceeded expectations. The ERTS program was renamed the "Landsat" program (to distinguish it from the planned Seasat oceanographic satellite program) prior to the launch of the second satellite on January 22, 1975. Five satellites have been launched to date.

Orbit Patterns - Landsat-4 and -5

Since Landsats-1,-2, and -3 are no longer operational, the following discussion only includes information on Landsat-4 and -5.

Landsat-4 and -5 were launched into repetitive, circular, sun-synchronous, near polar orbits. These orbits were lowered from 900 km to 705 km to aid in the improvement of the ground resolution and to make them potentially retrievable by the space shuttle. Each orbit takes about 99 minutes, with just over 14.5 orbits being completed in a day. This orbit results in a 16-day repeat cycle for each satellite, two days less than the previous Landsat generations (Lillesand and Kiefer 1994).

Sensors On Board - Landsat-4 and -5

Figure 1 shows the Landsat-4 and -5 satellite, including both the MultiSpectral Scanner (MSS) and TM sensors.

The MSS on board the Landsat satellite covers a 185 km swath width in four wavelength bands: two in the visible spectrum at 0.5 to 0.6 mm (green) and 0.6 to 0.7 mm (red) and two in the near infrared at 0.7 to 0.8 mm and 0.8 to 1.1 mm. These were designated as bands 1,2,3, and 4 (see Table 1). The spatial resolution of MSS data is 57 x 79m and the recoded radiometric resolution is 7 bits (0-128 possible brightness values), but the data is stored as 8 bit (0-255 possible brightness values) (ERDAS 1992).

The TM is a highly advanced sensor that incorporates a number of spectral, radiometric, and geometric design improvements relative to MSS. Spectral improvements include the acquisition of data in seven bands instead of just four. New bands included are in the visible (blue), mid-infrared, and thermal portions of the spectrum. The wavelength range and location of the TM bands have been chosen to improve the spectral differentiability of major earth surface features (Leckie 1991).

The TM bands are more finely tuned for vegetation discrimination than those of the MSS. For example, the green and red bands (bands 2 and 3) are narrower than the MSS red and green bands (Table 1). The near-infrared TM band (4) is narrower than the combined bands of the MSS and this region is of maximum sensitivity to plant vigour. Sensitivity to plant water stress can be obtained in both of the TM mid-infrared bands (5 and 7) and plant stress discrimination is also aided by the TM blue band (1). The spatial resolution of TM is 30m x 30m for all the bands except the thermal (band 6) which has a spatial resolution of 120m x 120m and is resampled to 30m x 30m to match the other bands (ERDAS 1992; Lillesand and Kiefer 1994).

Table 1. Landsat MSS and TM System Characteristics.

	MSS	TM
Spectral Characteristics		
Spectral bandwidth	1. 500-600nm 2. 600-700 3. 700-800 4. 800-1100	1. 450-520nm 2. 520-600 3. 630-690 4. 760-900 5. 1550-1740 6. 10400-12500 7. 2080-2350
Radiometric resolution	7 bits (stored as 8 bits)	8 bits
IFOV (Instantaneous Field of View)	79m*	30m**
Swath width	185km	185km
Platform Characteristics		
Orbit:	Sun-synchronous	Sun-synchronous
Altitude:	705km	705km
Repeat Cycle:	16 days	16 days

* spatial resolution of MSS data is 57m x 79m

**spatial resolution of TM data is 30m x 30m for all bands except thermal band (6) which is 120m x 120m, but is resampled to 30m x 30m.

Source: Lillesand and Kiefer 1994

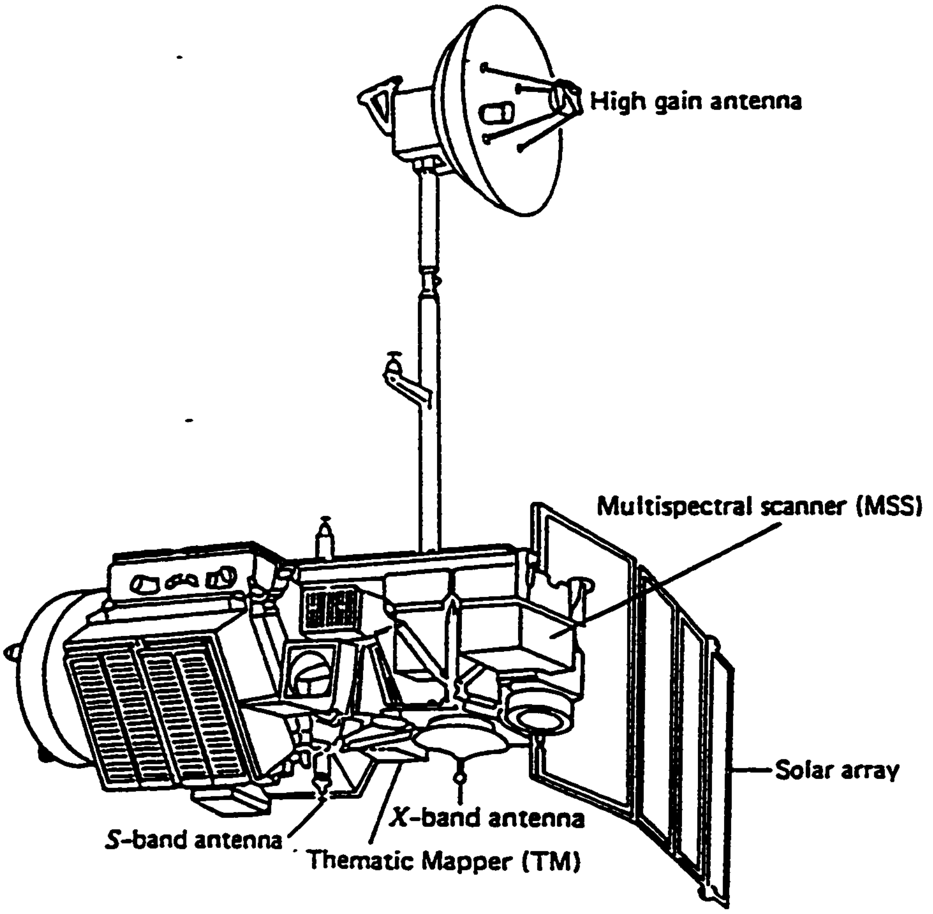

Figure 1. Schematic of the Landsat-4 and -5 observatory configuration including Thematic Mapper (TM) and Multispectral Scanner (MSS). Source: Lillesand and Kiefer 1994.

2.3.3 SPOT Satellite Program

In early 1978 the French government developed the Systeme Pour l'Observation de la Terre, or SPOT program. From the beginning, SPOT was designed to be an operational, rather than experimental program. The first satellite in the program, SPOT-1, was launched in French Guyana on February 21, 1986.

It was the first satellite to provide full-scene stereoscopic imaging from two different satellite tracks.

SPOT-1 was not used after December 31, 1990; SPOT-2 was launched on January 21, 1990, and SPOT-3 was launched September 25, 1993 (Lillesand and Kiefer 1994).

Orbit Patterns

Similar to the Landsat satellites, the SPOT satellites have a circular, near polar, sun-synchronous orbit. The area under the orbit pattern on the earth can be imaged using the same viewing angle giving stereo viewing abilities. This ability to "revisit" any given point is important in two respects. Firstly, it increases the potential frequency of coverage of areas where cloud cover tends to restrict the ability to remotely sense the surface of the earth under the cloud. Secondly, it gives the opportunity to view a given area at frequencies ranging from successive days, to several days, to a few weeks. Several application areas, particularly within agriculture and forestry, require repeated observations over these types of time frames (Leckie 1991; Lillesand and Kiefer 1994).

Sensors On Board

The SPOT satellite system weighs approximately 1750 kg and the main body is approximately 2m x 2m x 3.5 m (Figure 2). The solar panel has an overall length of approximately 15.6 m. These sensors on SPOT consist of identical High Resolution Visible (HRV) imaging systems and auxiliary magnetic tape recorders. Each HRV is designed to operated in either 2 modes: 1) a 10 m resolution "panchromatic" (black and white) mode over the range 0.51 to 0.73 mm or 2) a 20 m resolution multispectral (colour infrared) mode over ranges 0.50 to 0.59, 0.61 to 0.68, and 0.79 to 0.89 mm (see Table 2) (Leckie 1991; Lillesand and Kiefer 1994).

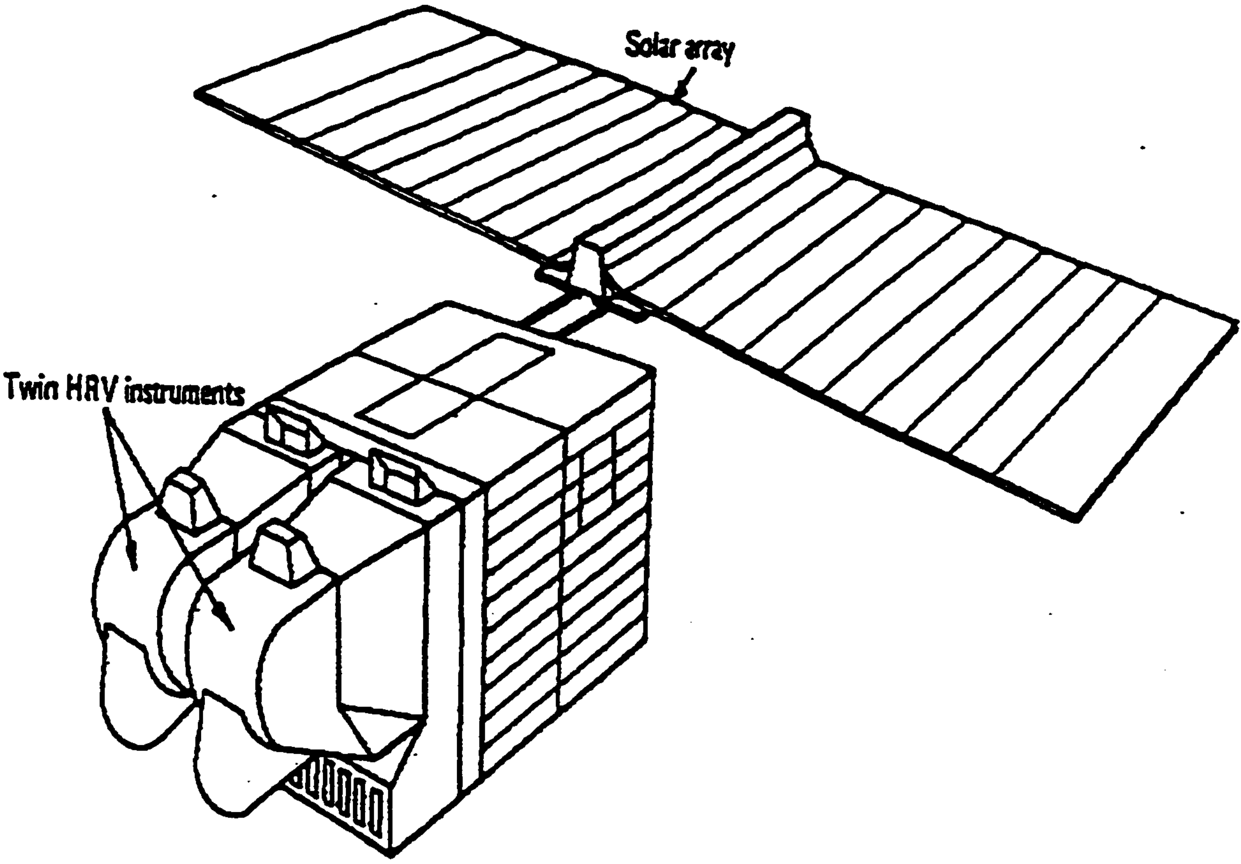

Figure 2. SPOT observatory configuration. Source: Lillesand and Kiefer 1994

Table 2. SPOT System Characteristics

	Panchromatic	XS
Spectral Characteristics		
Spectral bandwidths	1. 510-730nm	1. 500-590nm 2. 610-680nm 3. 790-890nm
Radiometric resolution	8 bits	8 bits
IFOV (nadir)	10m	20m
Swath width	60-80km	60-80km
Platform Characteristics		
Orbit:	Sun-synchronous	Sun-synchronous
Altitude:	832km	832km
Repeat cycle:	26 days	26 days

Source: ERDAS 1992

2.3.4 NOAA Satellite Program

Meteorological satellites were designed specifically to assist in weather prediction and monitoring. These satellites incorporate sensors that have very coarse spatial resolution compared to land-oriented systems. They also have the advantage of global coverage at very high temporal resolution. Therefore, meteorological satellite data are useful in natural resource applications where frequent, large area mapping is required and fine detail is not. Another advantage is that the coarse spatial resolution also greatly reduces the volume of data to be processed for a particular application (ERDAS 1992).

The National Oceanic and Atmospheric Administration (NOAA) launched the first of these meteorological satellites in the United States. The NOAA satellite is in a near-polar, sun-synchronous orbit similar to that of Landsat and SPOT.

There have been several generations of satellites launched and flown in the NOAA series. Only the latest missions, NOAA-6 through NOAA-12, carried the Advanced Very High Resolution Radiometer (AVHRR) (see Figure 3). The swath width of this sensor is 2400 km and coverage is acquired at a ground resolution of 1.1 x 1.1 km (1 km pixel) at nadir (see Table 3) (ERDAS 1992). NOAA receives AVHRR data at full resolution and archives them in two different forms. Selected data are referred to as local area coverage (LAC) data. All data are sampled down to a nominal resolution of 4 km and are referred to as global area coverage (GAC) data. LAC and GAC data are available as both 10 bit packed and 16 bit unpacked data. Packed data are compressed to fit more data on the tape (Kidwell 1990; ERDAS 1992).

