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Development of a methodology for monitoring changes in Ghanaian forest reserves

Asare, Veronica Nana Ama

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DEVELOPMENT OF A METHODOLOGY FOR MONITORING CHANGES IN GHANAIAN FOREST RESERVES

By

Veronica Nana Ama Asare

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ABSTRACT

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The Ghanaian Forests are a significant component of the country's development. Occasioned by the rapid population growth of the country, increasing phenomena such as shifting agriculture, logging, fuelwood harvesting and fire outbreaks have claimed over 70 % of the original forests. The reduction of forests has stimulated the development of management tools to control forest depletion. In order to focus the intervention of forest managers and environmental planners, the rate and impact of forest depletion must be monitored and well documented. Financial constraints and the lack of adequate maps have hindered the setting up of effective monitoring mechanisms. This study illustrated the feasibility for using Landsat data and GIS to map changes in the Ghanaian forest reserves. GIS was used to create the initial database for the study. Three image analysis change detection methods namely image algebra (image differencing), spectral temporal and spectral temporal principal component analysis were employed. The results of the analysis showed that spatial distributions of the changed areas produced by all three methods were similar, varying only in the extent. The remote sensing image analysis required the information stored in the GIS database for rectification and for the assessment of the classification procedure. A quantitative accuracy assessment was not possible for the procedures due to limited ground truthing. The use of GPS in field data collection was demonstrated by its use in delineating the boundary of a selected reserve. The GPS data was able to adequately display the reserve boundary, the spatial distribution of Taungya and farms along the boundary as well as relocated boundary pillars. All new layers of information generated from the research were displayed and stored in the GIS. Finally, the importance of the outlined procedures in the monitoring of Ghanaian forest and the limitations of the study were discussed.

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To the memory of my father: Mr. Ernest Edmund Asare.

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Veronica Nana Ama Asare.

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1.0 INTRODUCTION

Today's forestry is challenged as never before to meet diverse and conflicting demands on forestland and resources. Forests are a national heritage that must be protected in the interest of society; at the same time, they are a resource that must be utilized for the well being of that same society. In many instances, the latter function has dominated with little or no regard to the former. The result is a decline in forest resources.

The Ghanaian Forests are a significant component of the country's development. Besides ecological benefits, the forests contribute to the economic and social well being of the people. Ecologically, the forests protect the fragile tropical soils by preventing erosion and recycling nutrients. They also serve as a protective barrier against the dry northeast winds that blow over the country and maintains a suitable microclimate for agriculture particularly the production of the Ghana's most important crop; cocoa. Further, the forests protect watersheds and maintain biodiversity by providing a habitat for numerous plants and animals (Prah 1994).

Economically the forest industry is the third foreign exchange earner after cocoa and minerals. For example in 1995 timber exports contributed 9 percent of the total external earnings of Ghana and 11 % of the Gross Domestic Products (GDP) (FAO 1997). The industry employs over 100 000 individuals, and provides a livelihood for well over 3 000 000 people. In recent times the forest sector serves as support for the growing tourist industry (WTO 1997). The social contribution of the forests stems from the provision of the basic needs of the people in the form of non-timber forest products (NTFP) and many other intangible benefits such as cultural symbols, ritual artifacts and sacred groves.

Unfortunately, the exploitation of the numerous benefits from the forest has eroded the resource. Occasioned by the rapid population growth of the country, increasing phenomena such as shifting agriculture, logging, fuelwood harvesting mining and fire outbreaks have been claiming a great extent of the forests. It has been estimated that over 70 % of the original 8.22 million hectares of closed forest in Ghana have been destroyed (IIED 1992; Ntiamoa-Baidu 1992). The reduction of forests threatens ecological sustainability and socio-economic development. This realization coupled with increasing local and international outcry over environmental issues relating to forestry has stimulated the development of management tools to control forest depletion.

In order to focus the intervention of forest managers and environmental planners, the rate and impact of forest depletion must be monitored and well documented. Such information is essential to support the implementation of appropriate policy responses to forest depletion. Further, monitoring improves the basis for understanding the mechanisms or events that create changes in the forest ecosystem.

Previously, changes in the forest Ghanaian cover were not efficiently monitored and depletion rates were mere estimates or quotations from out-dated publications from 1960’s and 1970’s. However, the trend has changed and the issue of deforestation and forest management is receiving a great deal of attention. A major hindrance to setting effective monitoring mechanisms in place has been the prohibitive cost associated with conventional surveys. Financial constraints led to the abandoning of regular field surveys initiated in the sixties (Prah 1994). The need for a national inventory had long been expressed but was withheld due to similar constraints until the ODA provided financial assistance in 1985. From then until 1989 a total of 500,000 ha of reserves were sampled and inventoried using traditional survey methods (Francois 1989). Though valuable information relating to the status of Ghanaian forest was obtained the survey was time consuming and was not considered cost effective. The project was to continue to cover all forest reserves but once again it has been constrained (Flint and Hardcastle 1992).

The challenges of the national inventory have urged the resource managers to explore new ways of handling large volumes of forest resource data. There is the need for development of a method that is efficient, cost effective and rapid for change detection, documentation and mapping of the forest environment. Much interest has been expressed in the possibility of using remote sensing and geographic information systems (GIS). In this regard various workshops and training sections have been organized.

Remote sensing coupled with GIS play an important role in monitoring vast geographic areas. Remote sensing data are advantageous for characterizing land cover change because they are objective and spatially comprehensive. GIS is useful for describing, querying and displaying spatial patterns in vegetation cover. The integration of remote sensing image analysis and GIS to measure and monitor land cover change is therefore a logical and useful synthesis. Accordingly, this research targets the following objectives.

1. To evaluate the potential of image analysis with Landsat imagery to detect vegetation change in forest reserves over a period of time.
2. To map out the vegetation changes derived from Landsat image analysis in a GIS environment.
3. To propose an inventory system for on going monitoring of the Ghanaian forests.

2.0 LITERATURE REVIEW

2.1 FOREST RESERVATION

Forestry in Ghana dates back to 1906 when the timber protection ordinance was passed to control the felling of "commercial tree species" (TEDB 1991; MLF 1994). Prior to this period, exploitation of the forest was largely restricted to subsistence agriculture. Only small portions of the High Forest Zone were cultivated at any given time. Farmland was allowed to revert to forest after two or three years of cropping. As such almost all the High Forest Zone was covered with mature forest. Products, such as Gum copal, rubber and kola, which constituted the first products to be traded in, were obtained primarily in the wild from the forests. The first export crop of significance to be cultivated in the zone was coffee. There was also an upsurge in the production of oil palm for export in the mid-nineteenth century (Hall and Swaine 1981).

Yet all the foregoing, crops were insignificant compared to cocoa (*Thebroma cacao*) which was introduced in 1878. Upon its introduction, farmers in the eastern part of the zone eagerly adopted cocoa and by 1911 Ghana was the World's leading producer of cocoa; a position held until 1978. By 1900, the forests were rapidly being cleared for farming (especially cocoa farming). The alarming rate of forest destruction necessitated the formulation of legislation to reserve at least a portion of the forest (Hall and Swaine 1981). Accordingly, the Forestry Department was established in 1909. The main concern of the early foresters was the danger that the savanna would creep into the forest zone. This concern was based on the existence of little patches of savanna within the northern forest margin (Thompson 1910). A report by a British forester, H. N. Thompson (1910), stressed on the value of the forests as having significant influence on climatic conditions of the country and highlighted agricultural development as the main cause of deforestation. The need for governmental commitment and the enactment of forest legislation for the protection of the forests was also emphasized (Prah 1994). Consequently, a forest bill proposing the establishment of reserves was drafted in 1911. Opposition from local people who interpreted the move as a means for the Colonial Government to expropriate native land prevented the bill from becoming a law (Prah 1994). In Ghana, a system of multiple rights to land exists, whereby, land is owned by entire communities. Chiefs (stools) hold the land in trust, for the benefit of subjects. The stool could lease the land to farmers who paid taxes expressed as a share of produce from the land. Subjects of the stool had the right to hunt game, fish in rivers, pan rivers for gold and collect any other forest products not cultivated by the tenant (farmer) (Amanor 1996). It was the protection of these rights that prompted the local people's initial objection to forest reservation.

However, between 1909 and 1914, the Forestry Department toured the forest zone, improving knowledge of the flora and locating areas for eventual reservation until the First World War caused the closure of the department. After the war, the local authorities were persuaded to pass bylaws to reserve part of their forests voluntarily. However, the formation of reserves under the native bylaws was made slowly and as at 1923 only 260 km^2 had been reserved. Eventually, a forest ordinance was passed in 1927 giving the government power to order reservation where local people continued to resist. A target of 15 500 km^2 of reserves was set and by the beginning of the Second World War, in the face of much opposition, this target had virtually been achieved (Hall and Swaine 1981).

The main values of the forest were defined as shelterbelts against the Savanna winds, protection of watersheds, control of local climate and landscape stability (Hawthorne and Abu-Juam 1995). These values are depicted in the orientation, distribution and some of the small sizes of the reserves (Danso 1996).

Based on figures in the 1980's the proportion of each forest type that is reserved is Wet Evergreen 29 %, Moist Evergreen 31 %, Upland Evergreen 100 %, Moist Semi-deciduous 20 %, Dry Semi-deciduous 17 %, Southern Marginal 4 % and South-east Outlier 29 % (IUCN 1988).

Reservation did not alter ownership of forestland except in isolated instances where ownership disputes forced Government to purchase rights. The 1927 ordinance allowed two options for management of the reserves. Management could be either by the owners under the direction of Forestry Department or by the Forestry Department (on the Government's behalf) for the benefit of the owners (FAO 1986). In practice, the latter option was peremptory. The Forestry Department allowed the land-owning communities access to forest produce for domestic purposes only. Entry for commercial purposes requires the consent of the department (IIED 1993). The boundaries of reserves were clearly demarcated (FAO 1985) and cocoa farms existing within the boundary at the time of demarcation, were allowed to persist (Hall and Swaine 1981). Such farms are called admitted farms.

Planned forest management within the forest reserves of Ghana became operational after the adoption of the first forest policy in 1948 (Prah 1994; MLNR 1996). The reserves were categorized into working circles (WC) over which different management objectives were pursued. The working circles are:

- the productive WC which occupied 73 % of the total area reserved and is to be managed for the sustainable yield of timber;
- the protection WC occupying 27 % of reserves and managed solely for environmental purposes and;
- the research WC, which occupies an insignificant portion of reserves and managed for scientific research.

Implementation of sound management was restricted by lack of inventory data. Up to 1956, most of the productive forest was covered by 2.5 - 5 percent stratified random enumeration surveys. The survey, like management at the time was commercially oriented (Prah 1994) concentrating on the volume of marketable timber. The composition of Ghana's tropical forests is typical of its kind, a heterogeneous mixture of numerous species. Unfortunately exploitation is heavily biased towards very few species (Brookman-Amissah 1981). The species were grouped into four classes depending on their economic value at the time. Various silvicultural systems, involving various regimes of canopy manipulations were tried to induce natural regeneration and enhance the growth of the preferred species. However, the silvicultural systems induced the regeneration of less desirable, light demanding and fast growing species (Brookman-Amissah 1981; FAO 1985; Prah 1994). The silvicultural systems practiced included Tropical Shelterwood System

(TSS), Enrichment planting, Modified Selection System (MSS) and Girth Limit System. Prah (1994) gives details of the various silvicultural systems.

Concerns about the ability of the natural forest to meet the country's growing demand of wood in the long term also led to the adoption of the Taungya System from Southeast Asia. The system was basically an agroforestry approach where food crops were cultivated in alleys of tree crops until canopy closure. Of the estimated 500 km^2 of plantations that were established under the system only 105 km^2 (33 %) were considered successful. Teak was the most successful species cultivated. Indigenous hardwoods species were widely planted but with very low success (Prah 1994). As a result of the successive failure of silvicultural systems, permanent sample plots were initiated throughout the forest zone in 1969 to obtain information about growth and silvicultural measures necessary for satisfactory growth of the forest (Prah 1994).

2.2 DEFORESTATION

Deforestation is the clearance and conversion of forestland to other usage (Whitmore and Sayer 1992). From pre-agriculture to the present, scientific evidence suggests that the world's forest area has declined by one-fifth, from about 5 to 4 billion hectares (WRI 1990). Historically, the forests have diminished as pressures have been placed on them by expanding human populations. The need for land for non-forest purposes and demands on the timber resource have combined to reduce the forest resource. A countervailing force in favour of the forest, however, has been the recognition of the importance of the forest for environmental protection. As a result, in some places, especially in the temperate regions, marginal agriculture has ceased and the forest has been reintroduced, through both natural and artificial processes (Sedjo and Lyon 1990; WRI 1991). Forest management still poses acute policy issues, as industrialists, loggers, naturalists, hikers and hunters urge their conflicting interests, but in much of the temperate world, the forest area is stable (Repetto 1988; Sedjo and Lyon 1990).

In contrast, in the tropical regions of the world, the forest area continues to diminish (Repetto 1988; Sedjo and Lyon 1990; Johnson 1991; WRI 1991). Despite increased technology to assess the rate of tropical deforestation, figures are extremely variable and much debated. The most cited figures are those of the UN Food and Agriculture Organization (FAO) that initially specified the rate of Tropical deforestation at 11 million hectares per year; 7.5 and 3.8 million hectares of closed and open forests respectively (FAO 1981). Recent remote sensing revealed that these figures were underestimated. Hence, in 1990 the FAO released a new estimate of 17 million hectares per year whilst the World Research Institute (WRI) estimated 20 million hectares. Large as they are, these figures denote only the areas converted to other land uses. However, tropical forests are also deteriorating in quality. Each year, over four million hectares of virgin forests are logged becoming secondary forests (Melillo *et al.* 1985). Meyers (1980) summed the issue as:

> The tropical forests are undergoing conversion - including disruption, degradation, impoverishment, depletion and outright destruction, i.e. forms of conversion that range from marginal modification to fundamental transformation.

The situation is no different in the tropical forest of Ghana. Annual reports of the Forestry Department (FD) indicate that deforestation, which began about a century ago, has been accelerating. In Ghana deforestation is not efficiently monitored and current rates are best estimates (IIED 1992). Generally, it has been estimated that over 70 % of the original 8.22 million hectares of closed forest in Ghana have been destroyed (IIED 1992; Ntiamoa-Baidu 1992). More specifically, between 1937/38 and 1980/81 the area of the high forest reduced by 64 %. In the 1980's the annual rate of deforestation was estimated at 2 % (World Bank 1988). According to current estimates for 1990 - 95 this rate has been reduced to 1.3 % (FAO 1997), but this should be viewed in the light that only thirty percent of the resource remains.

2.2.1 Causes of Deforestation

Deforestation is prompted by population growth. In 1993 it was estimated that Ghana's 17 million population is rapidly increasing at a rate of 3.12. This rapid increase provides the impetus for the causes of deforestation, which include: increasing demand for agricultural land, fuelwood harvesting, logging, forest fires and mining.

2.2.1.1 Demand for Agricultural Land

Agriculture is the pre-eminent economic activity in Ghana. It supports 70 % of the population, occupies 65 % of the available land base, and contributes more than 50 % of the national revenue (Allotey 1988). The method of cultivation is the shifting agriculture or bush fallow and involves slashing and burning of forestland. Under the system long fallow periods allow the restoration of soil and vegetation cover to develop. Nonetheless, increase in demand associated with population growth, does not permit the long fallow periods necessary for forests to regenerate. Increased cash cropping has compounded the demand for subsistent agriculture (MLNR 1996).

Further, abetted by government policy that allowed the conversion of unreserved forestland, shifting cultivation has left very little forests outside forest reserves (Prah 1994; TEDB 1991). According to estimates in the annual reports of the FD, the proportion of forest outside reserves declined from 20 % in 1955 to 5 % in 1972. The most devastating aspect of shifting cultivation is the use of fire. During the dry season, fires occur in both the savanna and forests, many due to uncontrolled farm fires. Presently the demand for agricultural land is leading to encroachments in the forest reserves (IUCN 1988).

2.2.1.2 Fuelwood Harvesting

The prime source of energy in Ghana is from biomass, in the form of fuelwood and charcoal, which accounts for more than 80 % of the country's total energy consumption. In rural communities, where population is concentrated dependency on fuelwood exceeds 95 %. The average annual consumption is about 700,000 tones. However, most of this volume is derived from trees felled in the savanna zone and from logging residues (MLNR 1996). Actual contribution of the use of wood for fuel to deforestation has not been investigated. However, it is widely believed that the effect is concentrated in the transition and savanna zones and the impact on the high forest zone is minimal (MLNR 1996).

2.2.1.3. Logging/Timber Harvesting

Excessive logging has been an important contributor to deforestation. Initially, timber was extracted from unreserved forests. Logging preceded the conversion of these forests to agricultural land. As the forests outside reserves kept diminishing the bulk of the timber supplies from the reserves has increased. Timber extracted from the reserves has risen steadily from 13 % of total production in 1958, to 51 % in 1971, 58 % in 1973, 70 % in 1974, and 78 % in 1975 (Brookman-Ammisah 1981). Annual reports of the Forest Product Inspection Bureau (FPIB) indicate that these figures increased further to 82 % and 81 % in 1990 and 1991 respectively. After which period measures such as restriction of log export (MLNR 1996) and the withdrawal of degraded forest reserves from harvesting (Prah 1994) were taken to reverse the situation.

However, these figures relate only to data officially recorded by the FD and FPIB. By its' nature, illegal timber harvesting is difficult to determine. It includes extraction by authorized concessionaires who fell trees beyond yield specified by the FD and other operators who harvest trees without felling permits (MLNR 1996). Besides, logging damages the residual forest. A survey indicated that 10 % of established trees were damaged at an extraction rate of two trees per hectare (IUCN 1988). Further, the loading area and roads suffer particularly from soil erosion and poor regeneration (Hawthorne and Abu-Juam 1995).

2.3.1.4. Forest Fires

The increased battering of the forests would have had milder consequences had it not been for fires that run more readily through disturbed forest patches. It is well appreciated that fire cannot easily penetrate the intact closed forest due to the moisture retention capacity of the vegetation (Foggie 1962).

Fires occur annually in the dry season usually from November to May. Although some fires start from natural causes many result from activities of farmers, hunters and palm wine tappers. These fires which were previously a mild, peripheral and occasional threat have escalated due to the degraded nature of forests resulting from excessive logging (Hawthorne 1994; MLNR 1996).

Fire has a negative effect on forest regeneration contributing significantly to deforestation (MLNR 1996). Hawthorne, (1994) discussed the influence of fire on forest regeneration in Ghana. Burnt forests are dominated by weeds such as *Chromolaena odorata* (acheampong) (Danso 1996) and are more prone to burn in future (IIED 1993; MLNR 1996). Records indicate that, only 20 % of the High Forest Zone is covered by forest that has not experienced fires regularly (MLNR 1996). Currently, fire is the greatest threat to the long-term survival of the semideciduous forest, which constitute about 50 % of the forest area in Ghana (Ghartey 1989; Hawthorne 1991; MLNR 1996).

2.2.1.5 Mining and Quarrying for Minerals

Mining and quarrying for gold and diamonds, especially by the small-scale operators and large-scale mining for bauxite and manganese pose serious threats to forest in the High Forest Zone (MLNR 1996). Whilst underground gold mining uses substantial amounts of wood for pit props; surface mining operations remove both forest biomass and soils (Hawthorne and Abu-Juam 1995).

2.2.2 The Need to Control Deforestation

The impacts of forest depletion occur along multiple dimensions mirroring the many values of the forests. A well-managed forest is a constantly self-renewing resource producing many benefits (Poore and Sayer 1991). These benefits range from ecological through social to economic. Further, their influence extends from local to the global environment. Table 2.1 provides a summary of the benefits:

The harmful aspects of tropical deforestation have been documented at length (Barney 1980; Myers 1980, 1984; Kummer 1992). Negative effects of deforestation (like forest values) can be separated into three broad scales: macro (global), meso (national and regional), and micro (local) (Kummer 1992).

Table 2. 1 Summary of forest benefits at various levels. Source: Segura *et al.* 1996.

Benefits from the Forest	Global	National	Local
Maintenance of biological diversity	X	X	X
Climatic change	X	X	
Microclimate regulation			X
Maintenance of hydrological cycle	X	X	X
Soil and water quality conservation		X	X
Wind and noise control			X
Wood products			X
Non-wood products			X
Natural scenery	X	X	X
Recreation and ecotourism		X	X
Cultural and Religious services	X	X	X

The macro effect of reduced tropical genetic diversity due to deforestation is probably the most important and has received the most attention in the literature (Barney 1980; Myers 1980, 1984; Repetto 1992; WRI 1991). According to Myers (1984), the value of the tropical forests springs from their biological diversity. They constitute some of the world's oldest and richest ecosystems, containing more than fifty percent of all species of plants and animals on some six percent of the world's surface area (Poore and Sayer 1991; WRI 1991). Some of these species have made important contributions through their genetic resources to modern agriculture, medicine and industry. Genetic material from tropical forests have been used by plant breeders to produce disease and pest resistance in crops such as coffee, cocoa, bananas pineapples, maize and rice. Pyrethrins, rotenoids, and other insecticides have evolved in tropical plants and insect predators and parasites found in tropical forests control at least 250 different agricultural pests (Myers 1984).

Tropical plants are dominant in 80 percent of the world's health care. They have been used in the manufacturing of drugs for malaria, leukaemia, amoebic dysentery, hypertension etc. Current uses represent a minor fraction of the potential benefits as only a tiny fraction of these species has been investigated (Repetto 1988). Wilson (1992) stated that Tropical forests are a potential source of new wealth and scientific knowledge with unused plant reservoirs for food crops, pharmaceuticals, fiber, petroleum substitutes, and other products. Given the rapid rate of deforestation, the loss of species diversity has been estimated as three extinctions per day. At this rate, both current and potential benefits are being lost. Cures to AIDS and cancer may be lost before they are discovered (Johnson 1991; WRI 1990). Genetic material vital to crop stability and food security is also disappearing.

Besides the macroscale effect, reduced biological diversity due to deforestation has both mesoscale and microscale aftermath. The forest ecosystem provides a habitat for plants and animals that sustain local and indigenous population who rely greatly on this high level of diversity for minor forest products such as rattan, resins, gum, game, medicine and a vast array of naturally occurring foods (Johnson 1991; Kummer 1992). In Ghana, these minor products termed non-timber forest products (NTFP) feature prominently in the lives of the rural communities. Besides obtaining their basic needs, the rural people are sustained by the trade in NTFP. Important among these commodities includes bush meat (game), mushrooms, chewing sticks, food wrappers, traditional medicine and building poles

(Danso 1996). In places where forest cover have dwindled and reserves have became severely degraded few if any of these benefits remain. Because rural peoples' exploitation of the forest resource is largely confined to NTFPs many equate their fate to the rehabilitation of these forests. This dependence is vividly expressed in the lament of an old woman:

> The reserves have changed significantly because of excessive logging and bush fires...much of the game have disappeared... there are fewer mushrooms, pestles, building poles and medicine and there is more sickness now (CFM 1995).

Besides, export earnings from NTFPs are rising steadily and constitute a new area of employment for Ghanaians.

Forest clearing also leads to marked changes in climatic conditions at all scales. These climatic changes are brought about through effects on components of radiation and water budgets (Mather and Sdasyuk 1991). Forests influence the composition and heat retaining capacity of the atmosphere and the heat and water exchange characteristics of the earth's surface. Dwindling forest cover therefore results in instability in hydrological regimes (POORE AND SAYER 1991). A major hypothesis links deforestation to increase surface reflectance (albedo) and hence to surface temperature changes that could influence precipitation (Myers 1988).

In Ghana, there have been recording of more erratic rainfalls and droughts as the area under closed forest has diminished (TEDB 1991). The Ghanaian forests also serve as a protective barrier against the dry Northeast (Harmattan) winds that blow over the country between November and February maintaining a moist atmosphere for agriculture especially the production of cocoa the country’s most important commercial crop (Prah 1994).

On the macroscale, tropical forest destruction is contributing to increased atmospheric carbon dioxide levels. Biomass of the earth's various ecosystems act as reservoirs for carbon. The earth's forest stores 450 billion metric tons of carbon, which is 20 - 100 times, more carbon per unit area than croplands (WRI 1989). Not only the capacity to withhold carbon from the atmosphere is lost when forests are cleared; the stored carbon oxidizes and is released. For example the burning that follows most forest clearing in the tropics converts some of the stored carbon in vegetation into CO_2. As well, the decay of the remaining vegetation and the decline in soil organic matter adds additional CO_2 to the atmosphere contributing to global warming (Myers 1988). Deforestation is second only to the burning of fuels as a source of atmospheric carbon dioxide. Current estimates of such emissions range from 10 to 30 percent of the global annual carbon dioxide increase (Johnson 1991).

At the mesoscale and microscale, other effects of deforestation which, have received attention are large-scale soil erosion, land degradation, and flooding (Kummer 1992). Forests protect watersheds and ensure adequate quality and flow of fresh water. The multi-storied structure of the tropical forests with its vast amount of foliage helps break the impact of tropical downpour on the soil. This allows rainfall upon reaching the ground to percolate steadily into the soil or run off into streams and rivers at a gradual rate (Myers 1985). Conversely, the removal of forest cover (especially on sloping land) leads to soil erosion, increased runoff, and sedimentation that may increase downstream flooding during the rainy season or decreased stream flow in the dry season (Barney 1980; Myers 1980). In addition, erosion leads to the removal of the thin upper layers of soil and reduces the organic matter content and the potential for regeneration (Korem 1985; Zaimeche 1994).

Moreover, many tropical rainforest ecosystems survive on poor soils by quickly recycling the nutrients leached from dead leaves, plants and other organic matter before they can accumulate and decay in the top layer of the soil as in most temperate forests. Other vegetation such as agricultural crops is unable to duplicate this rapid and complex recycling ability of the rainforest. Consequently, the removal of the rainforest is accompanied by soil degradation through erosion and laterization or other processes (WRI 1991).

The issue of soil degradation is very important in Ghana. Ghanaian soils are susceptible to all forms of erosion. It has been observed that most soil nutrients are found in the topsoil (15 - 20 cm depth) and that the organic matter and plant nutrient content decreases sharply just below the topsoil. These soils are fragile and light textured and erode readily when devoid of vegetation. High incidence of erosion due to the removal of vegetation cover has been reported in some areas of Ghana (Asare 1992).

In addition, on the mesoscale and microscale, sustainable economic opportunities from timber are lost as potentially productive forest is destroyed (Kummer 1991). Indeed the economic development of many nations has been closely linked to the forest through the timber industry. In many places forests are still valued in terms of usable timber (Johnson 1991). Similarly the timber industry in Ghana plays a significant role in the nation's economic development. It is the third most important foreign exchange earner after cocoa and minerals. In 1995 timber exports contributed 9 percent of the total external earnings of Ghana and 11 % of the Gross Domestic Products (GDP) (FAO 1997). The industry employs over 100 000 individuals, and provides a livelihood for over 3 000 000 people. In a country where the level of unemployment is as high as 20 percent, the industry's ability to maintain such a level of employment is very significant (ACWP 1997).

Yet still another microscale effect is the loss of fuelwood. In the dry tropics this may be the immediate harmful effect of deforestation as it is the largest form of forest drain in such areas (FAO 1987). In Africa, deforestation has already meant large increases in time spent on fuelwood gathering (particularly by women). In Ghana, the prime source of energy is fuelwood and charcoal and in rural communities, where population is concentrated dependency on fuelwood exceeds 95 % (MLNR 1996).

Additional mesoscale and microscale effects include the loss of amenity and recreational resources as well as loss of cultural heritage. Forests enhance the scenic quality of the environment and provide opportunities for outdoor recreation for local residents and foreign visitors. As such, they serve as support for the development of tourism (Poore and Sayer 1991). In Ghana the tropical rainforests have been developed into nature parks for the ecology-minded tourist. Unique ecosystems where colonies of monkeys live in symbiotic relationship with the local human community as in the nature sanctuary at Buabeng-Fiema village in Brong Ahafo provides a great source of tourist attraction. Other rainforest related tourist attractions include the national parks at Kakum and the Ankasa Forest where the forests' nature trails provide a great way to view numerous birds and butterflies. Presently, tourism is the fastest growing sector of the Ghanaian economy. In the decade of 1985 - 1995, earnings from tourism grew from US $ 20 million to US $ 237 million, representing 3.5 per cent of GDP (WTO 1997).

Finally, Forests are part of the cultural heritage of the countries in which they occur. They contribute to the folklore and traditions of the people (Poore and Sayer

1991). In the stance of Ghana, the forests provide many intangible benefits such as cultural symbols, ritual artifacts and sacred groves. The sacred groves, which serve as burial grounds and sites for a variety of religious purposes often profoundly, influence local culture (Prah 1994).

Evidently, forests have an undisputed and vital role in sustaining the natural and human environment (FAO 1985). Consequently its depletion has adverse effects on all aspects of human existence. The recognition of this fact has initiated mechanisms and management practices to promote the sustainable yield of forest values.

2.4 FOREST INVENTORY IN GHANA

Forest inventory is a systematic procedure for collecting mensurational data on forest ecosystem, data processing and analysis, and summary presentation of the data by classes. In this sense, the forest inventory is defined as both the method of estimating the forest data and the estimates (the inventory) themselves (Cunia 1981).

To manage a nation's forest resources adequately, the forest manager must know where the natural resource occurs, their condition and their rate of change over time due to growth, mortality, or drain by harvesting in order to balance the many demands on the resource for optimum utilization. In this scheme of best use, inventory data are needed at all levels of management. The specific needs of management dictate the type of inventory utilized. The inventory systems can be classified as operational (stand), management, or national (regional) (Cunia 1981; FAO 1981a).

Operational or stand inventory is intensive and primarily designed to estimate the current values of the forest biomass. While estimates of forest growth may sometimes be of interest, they are seldom of primary concern. The data obtained from such inventory are used for specific purposes or for short-term planning such as timber sales, harvesting operations, planning silvicultural treatments or assessing the damage caused by epidemic diseases or insect, fires or windstorms (Cunia 1981; FAO 1981a).

The management inventory is designed to ensure a continuous flow of information about the general conditions of the forest resources (Cunia 1981). The inventory estimates apply to relatively large areas such as entire management units (Cunia 1981; FAO 1981a). The results are expressed as general statements about such factors as species composition, tree diameter distribution, average site quality and past trends in forest conditions.

Management inventory data are primarily used for medium- and long-range planning. They are used to calculate the allowable cut; to schedule logging operations (time and space); to plan for production increases; to make stand projections; or, to identify areas of applied research. In addition, the inventory system provides a means to monitor past stand projections. It provides an indication as to whether the consequences of the management decisions are as predicted (Cunia 1981).

The regional or national forest inventory is the most extensive, covering very large forest areas, such as an entire country or suitably defined geographic, economic, or political regions of the country. The main objectives are generally similar to those of the management inventory since estimates of both current values and rates of change of forest resources are normally required. However, the resource data collected are much more general in nature and they are used to address issues of national concern such as defining a national forest policy, expressing this policy as a set of laws and national programs, and creating the necessary organizational structure to carry out these programs.

In Ghana, the management of the permanent forest estates (forest reserves) has for a long time employed various field surveys to determine the volumes of timber as well as the growing stocks in individual reserves. The different types of inventory systems namely, operational, management and national are locally termed, stock survey, dynamic inventory and static inventory respectively.

2.4.1 Stock Survey

The stock survey provides quantitative information, which is used to determine whether or not a compartment within a reserve can be harvested. The survey provides information for the calculation of yield and identification of specific trees to be removed during harvesting. The process of stock survey and yield allocation for a standard 128-hectare compartment is costly and time consuming and may take up to a year. In order to avoid the expense of time and money on a compartment that may not be eligible for harvesting a pre-survey compartment inspection is carried out prior to the stock survey (FD 1995).

Compartments within forest reserves are demarcated based on written schedules. The initial step of planning a harvest is to produce a compartment map at a scale of 1:10 000 from the written schedules. The compartment map becomes the basis for the logging plan and is updated with information from both the pre-survey compartment inspection and stock survey (FD 1995).

The pre-survey compartment inspection is planned on the map. Access to the compartment is chosen and the areas to be inspected are sketched on the map before fieldwork begins. The inspection is conducted in three separate locations within the compartment covering one fifth of the total area of the compartment (FD 1995). During the inspection process, information regarding topography, stocking of Class I species, forest canopy and understorey conditions are recorded on the Compartment Inspection Form (appendix I). On the compartment map features to be considered during logging are marked. Such features include among others riparian areas, swamps, road and skid trail location and suitable sites for log yards (FD 1995).

Once the compartment Inspection has been completed, a decision is made whether or not to proceed with the stock survey. If a substantial portion of the forest has been degraded or topography is such that much of the forest cannot be logged, a stock survey is generally not carried out. On the other hand, if the compartment is found to be suitable for harvesting the stock survey operation proceeds. The total cost of the survey is borne by the concession holders (FD 1995).