NOAA satellites provide daily (visible) and twice-daily (thermal infrared) coverage. Images and digital tapes are used operationally for many applications requiring timely data. For example, NOAA AVHRR thermal data is used for water temperature mapping. In addition to surface water temperature mapping, AVHRR data have been used extensively in applications as varied as snow cover mapping, flood monitoring, vegetation mapping, regional soil moisture analysis, wildfire fuel mapping, fire detection, dust and sandstorm monitoring and various geologic applications (ERDAS 1992; Lillesand and Kiefer 1994).

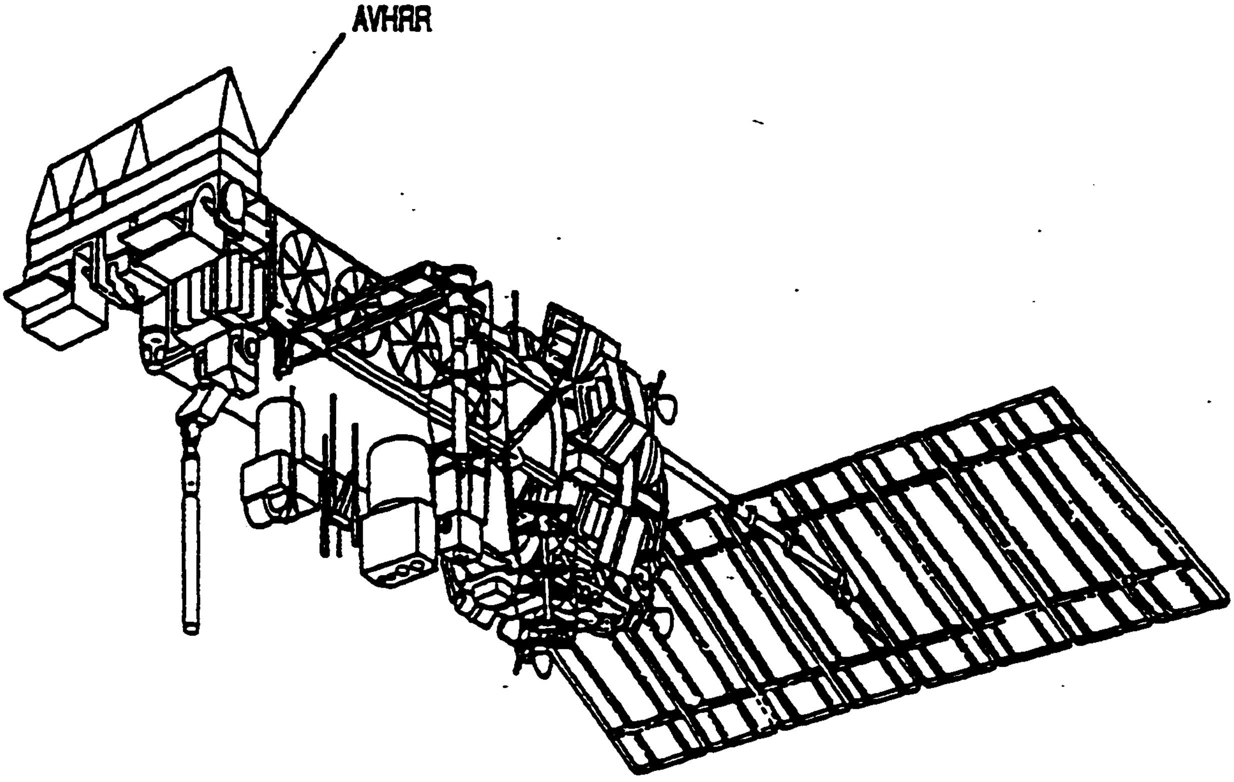

Figure 3. NOAA satellite configuration including the AVHRR sensor. Source: Burgan and Hartford 1993.

Table 3. NOAA AVHRR System Characteristics.

Sensor characteristics	
Spectral bandwidths	1. 580-680 nm
	2. 735-1100 nm
	3. 3550-3930 nm *
	4. 10300-11300 nm
	5. 11500-12500 nm
Radiometric resolution	10 bits (1024 level)
IFOV (nadir)	1.1 km
View angle	55.4 degrees (IFOV 6 km at swath edge) **
Swath width	2700 km
Platform characteristics	
Orbit:	Near-polar, Sun-synchronous
Altitude:	833-870 km
Inclination:	98.7
Period:	102 min
Equator crossing time ***	0730 and 1930 (even no.'d sat's) 1400 and 0200 (odd no.'d sat's)
Repeat cycle:	12 hours
Global frequency coverage:	1-2 days

* Band 3 will be replaced on future AVHRR sensors and the actual Band 3 will be used only for night imaging.
** The most usable portion within the swath of 2700 km is the area within ± 15 degrees. At 15 degrees, the area covered by a pixel is approximately 1.5 km and the repeated coverage for this reduced swath width is about 6 days.
*** Greenwich standard time (14:30 ascending and 2:30 descending [local time]).
Source: Ehrlich *et al.* 1994.

AVHRR data have been used extensively for large area vegetation monitoring. Typically, the spectral bands used for this purpose have been the channel 1 visible band (0.58 to 0.68 mm) and the channel 2 near infrared band (0.73 to 1.10 mm). Various mathematical combinations of the AVHRR channel 1 and 2 have been found to be sensitive indicators of the presence and condition of green vegetation. These mathematical quantities are referred to as vegetation indices (ERDAS 1992; Lillesand and Kiefer 1994).

2.3.5 Normalized Difference Vegetation Indices

Remote sensing techniques for vegetation monitoring use data recorded from the electromagnetic spectrum that provide a strong signal from vegetation while contrasting with the background material (Belward 1991). Previous research has shown that the red and near-infrared wavelengths satisfy this criterion, and by combining these two wavebands as vegetation indices they can be used to measure attributes of a vegetation canopy (Lechapt and Didier 1989; Belward 1991). The principle behind this is that the red wavelengths are in the part of the spectrum where chlorophyll causes considerable absorption of incoming radiation, and the near infrared wavelengths are located in a spectral region where spongy mesophyll leaf structure leads to considerable reflectance (Wolf 1996). Building up regular vegetation index images from sequential satellite overpasses adds the temporal dimension necessary for vegetation monitoring.

This ratio index can use data recorded at equivalent wavebands from different sensors (eg. Landsat MSS and NOAA AVHRR). The ratio is now widely referred to as a Normalized Difference Vegetation Index (NDVI):

$$\mathrm{NDVI} = \frac{(\text{near infrared} - \text{red})}{(\text{near infrared} + \text{red})}.$$

The NDVI is a bounded ratio ranging in value from -1 to +1 where negative values are associated with clouds, bare soil, water and low green vegetation densities. The higher values (closer to +1) are associated with photosynthetically active cover. By inference, the higher the NDVI value, the greater the amount of green vegetation (Lechapt and Didier 1989; Belward 1991; Wolf 1996).

The very large changes in green biomass production that are possible from year to year in the Sahel region (the semidesert fringe of the Sahara that stretches from Mauritania to Chad) were demonstrated by applying the NOAA AVHRR NDVI approach. A data set covering all the Sahel from the 1984 notorious drought and famine year was compared with a corresponding data set from the 1985 wet season. Although the varying NDVI was interpreted in terms of north-south oscillating vegetation boundaries (inter-annual changes of 50 to 250 km), it appears to have demonstrated large time and spatial variations in green biomass productivity (Belward 1991).

Information on crop characteristics is sometimes needed to develop site specific agricultural management practices. The cost of traditional field measurements (man-in-the-field inventories) becomes a constricting factor when applied to large areas. The use of data from satellite-borne sensors is a practical alternative to field measurements, provided suitable spectral vegetation indices can be developed (Thenkabail *et al.* 1994a). Using vegetation indices to study crop characteristics including leaf area index, wet biomass, dry biomass, and plant height have primarily relied on near-infrared and red wave band-based indices.

A number of methods have been developed to separate vegetation from soil information in satellite data. Two common methods for agricultural purposes are band ratios, in which the bands are chosen to maximize the contrast between vegetation and soils (Ustin *et al.* 1986), and tasseled cap transformation, where the brightness feature relates to the soil reflectance of an image and the greenness feature relates to green vegetation present in an image (Lillesand and Kiefer 1994). The tasseled cap transformation was originally derived for Landsat MSS data and this process rotates the four MSS bands in such a way that the majority of information is contained in the two components mentioned; brightness and greenness. A third component called wetness, relates to canopy and soil moisture, and was extended to the Landsat TM data where the six bands of reflected data are effectively combined as the transition zone between soils and vegetation (Crist and Kauth 1986; Lillesand and Kiefer 1994) . However, band ratios are sensitive to the variations in soil brightness characteristics of arid lands and do not predict vegetation well. A potentially more reliable method is derived from scatterplots of TM band pairs (Ustin *et al.* 1986). For a wide range of rocks and soils, red and near infrared reflectances (TM 3 and TM 4) are highly correlated. Vegetation spectra depart from the rock-soil baseline because photosynthetic pigments reflect little red light, whereas leaf and canopy structure reflect much of the incident near infrared energy (Ustin *et al.* 1986).

The micro-environment near the plant surface can be altered by cultural and agricultural management variables including drainage, landform, soils, tillage, planting date and configuration, stand density, fertilization application, irrigation treatments, cultivar types, and row spacing, and stresses such as insects, disease and drought (Thenkabail *et al.* 1994a&b). Airborne and ground-based spectral observations are frequently used to study impacts of agricultural management practices on crop growth and yield. Routinely available data from polar orbiting satellites permit the study of agricultural crop attributes on a regional basis such as river watersheds, counties or states (Thenkabail *et al.* 1994b).

From a review of vegetation studies, the following are a couple of uses:

- Multi-temporal NDVI have been used to describe vegetation primarily in a qualitative way. Few studies have addressed correlation of NDVI with ground truth to provide for an in-depth study of land-cover characteristics;
- Multi-temporal NDVI have also been used extensively in the Sahel region for early famine warning and locust and grasshopper habitat monitoring (Ehrlich *et al.* 1994).

2.3.6 Environmental Applications

Some of the environmental applications of AVHRR data include land-cover mapping, vegetation dynamic studies, tropical forest monitoring, vegetation production estimation, fire risk assessment, and biophysical parameter estimation (Ehrlich *et al.* 1994). All five AVHRR bands have found some application in land-cover studies. However, bands one and two, in the form of NDVI composites have, among others, been used by Bartholome (1990); Bartholome (1991); Chuvieco and Martin (1994); Conese *et al.* (1991); Ehrlich *et al.* (1994); Green *et al.* (1994); Kidwell (1990); Thenkabail *et al.* (1994a and b); Tucker *et al.* (1991). There are several land-cover variables that can be directly estimated using AVHRR data according to IGBP (1992). These include vegetation indices, the earth's albedo, solar radiation flux at the surface, evapotranspiration, and surface temperature. Vegetation indices are required for the estimation of leaf area index, photosynthetic capacity and primary productivity. Many of the multi-temporal studies conducted to date describe vegetation dynamics using NDVI (Bartholome 1990; Tappan *et al.* 1990; Bartholome 1991; Ehrlich *et al.* 1994; Green *et al.* 1994; Thenkabail *et al.* 1994a and b). Applications of AVHRR data to vegetation production include early warning systems and agricultural assessment in the Sahel region.

Wylie *et al.* (1992) used AVHRR for range production assessment in the Sahel area. Wylie regressed biomass ground measurements with NDVI through the computation of the average integrated NDVI, a time-weighted NDVI average. The exercise allowed the production of pastoral maps for five years of investigation capable of showing both drought years and years favourable for livestock herds.

AVHRR NDVI composites have also been used for monitoring grasshopper and locust habitats in Sahelian Africa (Tappan *et al.* 1991). Grasshopper and locust monitoring is an ongoing project where NDVI composites are used in conjunction with data sets such as the political boundaries of the region within a Geographic Information System (GIS) framework. The repeated coverage of the AVHRR sensor allows a continuous monitoring of vegetation conditions. This, in combination with known meteorological conditions can be used to predict problems in pest populations.

2.3.7 NDVI and Vegetation Monitoring

NDVI has been used for monitoring all stages and types of vegetation. A paper by Azzali (1990) describes a correlation of agricultural crop production and yearly NDVI for Zambia and Somalia. By using 7 km resampled NDVI-data they found reliable indications on crop production where the dominant land use is agriculture which implies that the agricultural areas need to be identified first by means of high resolution satellite images (Landsat MSS).

A study was conducted that suggested that woody biomass and tree cover estimates in farmlands of the semiarid zone of West Africa could be most accurately derived from NDVI (Nichol 1988).

Remote sensing using near infrared and red wavelengths of the electromagnetic spectrum has been shown to have potential for estimating forest functioning and Leaf Area Index (LAI). Maps showing the vegetation of Africa, North America and the entire world have been produced using NDVI derived from remotely sensed data (Coops 1996).

A common approach for interpreting AVHRR data is to acquire imagery over one year's time and calculate NDVI to document vegetative phenology. This identifies distinctive phenological sequences that can be attributed to vegetation types, crop development and regional climate conditions (Evans and Czaplewski 1995).

A complicating factor of NDVI, if it is to be used for vegetation identification, is that there can be confusion between different cover types that show the same NDVI. For example, suppose that forest land in a region has spectral reflectance values of 20 and 40 for the visible and near infrared channels in AVHRR data. Grassland in the same region may have values of 30 and 60 for the same two channels. These two cover types are distinguishable in the separate spectral channels but the NDVI for each are the same (a rounded value of 0.33). In this case, the use of NDVI's filters out useful information and causes confusion. This example from Evans and Czaplewski (1995) is from a single-date image, but with multiple-date imagery it is possible that some NDVI's would be the same for otherwise different cover classes.