A team of 15 specialists, whose competence in the survey procedure is tested periodically, conducts the stock survey. The team consisting of a Technical Officer (TO), two forest guards and twelve laborers is able to complete a survey of a standard compartment (128 hectares) within 20 days (FD 1995).

The survey is planned on the compartment map. The longest compartment boundary is selected as a base line and labeled "A" and the opposite boundary labeled "B" on the map. Strip lines numbered sequentially are marked along the length of the compartment running from "A" to "B" at thirty-meter intervals. Every odd numbered strip line is labeled as a survey line and even numbered strips labeled flank lines. Wooden posts to be erected at the beginning and end of each strip line are marked and numbered sequentially with a suffix "A" or "B" depending on which boundary it is located. Figure 2.1 shows the layout of the stock survey lines.

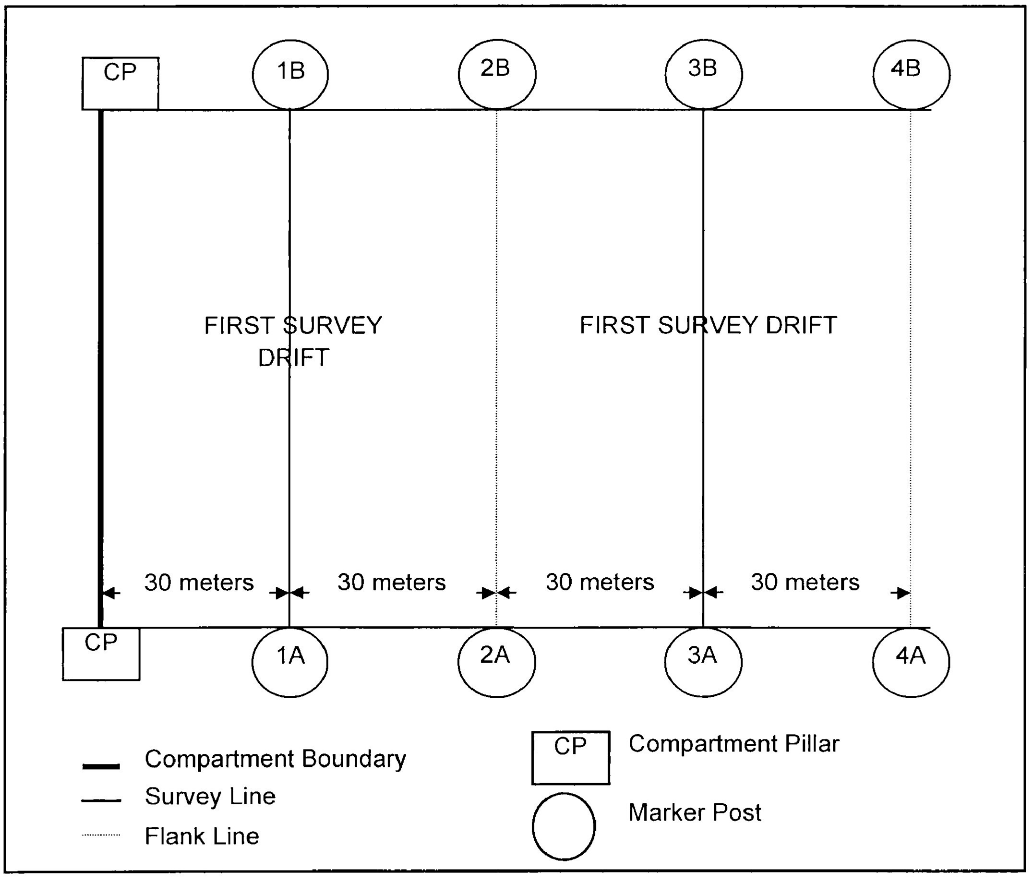

Figure 2. 1. Arrangement of stock Survey lines. Source: FD 1995.

On the field the survey commences with re-demarcation of the compartment boundary. The boundary is cleared of all vegetation to a width of two meters; any missing compartment pillars are replaced. Demarcation of strip lines begins from a corner of the compartment along the "A" boundary. The lines are cut parallel on a continuously monitored compass bearing and are also cleared of vegetation to a width of two meters. The stock survey team is allocated tasks as follows:

- The TO supervises all activities and records all the necessary information in the field book (appendix II).
- The forest guards (technical assistants) act as "sweepers" moving between the flank and survey lines and assist the TO by checking the accuracy of tree identification and measurements. They also ensure that all tree measurements are recorded.
- Two “tree spotters”, identify tree species, measure (non-buttress trees) and inscribe stock survey numbers on the trees.
- Hypsometer or tangent stick man and assistant measure the diameter of buttress trees.
- Two "chain men" measure the survey line.
- Two laborers clean (weed) the survey lines.
- Four laborers clean the boundary line.

The team is arranged on the field as in figure 2.2. Two strips on either side of the survey line are enumerated at a time to make up an enumeration drift of sixty meters wide. Information on all FIP class 1 species with a diameter of fifty centimeters or more is recorded. For each tree the subsequent information are recorded.

- The distance along the survey strip.
- The perpendicular distance from the survey line.

- A species code.
- The diameter at breast height (dbh).
- A serial number termed the stock survey number.

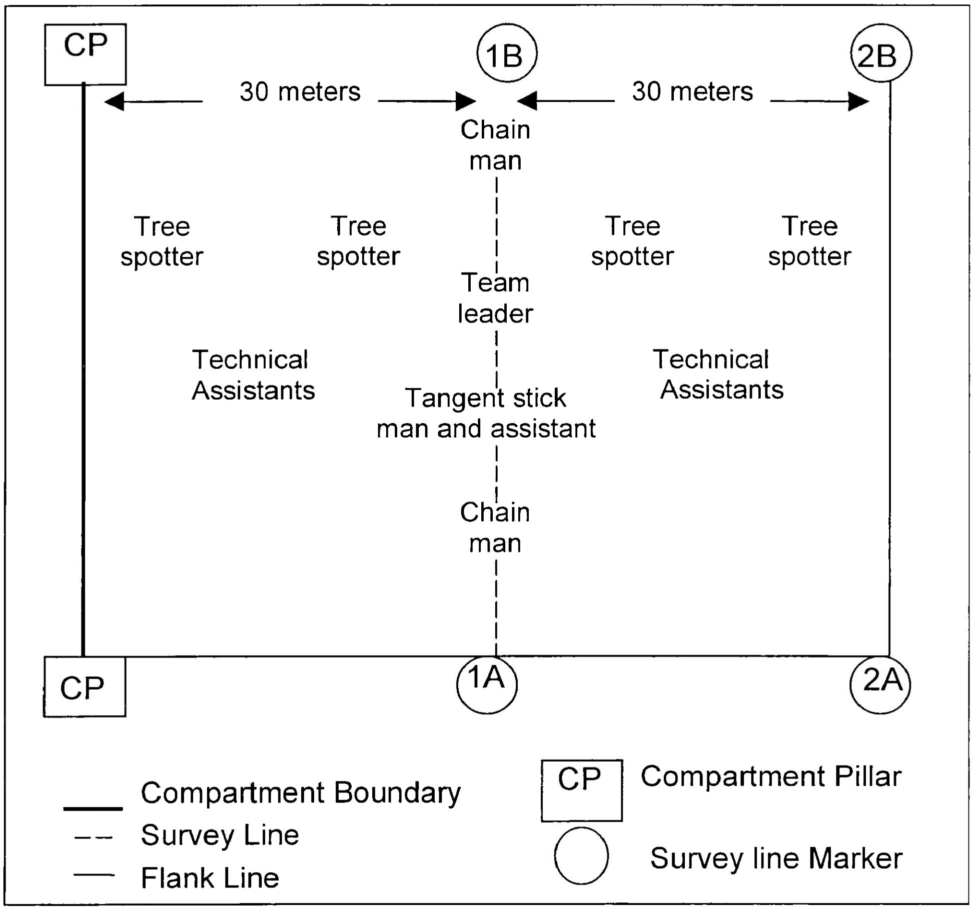

Figure 2. 2 Field Arrangement of the Survey Team. Source: FD 1995.

Further, site information and forest condition scores are also recorded. The site information include, ground slope recorded at every sixty meters along the survey line, rivers and streams, roads and skid tracks, swamps, farms, rocky outcrops and evidence of damage caused by fires. A forest condition score based on a visual assessment of the area in the immediate vicinity of the observer (approximately twenty-meter radius) is also recorded at sixty-meter intervals along the survey strip (FD 1995).

Upon completion of the stock survey a 10 % check survey is conducted (by a different team) to ascertain the accuracy of the stock survey. The check survey for a standard 128-hectare compartment consists of complete re-measurement of four enumeration drifts. It normally lasts two days.

2. 4.2 Dynamic Survey

In order to monitor the growth and dynamics of the forest continuously, Permanent Sample Plots (PSPs) have been established in some of the productive forest reserves since the 1960s. These plots were covered by a 2.5 - 5 % stratified random enumeration every five years. The intent was to obtain data on growth and mortality of the forest as well as a means of monitoring the effects of harvesting on the sustainability of the forest (Prah 1994). Initially only few commercially desirable tree species were measured. However, to reflect the increased use of species and the dynamics of the forest in more detail this method of selecting trees was abandoned in 1985 and all trees greater than 10 cm dbh are measured (Blackett 1989). All the measured trees are marked and numbered to enable comparative measurements during subsequent inventories. Presently, a total of 600 PSPs has been established: ten in each Forest Management Unit (FMU) within the High Forest Zone (Prah 1994). Data from the dynamic surveys are used to compute growth models and improve the allocation of yield.

2.4.3 The National Inventory (Static inventory)

The need for national growing stock estimates of the Ghanaian forests became paramount after the temporary shortening of the felling cycle in 1970's (Francois 1989). The ever-increasing pressure on the forest by the Timber industry exacerbated this need and gave rise to the fear that demand was outstripping supply (Blackett 1989). Unfortunately, a national inventory could not be undertaken due to financial constraints until some assistance was forthcoming under an FAO/UNDP project in the Subri Forest Reserve area in 1980. Although this project inventoried just about 150 000 ha of forest area, the project initiated the formation of a forest inventory unit within the Forestry Department (Francois 1989). The national inventory itself commenced in 1985 with financial assistance from the Overseas Development Administration (Francois 1989).

The national inventory, which was referred to as the Forest Inventory Project (FIP), was carried out in temporary sample plots obtained through a 0.25 % sample of reserves (Blackett 1989; Prah 1994). These reserves were selected by a stratified systematic sampling method. The stratification was based on the major ecological zones of the High Forest; the total area sampled being directly proportional to the reserved area within the zone (Blackett 1989). To achieve the 0.25 % sampling intensity one-hectare plots were laid out at intersections of a 2 x 2 kilometer grid. The grid was then randomly superimposed on maps of the forest reserves to select plot location. On the field, the plots were established using compass and chain survey from boundary pillars or other geographic features (Blackett 1989). All trees above 30-cm dbh in each sample plot were measured (Blackett 1989; Prah 1994). In all 1332 plots were enumerated covering an area of 546 600 hectares within 43 reserves (Blackett 1989).

The FIP as it was conducted was time involving and costly. It took about 4480 man months to complete the fieldwork and the total costs were 1.1 million pounds sterling from the ODA and 59 million cedis from the Government of Ghana. The project was to continue to cover the entire reserves but once again it has been constrained. The project revealed that though the reserve boundaries have stood to the onslaught of time the forest resource within them have significantly eroded.

2. 5 REMOTE SENSING

Remote sensing is the art and science of obtaining information about an object, area or a phenomenon from a distance (Fischer *et al.* 1976; Aronoff 1989; Lillesand and Kiefer 1994). According to Aronoff (1989), the science of remote sensing provides the instrument and theory to understand how objects can be detected whilst the art of remote sensing is the development and use of analysis techniques to generate useful information.

Remote sensors are made up of detectors that obtain information about natural phenomena by measuring electromagnetic radiation (EMR). The EMR covers a broad range of wavelength, travels at the speed of light (3×10^8 m s^{-1}) and interacts with objects upon reaching them (Aronoff 1889; Jensen 1996; Wilkie and Finn 1996). Interaction of energy and matter is object specific and therefore variations in the amount and wavelength of detected EMR give objects or phenomena distinctive spectral signature and makes it possible to distinguish between different features (Aronoff 1889; Jensen 1996; Wilkie and Finn 1996). Figure 2.3 exemplifies the reflectance characteristics of green vegetation, soil, and water in the visible and near infrared wavelengths of the electromagnetic spectrum.

Remotely sensed data are obtained using either passive or active remote sensing systems. Passive sensors record naturally occurring EMR (primarily solar radiation) that is reflected or emitted from terrain features (Jensen 1996; Wilkie and

Finn 1996). Two categories of passive sensors can be identified namely photographic and non-photographic. Photographic systems operate in the visible and near infrared portions of the spectrum (0.36μm - 0.9μm) whereas non-photographic sensors can operate from the range of X-ray to radio wavelengths (Barrett and Curtis 1992).

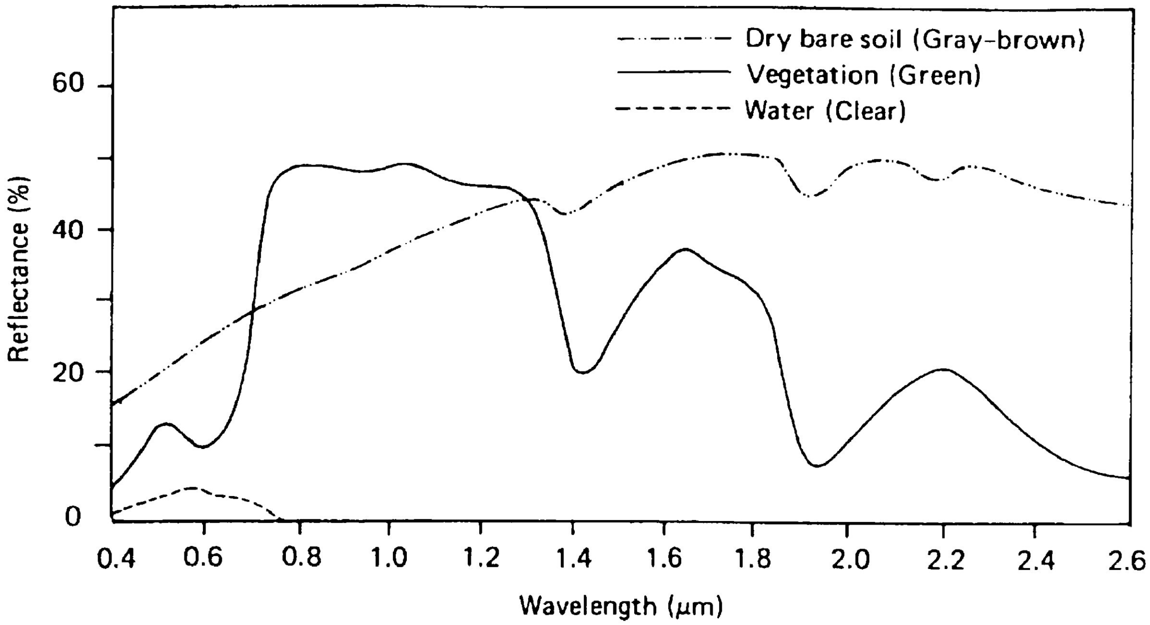

Figure 2. 3 Typical Spectral reflectance of soil vegetation and water. Source: Lillesand and Keifer 1994.

Active sensors on the other hand, bathe terrain with their own source of EMR and record the amount of radiation flux returning to the sensor system. Since such radiation are generated under relatively controlled conditions, much can be obtained about the way in which they are affected by features in the environment (Jensen 1996). Radio Direction and Ranging (Radar) is a common example of an active system exploiting EMR.

A major prerequisite for understanding both the practical and conceptual aspects of remote sensing is the knowledge of image resolution. In broad terms image resolution is the ability of the remote sensing system to record and display fine detail (Campbell 1996). Specifically four types of resolution can be distinguished: spectral, spatial, radiometric and temporal. Spectral resolution refers to the dimension and number of wavelength intervals in the electromagnetic spectrum to which a sensor is sensitive (Simonett 1983; Jensen 1996; Wilkie and Finn 1996). Spatial resolution is the size of the ground patch resolved by the sensor described either as an angular or a distance measure (Erdas 1997). Radiometric resolution defines the sensitivity of the sensor to differences in the intensity of radiant flux reflected or emitted from the terrain, object or phenomenon of interest (Jensen 1996; Wilkie and Finn 1996). That is the ability of the sensor system to record different levels of brightness values (Campbell 1996). Usually, this is referred to as the number of bits the recorded energy is divided into (Erdas 1997). Finally, temporal resolution indicates how often a sensor obtains imagery of a particular area (Erdas 1997; Campbell 1996; Jensen 1996; Wilkie and Finn 1996).

There are many Remote sensing data acquisition options available. These options can be generally classified based on three platforms: ground, airborne and spaceborne observation platforms. The figure below depicts Barrett and Curtis' (1992) classification of remote sensing platforms based on these categories. Each platform has its own particular advantages and disadvantages. Terrestrial and airborne platforms offer very high spatial resolution but provide localized and simultaneous coverage. Satellite (spaceborne) platforms on the other hand provide a more synoptic view of the landscape at a relatively coarse spatial resolution. As a result of the trade-off between spatial resolution and area coverage, selection of appropriate platform form depends on whether the question to be address is localized and refined or more regionalized and coarse-grained (Wilkie and Finn, 1996). However, it is not uncommon for remote sensing applications to involve multi-platform operations (Barrett and Curtis, 1992).

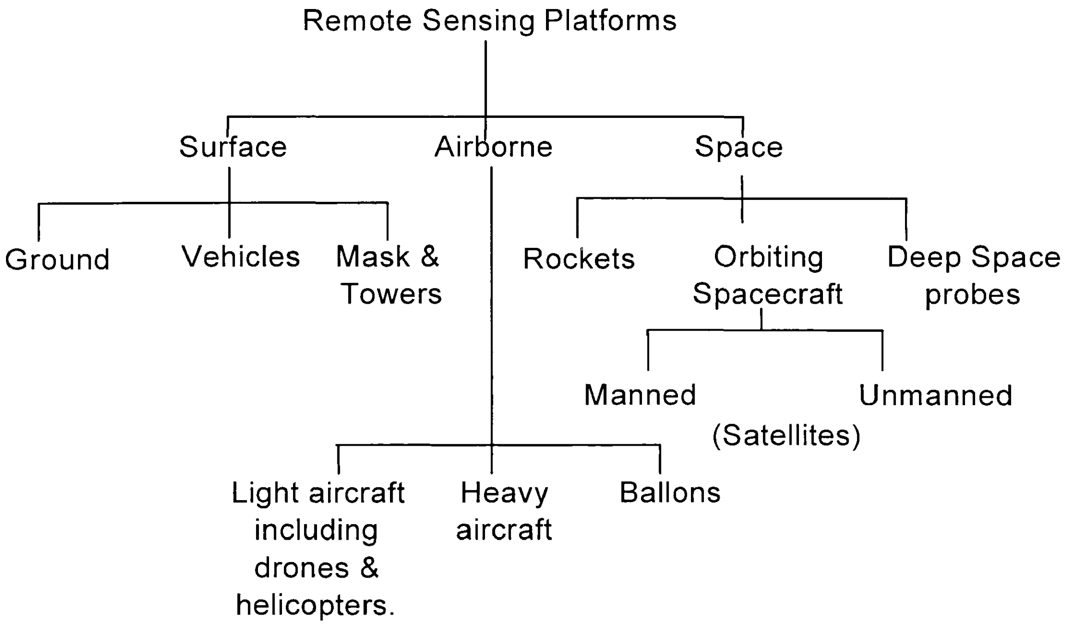

Figure 2. 4 Remote Sensing Platforms. Source Barrett and Curtis 1992.

In spite of the spatial trade-off, satellite platforms offer several distinct advantages over terrestrial and airborne platforms (Barrett and Curtis 1992; Erdas, 1997; Wilkie and Finn, 1996). These include but not exclusively:

- Stability of platform;
- Frequent and repeated coverage;
- Consistency in the manner in which data are recorded;
- Lower cost of obtaining and interpreting data for larger areas.

The listed capabilities renders satellite remote sensing well suited to monitoring many of the world's broad scale environmental problems (Campbell 1996).

2.5.1 Satellite Remote Sensing

Initial efforts aimed at imaging the earth surface from space were rather incidental outcome of the development of meteorological satellites. Beginning in 1960 with the series of Television and Infrared Observation Satellite (TIROS), early weather satellites return very coarse and virtually indistinct images of the earth's surface (Lillesand and Kiefer 1994; Campbell, 1996). As the sensors on board the meteorological satellites were refined the images become more distinct. The exciting future of remote sensing from space became even more apparent during the manned space programs of the 1960's: Mercury, Gemini, and Apollo. As earth resources imaging was not the primary goal of the of these endeavors hand held cameras were used and overall quality of the acquired images were poor. However, the ventures demonstrated that useful and sometimes unique earth resources data could be obtained from space (Lillesand and Kiefer 1994). According to Campbell (1996), these earlier systems provided both the design and operational experience necessary for the successful operation of current earth observation satellites.

Presently, earth observation satellites consists of scanners with sensors made up of detectors calibrated to record reflected electromagnetic energy as brightness values within specific regions of the EMS (Jensen 1996). Two important satellites that have provided the majority of remotely sensed digital images in use today are the EOSAT's Landsat and French SPOT satellites (Erdas 1997). The subsequent sections describe these satellites and the relatively new Indian Remote Sensing satellites, which offers very promising resolutions.

2.5.1.1 Landsat

The glances of the earth resources provided by the early meteorological satellites and manned spacecraft missions provided the impetus for NASA with the cooperation of the US department of interior to initiate a study of the feasibility of a series of Earth Resources Technology Satellites (ERTS) in 1967. The program resulted in a planned, sequence of six satellites that were given before launched designations as ERTS A, B, C, D, E and F to become ERTS 1, 2, 3, 4, 5 and 6 after successful launch into prescribed orbits. ERTS A was launched in 1972, as the first satellite designed specifically for the acquisition of data of the earth resources. Prior to the launch of ERTS B in 1975, NASA renamed the ERTS program Landsat (Land Satellites) program (to distinguish it from the planned seasat oceanographic satellites program) (Lillesand and Keifer 1994). Table 2.2 highlights the characteristics of Landsat 1 through 6 missions.

Table 2. 2 Landsat Missions.

Satellite	Launched	Retired	Sensors	Orbit
Landsat 1	23rd July 1972	6th January 1978	MSS, RBV	18 day/ 900 km
Landsat 2	22nd January 1975	27th July 1983	MSS, RBV	18 day/ 900 km
Landsat 3	5th March 1978	7th September 1983	MSS, RBV	18 day/ 900 km
Landsat 4	16th July 1982	Operational	TM, MSS	16 day/ 705 km
Landsat 5	1st March 1978	Operational	TM, MSS	16 day/ 705 km
Landsat 6	5th October 1993	Failed upon launch	ETM	16 day/ 705 km

The first generation of Landsat (Landsat 1, 2 and 3) were launched into a near circular, sun-synchronous, near-polar, orbit at a nominal altitude of 900 km. The orbit was selected so that satellite ground trace repeated its earth coverage at the same local time every 18 days. The satellites were also designed and operated to collect data over a 185-km swath. On board these satellites were two sensor systems: the Return Beam Vidicom (RBV) Camera and the Multispectral Scanner (MSS). The

RBV was a Camera-like instrument designed to provide relative to the MSS high geometric accuracy but lower spectral and radiometric detail (Barrett and Curtis 1992; Lillesand and Keifer 1994; Campbell 1996). On Landsat 1 and 2 the RBV system consisted of three (television-like) cameras aimed to view the same ground area simultaneously; each sensing a different segment of the spectrum such that the images they acquire register to one another to form a three band multispectral representation. On Landsat 3 the spatial resolution of the RBV system was improved through the implementation of a two-camera broad band system (i.e. two panchromatic cameras) (Campbell 1996). However, due to technical malfunctioning of the RBV sensors, the MSS replaced it as the primary sensors on all three satellites (Barrett and Curtis 1992; Lillesand and Kiefer 1994; Campbell 1996).

The MSS on board Landsat 1 and 2 was a four-channel system covering two bands in the visible and two in the near infrared wavelengths of the spectrum. In addition to these bands a thermal band was incorporated into the MSS onboard Landsat 3. Unfortunately, operating problems cause the thermal band to fail shortly after launch. Thus all three MSS systems effectively produced data in the same four bands. Table 2.3 details the characteristics of the MSS data. In general the data acquired by MSS, were found to be much better than anticipated and demonstrated the merits of satellite observation of the earth by proving its utility across a broad range of applications. Currently, the first three Landsat are no longer in service, nevertheless they have acquired a large library of images that are available as a worldwide baseline reference (Campbell 1996).

Table 2. 3 Characteristics of MSS data. Complied from Campbell 1996.

Band	Resolution			
	Spectral	Radiometric	Spatial	Temporal
1	0.5-0.6 μm	7 bits	79 m	18 day
2	0.6-0.7 μm	7 bits	79 m	18 day
3	0.7-0.8 μm	7 bits	79 m	18 day
4	0.8-1.1 μm	7bits	79 m	18 day

The second generation of Landsats (Landsats 4 and 5) carried an identical MSS as well as the Thematic Mapper (TM) which is a more sophisticated version of the MSS on an improved platform launched into orbits with similar characteristics as its predecessor but at a nominal altitude of 705 km. The lowered nominal altitude allows for a temporal resolution of 16 days (Barrett and Curtis 1992; Lillesand and Kiefer 1994; Campbell 1996).

The second sensor on board, the TM, is an advanced system incorporating radiometric and geometric improvements relative to MSS. The spectral improvements of the sensor include the acquisition of data in seven instead of four bands. Further, the wavelength range and the allocation of the TM bands have been chosen to improve the spectral differentiability of major earth features (Campbell 1996; Lillesand and Kiefer 1994). Table 2.4 lists the characteristics of TM data.

Table 2. 4 Characteristics of Landsat TM. Complied from Campbell 1996.

Band	Resolution			
	Spectral	Radiometric	Spatial	Temporal
1	0.45-0.52 μm	8 bits	30 m	16 days
2	0.52-0.60 μm	8 bits	30 m	16 days
3	0.63-0.69 μm	8 bits	30 m	16 days
4	0.76-0.90 μm	8 bits	30 m	16 days
5	1.55-1.75 μm	8 bits	30 m	16 days
6	10.4-12.5 μm	8 bits	120 m	16 days
7	2.08-2.35 μm	8 bits	30 m	16 days

The next in the series of Landsats (Landsat 6) was designed to occupy an identical orbit to Landsats 4 and 5. The sensor onboard, the Enhanced Thematic

Mapper (ETM) incorporated the same seven spectral bands with the same spatial resolution as the TM. The ETM's major improvement over the TM was the addition of a panchromatic band operating in the 0.50 μm - 0.9 μm range with a spatial resolution of 15 meters. Unfortunately, Landsat 6 with its ETM did not achieve orbit when launched on October 1993 (Lillesand and Kiefer 1994). Presently, the scheduled launch for Landsat 7 has been delayed due to necessary changes in the design of the electrical power supply of its main sensor (Isbell *et al.* 1998). This sensor, the Enhanced Thematic Mapper Plus (ETM+) is designed to response to improvements long requested by the data user community while maintaining the essential characteristics of Thematic Mapper type data. Similar to the ETM, the spectral bands present on the TM of Landsats 4 and 5 are part of the ETM+. Ground resolution remains unchanged at 30 meters, except for the thermal band that the resolution is increased from 120 meters to 60 meters. A panchromatic band with 15-meter resolution has also been added for rectification and image sharpening (Komar *et al.* 1998).

2.5.1.2 SPOT

Spot - Le Système Pour l'Observation de la Terre was conceived and designed by the Centre National d'Etudes Spatiales (CNES) with the cooperation of other European organization. From its inception the SPOT system was designed as a commercially oriented program to provide high quality service and data for an operational user community. Initiated in 1977 the program began operation in 1986 with the launch of SPOT 1. This was followed by SPOT 2 in 1990 and SPOT 3 in 1993 (table 2.5).

Table 2. 5 SPOT Missions. Compiled from Campbell (1996) and SPOT Image (1998)

Satellite	Launched	Status	Sensors	Orbit
SPOT 1	22nd February 1986	Backup to SPOT 2	HRV (2)	26 day/ 830 km
SPOT 2	21st January 1990	Primary Satellite	HRV (2)	26 day/ 830 km
SPOT 3	25th September 1993	Operational	H RV (2)	26 day/ 830 km
*SPOT 4	24th March 1998	Operational	HRVIR/ Vegetation Instrument	26 day/ 830 km

*Discussed subsequently.

All three satellites have a circular, near polar sun-synchronous orbit at a nominal altitude of 832 km. The orbit pattern for SPOT repeats every 26 days (temporal resolution). Additionally, SPOT sensors have oblique or off-nadir viewing capability, which allows the acquisition of data for a given area at frequencies ranging from successive days, to a few weeks. This increases the potential for acquiring good quality images of areas where cloud cover is recurrent or problematic. Alternatively, the same area can be imaged from separate positions (different satellite passes) to acquire stereo coverage (Lillesand and Kiefer 1994; Campbell 1996).

The SPOT sensors consist of two identical High Resolution Visible (HRV) imaging systems and auxiliary magnetic tape recorders. Each HRV has a ground swath of 60 km wide and can operate independently either in a panchromatic (PAN) or multispectral (XS) mode. In the PAN mode the HRV provides fine spatial detail but records a rather broad spectral region. On the contrary, in the XS mode the sensor records three bands of finer spectral resolution but coarse spatial resolution. The spectral and spatial image characteristics of SPOT PAN and XS are given in the subsequent table. It is possible to enhance the lower spatial detail of the XS images by superimposing them on the fine spatial detail of PAN images of the same area (Campbell 1996).

On March 24th 1998, SPOT 4 was successfully launched with enhanced performance and capability compared to its predecessors. A principal feature of SPOT 4 is the High Resolution Visible and Infrared (HRVIR) sensor, which is a modification of the HRV, ported on SPOTs 1-3. HRVIR is similar to the HRV but possess an additional spectral band in the middle infrared (1.58µm to 1.75µm) that offers better vegetation discrimination. In its multispectral (XS) mode therefore the HRVIR acquires four bands of data (1,2,3, and middle infrared) at a 20-meter resolution. In the monospectral mode, the 10-meter resolution panchromatic band (0.51µm to 0.73µm) has been replaced with a band identical to band 2 (0.61µm – 0.68µm). In other words, band 2 is operated in both a 10-meter and 20-meter resolution modes. This allows for onboard registration of all spectral bands (SPOT Image 1998).

Table 2. 6 Characteristics of SPOT images. Complied from Campbell 1996.

Band	Resolution			
	Spectral	Radiometric	Spatial	Temporal
XS 1	0.50-0.59 µm	8 bits	20 m	16 days
XS 2	0.61-0.68 µm	8 bits	20 m	16 days
XS 3	0.79-0.89 µm	8 bits	20 m	16 days
Pan	0.51-0.73 µm	8 bits	10 m	16 days

In addition SPOT 4 carries an auxiliary instrument termed the Vegetation Instrument. This Vegetation instrument is a wide-angle (2000-km-wide swath) earth observation instrument offering a spatial resolution of 1 km (at Nadir) and high radiometric resolution. It uses identical spectral bands as the HRVIR instruments (plus an additional band known as B0 (0.43-0.47 µm) for oceanographic applications). The ability of the high-resolution (HRVIR) and low-resolution (Vegetation) instruments to acquire imagery simultaneously, and their use of identical spectral bands offer unique advantages for easier interpretation at a variety of scales (SPOT Image 1998).

2.5.1.3 Indian Remote Sensing

The evolution of the Indian space program is quite unique demonstrating how effectively a high-technology program can be conceived and implemented by a developing country. Utilizing the benefits of international cooperation effectively, India today has a viable, integrated, self-supporting space program. After carrying out a series of air-borne remote sensing experiments, India set up a Landsat data reception center in 1975 to learn the art of remote sensing data reception, analysis and utilization (NASA 1998). From this modest beginning and following the successful demonstration flights of two coarse-resolution remote sensing satellites (Bhaskara 1 and Bhaskara 2 launched in the 1979 and 1981), the Indian Space Research Organization (ISRO) initiated a series of high-resolution earth observation satellites – The Indian Remote Sensing Satellite (IRS) – in 1988 (Government of India 1989; Campbell 1996). Currently, seven satellites have been launched in the series, six of which have been successful. The launch dates, sensors, and operational status of the various satellites are indicated in table 2.7.