For the purposes of this report and for detecting greenness in northern Ghana the actual type of "green cover" is not important. This could become an important factor for determining what vegetation type is declining or decreasing; grasslands, tree species, forest reserves, etc..

2.3.8 Remote Sensing in Africa

The collection and use of land information was introduced in Africa by the colonial powers. This consisted mainly of producing political and administrative maps defining territorial boundaries. The tools used to produce land information evolved from strictly ground-based surveys to aerial photogrammetry and, more recently, satellite imagery (Falloux 1989).

Surveying was introduced with early colonization in Africa. Until roughly the end of World War II, topographic works and mapping were carried out according to conventional techniques of ground surveying. Remote sensing through photogrammetry, a technique extensively developed during the war, gradually replaced exclusive ground surveys for mapping (Falloux 1989).

Until the 1950s and 1960s, colonial agencies performed mapping through aerial remote sensing, mainly with their own European staff, and with much of the processing done outside Africa. Before or immediately after independence, these agencies made major investments to establish surveying and mapping branch agencies in Africa, for the topographic ground work complementary to aerial surveys. In association with mapping, they also developed other data systems on natural resources (hydrology, climatology, soils, land use, forestry, etc.) (Falloux 1989).

Immediately after independence, the mapping agencies of the former colonial powers generally continued to assist the newly-independent national surveying and mapping agencies, with a new focus on training African staff. Their assistance has since declined, due in part to the desire of the new agencies to be fully independent. These African agencies have been weakened by their lack of trained staff and their low priority in the new governments: mapping and remote sensing were often seen as a costly, low-priority investment. By the 1970s, the activities of national surveying and mapping agencies in most African countries had dwindled to minimal levels, sometimes too low even for proper maintenance. This also happened to agencies in charge of managing renewable resource information (Falloux 1989).

As technology advances, so does our ability to change our surroundings. Changes made on the surface of the earth today are more extensive and occur more rapidly than ever before. The ramifications of these changes have become more significant as the world's population grows, the available land base declines, and the resiliency of our environment becomes increasingly burdened (Green *et al.* 1994). Planners and resource managers need a reliable mechanism to assess these consequences by detecting, monitoring and analyzing land-use changes quickly and efficiently. The demand for an efficient land cover detection system currently exists among a variety of local, state, federal, and private organizations in Africa. While extensive research has been completed on the effectiveness of various change detection technologies, very little has been accomplished for implementing the technologies in a production environment (Green *et al.* 1994).

2.3.9 VEGETATION MONITORING and TECHNOLOGY

Understanding the effects of modern technological civilization on the biosphere requires greatly improved global estimates of the spatial distribution and temporal dynamics of major types of terrestrial vegetation, as well as information on biomass, productivity, and exchange of energy and chemical elements between the vegetation and the atmosphere, oceans and soils. Past estimates of these vegetation characteristics have been, by necessity, based on extremely limited data; they have been little more than expert testimony of knowledgeable ecologists and biogeographers. Advances during the past decade in satellite remote sensing technology and computer processing, however, have made accurate, repeatable measurements of these characteristics possible (Botkin *et al.* 1984).

2.4 REMOTE SENSING AND VEGETATION

2.4.1 History of Remote Sensing of Vegetation

There are three major periods in the history of remote sensing of vegetation. The first extended from the invention of the airplane to the 1950s. Aerial photography developed rapidly in response to the needs for military reconnaissance during World War I. By the late 1920s stereoscopic aerial photography was well developed. In the early 1930s the United States Department of Agriculture's (USDA) administration systematically photographed farm and ranch lands throughout the United States (Botkin *et al.* 1984). This practice became routine in the 1950s and 1960s as black and white photographs of US agricultural lands were taken for use in the USDA's farm programs. Around the same time the US Forest Service began a program to photograph the large areas of US timber reserves (Botkin *et al.* 1984).

Early aerial reconnaissance of forests used stereoscopic photographs taken from low-flying aircraft. Manual analyses, in which a person uses photos to draw maps and interpret the scene, produced measurements of tree species composition, tree height, crown area and closure, and the number of trees per unit area. These data were combined with ground measurements to estimate merchantable timber for large regions (Botkin *et al.* 1984).

By the early 1960s, multispectral instruments were available that measured light in a series of wavelength ranges and produced a digital output. Such output can be computer-sorted according to a statistical or mathematical algorithm. In 1971, a year after southern corn leaf blight had caused extensive damage to the US's corn crop, a Corn Blight Watch Experiment was initiated. This project used computer-assisted interpretation of infrared aerial photographs to assess the levels of infection present, estimate the land area affected, project the effect on yields, aid in the control of the blight, and assess the applicability of techniques developed to similar future situations (Botkin *et al.* 1984).

As mentioned earlier, the first earth resources satellite, Landsat-1, was launched in July 1972. Some early research using this satellite focused on crops and demonstrated that a series of images obtained over several dates improved accuracy in classifying vegetation. This research also brought out two major difficulties that are still under study: the mixed pixel problem and the signature extension problem. When two or more types of vegetation occur within a given pixel creating a mixed pixel, the probability of correct classification for that pixel can be significantly decreased. When correlations developed for one area are used to classify a different area, the probability of correct classification again decreases; this is the signature extension problem (Botkin *et al.* 1984).

The first major program with direct applications, the Large Area Crop Inventory Experiment program (LACIE), began in 1974. Its purpose was to forecast world-wide harvests of wheat using satellite remote sensing. LACIE produced particularly good estimates of wheat acreage in areas having large field sizes, such as those in the United States, Soviet Union, and Argentina. In 1978 LACIE experiments were extended to more types of crops, as well as to forecasts and rangelands under the Agricultural and Resource Inventories Surveys through the Aerospace Remote Sensing project sponsored by NASA and the USDA (Botkin *et al.* 1984).

Research on crops in the 1960s and 1970s demonstrated that timely vegetation resource surveys were feasible. The research showed that knowing vegetation type, phenology, and certain conditions at the start of the growing season (including the time of emergence or planting and the soil moisture content), a strong basis for predicting production could be made. Landsat and meteorological satellites could then be used during the growing season to check whether there had been a deviation in conditions, such as an occurrence of a plant disease or an unforecast drought. These programs have led to major advances in the processing of remote sensing imagery (Botkin *et al.* 1984).

During the 1970s, digital remote sensing from aircraft and satellites had been applied to forest and range inventory and monitoring. Landsat data are now used to produce landcover maps for rangeland and, combined with digital terrain information, to produce managerial maps for terrestrial assessments (Botkin *et al.* 1984).

A general research advancement in the 1970s was a better understanding of how the different wavelength bands provide different kinds of information, and how ratios of different bands give information that can be inferred. The spectral region between 0.74μm and 1.1μm exhibits sensitivity to total plant biomass. Analyses of spectral data generally involve transformations of the raw data into a usable format. Most of these transformations use ratios of measurements taken from at least one band in the near infrared region (0.7-0.9 μm) and one band in the red region (0.6-0.7 μm). Green vegetation has high absorbance and low reflectance in the red region and, low absorbance and high reflectance in the infrared region which gives investigators a value to determine the "greenness" of an image.

One method of determining greenness involves the use of the NOAA satellite and the Advanced Very High Resolution Radiometer (AVHRR), which obtains data over larger areas and at more frequent intervals than the Landsat satellite. It measures reflected radiation in the visible, near-infrared, and thermal infrared wavelength bands and has a resolution of 1 km (Botkin *et al.* 1984).

Other areas of advancement in remote sensing studies of vegetation include the development of techniques for monitoring vegetation state and predicting crop yields; inventorying forests accurately and more cheaply than before; using repeated measurements over time for identifying vegetation type and monitoring seasonal production; and combining information from several wavelength bands to better reveal vegetation characteristics (Botkin *et al.* 1984).

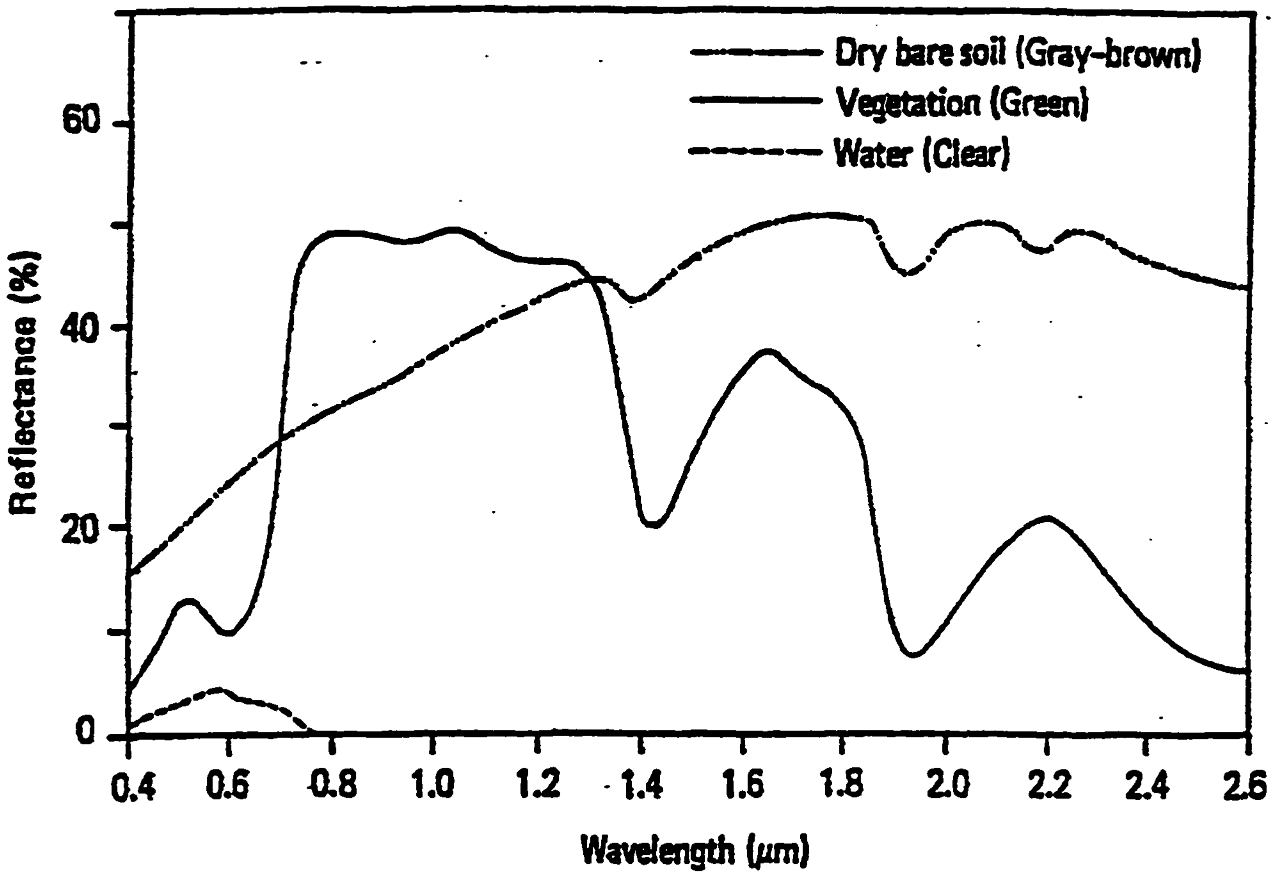

Figure 4. Typical spectral reflectance curves for vegetation, soil, and water. Source: Lillesand and Kiefer 1994.

The next major challenge for studying vegetation from space will be to devise methods to estimate biomass and net primary production for all major vegetation types. Recent advances in remote sensing and in ecological and forestry research suggests that this can be done. Remote sensing offers the potential to measure spatial variation, monitor temporal changes, and estimate the error associated with average values. Land cover and its changes over time can be monitored for large regions. With the continued development of algorithms relating remote sensing to ground measurements, biomass and biological productivity can be estimated with an improved accuracy (Botkin *et al.* 1984; Lechapt and Didier 1989; Iverson *et al.* 1989).

2.4.2 Monitoring Vegetation using Remote Sensing

Remote sensing offers a great potential to obtain geographically referenced information using a single, consistent method over a large area with uniform, reliable accuracies, and to repeat the measurements over time so that changes can be detected (Falloux 1989). However, Sub-Saharan Africa has not used remote sensing technologies for renewable resource management until very recently. The initial mapping capacity built up at the country level in the 1950s and 1960s has seriously deteriorated from technical, institutional and financial viewpoints. The mapping network in sub-Sahara Africa is far from complete; basic maps cover only parts of the continent and are outdated. Recently the use of remotely sensed techniques shows wide capabilities in the field of environmental monitoring, particularly regarding vegetation (Falloux 1989). The advantages presented by these techniques with respect to the usual methods for data collection has led to their increased use in many developed countries where the knowledge and the devices for their application is available. The major potential of remote sensing is connected to its use in developing countries where there is little information about the often severe environmental conditions. It is these conditions that need frequent monitoring for improving agriculture and preventing land degradation (Falloux 1989; Conese *et al.* 1990).

Current assessment of living vegetation condition relies on various traditional methods of sampling such as soil analysis, species tallies within small transects, timber inventories and crop yield assessments. While such measurements can be quite accurate, they are difficult to obtain over a broad area, so they fail to show changes in the pattern of vegetation greenness across the landscape (Burgan and Hartford 1993; Okin 1996b). Monitoring vegetation greenness with satellite data covers large geographic areas, the assessment is updated weekly, the data is easily obtained, and it is relatively inexpensive (Burgan and Hartford 1993). However, this monitoring system must be usable by the end user - the land resource manager in the field, otherwise any advancements gained in technology may not be used to their full potential.