IRS-1A and IRS-1B were launched into 22-day repeating orbits of 905-km mean altitude and 99 degrees inclination. Both satellites host a trio of Linear Imaging Self-Scanning (LISS) remote sensing instruments working in four spectral bands: 0.45μm - 0.52 μm 0.52μm - 0.59 μm, 0.62μm - 0.68 μm, and 0.77μm - 0.86 μm. LISS-1 images a swath of 148 km with a resolution of 72.5 meters the two identical LISS II instruments (LISS-IIA and LISS-IIB) exhibit a narrower field-of-view (74-km swath) but are aligned to provide a composite 145-km swath with a 3-km overlap and a resolution of 36.25 m (CHAART 1998).

Table 2. 7 IRS missions Complied from CHAART (1998); FAS (1998) and TELSAT (1998).

Satellites	Launch Date	Status	Sensors	Orbit
IRS-1A	1988		LISS I & II	22 days/905 km
IRS-1B	1991	Operational	LISS I & II	22 days/905 km
IRS-1E	1993	Lost at launch	LISS II	------
IRS-P2	1994	Operational	LISS II	24 days/817 km
IRS-1C	1995	Operational	PAN, LISS III, WiFS	24 days/817 km
IRS-P3	1996	Operational	MOS-A, MOS-B, MOS-C, WiFS	5days/817 km
IRS-1D	1997	Operational	PAN, LISS III, WiFS	24 days/817 km

IRS-1E, which was a modified IRS-1A, equipped with LISS-I and a German Monocular Electro-Optical Stereo Scanner was lost when its launch vehicle failed to achieve orbit in 1993. Subsequently, IRS-P2 was launched into an 817-km, sun-synchronous orbit with a temporal resolution of 24 days. IRS-P2 carried the LISS-II system similar to that of IRS-1A and IRS-1B but with a ground resolution of 32 m X 37m. The total swath width imaged by IRS-P2 is 131 km (CHAART 1998).

The Indian Remote Sensing began a new Era with the Launch of IRS-1C in 1995. This satellite and its identical twin IRS-1D launched in 1997 carry three different imaging sensors: A four channel LISS-III, a panchromatic scanner (PAN), and a two channel Wide Field Scanner (WiFS) (table 2.7). These satellites have a polar, circular, sun-synchronous 817-km orbit with a 24-day repeat cycle. In addition the PAN can be pointed for 5-day repeat off-nadir viewing. The LISS-III sensor provides multispectral data collected in four bands of the visible, near infrared and middle infrared regions. The spectral resolution and swath of the visible and NIR bands are 23.5 m and 141 km and that of the mid-IR region is 70.5 m and 148 km respectively. The Panchromatic sensor sacrifices swath width for higher resolution by providing data with a spatial resolution of 5.8 m at a ground swath of 70 km and a temporal resolution of 5 days. The 5.8-meter resolution can be resampled to 5 meters and is currently the best of any civilian remote sensing satellites. The third sensor - WiFS collects data in two spectral bands and has a ground swath of 810 km with a spatial resolution of 188.3 m (CHAART 1998).

Between the launching dates of IRS-C and IRS-D an experimental IRS-P3 was launched in 1996. This satellite carries two different imaging sensors: Modular Optoelectronic Scanner (MOS) and Wide Field Scanner (WiFS). The satellite has a polar, circular, sun-synchronous 817-km orbit with a 5-day repeat cycle. The MOS has a swath width of 200 km and provides 18 spectral bands with a 500 m spatial resolution in the visible, NIR and MIR wavelengths. The WiFS on the other hand has a swath width of 770 km and provides data with 188m spatial detail in three bands namely red, NIR and MIR (CHAART 1998).

2.6 GLOBAL POSITIONING SYSTEM

A relatively new technique of field data collection that is increasingly being employed in forestry is satellite navigation systems or Global positioning systems (GPS). GPS is a 24-hour, all weather satellite base radio navigation system developed by the United States Department of Defense (DoD). The system is composed of three segments: the space, control, and user segments. The space segment consists of a constellation of 24 orbiting satellites, in about 20 000 km orbits. The control segment is a network of five ground stations that operate and closely monitor the satellites' orbits so that precise locations of the satellites are known. The user segment consists of the GPS backpack or handheld receivers and a worldwide user community (Clarke 1997; Hoffmann-Wellenhof *et al.* 1994).

Essentially, satellites and ground base receivers transmit similar coded radio signals such that the time delay between emission and reception can be used to compute the distance between the satellite and the receiver. Three or four range measurements can be used to establish a three-dimensional position. The accuracy of the GPS computed position ranges from “geodetic quality” (within centimeters) to “resource quality” (within meters) depending on the receiver quality and collection method (Jasumback 1992).

Kruczynski and Jasumback (1993) classified GPS accuracy into four generic levels. Of these two are based on autonomous operation (the use of one receiver) whilst the other two are based on differential operation (the use of a second receiver at a known location). Level 1 accuracy, termed the standard position service (SPS) is achieved by autonomous operation of a GPS receiver and includes an error deliberately induced by the DoD. This error source is referred to as selective availability (SA) and it is regulated such that SPS yields a horizontal accuracy of 100 meters (2 drms). The SPS is provided at no cost to civilian and commercial users worldwide. The U.S. military, its allies and a select number of authorized users, use a decryption key to remove the SA errors and obtain a level of service termed the Precise Positioning Service (PPS) with a specified accuracy of 16 meters. In practice there are several additional sources of errors besides SA that affect the accuracy of a GPS derived position. These include satellite clock and ephemeris errors, errors due to poor satellite geometry, (Geometric Dilution of Precision (GDOP)), unmodeled ionospheric and tropospheric effects (atmospheric delays) and Multipath errors (the combination of direct and reflected signals) (NRC 1995; Kruczynski and Jasumback 1993).

Users can overcome most of these errors with the exception of Multipath by the use of differential GPS (DGPS) techniques. DGPS is based on knowledge of a highly accurate geodetically surveyed location of a reference or base receiver. The reference receiver computes a correction factor by comparing its known location to the GPS derived position or observed code ranges. The correction factor is then applied to a roving or field receiver to obtain an improved position (NRC 1995; Kruczynski and Jasumback 1993; Hofmann-Wellenhof *et al.* 1994). This usually occurs as a post processing task using data recorded at a base station or can be performed in real time by the use of a radio link between the reference and the field receivers. The capability of DGPS is based on the fact that GPS satellites error sources are comparable over a region of 500 km and are therefore virtually eliminated by differential processing. However, multipath errors, since they are not common to both receivers (reference and field) cannot be removed by differential techniques and can only be reduced by a multipath antenna. Proper algorithms are important to an accurate, differential GPS solution. If the receiver uses the code that modulates the GPS carrier frequency, differential GPS can yield accuracy between 3 to 6 meters (Trimble 1999). This type of DGPS that is achieved from code-phase measurements can be referred to as level 3. In level 4, referred to as the carrier phase, the receiver actually measures the phase of the carrier signal. The carrier phase usually requires the use of dual frequency receivers. Typical accuracy for this level is in the order of a centimeter; but it requires mathematically intense computations, and operations are sensitive to signal blockage and user motion (Kruczynski and Jasumback 1993; Hofmann-Wellenhof *et al.* 1994).

Numerous applications of GPS for field activities in forestry have been documented (Kruczynski and Jasumback 1993; Lui and Brantigan 1995; D'Eon 1995; Gillis and Leckie 1996; Courteau 1996; Tortosa and Beach 1996). The impact of the technology is due to cost and time savings as well as accuracy improvements over traditional mapping and surveying methods. Another major advantage of GPS over these traditional methods is that its use does not require a line of sight between adjacent surveyed points. Further, the ability to walk or drive around collecting co-ordinate information at sample points by GPS has obvious implications.

Generally monitoring forest condition and inventories involve the use of permanent sample plots (PSP) and temporal sample plots (TSP). Work by D'Eon (1995) showed that GPS offers quick, accurate, precise and easy solution to the problem of reporting the location of these sample plots. Another study by Liu and Brantigan (1995) compared differential GPS for forest traverse surveys with the compass-and-chain surveys in eight forest stands and established that DGPS surveys of forest stand boundaries could meet or exceed accuracy standards and is more cost-effective than the traditional compass-and-chain traverse. In operational forest management Courteau (1996) indicated that among other things, GPS navigation means rapid and accurate cutblock boundary demarcation, monitoring of machinery, accurate location of sample plots and rapid harvest plan updates as every harvested tree can be georeferenced along with its diameter and species. In a field test in Zaire, Wilkie (1989), observed that GPS performed under demanding conditions and was able to obtain three-dimensional positions in inaccessible areas often moderately enclosed by vegetation. He thus concluded that GPS technology is practical means of obtaining accurate geographic location data in inaccessible, poorly mapped regions of the world. GPS data have also proved effective in mapping forest fires (Tortosa and Beach 1996; Lawrence *et al.* 1995), surveying and updating forest road network (Gillis and Leckie 1996; Johansson and Gunnarsson 1998; Lawrence *et al.* 1995; Eggleston 1992), mapping clear cuts (Bergetron and Jasumback, 1990) and real-time monitoring of thinning performance (Thor *et al.* 1998).

2.7 GEOGRAPHIC INFORMATION SYSTEMS

The scope of Geographic Information Systems (GIS) is extremely broad integrating many subject areas (DeMers 1997). Attempts to incorporate all these subject areas have resulted in numerous definitions of the term GIS each developed from a different perspective or disciplinary origin (Chrisman 1997). Cowen (1990) argues that GIS is best defined as a decision support system involving the integration of spatially referenced data in a problem solving environment. This definition well emphasis the ultimate application of GIS. However, most common definitions emphasize the main components as well as sub-functions of GIS (Clarke 1986; Rhind 1988; Dueker and Kjerne 1989; Aronoff 1989). Accordingly, the term GIS is applied to computer-assisted systems (hardware and software) for the capture, storage, retrieval, analysis, and display of geographically referenced data.

Geographic data are commonly classified into three fundamental components of attribute, space and time (Chrisman 1997; Aronoff 1989). Attributes describe the properties of features and are maintained in a database management system

(DBMS) while the spatial elements are described in one of two general types of spatial structure: vector and raster. Vector structures are those in which discrete elements, points, lines, and polygons, are represented digitally by a series of two-dimensional coordinates (x and y) which imply magnitude and direction (Smith and Maidment 1995). A raster or cell-based structure is represented by a geometric array of rectangular or square cells, each with an assigned value. The third fundamental component of geographic information time though often not explicitly stated is critical as features at specific locations are described as they existed at a point in time.

Originally developed as a cartographic tool, GIS has evolved to be a powerful tool for spatial data management. GIS is characterized by the unique ability to overlay data layers and perform spatial queries to create new information, the results of which are automatically mapped and tabulated. Within a GIS, graphical elements depicting the location and shape of features are dynamically linked to attributes, allowing complex analysis of multiple spatial and non-spatial data sets (Aronoff 1989; Smith and Maidment 1995).

Forestry like many natural resources management applications employs a wide range of information ranging from forest inventories to identification of local community needs and markets. Organizing, analyzing and presenting relevant information to planners, policy markers and managers is thus a major component of forestry. Over the last two decades GIS concepts and applications have heralded a new era in forestry allowing the organization, evaluation and presentation of information in ways that were not previously possible. From its inception GIS has been associated with mapping of forest areas and other natural resources. Currently, GIS continues to be useful for automation of both conventional and thematic maps providing an effective solution to the problem of maintaining a current resource inventory since reports of recent burns, cuttings and applied silviculture can readily be incorporated in a GIS (Dangermond 1991). For example in North America, the earliest motivation for GIS in forestry was the ability to update inventory on a continuous basis by topographical overlay of records, reducing the average age of inventory from the existing 10 years to a few weeks (Tomlinson 1990). The production of GIS derived reports and statistics is equally important for monitoring and management related purposes.

The multi-thematic nature of GIS databases gives GIS unique modeling capabilities that can be used to provide simultaneous considerations of a number of issues in developing management plans. Simple models include automating the calculation of timber yields, locating land uses (haul roads, recreational facilities), selecting timber for harvest or conservation, identification of sensitive areas for preservation and evaluation of possible alternative approaches to managing forest stands. More complex modeling efforts include attempts to predict forest fires and how best they can be suppressed, effects of environmental pollution on forest ecosystems and how rapidly certain forest areas will become deserts or depleted. Further aspatial models can be developed to address the question of how economic, climatic, hydrologic and other processes interact with geographically disposed forest resources (Dangermond 1991).

2.8 INTEGRATING REMOTE SENSING, GIS AND GPS

Recent development in remote sensing, GIS and GPS offer new opportunities in handling spatial data. Advances in computer hardware and software make the technologies of GPS and GIS as well as the science of remote sensing available on the desktop so that decision makers in forestry and other natural resources fields can promptly address problems and make informed choices among alternative course of action (Green *et al.* 1995). Although these disciplines have evolved separately they are often integrated in one way or the other and used in various applications.

Ultimately, remote sensing and GIS are both used in acquiring, analyzing and reporting information about the earth's resources. As variants of digital data the two disciplines complement each other. Lachowski *et al.* (1992) indicated that the full range of benefits from GIS awaits on the quality of input data. The most important aspects of data quality are accuracy, timeliness and completeness. The extent of coverage of satellite imagery, locational precision, spatial and temporal resolution satisfies these requirements. The use of digital imagery offers the additional advantage of computer compatible format that can be input directly into GIS (Aronoff 1989; Lachowski *et al.*1992; Hoffer 1994; Jensen 1996). Consequently, digital satellite images have been used in conjunction with GIS for large area forest assessment (Lachowski and Dietrich 1979), change detection (Sader 1988) and statewide forest inventories (Winterberger and Laban 1988). Similarly, GPS generates a wealth of operational information that can be input directly into GIS (Gerlach 1990; Greer 1993; Kruczynski and Jasumback 1993; Courteau 1996; Johansson and Gunnarsson 1998; Hellström 1998).

On the other hand, remote sensing analysis can often be improved by ancillary information that can be retrieved from GIS (Jensen *et al.* 1994; Aronoff 1989; Lousma 1993; Price *et al.* 1994; Hoffer 1994) or derived by GPS (Zhang *et al.*

1997; Hoffer 1994; Gillis and Leckie 1996). Westmoreland and Stow (1992) indicated that optimum uses of ancillary data to facilitate digital image analysis require an understanding of the data in the context of a particular application and how it will contribute to the interpretation process. Understanding the rules and synergistic relationship between remote sensing and GIS can yield results that communicate effectively (Jensen 1996). Besides, most remote sensing data are eventually summarized as enhanced images, maps (image or thematic), spatial database, statistics or a graph. The final output may not only require remote sensing but the cartographic and or the statistical ability of GIS.

2.9 DIGITAL CHANGE DETECTION

This section describes the process of extracting meaningful change information from multiple date satellite imagery using image processing and GIS techniques. The basic processing steps include image preprocessing, change detection using GIS algorithms, image classification and accuracy assessment.

2.9.1 Pre-processing of Satellite Data

Inherent errors that can degrade the quality of remote sensing data often creep into the data acquisition process as a result of both the curvature of the earth surface and the sensor being used (Erdas 1997; Duggin and Robinove 1990; Lunetta *et al.* 1991). Such errors can in turn, have an impact on the accuracy of subsequent image analysis. As such it is usually necessary to pre-process the remotely sensed data prior to the major image analysis (Teillet 1986). Jensen (1996) states that both internal and external errors must be determined in order to be corrected. Internal errors, which are created by the sensor, are generally predictable and constant and may be determined by prelaunch or in-flight calibration measurements. Conversely external errors are variable in nature and result from platform perturbations and the modulation of atmosphere and scene characteristics. Such unsystematic errors may be determined by relating points on the ground (ground control points) to sensor measurements. Many authors (Teillet 1986; Crippen 1989; Helder *et al.* 1992; Jensen 1996) have given details of the various errors and how they can be corrected. Generally there are two types of data corrections: radiometric and geometric. Radiometric corrections address variations in pixel brightness values (BVs) or digital numbers (DNs) whereas geometric corrections address the relative positions of pixels (Jensen 1996).

2.9.1.1 Radiometric Normalization of Multi-Date Images

The use of multiple dates remotely sensed data to identify changes is depends on there being a vigorous relationship between remotely sensed brightness values (BVs) and actual surface conditions. However, the radiance or BVs of earth features measured by remote sensing systems is influenced by factors such as sun angle, Earth/sun distance, detector calibration differences (between the various sensor systems), atmospheric condition, and sun/target/sensor geometry (phase angle). Any extraction of biophysical information or multi-temporal analyses from remotely sensed data must be preceded by radiometric normalization corrections to match the detector calibration, astronomic, atmospheric, and phase angle conditions present in a reference scene (Jensen 1996).

Image normalization diminishes pixel BV variation caused by non-surface factors and ensures that image properties being analyzed are directly controlled by surface conditions or terrestrial features of interest. It is achieved by developing regression equations between the brightness values of "normalization targets" or pseudoinvariant ground target (i.e. targets that do not change from image to image) present in images to be compared.

2.9.1.2 Geometric Correction (Image Rectification)

Remotely sensed data commonly contains both systematic and unsystematic geometric errors. Most commercially available remotely sensed data have systematic errors corrected using platform ephemeris data or knowledge of internal sensor distortion. Unsystematic errors however, unless processed remains in the image rendering it nonplanimetric. The process of projecting an image onto a planar surface using a polynomial order such that it has the integrity of a specified map and conforms to other geocoded images is termed Image rectification (ERDAS 1997). Image rectification involves two basic operations namely spatial and intensity interpolation.

Spatial interpolation involves identifying the geometric relationship between input image pixels locations (source ground control points) and the associated map coordinates of the identical points (reference ground control point). Polynomial equations are then fitted to the ground control point (GCP) data using least square regression to model the distortions between corresponding GCPs. The choice of the order of the polynomial equation depends on the distortion in the imagery and the degree of topographic relief. Images of hilly terrain generally have greater distortion and require the use of higher order polynomials (non-linear) as compared to less complex images of flat terrain which may require a first order (linear) transformation (Jensen 1996; ERDAS 1997).

When the transformation matrix is calculated the inverse of the matrix is used to retransform the corresponding reference GCPs back to the source GCPs' coordinate system. Any disparity between the source and the retransformed GCPs represent image distortions not corrected by the transformation. Such distortions are expressed as a root mean square (RMS) error, which is a measure of the accuracy of the transformation. The RMS error is measured as distance in pixel widths of the input image and is calculated by the subsequent distance equation:

$$\mathrm{RMS} = \sqrt{(x_r - x_i)^2 + (y_r - y_i)^2}$$

where:
x_i and y_i are the input co-ordinates
x_r and y_r are the retransformed co-ordinates

Accurate spatial registration of images is essential for multiple date analysis such as change detection, since misregistration between the images may result in the identification of spurious areas of change. Jensen (1996) recommends that rectification for multiple date analysis should result in a RMS of 0.5 pixels or less.

The next phase of the rectification process is the intensity interpolation, which is commonly referred to as resampling. This phase involves the extraction of brightness values from the input unrectified image to the output rectified image. Since the grid pixels in the input and the output images rarely match, a resampling method is required for the calculation of new data file (brightness) values for the output image (Jensen 1996; ERDAS 1997).

2.9.2 Change Detection Algorithms

Significant efforts have gone into the development of change detection methods using remote sensing data (Jensen *et al.* 1987; Jensen *et al.* 1991, 1993; Wheeler 1993; Green *et al.* 1994). Various analytical approaches differing in complexity, computational intensity, and ease of interpretation have been employed in change detection studies. Some commonly used digital change detection approaches include:

- Write Function Memory Insertion Change Detection;
- Multi-Date Composite Image Change Detection;
- Image Algebra Change Detection;
- Post-Classification Comparison Change Detection;
- Multi-Date Change Detection Using A Binary Mask;
- Multi-Date Change Detection Using Ancillary Data and;
- Change Vector Analysis (CVA).

Jensen (1996) describes in detail these common change detection procedures and their relative advantages and disadvantages.

Write Function Memory Insertion Change Detection involves visual identification of change in the imagery whose individual bands has been inserted into specific write function memory banks (red, green, and/or blue) in the digital image processing system (Jensen *et al.* 1993b). The technique makes it possible to visualize and compare two and even three dates of satellite imagery at a time but does not produce a classified land cover database for the imagery involved. Nevertheless, it has been described as an excellent analog method for quickly and qualitatively assessing the amount of change in a region and might serve as an initial step in the selection of a more rigorous change detection techniques (Jensen 1996).

Multi-Date Composite Image Change Detection also referred to as Spectral-temporal Change Detection involves the extraction of change information by analyzing a single merged rectified dataset containing spectral data from multiple dates (multi-temporal image) in one of several ways. An unsupervised classification of the multi-temporal dataset as exemplified by the work of Muchoney and Haack (1994) will result in the creation of 'change' and 'no-change' clusters, which must be labeled accordingly by the analyst (Jensen 1996).

Principle component analysis (PCA) may also be used to detect change from multi-temporal datasets. PCA is a multivariate statistical technique that isolates inter-image change by transforming linear combinations of band data into components that account for the maximum (1^{st} component) and successively lower proportions (2^{nd} and higher order components) of variance among image layers. When a multi-temporal image is subjected to a PCA based on variance-covariance matrices or a standardized PCA based on analysis of correlation matrices, the result is the computation of eigenvalues and factor loadings used to produce a new, uncorrelated image dataset. Usually, several of the new bands of information are directly related to change. However it may be difficult to interpret and label each component image. Nevertheless, the method is valuable and is frequently used. Lodwick (1979), Byrne *et al.* (1980), Richards (1984), Fung and LeDrew (1987, 1988) and Eastman and Fulk (1993) have used PCA in land cover change detection. The advantage of all Spectral-temporal Change Detection is that only a single classification is required.

Image Algebra Change Detection is the identification of change between two images by image differencing or ratioing the same bands in two rectified images. Image differencing involves band-by-band subtraction of digital numbers (DNs) of imagery of one date from that of another (Jensen 1996). Frequently, a median value is added to the differenced dataset to eliminate negative values, prior to standard unsupervised classification. Examples of change detection derived by image differencing are provided by Robinove *et al.* (1981), Runesson (1992), Cablk *et al.* (1994), and Muchoney and Haack (1994).

Although broad-scale land use changes may often be readily detected using raw spectral data, more subtle changes such as vegetation stress may be more difficult to identify. In such cases, specific band ratios or band combinations may facilitate change detection. Perry and Lautenschlager (1984) review many of the most widely applied vegetation indices. In some instances both image differencing and band ratioing are applied in the change detection process. For example, Cablk *et al.* (1994) employed image differencing of Landsat TM 7/4 band ratios and NDVI data ((IR-R)/(IR+R)) to accurately identify forest stands affected by high winds and saltwater intrusion. In another example Green *et al.* (1994) employed image differencing of Landsat TM 3/4 of two images. A critical element of both image differencing and band ratioing change detection is deciding where to place the threshold boundaries between "change" and "no-change" pixels (Jensen 1996). The amount of change selected and eventually recoded for display is often subjective and must be based on familiarity with the study area. There are also analytical methods, which can be used to select the most appropriate thresholds (Jensen 1996).

Post-classification change detection requires rectification and classification of each of the remotely sensed images involved. The resultant classes from the two or more digital datasets are then compared on a pixel by pixel basis using a change detection matrix. The method is widely used and easy to understand and when conducted by skilled analysts it represents a viable technique for the creation of change detection maps. However, the accuracy of the change detection is heavily dependent on the accuracy of the individual date classification map (Rutchey and Velcheck 1993). Individual classification maps used in the post-classification change detection method must therefore be extremely accurate (Augenstein *et al.* 1991; Price *et al.* 1992). Wickware and Howarth (1981), Estes *et al.* (1982), and Muchoney and Haack (1994) provide examples of post-classification change detection.

Multi-Date Change Detection Using a Binary Change Mask involves a traditional classification of a rectified base (Date 1) image followed by the analysis of a multi-temporal image (Date 1 and Date 2) using various image algebra functions to produces a new image file. The results of the algebra is then recoded into a binary mask file, consisting of spectral "change" and "no-change" pixels between the two dates. The change mask is then overlaid onto the second image (Date 2) and only those pixels, which are detected as having changed, are classified in the second image. A traditional post-classification comparison can then be applied to yield change information. Many pixels with sufficient change to be included in the mask of candidate pixels may not qualify as categorical land cover change. The technique does not only reduce effort by allowing the analysts to focus on the area that has changed between dates but may also reduce change detection errors (omission and commission) (Jensen 1996). However the method is complex, requiring a number of steps and the final product depends on the quality of the "change/no-change" binary mask (Dobson and Bright 1993; Jensen *et al.* 1993a).

Multi-Date Change Detection Using Ancillary Data Source is simply the substitution of the base image with an existing land cover map. The second date imagery is classified and then compared on a pixel by pixel basis with the land cover map using post-classification comparison methods. Advantages of the method include the use of a well-known ancillary data source and the possible reduction of change detection errors (omission and commission). Also, only a single classification of the second image is required for the production of detailed change information. In addition, the final product can be used to up-date the land cover map (Jensen 1996). As with any post classification comparison, however, the accuracy of the change detection is based on the accuracy of both input databases.

Change vector analysis is an empirical method used to detect radiometric changes based on multidate satellite data, and is characterized by vectors representing the magnitude and direction of changes present in the data (Malila 1980, Michalek *et al.* 1993). Other applications of CVA are described in articles by Johnson (1994), and Lambin and Strahler (1994).

2.9.3 Image Classification

Image classification, also referred to as image segmentation, is the process of sorting pixels into a finite number of categories based on their DNs or data file values. During classification, statistics are derived from the spectral characteristics of all pixels in the image and the pixels are then sorted based on mathematical criteria. The classification process can be broken down into two parts - training and classifying based on a decision rule (ERDAS 1997). Training is the process of defining the criteria by which patterns are recognized and can be performed with either a supervised or unsupervised method. Standard supervised and unsupervised classifications are well documented.

In a supervised classification, the analyst "trains" the classifier by extracting mean and co-variance statistics for known phenomena in an image (Gong and Howarth 1990). These statistical patterns are then passed through a minimum-distance-to-means algorithm where unknown pixels are assigned to the class nearest in n-dimensional feature space, or to a maximum-likelihood classification algorithm, which assigns an unknown pixel to the class in which it has the highest probability of being a member. Care needs to be exercised in the selection of training samples (Mausel *et al.* 1990). In an unsupervised classification, the computer is allowed to query the multispectral properties of the image and identify a number of mutually exclusive clusters in n-dimensional feature space (Chuvieco and Congalton 1988). The spectral clusters must then be converted /labeled into meaningful categories such as Land Cover Classes.

2.9.4 Accuracy Assessment

Classifications of remotely sensed images are subject to error and uncertainty. To assess classification accuracy, ground truth (reference) data are needed for a number of sample locations for each class. Accuracy is defined in terms of misclassifications, where by a pixel is assigned to the wrong class. Misclassifications are usually presented in the form of a matrix, which is referred to as a confusion or error matrix. The error matrix can be used to generate various statistics that characterize the accuracy of a classification technique. For example, the overall accuracy compares the number of pixels correctly classified (those appearing on the diagonal of the matrix) to the total number of pixels sampled. Other statistics that can be generated from the error matrix include errors of omission (producer's error) and errors of commission (user's error). These are based on individual classes, and are achieved by dividing the number of pixels that are incorrectly classified by either the column or row totals, respectively. Additional discussion of accuracy assessment techniques can be found in articles by Congalton (1988, 1991) and Congalton and Green (1999).

3.0 STUDY AREA

3.1 THE HIGH FOREST ZONE OF GHANA

Ghana is situated in middle of the West Coast of Africa between latitudes 4° 44' N and 11° 11' N and longitudes 3° 15' W and 1° 15' E. (Borota 1991). The country extends northward from the coast for 676 km and 537 km at its widest point along the coast (Prah 1996). Overall, it covers an area of 238,539 km^2 (FAO 1986; Borota 1991). The vegetation is closely related to climate and can be classified into two major ecological zones namely the Savanna and the High Forest Zone (figure 3.1). The Savanna, largest ecological zone covers approximately two-thirds of the country's land area and can be distinguished into the Sudan Savanna, Guinea Savanna and the Coastal Savanna.

The study was based within the High Forest Zone, which is located in the southwestern third of the country. It covers an area of 8.2 million ha, approximately 34 % of the country. The forests, which characterize the zone, mask the fragility of the soils. These soils contain little humus and are extremely vulnerable to nutrient leaching, suffering a rapid decline in fertility when devoid of vegetation cover or subjected to intense cultivation. The area produces most of Ghana’s timber, cocoa, coffee and oil palm. The zone is characterized by two rainy seasons peaking in June and October. Temperature variation in the High Forest Zone is rather slight. The mean monthly maximum in the hottest month (February or March) is between 31 -

33 ^{O}C and the mean monthly minimum in the coldest month (December or January in the northern part and August in the south) is between 19 - 21 ^{O}C (Hall and Swaine 1981).

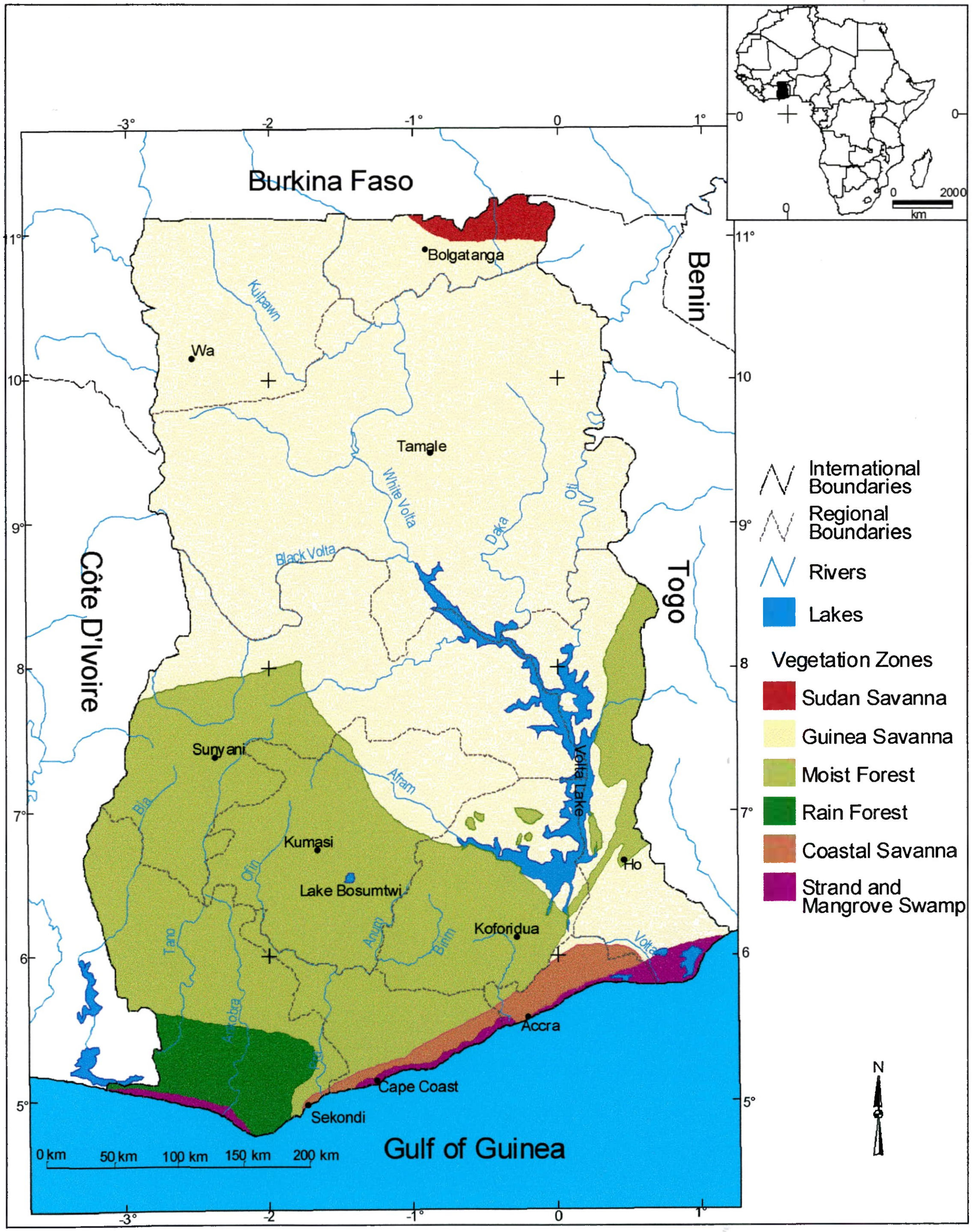

Figure 3.1. Ecological Zones of Ghana. Source: Atta-Quayson, 1987.