Vegetation Response

Native vegetation can respond in predictable ways to a variety of stresses. This response may be at the cellular level, the morphological/macroscopic level, or the community level, depending on the intensity and duration of the stress. Figure 5 illustrates this concept (Rock *et al.* 1993).

Native vegetation is sensitive to stress factors associated with environmental change (moisture levels, nutrient levels, temperature, human-induced factors). The ability to remotely detect subtle levels of change (the response to stress) in the vegetation can prove to be a very useful indicator of environmental change. Remote sensing techniques using satellite multi-spectral data provide an accurate means of detecting, quantifying, mapping and monitoring change in vegetation on local, regional and global scales. Change at different scales in both vegetation kind (vegetation type, species associations, etc.) and vegetation condition (state of health, degree of deforestation, seasonal stage of growth, etc.) can be studied using various sensor systems and image processing techniques. Table 4 summarizes some of the available satellite data currently used for change detection purposes.

Vegetation change at the plant level (cellular and morphological) can often be detected spectrally by remote sensing techniques before it is observed by the naked eye in the field. In a spatial context these changes tend to be scattered and more of a fine-scale phenomenon. To remotely detect plant-level changes requires high spatial and spectral resolution sensors targeted to capture data at a specific location or of a particular species. The resulting spectral signatures show subtle chemical and physiological changes in needles or leaves of individual trees and tree canopies. Deforestation, however, is a vegetation change that is direct and conspicuous. This change can be detected with very coarse spatial scales of 1-4 km in some areas and is easily detected with a simple set of spectral band combinations (Rock *et al.* 1993).

Deforestation can create significant alterations of the basic features of vegetation including primary productivity, standing biomass and soil organic matter. Such vegetation change is significant and is spread globally, but the exact rate and geographic distribution of deforestation are not clearly known. To date, the best estimates of global deforestation have been compiled from national-level surveys. These surveys provide little insight into long-term deforestation trends because they are often compiled for one or a few inventory years. Objective reports of changes in forest cover have been recently obtained from satellite data where deforestation rates are reported directly. This direct information flow provides a capability for initiating monitoring efforts. Regional to global-scale monitoring of deforestation using fine spatial resolution imagery (20-80 m pixels) can be time consuming, computationally difficult, and expensive (Rock *et al.* 1993).

Table 4. Summary of current satellite sensor systems.

Satellite sensor system	Spatial resolution	Spectral coverage	Repeat Cycle	Time period covered	Spatial domain
SPOT	10 m panchromatic 20 m multispectral	0.51-0.73 um 0.50-0.89 um	26 days	1986-present	local to regional
Landsat TM	30 m reflected 120 m thermal	0.4-2.2 um 8.0-12.0 um	16 days	1982-present	local to regional
Landsat MSS	80 m reflected	0.5-1.1 um	16 days	1972-present	local to regional
NOAA-7,-9 AVHRR	LAC (1 km) GAC (4 km)	0.6-1.1 um	daily, composited monthly	1982-present	regional to global

Source: Rock et al 1993

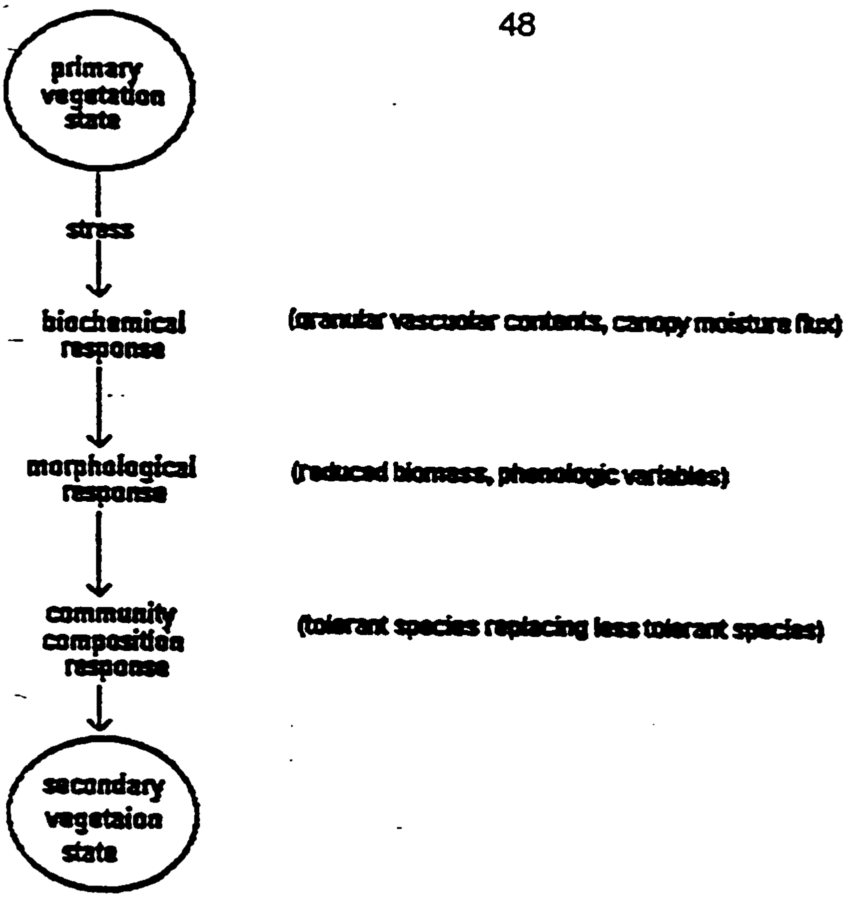

Figure 5. A schematic representation of vegetation response to varying degrees of stress. Initial exposure to nonlethal levels of stress results in previsual cellular-level change. If stress is chronic or intense, visual (morphological) damage will result. With continued stress, community level changes will occur. Examples of each type of change are given to the right. Source: Rock *et al.* 1993.

2.4.3 Information Relationships

The information needed for land management is often not visible on satellite images and consequently, must be inferred from the imagery by manipulating the raw data. For example, instead of the data required for soil fertility measurements, a value of the topsoil reflectance is obtained and the fertility values are inferred, and instead of the required data needed to determine land use activities, crop reflectance values are measured and the land use activities are inferred from this information (Rock *et al.* 1993; Bronsveld *et al.* 1994a).

The vegetation/land change associated with deforestation is more obvious with the naked eye on a remotely sensed image than forest degradation which involves physiological plant changes at the cellular level. The loss of biomass per unit area associated with forest degradation is significantly less than deforestation and can occur within an intact canopy (Bronsveld *et al.* 1994b).

In regions experiencing direct deforestation, forest decline, fuel wood culling from forests, selective timber harvest, and forest livestock grazing are all examples of degrading land uses. Natural forests can experience degradation because of subtle changes in microclimatic conditions. These changes can occur because of loss of canopy cover and evapotranspiration in regions of large-scale deforestation (Rock *et al.* 1993). Remotely sensed images can be used to detect land cover changes where aspects of activity (land use) can be inferred from land cover characteristics (Bronsveld *et al.* 1994b).

Technology development during the 1980s and 90s offers the possibility of collecting and analyzing relevant environmental data. For national and regional environmental monitoring there are no practical alternatives to the use of repeated satellite observations (Hellden 1991); aerial photography or field data collection to cover the same geographic area would be too expensive and labour intensive. These satellite data sources complement the analysis of conventional national statistics (demography, precipitation, agriculture) and other field-collected data of biophysical and socio-economic origin. Archived remotely-sensed data is often the only available data source for retrospective analysis of land use and vegetation cover (Hellden 1991).

2.4.4 Applications of Landsat MSS and TM Data for Vegetation Monitoring

Few attempts have been made to investigate the relationship between woody cover and reflectance data recorded by satellites for semi-arid vegetation types in Africa. There was an attempt by Vujakovic (1987) to identify relationships between Landsat MSS data and various vegetation parameters, including woody cover in Tanzania, however, no relationships could be found.

A study completed by Thenkabail *et al.* (1994b) examined vegetation indices from Landsat-5 TM to study the impact of agricultural management and cultural practices on soybean (*Glycine max*) and corn (*Zea mays*) crop growth and yield from farms in Seneca County, Ohio. Their study is important because it shows that vegetation indices were able to identify significant differences in the responses of different management combinations (Thenkabail *et al.* 1994b).

A similar study by Thenkabail *et al.* (1994a) (using the same data as Thenkabail 1994b) showed the use of Landsat-5 TM data to evaluate soybean and corn crop growth characteristics, and compared the performance of red and near-infrared vegetation indices with vegetation indices involving mid-infrared wavebands. This study was able to demonstrate the usefulness of the mid-infrared bands of Landsat-5 TM for studying crop growth and yield variables. The indices which used the mid-infrared TM bands 5 and 7 performed equal to, or better than, indices based on the widely used near-infrared TM band 4 and the red TM band 3. This was a surprising result considering that indices using mid-infrared wavebands are rarely used (Thenkabail 1994a).

Ustin *et al.* (1986), using data from the region of southeastern California, illustrated how TM satellite data may help analyze semi-arid vegetation, and discussed how spectral data can be transformed to give a variety of ecological information. They discuss four techniques which can be used individually or in combination to draw inferences regarding edaphic variation, community composition, canopy architecture, and physiological or phenological activity. These techniques are as follows:

1) vegetation indices,
2) correlating vegetation and spectral characteristics,
3) multi-spectral clustering models, and
4) multi-spectral mixing models.

By using a variety of analytical methods on a common data set, considerable qualitative and quantitative information emerges about environmental conditions. Using multi-temporal imagery, comparisons should yield information regarding phenological cycles and physiological conditions of vegetation for short time intervals or habitat changes and successional processes for longer time periods (Ustin *et al.* 1986).

Statistical frameworks required for inventorying and monitoring land cover over large areas have existed for decades (Nelson *et al.* 1987). The application of these statistical models for quantitative evaluation of land cover area and change using remotely sensed data also has a long history. Numerous efforts have used Landsat MSS imagery as the primary stage in multistage sampling designs. Nelson *et al.* (1987) references many researchers who have documented the advantages of stratification using Landsat MSS digital data. Nelson *et al.* (1987) provided a complete wetlands census using MSS data and interpreted MSS hardcopy imagery and aerial photos to estimate irrigated farmland area. In these studies, the MSS data provided synoptic coverage with a single MSS scene covering over 30,000 km^2 (185 km x 170 km).

To assess vegetation change at the country, subcontinental and continental level, Landsat MSS data must be considered as a sampling tool. Assessment of regions that require many Landsat scenes may not be possible due to unavailability or the high acquisition cost. Using coarse resolution data (for example, AVHRR) is suggested for primary enumeration of large areas (Nelson *et al.* 1987). The MSS data can then be used to correct or adjust coarse resolution estimates.

2.4.5 Applications of NOAA AVHRR Data for Vegetation Monitoring

Terrestrial scientists are studying the earth's surface by using satellite remote sensing at a variety of spatial and temporal scales. Recent global and regional land-cover studies have focused on the National Oceanographic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) because of the daily coverage, synoptic overview, and data volume available with this satellite (Ehrlich *et al.* 1994). AVHRR is presently considered more manageable for global scale studies than either Landsat or SPOT data. Ehrlich *et al.* (1994) have reviewed the applications of NOAA AVHRR data for environmental monitoring. They found that all 5 AVHRR bands are useful in land-cover studies, however; the majority of the land characterization research papers they reviewed used AVHRR/NDVI as the main data source. Multi-temporal NDVI datasets have found wide use in describing vegetation phenology. AVHRR thermal bands have also been employed by a number of researchers for surface temperature mapping and land-cover discrimination (Ehrlich *et al.* 1994).

The scientific community that studies global change has identified the AVHRR data set as an important database for land-cover mapping and land processes modelling at continental and global scales (IGBP 1992). AVHRR was designed for imaging cloud cover; and, because of its availability and spectral properties, it has been readily adopted by the terrestrial scientific community for coarse scale land-cover studies (Ehrlich *et al.* 1994).

Some of the properties which make AVHRR data (see Kidwell 1990 for detailed description) appealing to terrestrial scientists are listed as follows:

- AVHRR data include observations in the red and infrared part of the spectrum. These two bands have been extensively used for vegetation studies and are included on all civil earth-resource satellites. AVHRR also collects data in the thermal part of the spectrum which is increasingly being used for vegetation differentiation and mapping (Ehrlich *et al.* 1994).

- The daily acquisition of AVHRR coverage makes it useful for temporal studies. Weekly or bi-weekly cloud-free composites can be generated for a large part of the world (Ehrlich *et al.* 1994).

- The relatively coarse spatial resolution of the AVHRR sensor has been shown to be useful for studying continental and global processes and phenomena, also data volume can be kept to a manageable size (IGBP 1992).

- AVHRR data are relatively inexpensive when compared to satellite products with finer spatial and spectral resolution like Landsat MSS and TM (Ehrlich *et al.* 1994).

The main inefficiencies of the AVHRR sensor include:

- the lack of radiometric calibration coefficients, and
- the high slant angle which distorts radiometric readings at extreme off-nadir angles (IGBP 1992).

Both factors alter the radiometric signal arriving at the sensor. The first factor is currently being investigated by several research groups that are attempting to develop a sound radiometric calibration procedure. The distortion introduced by the extreme scan angle, on the other hand, can only be reduced by limiting the use of data to a fraction of the imaging angle close to nadir (Ehrlich *et al.* 1994).

2.4.6 Global Scale Vegetation Studies

A detailed analysis of a NDVI global dataset was performed by Justice *et al.* (1985). The temporal patterns of NDVI have unique distinguishing features for different plant communities of the world. A temporal integration of NDVI has been shown to provide a good indicator of the productivity of grasslands and of different biomes in North and South America. In addition, the temporal NDVI variation has been shown to be correlated with temporal variation of atmospheric CO_2 concentration (Tucker *et al.* 1986). This correlation is explained by the depletion of atmospheric CO_2 by growing vegetation through photosynthesis, while decomposition of vegetation increases CO_2 concentration (Rock *et al.* 1993).