The forests exhibit a three-storey structure in addition to a herbaceous ground flora and shrub layer (Prah 1996). There is a lower storey of heavily branched trees about 20 meters in height. Above this is an upper canopy with trees up to 40 meters in height and a discontinuous emergent layer of trees up to 65 meters (FAO 1985). The vegetation within the zone is diverse and largely determined by a complex interaction of environmental factors with particular reference to rainfall and its distribution throughout the year (Baidoe 1968). There is a gradual change in the forest, from the southwest where the rainfall is highest and forest is evergreen, towards the Savanna boundaries in the east and north where the forest is dry and deciduous. Various categorizations of this variation have culminated into the classification of Hall and Swaine (1976) of forests. Seven types of forests have been identified: the Wet Evergreen, Moist Evergreen, Upland Evergreen, Moist Deciduous, Southern Marginal, Southeast Outlier, and the Dry Deciduous forests (figure 3.2).

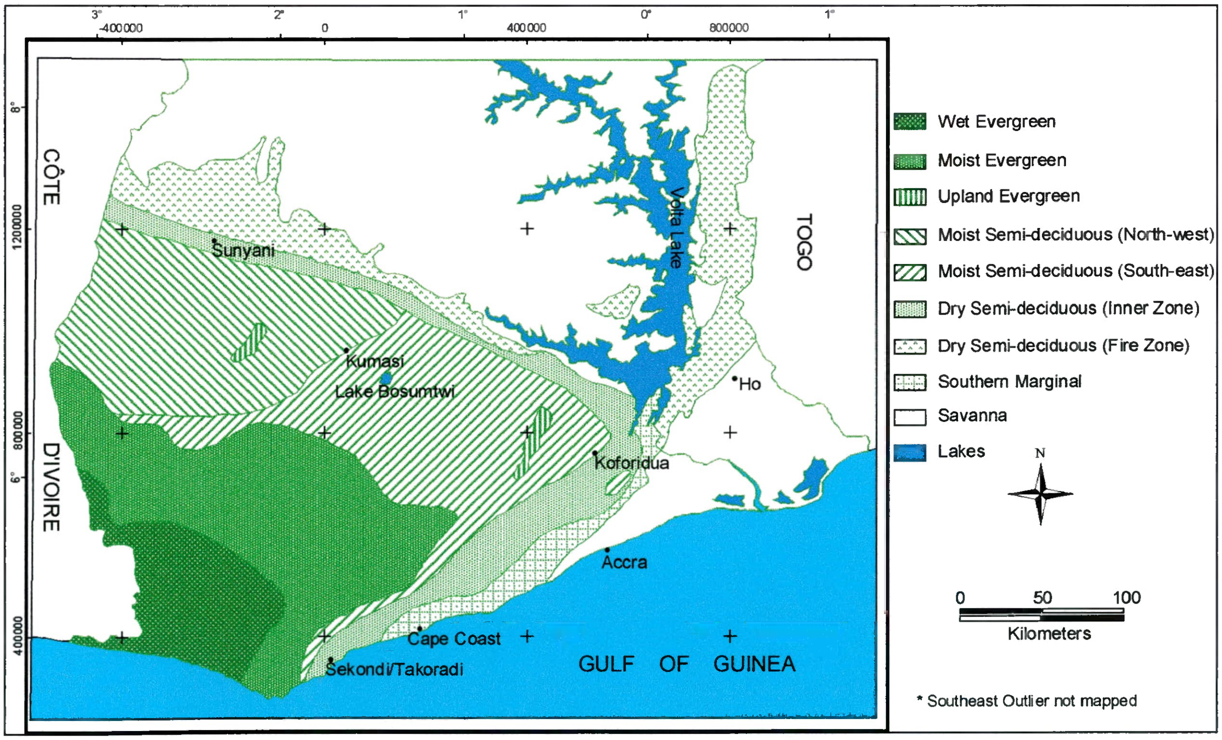

Figure 3.2. Forest Types within the High Forest Zone.

Based on the availability of appropriate satellite data (discussed in the next chapter) three reserves were selected for the study. The next subsection describes the selected reserves, which included Asukese, Bia Tano and Tinte Bepo forest reserves.

3.1.1 Asukese Forest Reserve

The Asukese Forest Reserve (figure 3.3) together with Amama Shelterbelt constitutes the Forest Management Unit (FMU) 17. The FMU, which covers an area of 31119 ha (311.19 km^2) is currently located in the Sunyani Forest District and lies between latitudes 7^{O} 05' and 7^{O} 15' north, and longitudes 2^{O} 24' and 2^{O} 38' west. The reserve boundaries like all other reserves are pillared at 800-meter intervals and at all major changes in direction. The Asukese Forest Reserve was constituted under the Native Authority bylaws.

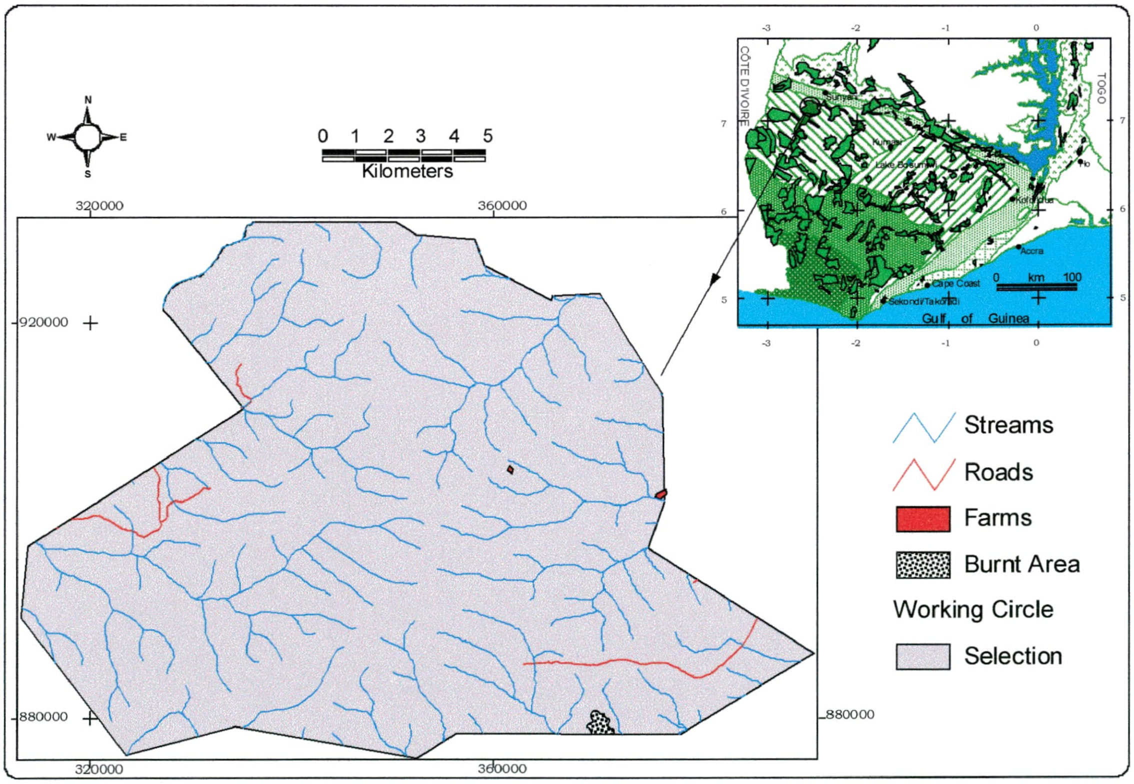

Figure 3.3 Asukese Forest Reserve

It was established in 1936 with ownership being vested in the then Governor of Gold Coast (Ghana) in trust for the land owning stools of Kenyase, Atronie, Ntotroso and Dorma (Nolan and Twumasi 1993).

The topography of Asukese has been described as a highly dissected plateau with an average altitude of 260 meters (Working Plan 1964). A crescent shaped ridge runs across the reserve from north to south connecting three knolls (hillocks) (all over 300 meters altitude) that form the watershed for the streams within the reserve. To the east of the watershed are wide valleys, which separate into two other knolls. Long U-shaped valleys dominate the western portion of the reserve (Nolan and Twumasi 1993).

A major drainage feature is the presence of a lake in the depression between the sources of Asukese and Kentewari streams, the two main streams within the reserve. The majority of streams and rivers flow in an east-west direction into the tributaries of the Bia and Tano Rivers. Most of the small streams dry up during the Harmattan season (Nolan and Twumasi 1993).

Asukese forest reserve lies in a humid climatic zone with the average rainfall of 1 270 mm. The highest recordings of rainfall are between May/June and September/October. The Dry Season or Harmattan in the months of December to March is quite evident with its typical hazy climate. The soils of the reserve are predominantly sandy loam; however, in the southeast portion soils are mostly silty clay. Deep, reddish-brown gritty clays are also present (Nolan and Twumasi 1993).

The reserve forms part of the MSNW Forest Type (Hall and Swaine 1976). Prior to exploitation, these reserves were composed of a three storied structure except in the southwest portion where there has been localized proliferation of emergents that reached a height of up to 50 meters. Presently, the reserves have been exhaustively exploited resulting in a highly degraded residual forest. Fires have also exacerbated the degraded conditions of the reserve, particularly in the north and eastern portion. Besides, fire is a major threat to the potential of afforestation in excessively logged areas. In severely damaged areas, there is no residual forest, only isolated large trees of uneven storied architecture, with the ground flora being entirely dominated by *Chromolaena* and *Marantaceae* (Nolan and Twumasi 1993).

3.1.2 Bia Tano Forest Reserve

Bia Tano forest reserve (figure 3.4) lies to south of Asukese forest reserve approximately between latitudes 6^0 49’ and 7^0 06’ and longitudes 2^0 40’ and 2^0 31’. This location covers an area of 18 787 ha. The relief is relatively gentle lying between 210 and 280 meters. The reserve is fairly well drained and forms part of the watershed for the Bia and Tano rivers from which it derives its name. A few waterlogged areas occur in depressions along the tributaries most of which dry up during the dry season (FD/ODA 1989). Ownership of the reserve is vested in the Golden stool with Akwaboa, Hiawu, Gyadu and Kumani Stools as the caretakers (Working Plan 1962). The reserve was established in 1937. Ecologically, Bia Tano possesses similar characteristics as Asukese forest reserve forming part of the MSNW forest type. Soils and rainfall patterns are also similar. The soils are forest ochrosols and annual rainfall exhibits the typical bimodal pattern of the High Forest Zone (FD/ODA 1989).

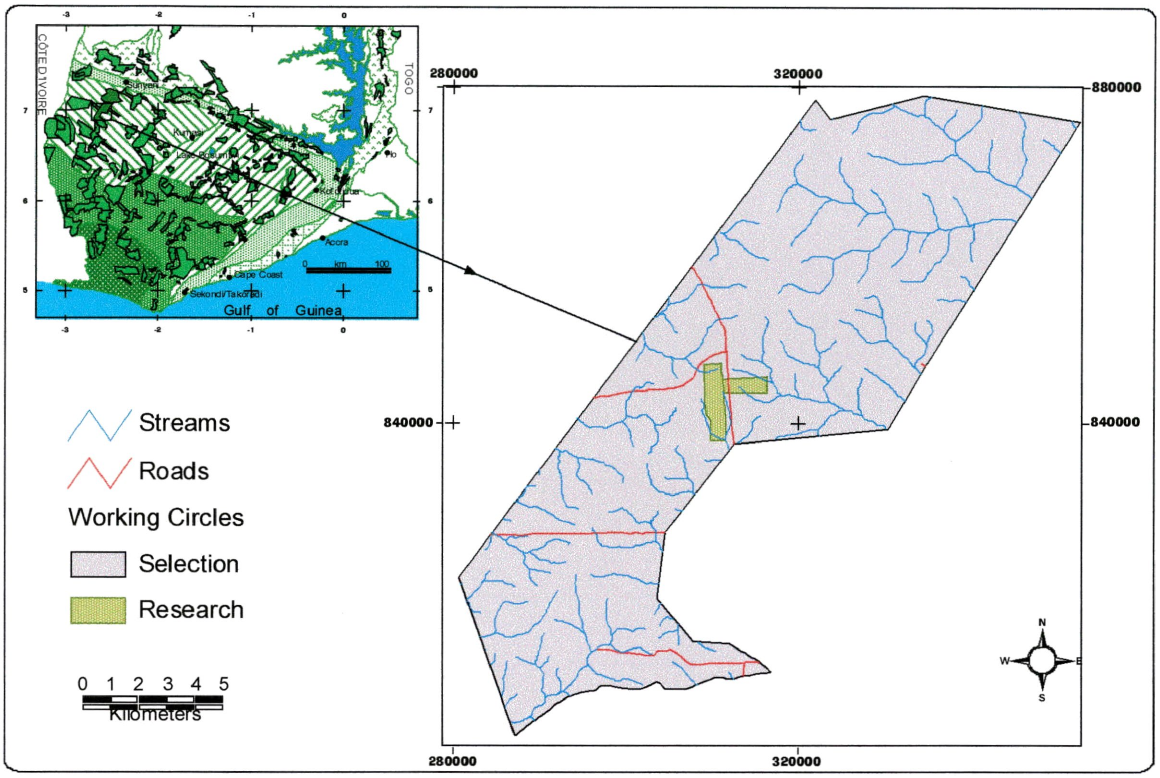

Figure 3.4 Bia Tano Forest Reserve.

For nearly two decades after reservation the forest was managed solely for protection; and exploitation was restricted to only minor forest products. In the 1940s a silvicultural research center covering an area of three square miles (780 ha) was set up within the reserve. Regeneration within the center was attempted using the TSS, which was eventually abandoned due to high costs. Since 1955 the forest has been selectively logged. No permitted farms exist within the Bia Tano forest reserve. Until 1983 the problem of fire within the reserve was minimal. However, threat of fire has been increasing since and fire occurs at numerous places during the dry season (FD/ODA 1989).

3.1.3 Tinte Bepo Forest Reserve

The Tinte Bepo Forest Reserve (figure 3.5) constitutes FMU 36 and derives its name from the highest hill within the reserved area. It lies between latitudes 6^0 33' and 7^0 03' north and longitudes 1^0 55' and 2^0 06' west within the Kumasi West Forest District in the Ashanti Region. The gross area of the FMU is 115.54 km^2 and is made up of three contiguous blocks: the East, Main and West blocks covering 29.345 km^2, 37.322 km^2, and 48.873 km^2 respectively (Addey 1993).

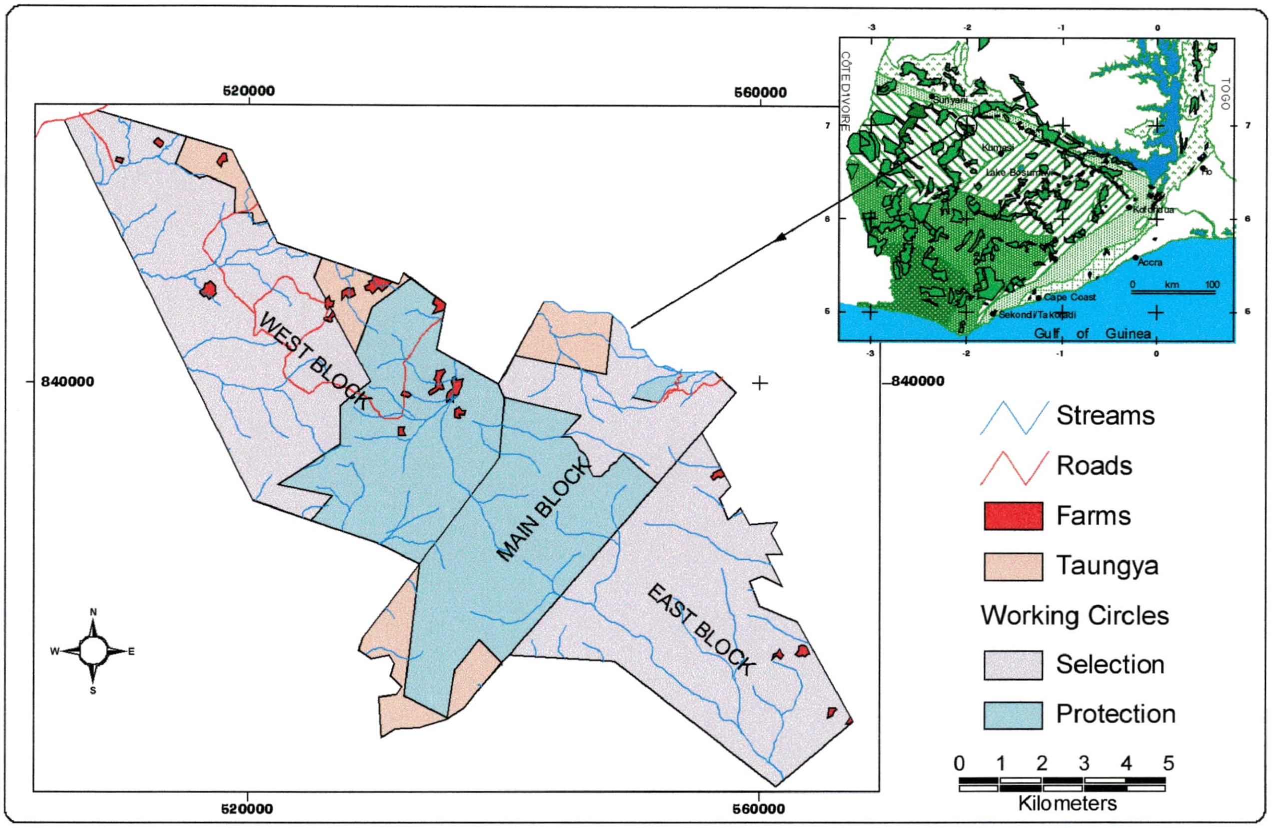

Figure 3.5 Tinte Bepo Forest Reserve

Tinte Bepo was constituted as a Forest Reserve under Kumasi Native Authority Rules in 1949. Ownership of the reserve is vested in the Golden Stool, however, the stools of Hia, Kronti, Bechem and Akyempim act as caretakers on behalf of the Asantehene. The terrain within the reserve is generally hilly, particularly at the central portions with an average height of 365.76 m above mean sea level. Within the main block is the highest peak, Tinte Bepo with an altitude of about 535.5 meters above sea level. There are also four isolated hills with steep sides in the mid-east portion of the reserve (Addey 1993).