Remotely sensed data can be acquired which relates to the state of health and damage, species/community distribution patterns, deforestation, and seasonal development of vegetation at scales ranging from local to global. In developing strategies for the study of global change, remote sensing input, such as that relating to vegetation and its parameters, will be an important component (Rock *et al.* 1993).

2.4.7 Human Activities

The global distribution of vegetation reflects large scale variations in temperature, precipitation, and various other environmental factors. A dynamic phenological and successional landscape of natural communities has given way to humans insisting on continually modifying this natural landscape. Therefore, the state of the world's vegetation must be viewed as a constantly shifting mosaic of land-cover types that are determined by both the physical environment and human activities (Rock *et al.* 1993).

Human activities and influences have shaped natural landscapes for a long time. In forested landscapes, one end of the gradient of change is deforestation, a most obvious and direct form of human-induced vegetation change. At the other end is forest degradation and decline, a more subtle and indirect result of human activity. As a result of such a vegetation change there has been a reduction of the amount of carbon stored on land and an increase of carbon in the atmosphere. This net increase of carbon to the atmosphere is caused by the historical trend of forest conversion to agricultural land and other human uses that reduce the amount of carbon stored in plants. These human alterations to the native vegetation cover have influenced other atmospheric constituents and biogeochemical cycles (Rock *et al.* 1993).

2.5 SUMMARY

The earth's terrestrial vegetation is an important component of the biosphere. Vegetation helps prevent land degradation and soil erosion; it regulates the local and global climate; and it protects and generates humus which is important for producing more healthy vegetation. There are many disturbance factors affecting global vegetation: general land degradation, desertification, deforestation, agricultural practices, grazing, and bush fires. In developing countries, these physical factors of disturbance are related to the rise in human population and the associated demands on the environment. Another real problem facing developing countries is the lack of current information on the natural resources that is needed to make sound decisions regarding natural resource management. Remote sensing provides an accurate, up-to-date ability to detect change and monitor vegetation. Vegetation indices derived from remotely sensed satellite images allow natural resources to be monitored and provides the necessary information needed to make responsible management decisions.

SECTION 3

3.1 INTRODUCTION

Vegetation monitoring using remote sensing is a valuable way to determine where land degradation is occurring over large geographical areas. The Normalized Difference Vegetation Index (NDVI) is one tool used to monitor vegetation using remotely sensed images.

Section III covers background information of Ghana, a description of the two data sets, methodology, results and discussion, and conclusions for each Project.

Project I sets out to illustrate that NDVI is a vegetation index that is independent of the system that is used to produce it.

Project II is an examination of how using NDVI and incorporating critical values is useful for monitoring vegetation in Ghana. The scope of this project only extends to detecting the presence or absence of vegetation during the dry season in Ghana. This is accomplished using NDVI and applying published critical values to the study area in northern Ghana.

3.2 BACKGROUND INFORMATION OF GHANA

Some background information of Ghana is included at this point because the Landsat TM data chosen covers an area in northern Ghana and the NOAA data covers the whole country of Ghana.

3.2.1 Geography

Ghana lies in a central position on the southern coast of West Africa. Covering 238,538 km^2 and lying between 5° and 11° north latitude, and 3° west and 1° east longitude, Ghana is bordered by Cote d'Ivoire to the west, Togo to the east and, Burkina Faso to the north. With its rectangular shape, it extends some 675 km inland with a coastline of 567 km (Figure 6). The land mass is one quarter the size of Ontario, yet Ghana has a population in excess of 17.6 million as of July 1996 (Anon. 1997).

Rainfall is greatest in the south-west of Ghana where over 2,000 mm falls annually. Moving further inland results in a decrease in rainfall amounts, but most of the southern third of the country receives between 1,250 and 1,500 mm per year. The eastern coastal plain is an exception where precipitation is less than 1,000 mm per year; this is as dry as the northern savanna areas. In the south, the rains fall in two seasons which peak around June and October. In the north there is a single rainy season from April to October and the annual rainfall is about 1,250 mm. Average temperatures over the whole country are steady around 26-29°C. In the north, they tend to drop between December and February when the cool Harmattan winds blow from the Sahara, bringing dust and lowering the relative humidity. There is a large daily temperature range (about 15°C) during the dry season (WCMC 1988; IIED 1992).

3.2.2 Vegetation

The vegetation of Ghana varies from wet evergreen forest in the south-west to dry northern guinea savanna in the north. The ecological zones of Ghana include rain forest (3 percent), moist forest (31 percent), coastal savanna (5 percent), interior savanna (57 percent), and Volta Lake (4 percent) (IIED 1992) (see Figure 6). The forests are dominated by trees over five metres high, which have interlocking crowns that shade out patchily distributed grasses beneath them. Within the savanna areas, there are distinctive gallery forest formations along rivers. The distinction between forest and savanna vegetation is remarkably clear, with little intermediate woodland on the fringes, probably because farming activities and fires exaggerate the savanna-forest boundary (WCMC 1988).

The vegetation zones of Ghana are distinguished as moist semi-deciduous forest, guinea savanna, Sudan savanna, rain forest, coastal scrub and grassland, and strand and mangrove zone (Figure 6) (WCMC 1988, IIED 1992). It is the guinea savanna and Sudan savanna zones that are examined in this study.

There are an estimated 9 million ha of woodland within the interior savanna zone, of which about 0.9 million ha occur within forest reserves. Most of the woodland is found in the northern region, producing woods ideal for charcoal production. Savanna woodland is also a major source of fuelwood and house poles, but virtually no sawn timber is produced from savanna wood (IIED 1992).

Only 12 percent of Ghana (28,680 km^2) is classified as arable or permanently cropped land. The interior savanna zone is generally unfavourable for agriculture, mainly due to the limited availability of water and the presence of tsetse flies. Agricultural activity in this zone is concentrated around large population centres, notably Tamale, Lawra, Wa and Bawku (IIED 1992).

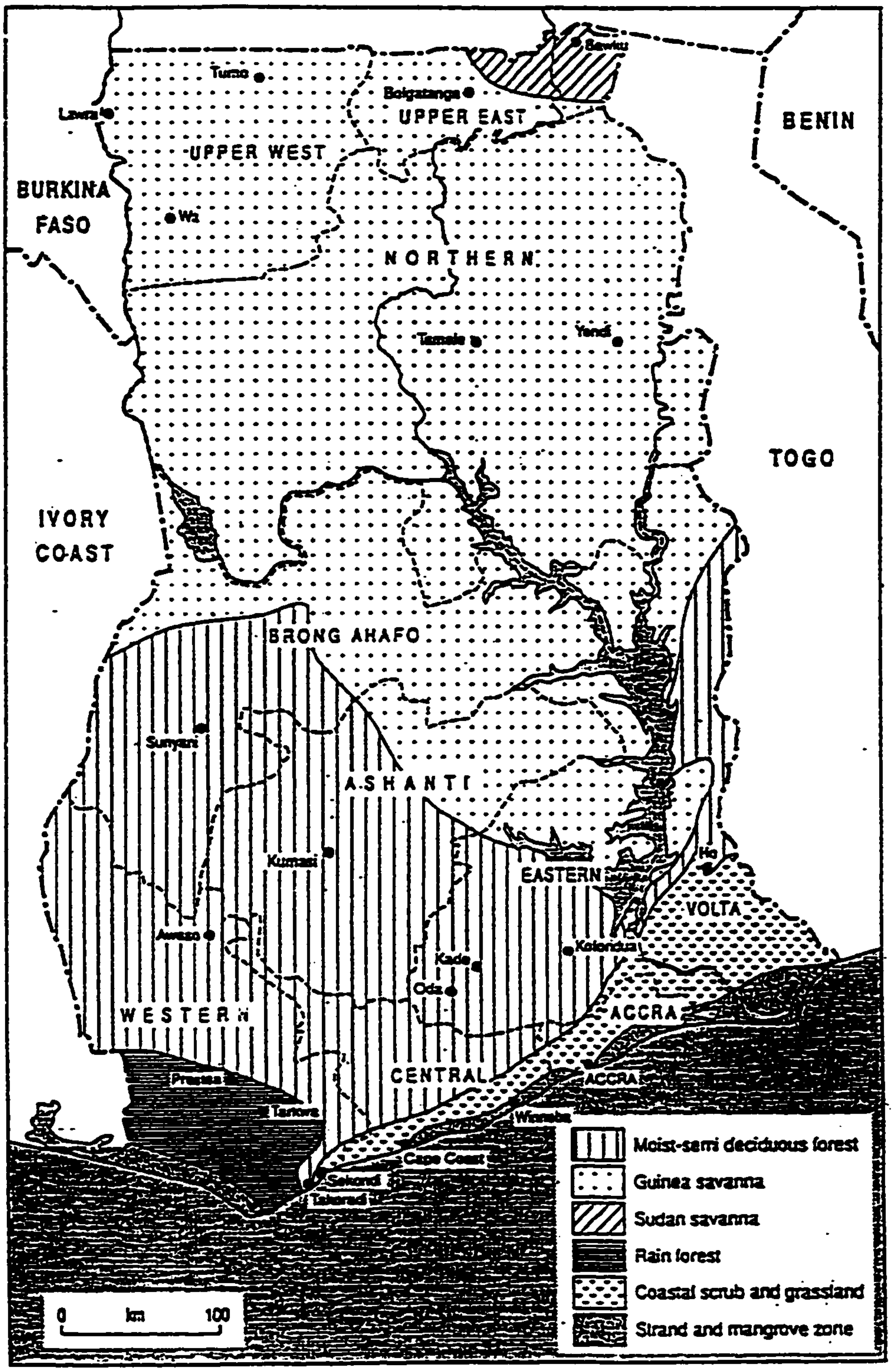

Figure 6. Vegetation zones of Ghana. Source: IIED 1992.

Within the interior savanna zone there are a number of different vegetation types. The dry forest consists of a single deciduous tree layer that provides a dense cover. The woodland consists of two vegetative layers: dry deciduous trees with at least 40 percent cover, and dense herbaceous cover. The treed savanna consists of two vegetative layers: tall grasses and dense herbaceous vegetation and scattered deciduous trees that comprise less than 15 percent cover (Achard and Blasco 1990).

The main food crops produced through agriculture in this country include maize, cocoyam, cassava, millet, guinea corn, plantain, yam and rice. The main cash crops are cocoa, oil palm, coconut palm, cotton, rubber, sugar cane, tobacco, citrus, and kenaf (used for fibre bags) (IIED 1992).

3.3 DATA SET DESCRIPTION

3.3.1 Landsat TM

A full Landsat TM image was obtained dating from January 1991, the dry season in Ghana. The full image covers 11°15' north to 10° north Latitude and 1° west to 0° Longitude. From the original seven channel image, the green, red and middle infrared channels (TM channels 2, 3, and 5) were used as a subset for studying NDVI. The pixel size of the image was 30m x 30m and the image was not rectified.

Figure 7 shows the rectified full Landsat TM image projected to the Transverse Mercator system displayed as a RGB (red, green, blue) composite where TM channel 5 (middle infrared) is displayed as red, TM channel 3 (red) is displayed as green and TM channel 2 (green) is displayed as blue. Displaying the image this way shows the physical features of the image. The drainage system of the area, the Gambaga Escarpment (a scarp running in an east/west direction across the right half of the image), some cloud cover and the shadows produced by the clouds are all identifiable on the RGB colour display image.

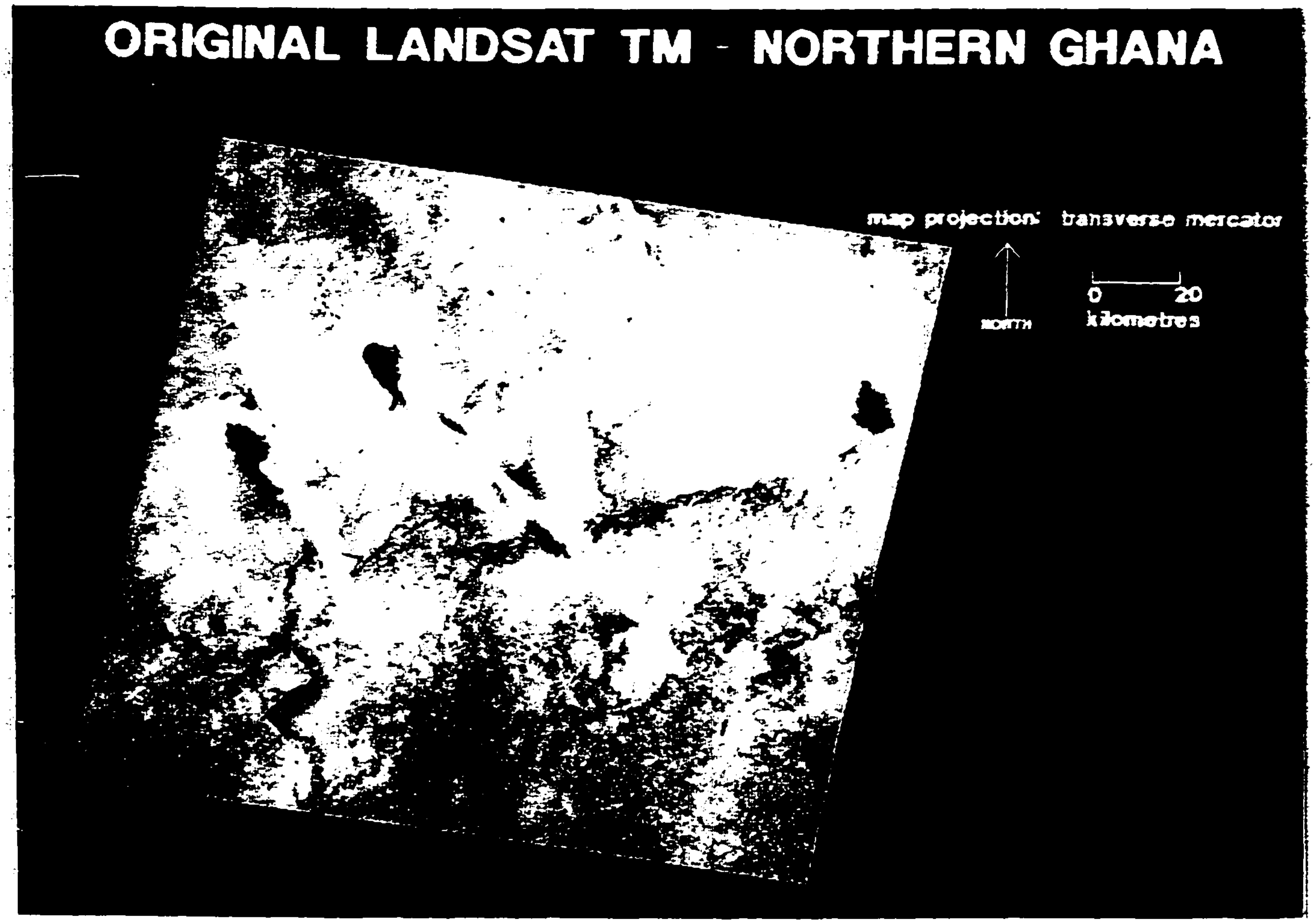

Figure 7. RGB colour display with TM5 displayed as red, TM3 displayed as green and TM2 displayed as blue.

3.3.2 ARTEMIS

The dataset used for Project 2 are NDVI images built up by the National Aeronautical Space Agency (NASA) and the Goddard Space Flight Centre with the Africa Real Time Environmental Monitoring and Information System (ARTEMIS) project of the Food and Agriculture Organization (FAO) stored on a compact disc. The dataset contains 10 years of NOAA AVHRR NDVI data over Africa ranging from August 1981 to June 1991. NDVI data from the NOAA AVHRR sensor was used to establish annual and seasonal variations in earth surface reflectance. Acquired on a daily basis, the data was treated to produce a 10-day composite image which was virtually cloud free through a maximization of the pixels (pixels with the highest NDVI values are selected for the 10-day composite image).

One 10-day composite NDVI image, from here on called ARTEMIS data or image, was extracted from the dataset that covered the first 10 days of January 1991, the same time period as the Landsat TM image. This extracted ARTEMIS image covers the same geographical area as the Landsat TM image. The data was resampled to a 7.6km x 7.6km pixel size in the Hammer Aitoff projection system.

3.4 METHODOLOGY

Image processing was performed on a SUN workstation and an IBM PC using ERDAS (Earth Resources Data Analysis System) software. Some GIS procedures were performed with PC Arc/Info.

3.4.1 LANDSAT TM DATA PREPARATION

Imagery gathered by satellites is a representation of the irregular surface of the earth. The Landsat TM image was geometrically corrected so that it can be represented on a planar surface. Rectification is the process of projecting data onto a plane and making it conform to a map projection system. During the rectification process the grid of raw data was projected onto a new grid. Resampling is the process of extrapolating data values for the pixels on the new grid from the values of the old grid.

The Landsat TM image was geometrically rectified to the Transverse Mercator map base using 30 ground control points on 1:50,000 National Survey of Ghana maps. A least squares regression method was used to calculate the transformation matrix from the ground control points. This resulted in a Root-Mean-Square (RMS) error of less than one pixel. A cubic convolution interpolation method was used to resample the image to a 50m x 50m pixel size from the original 30m x 30m pixel size.

The cloud cover and the resulting shadow present on the image were removed by digitizing a polygon around the cloud and shadow so that these pixels could be clipped from the image.

A low-pass filter was then used to smooth the Landsat TM image and reduce the effect of noise pixels. Noise pixels may be the result of electronic interference or flaws in data transmission procedures or processing. Noise can be random or periodic and its presence can partly mask or completely degrade the true radiometric information of an image. Random noise can be a pixel whose digital number does not present any relationship to its neighbourhood, resulting in a "salt and pepper" effect (Centeno and Haertel 1995).

3.4.2 ARTEMIS DATA PREPARATION

The 10-day composite ARTEMIS image was extracted from the dataset and imported as a TIFF-extension file into the ERDAS software for rectification. A sub-set of the ARTEMIS data was geometrically rectified to the Transverse Mercator map base using the Landsat TM image. A nearest neighbour algorithm was used to resample the ARTEMIS 7.6km x 7.6km pixels to 7,000m x 7,000m pixels. The RMS error was less than one pixel.

The cloud and shadow polygons created from the Landsat TM image were applied to the ARTEMIS image and the pixels within the polygons were temporarily clipped out of the ARTEMIS image.

3.5 CALCULATING NDVI

An NDVI is calculated by subtracting the visible red channel data from the near infrared (nIR) channel data and is normalized by dividing their sum.

$$\mathrm{NDVI} = \frac{(\mathrm{nIR} - \mathrm{red})}{(\mathrm{nIR} + \mathrm{red})}.$$

However, a problem was encountered when the NDVI was calculated from the Landsat TM using the red and near infrared channels. The resulting mean NDVI was very close to 0 (0.0003) and not consistent with the mean NDVI calculated from the ARTEMIS dataset (0.10). Since the acquisition dates and geographic location of the two images (Landsat TM and ARTEMIS) were the same, the mean NDVI of the two images should be the same as well.

To ensure there were no errors present in the Landsat TM data, or in the methodolgy used to create the NDVI, the vendor, EOSAT, was contacted for technical support. EOSAT suggested that an image acquired over an arid area like northern Ghana and an image acquired during the dry season when very little vegetation is present may not provide enough contrast between the near infrared and red channels, a combination which usually provides good contrast for use in NDVI (Belward 1991, Coops 1996). EOSAT suggested substituting the middle infrared channel (TM 5) for the near infrared channel (TM 4) in the NDVI equation. This proposal suggested that under the sparse vegetation conditions that were imaged from northern Ghana the middle infrared channel may provide a greater contrast and produce a more meaningful NDVI. Therefore, the modified NDVI equation used for this report is as follows:

$$\mathrm{mNDVI} = \frac{(\mathrm{mIR} - \mathrm{red})}{(\mathrm{mIR} + \mathrm{red})}.$$

3.5.1 LANDSAT TM DATA

The Landsat TM image was a subset of three channels: channel 1 was red (TM 3), channel 2 was green (TM2), and channel 3 was middle infrared (TM 5). Using these channels for the NDVI the equation would then be:

$$\text{NDVI} = \frac{(\text{Ch. } 3 - \text{Ch. } 1)}{(\text{Ch. } 3. + \text{Ch. } 1).}$$

For computer aided display and analysis the positive NDVI values between 0 and 1 are usually scaled to an 8-bit data scale.

As is common with most vegetation index scaling techniques reviewed from the literature, a constant is added to remove negative values and a multiplication constant is included to obtain the required range of values. Gregoire (1990) used the scaling equation of (NDVI x 200) + 50. Applying this equation scales the NDVI values of -1 to +1 to a new range of -150 to 250. For example, a calculated NDVI value of 0.10 would be scaled to a value of 70 for display on the screen. However, since the data can only be displayed within the range of 0-255 (8-bit data), all the negative values calculated for the scaling equation are displayed as zero values on the screen. To keep the discussion of NDVI values as simple as possible, only actual NDVI values (not the scaled values) will be presented here, that is, the range of values from 0 to 1.

The mean NDVI value of the Landsat image was calculated using ERDAS software.

3.5.2 ARTEMIS DATA

Since the ARTEMIS data was already presented as an NDVI image (the NDVI calculations having been completed by the FAO prior to distribution of the dataset) the mean NDVI value of the ARTEMIS image was calculated using ERDAS.

3.6 RESULTS AND DISCUSSION

This section is presented in two parts; results and discussion for Project 1 and results and discussion for Project 2.

3.6.1 PROJECT 1 - THE SYSTEM INDEPENDENCY OF NDVI

Most remote sensing techniques for vegetation monitoring use data recorded through those parts of the electromagnetic spectrum which provide a strong signal from vegetation while contrasting with background material (Belward 1991). The literature indicates that the red and near infrared wavelengths satisfy this criterion, and that combinations of these two wavebands as vegetation indices are useful as measurements of various attributes of a vegetation canopy such as the amount of vegetation cover, total biomass and vigour, and leaf area index (Bartholome 1990; Gregoire 1990; Belward 1991; Coops 1996 and FAO 1994). For this report the middle infrared wavelength was used to replace the near infrared wavelength with similar results and under the same assumptions as if the near infrared wavelength was used.

The mean NDVI calculated for northern Ghana from the Landsat TM image was 0.11, as calculated by ERDAS software using the NDVI formula in Section 3.5.1 Landsat TM Data. The mean NDVI calculated for the ARTEMIS image was 0.10, provided with the data on the compact disc. The difference in wavelength ranges and resolution of the two images are possible explanations for the slight difference in average NDVI values.

The two satellite data sets used to demonstrate that NDVI is an index useful for measuring vegetation attributes and can be obtained from any satellite system were Landsat TM and NOAA AVHRR. The red and middle infrared wavelengths of the Landsat TM data system are 630 to 690 nm and 1550 to 1740 nm respectively. The red and near infrared wavelengths used for calculating NDVI for the ARTEMIS data set are 580 to 680 nm and 735 to 1100 nm. NDVI is the vegetation index most frequently used for regional and local scale vegetation monitoring partly because of it's effectiveness as a substitute measure of biophysical parameters and partly because NDVI, unlike other vegetation indices, requires no *a priori* information concerning the imaged scene (Belward 1991). There is also the fact that the calculation of NDVI allows for the normalization for variations in viewing conditions specifically, the sensor used to collect the data.

The scale of the Landsat TM image was resampled to 50m x 50m pixels and the ARTEMIS image was resampled to 7000m x 7000m pixels. This vast difference in resolution can cause problems during assessment. With the low resolution of the ARTEMIS data the fine details of the vegetation are lost. One ARTEMIS pixel covering an area of 49,000 m^2 is averaging the spectral response of 19,600 Landsat TM pixels covering the same 49,000 m^2 on the ground. This means that the spectral detail of small patches of vegetation on the Landsat TM image will not be detected by the AVHRR sensor used to create the ARTEMIS image.

Accounting for the vast scale difference of the two images (Landsat TM having 50 m pixels and the ARTEMIS having 7000 m pixels) and the slight difference in wavelength characteristics, the mean NDVI for both images can be considered to be the same. This example demonstrates that NDVI is a vegetation index that when calculated from any remotely sensed image provides a uniform measure of vegetation characteristics regardless of the sensor the image originates from.

3.6.2 PROJECT 2 - THE USE OF CRITICAL NDVI VALUES FOR VEGETATION MONITORING AT THE REGIONAL AND NATIONAL LEVELS IN GHANA

Creating and displaying an NDVI image for monitoring purposes is a useful exercise on its own. Figure 8 is the resulting NDVI image calculated from the Landsat TM image of northern Ghana and gives a rough indication of where relatively higher levels of vegetation (NDVI values of 0.20 to 0.25) are located. The image illustrates the location of higher NDVI values, where higher NDVI values relate to photosynthetically active cover so that by inference, the higher the value the greater the amount of vegetation (Belward 1991). This image was obtained during the dry season, a period of very little active vegetation growth. To put the northern Ghana NDVI image into perspective, a study by Burgan and Hartford (1993) used NDVI to develop vegetation greenness images over the conterminous United States. They determined that 0.66 is the approximate maximum NDVI value obtained from observing dense, green vegetation from bi-weekly NDVI composites of the United States since 1990. Similarly, Lynham and Pierce (1997) conducted a study in Ontario to monitor vegetation greenness from a forest fire management perspective. They determined that the highest average annual NDVI was 0.50 found in North Bay, Ontario. Conversely, a study from West Africa on the effects of the dry season on the vegetation of river basins completed by Gregoire (1990) showed relatively low NDVI values of 0.25 for coastal watersheds and 0.20 for Niger tributaries. Malingreau *et al.* (1989) published 0.25 as an average NDVI value over savanna in December in Guinea and 0.15 over degraded woodland savanna in January. In comparison with the United States and Ontario studies, the highest NDVI of 0.25 from the Landsat TM image of northern Ghana in January is actually not very high at all. However, when compared with NDVI values of similar savanna conditions, the 0.25 NDVI value from northern Ghana corresponds to the relatively low NDVI values published for West African conditions (also 0.25).

Comparing the semiarid environment of northern Ghana to the lush temperate climate of the United States and Ontario is not a fair comparison; it simply demonstrates the importance of creating regional NDVI values for vegetation monitoring purposes. As well, the NDVI from the Landsat TM image is calculated from one date, whereas the maximum NDVI of the United States and

Ontario are composite of data over the whole year including many years worth of data and the average NDVI from Malingreau *et al.* (1989) was an average value over the month of December.

To determine whether an NDVI value of 0.25 obtained during the dry season in northern Ghana is too low for that region and for that time of year or whether that value is on-line, a system of monitoring NDVI values needs to be created for northern Ghana specifically. For the purpose of this project, it was important to show areas on the Landsat TM image that were non vegetated (NDVI values less than 0) versus areas on the image that showed higher levels of vegetation (for example, NDVI values greater than 0.16). A monitoring system that watches the areas of non vegetation and determines whether these areas are increasing (possibly caused by increased land degradation) is important for the region of northern Ghana. Creating critical values, or thresholds, below which a pixel from an NDVI image can be regarded as being non vegetated, sets the limits of NDVI values for a region that are more meaningful to that region.

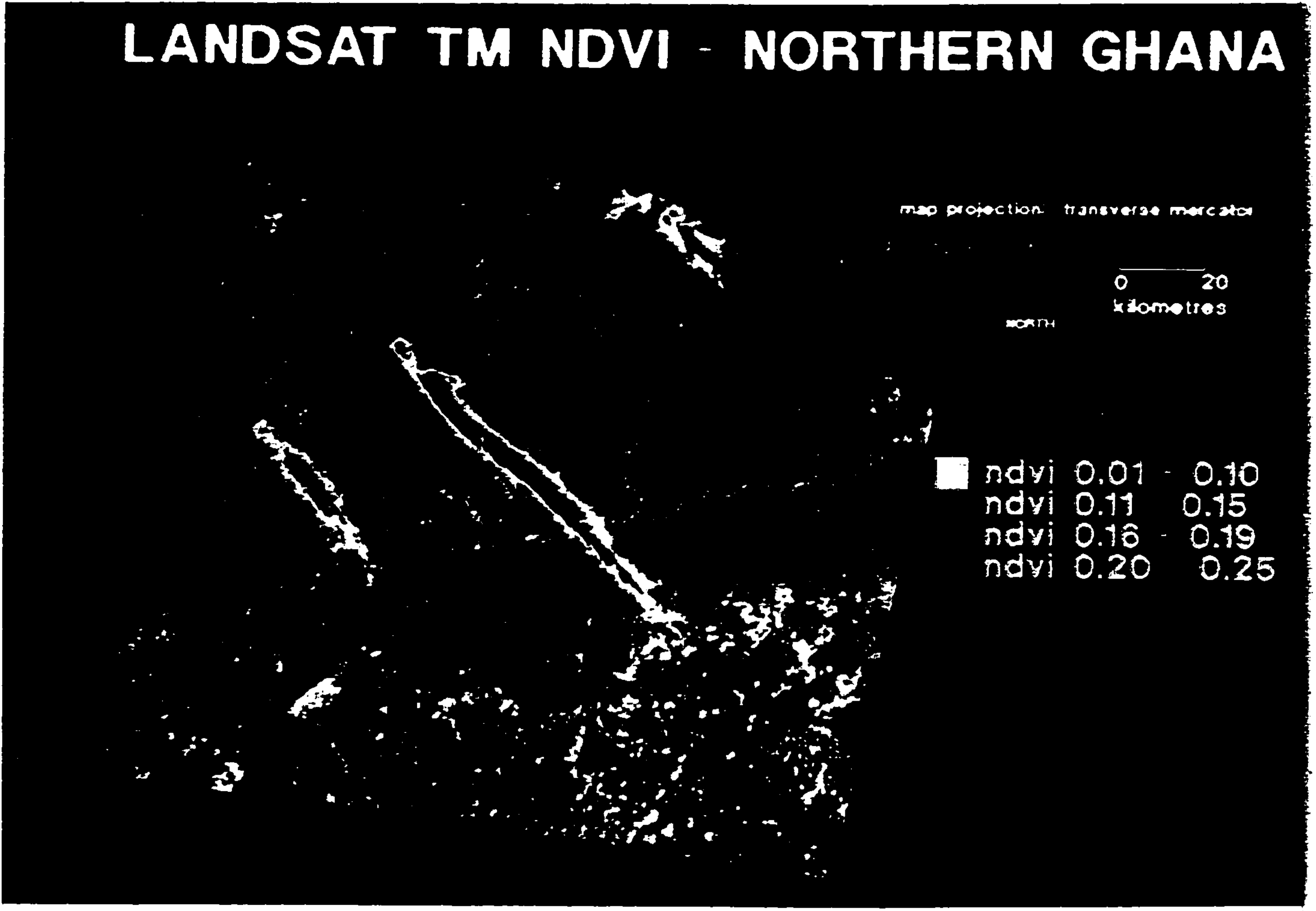

Figure 8. NDVI image of Landsat TM of Northern Ghana.

The Commonwealth Scientific and Industrial Research Organization (CSIRO) used the attributes of temporal NDVI to describe the timing, duration and intensity of photosynthetic activity of native eucalyptus which are determined primarily by seasonal variations in environmental conditions (CSIRO 1995a). CSIRO (1995a) have used the concept of critical values for their study in New South Wales, Australia for determining the growing period of different native eucalyptus species (*E. pauciflora* and *E. globiodea*). Their concept of defining the presence or absence of vegetation during the non growing season of eucalyptus using critical NDVI values was the principle applied in creating critical NDVI values for the northern Ghana region. Previous studies of eucalyptus by CSIRO in Australia have shown that the growing period of vegetation was unlikely to begin while NDVI values were less than 0.10. If this value of 0.10 is chosen as the lower most NDVI limit defining either the growing season or the presence or absence of vegetation, then only NDVI values above 0.10 would be considered photosynthetically active vegetation. This critical value of 0.10 was then applied to the NDVI image of northern Ghana.

Subsequent NDVI images obtained for the exact same geographical location can be compared to the original (the January 1991 image) using the critical value of 0.10 and problem areas can be defined quantitatively. For example, if the area of non vegetation during the dry season, those NDVI values less than 0.10, are increasing in area over the Landsat TM image, this could indicate an increase in the land degradation process and would be an indication that a closer look at that location may be necessary.

This concept of critical values is useful at the regional level, as was demonstrated by the Landsat TM NDVI image, and also at the national level. Figure 9 is the resulting NDVI image from the ARTEMIS dataset image in January 1991. Since this NDVI image covers the whole country of Ghana, which includes some closed tropical forest in the south, the NDVI scale in the Legend shows higher NDVI categories. The area on the ARTEMIS image (Figure 9) that corresponds to the location of the Landsat TM image is represented by a solid grey circle in the upper right corner of the image. This grey circle covers only two different NDVI range values on the ARTEMIS image. In fact, if the critical value of 0.10 is applied here, according to the ARTEMIS image, most of the Landsat TM image covers non vegetated land. However, by using higher resolution imagery to obtain more information about a potential problem area and by applying the critical value of 0.10 to the Landsat TM image, most of this image shows an NDVI that is above the critical value indicating photosynthetically active vegetation. The difference in these two results can be explained partly because of the resolution difference of both images.

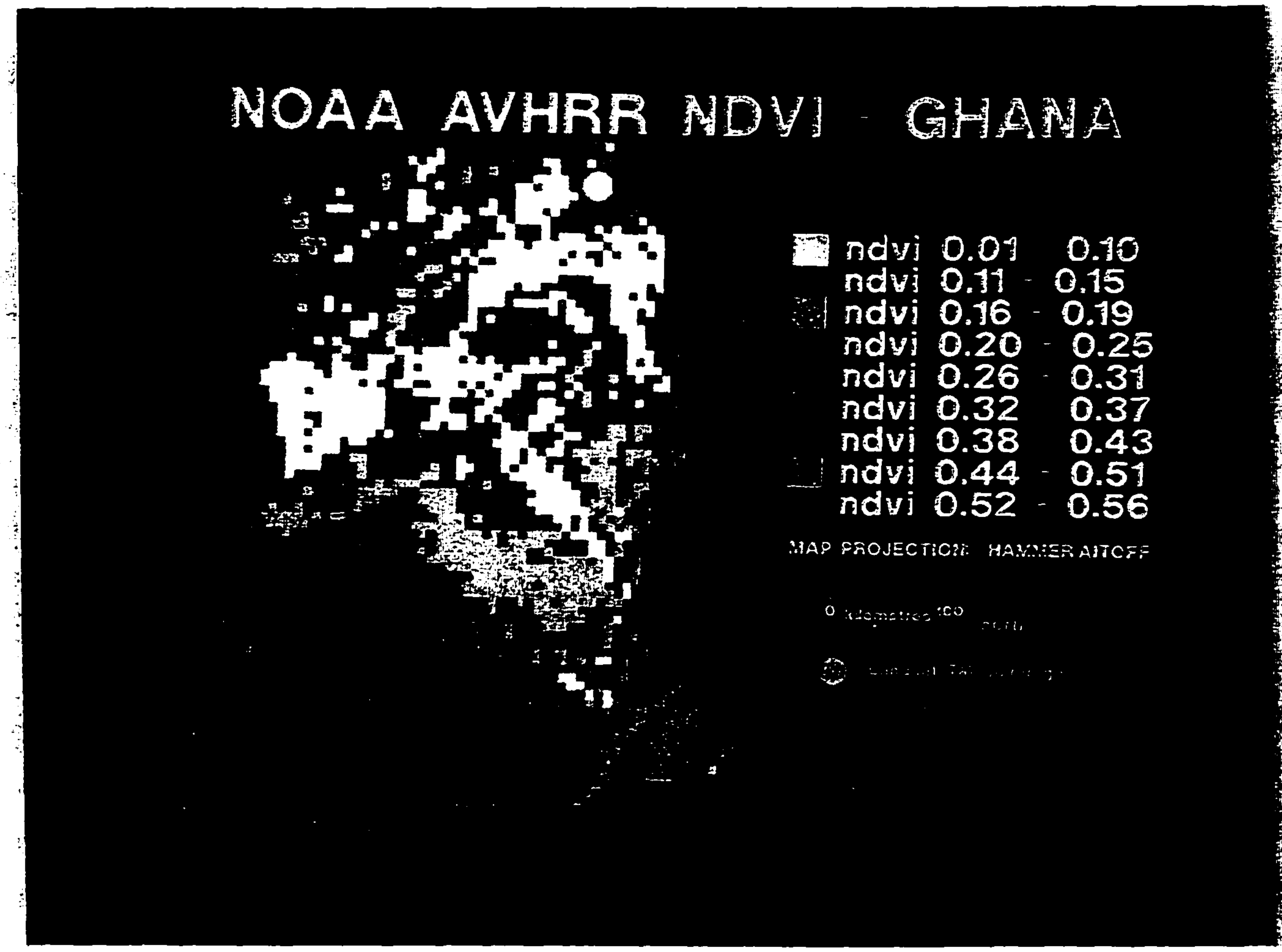

Figure 9. ARTEMIS NDVI image of Ghana - January 1991.

The low resolution of the ARTEMIS image does not account for small variations in the vegetation that the higher resolution Landsat TM image is able to detect. For example, the relatively high NDVI pixel values of 0.25 obtained on the Gambaga Escarpment in the Landsat TM NDVI image does not represent a large enough area of pixels so that the NOAA AVHRR sensor would detect them as areas of higher vegetation than the surrounding areas. The surrounding lower NDVI pixel values on the Landsat TM NDVI image envelop the higher NDVI values when this area is remotely sensed by a low resolution satellite sensor like the NOAA AVHRR. When a low resolution sensor like NOAA AVHRR is used to image the northern region of Ghana, the higher NDVI values detected with the Landsat TM sensor are averaged into the surrounding lower NDVI value pixels. This results in wider ranges of NDVI values for the ARTEMIS NDVI image.

Figure 10 is an NDVI image from the ARTEMIS dataset of Ghana from June 1990. This image was obtained during the active growing season and consequently shows much higher NDVI values than the January 1991 ARTEMIS NDVI image of Figure 9. Only a very few pixels fall below the critical value of 0.10 and these are mostly located in the very north of the country, closer to the Sahara Desert and very arid conditions.

The objective of Project 2 was to determine whether critical NDVI values could be used for vegetation monitoring at the regional and national levels in Ghana. The Landsat TM data showed that it is well suited for vegetation monitoring at the regional level and similarly, the NOAA AVHRR data was well suited for national level vegetation monitoring.

Using critical NDVI values for vegetation monitoring can be taken one more logical step. They can also be used for planning at the local level. For example, an area the size of the Bawku watershed in northern Ghana could use NDVI for land use planning at the local level to determine areas of healthy vegetation, areas of degrading farmland or areas requiring rehabilitation.

There are many organizations in West Africa with vegetation monitoring programs already in place. Some of these programs are using NOAA data for this work. In Ghana, where there are training programs in place at the Universities to produce resource managers with remote sensing and GIS skills, implementing and sustaining a vegetation monitoring program at the local level is feasible. A vegetation monitoring program where locally trained people will develop and implement the program will be more effective locally and have a greater chance of success and sustainability.

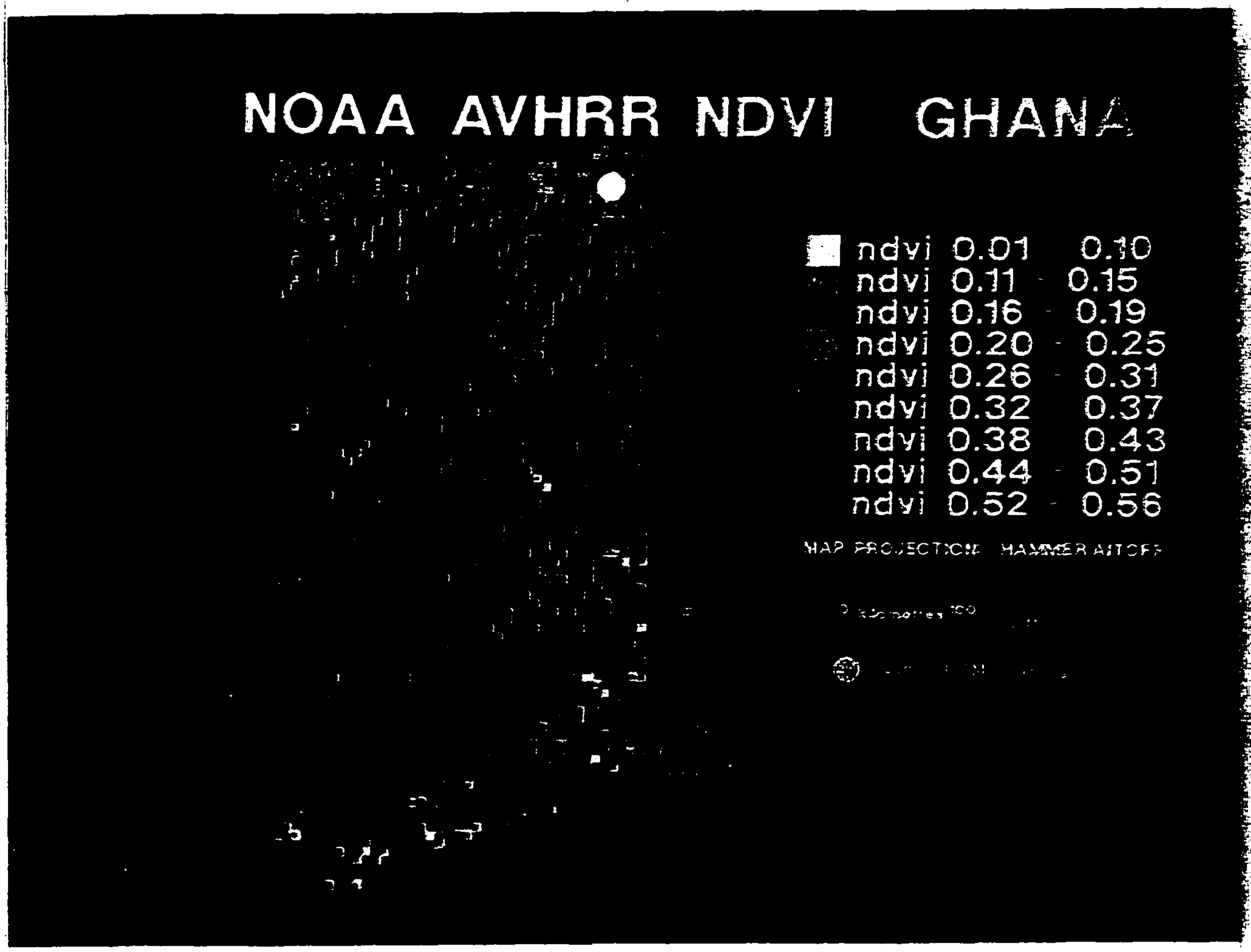

Figure 10. ARTEMIS NDVI image of Ghana - June 1990.

3.7 CONCLUSIONS

In developing countries, current vegetation monitoring programs rely on various methods of manual sampling and assessment. While such measurements can be quite accurate, they are difficult to obtain over broad areas and fail to portray changes in the pattern of vegetation across the landscape. A common problem in development planning is the inadequacy of information on the current land cover/land use and available resource base. Without this current, accurate information, those in charge of creating and implementing environmental policy cannot make decisions, or they may make incorrect decisions.

The frequent inadequacy of land cover and resource information may be due to many difficulties present in developing countries. For example: some regions may be inaccessible because of limited infrastructure, civil and military disturbances; lack of trained personnel, equipment, or funds to collect information properly. Also rapid changes in the resource base not detectable by traditional data collection methods, such as the high rates of deforestation in many areas of the world caused by increased population pressures, can cause difficulties. Spaceborne remote sensing has been able to provide this information for developing countries.

Two very important remote sensing systems that have been used for vegetation monitoring programs are the Landsat and NOAA AVHRR systems. A high spatial resolution remote sensing system such as Landsat can only provide relatively low frequency temporal coverage of large areas. Using high spatial resolution data also means large data volumes, especially where multi temporal data over large geographical areas are concerned. The disadvantages of high cost, high data volumes and low frequency of cover of Landsat data restricts the use of this data to specific users. The main advantage of high resolution data is the ability to obtain greater detail over the geographical area being monitored.

Agricultural lands, vegetation types, and non vegetated areas are easily identified on high resolution data.

The orbital and viewing parameters of low resolution data, like NOAA AVHRR, are such that global coverage is available on a daily basis and the lower data volumes make the analysis of long term time-series for large areas realistic. The advantages of NOAA AVHRR are the low volumes of data because of the low spatial resolution, the lower cost of the data compared to Landsat, and the high frequency at which the data can be obtained. The main disadvantage of low resolution data is the lack of spatial detail which results in generalizations over large geographic areas.

An important issue to consider when supporting the use of remote sensing for vegetation monitoring at regional and national levels is: who are the end-users of this information? Potential end-users of this information can be found at levels from the field to the continent. More realistically, the decision makers who are responsible for management tasks from regional to national levels will use the vegetation monitoring information most efficiently. National policy makers will use vegetation monitoring to direct money and resources to future problem areas identified. At this scale of management, NOAA AVHRR data is the most efficient method of monitoring vegetation. Regional resource managers may require more specific detail about the area they are monitoring, in which case, Landsat data may be more useful at this scale.

Already at the national level, to try and cope with the expressed need for information by decision-makers, several operational systems have been set up to monitor crop production and food availability in the Sahelian countries of West Africa. Three examples of monitoring programs are discussed below.

The Famine Early Warning Systems (FEWS), funded by the cooperation agency of the United States, collects all types of useful data in the countries that the program covers and transfers the data to the USA for analysis. Qualitative interpretations of AVHRR NDVI's are the main remote sensing input in this system. The objective is to provide information about the location of "at-risk populations" and aid relief efforts to help reduce lag time in food distribution during a famine crisis (Bartholome 1991).

The Global Information and Early Warning System (GIEWS) is a program run by the Food and Agriculture Organization of the United Nations. This program is oriented towards the routine production of pre-processed thematic outputs such as NDVI composites, rainfall estimates, and crop moisture availability maps. These products are then distributed to each country for further analysis and interpretation (Bartholome 1991).

The Africa Real Time Environmental Monitoring and Information System (ARTEMIS) has established a unique space based monitoring system to monitor developments of food crops and breeding conditions for desert locusts in Africa. This system uses high frequency environmental satellite data to produce images indicating the rainfall situation and the development of the vegetation at continental scales (Anon. 1996, FAO 1994).

The earth's vegetation is important for preventing surface temperature increases and soil erosion problems in every part of the world. Developing countries not only have to deal with increasing land degradation problems, but also with inadequate information on current land cover and land use. Frequent, accurate land cover and resource information is available from remote sensing data sources. Monitoring natural resources using remote sensing techniques and vegetation indices to create vegetation monitoring programs in developing countries will provide the necessary information needed to make responsible environmental decisions.

SECTION 4

4.0 USING VEGETATION MONITORING TO ADDRESS LAND DEGRADATION

There are many factors contributing to land degradation all over the world. Specifically, the removal of the earth's vegetation and the resulting increased desertification is a serious environmental problem for Ghana and the rest of Africa. Ghana has realized that to sustain themselves as a viable nation they must sustain their natural resources. This means that they must manage their resources in a responsible way and try to reverse or at least stop the current rate of environmental degradation in their country.

Earlier in this report, there were a number of vegetation monitoring initiatives discussed. A lot of work has already been done in the field of vegetation monitoring and some of these ideas can be applied to Ghana's situation.

One of the best tools developed for monitoring vegetation is the Normalized Difference Vegetation Index (NDVI). This index would allow a base line of vegetation levels for northern Ghana to be gathered throughout the year to detect any decreases in vegetation levels. This base line could be in the form of critical values, as presented in this report. Once these critical values are established, a monitoring program could be put in place where deviations in vegetation levels from these critical values would be recognized. Without the extensive geographical coverage of satellite remote sensing technology and NDVI, recognizing decreasing vegetation levels for an area the size of northern Ghana would be almost impossible.

As well, critical values mapped in a similar way as to what was presented in this report would allow observations and monitoring of potential problem areas. For example, it is thought that with increased global warming, the southern boundary of the Sahara desert is slowly migrating south. This would have devastating effects on farm and grazing land in northern Ghana and on the people trying to live there. With a monitoring program in place, critical values of vegetation levels could be evaluated to determine if this environmental degradation is actually increasing .

Such a monitoring program would show where higher levels of environmental degradation are geographically. This information would assist governments and NGOs in concentrating their efforts and money where they would be most effective instead of implementing "blanket" environmental aid programs.

4.1 RECOMMENDATIONS

1. The first recommendation from this report is that any future studies involving NDVI should be conducted using NOAA AVHRR imagery, not NDVI images from a preprocessed compact disc. Creating NDVI from raw NOAA AVHRR data and applying the same scaling equation to NOAA AVHRR data that was applied to the Landsat TM data allows a more direct comparison of the two datasets.

2. An accuracy assessment study should be conducted on Project 2 to verify that areas determined to be vegetated actually were vegetated, and to create meaningful critical values for the northern region of Ghana. This study was purely qualitative and was only a demonstration of the value of high resolution (Landsat TM) and low resolution (ARTEMIS) data for vegetation monitoring purposes.

3. A temporal dimension should be added to any study of NDVI that also includes data from the wet season, or data from all year. Using many images

obtained throughout the year over a number of years would allow the seasonal changes in vegetation growth to be taken into account when a vegetation monitoring program is in place.

4. Along with a temporal dimension, using archived NDVI data to create a baseline NDVI from which problems could be identified is important. Creating baseline NDVI images provides the resource manager with the ability to determine whether a very low NDVI image obtained at one point in time is significantly lower than the "normal" NDVI for that same time of the year.

SECTION 5

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IMAGE EVALUATION
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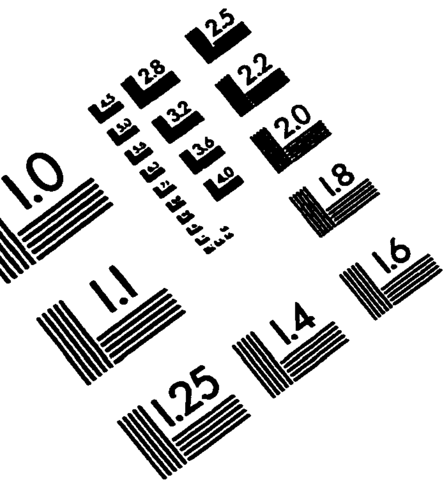

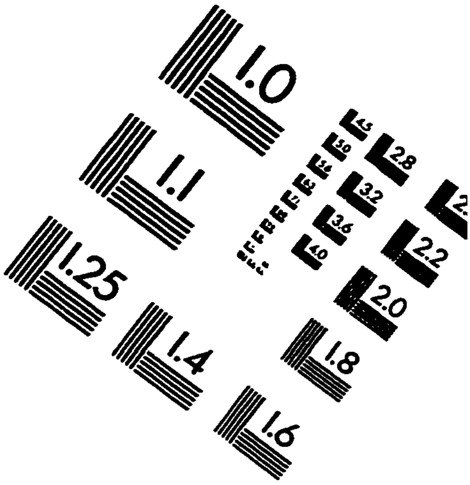

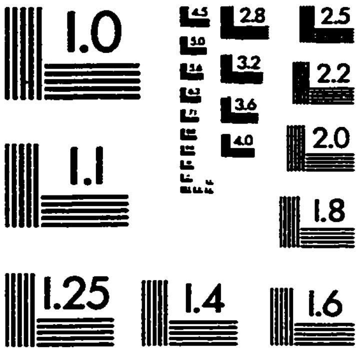

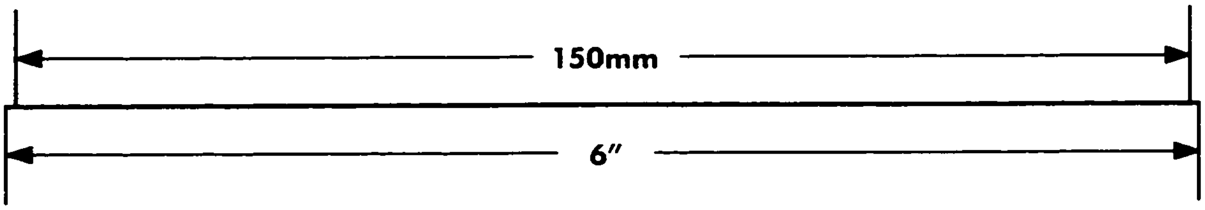

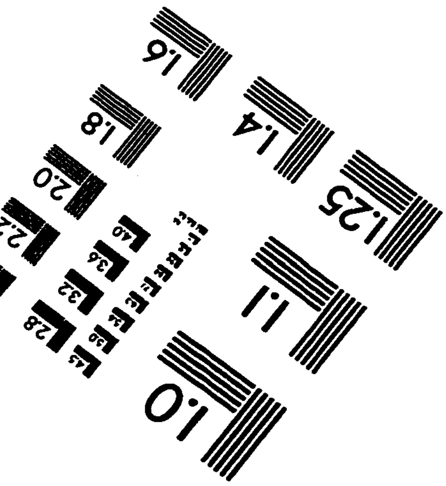

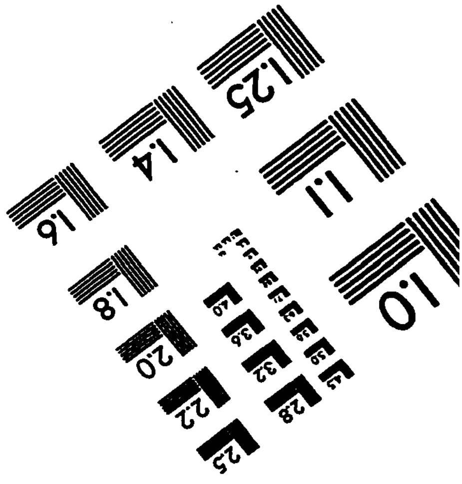

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