The FMU is located within the Tano-Offin watershed. Numerous streams flow through the Reserve and these include Abu, Aboabo, Nsakasu, Abotasu, Aworo, Anyinasu, Dwinyai and Denyami. Most of these dry up during the dry season. The reserved area is characterized by two rainfall seasons, peaking in May-June and September - October. Mean annual rainfall recorded in the area is 1250 mm. Dry season is between mid-November and mid-March with January being the driest month. Temperatures within the vicinity of the reserve are usually high, with mean maximum and minimum values of 33^0C and 21^0C respectively. Relative humidity is generally high with an annual mean of 80 % (Addey 1993). Forest ochrosol is the main soil type within the reserve and it extends over three geological formations namely, the Cape Coast Granite Complex and the Lower and Upper Birimian metamorphic rocks (Working Plan 1955).

Similar to Asukese and Bia Tano Forest Reserves, the Tinte Bepo Forest reserve forms part of the MSNW forest subtype (Hall and Swaine 1976). The typical three-storey structure can be observed in some parts of the reserve but in other portions of the Main and East Blocks, the vertical structure is broken as a result of fires. Trees in the upper canopy, which are made up of both deciduous and evergreen species of varying proportions, attain a height of about 30 m.

Previous exploitation has reduced quantity of most of the primary economic species occurring in the forest. Fires have also affected portions of the reserve and burnt areas are colonized by the habitual *Chromolaena odorata.* In the late 1960s and early 1970s the taungya system was introduced into this area. However, occasional fires and lack of proper maintenance have left most of the planted areas degenerated (Addey 1993).

Farming has been another factor that has contributed to the degeneration of this reserve. Eleven admitted farms were allowed during reservation. Besides fires that are associated with the shifting cultivation method employed in Ghana the extent of most of these admitted farms have increased as a result of encroachment. During the field survey detailed in the next section, instances were observed where boundary pillars had been relocated due to encroachment. It was further observed that the number of farms had increased in the name of taungya.

4.0 STUDY METHODOLOGY

The adequacy of a technique for data acquisition/collection is judged in terms of its reliability, validity and research objectives. As well the known effects of forest cover change are complex and variable and needs a holistic, analytical and multidisciplinary approach for better explanation at the micro-level. The research therefore employed a combination of data and methods, which have extensively been employed elsewhere and described by known authors in the field of environmental studies.

4.1 DATASET

The data used for the study included Ghana topographic maps, Forest Reserve Progress Maps, Landsat images, and GPS location data. The topographic sheets were obtained from the Ghana Survey Department in Accra. The Ghana Forestry Department provided the Forest reserve progress maps. The Landsat images were from two sources: the CIDA funded Ghana Environmental Literacy program (GEMLP) provided historical Landsat MSS data (1973 and 1975) and the Forestry Department of Ghana provided relatively current Landsat TM data (1989-1991). The fourth component of the dataset – the GPS data – was the result of a field survey conducted between July and August 1997.

4.1.1 Landsat Data

Three full Landsat scenes: one MSS and two TM scenes were selected for the study. The choice of digital imagery was based on season, percentage of cloud cover and a minimum of ten years interval between images that showed the same forest reserves. It is desirable to hold environmental variables constant when performing change detection. Seasonal consideration was to ensure some degree of agreement in atmospheric condition between imaging dates. Coincidentally, dry season images have a greater probability of being cloud free. Clouds in digital images do not only obscure the terrain but also produces shadows, which cause major classification problems (Jensen 1996). Ideally, cloud cover should be 0 %, however a maximum of 20 % cloud cover is considered acceptable. Based on the above criteria therefore the three reserves were selected and subsequently subset from the three images. The selected reserves as indicated earlier were Asukese, Bia Tano and Tinte Bepo.

All three reserves could be located on a single Landsat MSS scene. This scene covers approximately latitudes 06° 40' W and 07° 20' W and longitudes 003° 00' N and 001° 80' N and was acquired on the 25th of November 1973. Asukese and Bia Tano forests reserves could be located on one of the Landsat TM Scenes and Tinte Bepo forest reserve on the other. The former Landsat scene, which was acquired on the 2nd of January 1989, covers approximately latitudes 06° 20' and 08° 70' N and longitude 02° 04' W and 03° 37' W. The later image was acquired on December 16th, 1990 and covers longitudes 00° 29' W and 02° 03' W and latitudes 06° 20' N and 08° 07' N.

4.1.2 GPS Field data collection (Field Survey)

The purpose of the field survey was to obtain first hand information on the state of the selected forest reserve, and get coordinate positions using a global position system (GPS). The survey was conducted in the Tinte Bepo Forest Reserve and it involved the collection of GPS location data along the entire boundary of the reserve. Two Garmin SRVY II handheld receivers (a base and roving receiver) were used for the survey. These Garmin SRVY II are 8-channel receivers with large memory storage capacity (200 000 point locations), as well as attribute and descriptive data logging capabilities. The units are intermediate-level receivers that can be used in differential mode to achieve I to 3 meters accuracy.

The units were set up to collect positions in degrees of latitudes and longitudes. The positions collected were referenced to the WGS84 datum with altitude set to meters above Sea Level (geiod height). The Base Station was set up at a previously surveyed location at the University of Science and Technology in Kumasi. The station's coordinates were Latitude 06.6701861° N and longitude 001.5797141° W with an altitude of 277 meters. On the field both dynamic and static modes were employed for the data collection. Assisted by a technical officer and two forest guards the boundary of the reserve was walked in ten days. During the walk GPS location data was collected in the dynamic mode; however a static point was taken for a 5-minute period at every major turning point. Places where coordinate data could not be collected due to satellite unavailability were revisited after the ten-day period to recollect data. At the end of each survey both the data from the Base Station and the field receivers were downloaded onto a PC computer.

A lot of difficulties were encountered during the survey as a result of the rugged nature of the terrain, which was characterized by hills and steep slopes. But even more difficult was ascertaining the exact boundary at one half of the reserve. This was because at this half the boundary had not been well maintained and as such it was difficult to distinguish between the reserve and unreserved areas. Time was therefore taken off for the forestry personnel to re-demarcate the boundary with chain and compass and subsequently weed before the data collection could continue. It was also noted that the local people had taken advantage of the situation to relocate boundary pillars in order to expand their off reserve farms.

In addition to recording the boundary location, features such as farms and Taungya areas along or observable from the boundary were noted. In some instances, the walk was digressed well into the forest to acquire first hand information about the general condition of the reserve. In most of the areas visited there was evidence that the forest has experienced moderate to excessive logging. In many of the open areas, *Chromolaena odorata* (Acheampong weed) densely covered the entire ground. In other areas where this weed was absent the understorey was dominated by dense vine tangles. The central portion of the reserve seems to be the slightest disturbed. Some of the tree species encountered were *Triplochiton sclerexylyon* (Wawa) *Entandrophragma cylindricum* (Sapele) *Khaya spp.* (Mahogany) and *Ceiba pentandra* (Oyina). There were also encounters with both legal and illegal loggers, hunters and others removing NTFPs such as chewing sticks fuelwood and wrapping leaves (Marantaceae).

4.2 DATA PROCESSING

Landsat Image processing was performed with ERDAS IMAGINE 8.3.1 software. Ancillary GIS data was captured with Arc/Info software to aid the image processing. The GPS data was processed using the software package that comes with the Garmin SRVY II receivers. The data were then converted to Arc/Info coverages.

4.2.1 Arc/Info GIS Coverages

Topographic features namely reserve boundaries, roads and streams were digitized from the 1:50,000 Ghana map sheets. During the digitizing process a root mean square error (RMS) between 0.0 and 0.002 was maintained for the tic registration accuracy. The digitized features, each of which was stored as a separate coverage, were edited, after which topology was established and attribute data stored in tabular database was assigned to them. In Arc/Info unique identifiers stored with spatial and attribute data forms a dynamic link between the two types of data (ESRI 1992).

Since the Ghana Topographic sheets use a Transverse Mercator projection system in feet, the final coverages were transformed to the Transverse Mercator projection system. Prior to the transformation the tic locations which were recorded in latitude and longitude were projected to Transverse Mercator projection system using an Advance Macro Language (AML) file (Appendix III). The projected co-ordinates were then used to transform the coverages. The accuracy of the transformation was expressed by a root mean square (RMS) error that describes the deviation between tic locations in the digitized and the transformed coverages (ESRI

1992). High RMS errors may result from the digitizing procedure, map sheet distortions such as stretching or shrinking and/or inaccurate recording of coordinates. Initially, the RMS error for the six maps digitized ranged between 17 and 71 metres. At the map scale used for the study a maximum transformation RMS of 25 meters was considered acceptable. Four of the digitized maps satisfied this requirement with an error range of 17 to 23 meters. The RMS errors for the remaining two, topographic sheet numbers 0703D4 and 0602A1 were 45.1 and 70.5 meters respectively. The source of the high RMS errors was investigated by cross checking the recorded tic coordinates and re-digitizing the tics repeatedly. It was noticed that neither the recording nor digitizing of tics contributed to the error and the only possible cause would be distortions in the map sheets. Fortunately, a new set of map sheets were available so new tics were digitized from different 0703D4 and 0602A1 Ghana Topographic sheets and transformed. The new transformation RMS error for sheet number 0602A1 reduced considerably to 17.7 meters. Unfortunately a comparable error reduction could not be obtained for sheet number 0703D4 and an accuracy of 37.9 meters was obtained. In the absence of another map sheet this RMS error was accepted and used for the study. The two new sheets were thus digitized and new coverages created.

Progress maps produced by the forestry Department at a 1 : 62 500 scale were also digitized. These maps show the various working groups, farms, concessions, streams and roads in the reserves. Excluding the concessions all these features were each digitized as an Arc/Info coverage. On these maps however, there were no survey grid lines. There was therefore the need to obtain ground control points (tics) from the transformed coverages created from the topographic sheets in order to transform the new coverages. To achieve this all tics on both sets of coverages were deleted in ARCEDIT and new tics were added at identical locations on both. Zooming in as close as possible an attempt was made to position the tics as accurately as possible. Using roads and streams as backgrounds the tics were initially added to the coverages depicting the reserve boundaries. In all a total of 16 tics were added to each boundary coverage. All coverages were built after the additions. Empty coverages containing the new tics from the topographic sheets coverages were then created and the progress maps' boundary coverages were transformed to them. A number of the initial tics were deleted to reduce the RMS error. However, except for the coverage of Tinte Bepo that had an RMS error of 9.08 meters, those of Asukese and Bia Tano had higher errors of 55 and 40 meters respectively with a minimum of four tics. The command GET was used in ARCEDIT to copy the tics to the other coverages and the transformation process repeated.

4.2.1.1 GPS Data Processing

GPS data processing with the Garmin SRVY II software was fairly simple. A configuration identical to that used for the data collection was used for the processing of all the Garmin Files. The computer was configured to process the data in degrees of latitudes and longitudes. The positions were referenced to the WGS84 datum with altitude set to meters above Sea Level (geiod height). The display options were also set. Available options included the display of lines, points, identifiers, attributes and descriptions.

The known location of the base station (latitude, longitude and altitude) was used as inputs to process the base file (.BAS). The resultant corrected file (.COR) then served as input for processing the field data (.FLD files). The no scatter option was selected for the processing of the Base Station and Static field files, whereas the scatter option was used for the dynamic files. To produce accurate locational data the 3D computation method was selected, with a DOP of twelve and a mask angle of zero. At the end of every computation a report was displayed showing:

- The number of recorded points in the field data file;
- The number of points with insufficient satellite coverage;
- The number of points with no corresponding differential value;
- No of points outside the time limits;
- No of calculated points and;
- An indication as to whether a point (static) or line (dynamic) was created.

The number of calculated points were noted and any location with less than 50 % processed points was revisited. All lines and points created were displayed with their attributes and a plot file was printed out. The essence of this printout was to make the attributes available for the creation of the Arc/Info coverages. More attributes taken in a field notebook were also used for the same purposes.

Once the differentially corrected Garmin (.GRM) files were created they were edited using a spreadsheet to make them ready for the creation of coverages. All descriptive information at the beginning of the Garmin files was deleted. As well all other columns of information with the exception of the latitude and longitude columns were deleted. The Garmin file coordinate locations were stored in a Latitude (Y), Longitude (X), format. This format was changed to X, Y coordinates by simply interchanging the positions of the columns. Appendix IV shows an example of a raw Garmin file.

The edited X, Y (longitude, latitude) Garmin file was converted to the Ghana Transverse Mercator co-ordinate system with the Arc/Info command PROJECT and an AML file (Appendix V). Unlike the previous AML used to project the coverages of the topographic maps, this AML effected a datum transformation from WGS84 to LEH (leigon)* the Ghana datum.

In order to generate Arc/Info line and point coverages from the projected coordinate files, an ID number was added at the top of each file and an "end" statement at the tail. The final files were then submitted to the Arc/Info generate command to produce the coverages. Topology was created for the coverages with the build command and attribute data added in the INFO subroutine of Arc/Info.

4.2.2 Pre-processing of Landsat Data

The raw Landsat TM images purchased from EOSAT had a Y-shift of 61 pixels for channels four and seven. To correct this shift, 7-channel blank images were created. The original images were then placed into the blank images, such that channels 1, 2, 3, 5 and 6 were placed 61 pixels lower than channels 4 and 7. The relevant sections (the three reserves) were then subset from the full Landsat scenes. The two adjacent reserves, Asukese and Bia Tano were subset together and Tinte Bepo was subset separately. In all four image subsets were created: two Landsat TM and two MSS scenes.

To avoid unnecessary uptake of computer storage space as well as

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* LEH (Leigon) is the Datum assigned to Ghana in Arc/info 7.2.1.

processing time the dimensionality of the TM images were reduced, by eliminating redundant channels 1 and 6. The images were then rectified to the Ghana Transverse Mercator projection system in feet using the Arc/Info coverages.

Due to the relatively flat terrain of the Asukese and Bia Tano forest reserves, a linear transformation was considered appropriate for the images depicting these reserves. A second order polynomial was used for Tinte Bepo because of the rugged nature of the terrain. Eighty-five GCPs were initially located on both the Landsat TM image of Asukese and Bia Tano and the corresponding Arc/Info coverages. All GCPs were selected at distinct points such as roads and streams intersections. With ERDAS imagine software Automatic Transformation Calculation can be turned on, so that when the minimum (depending on the order of the transformation) input GCPs and their corresponding reference GCPs have been selected a transformation matrix is computed. After selecting several pairs of GCPs an automatic GCP prediction tool can be used to predict the corresponding location of a GCP selected from the input image or reference map. There is also an indication of residuals (RMS in both x and y directions), contributions of each GCP and the total RMS errors. GCPs that contributed a high RMS error were selected and deleted. The residuals, contributions and RMS error updated automatically as GCPs were edited and the transformation recalculated. A total of fifteen GCPs were deleted to obtain an RMS error of 0.15 pixels. The pixels were then resampled from 30 meters to 164.042 feet (50m) using a cubic convolution resampling method. The above procedure was repeated for the Landsat TM image subset of Tinte Bepo. In this case, of the 55 GCPs that were selected initially, 43 were used in a second order polynomial to achieve an RMS error of 0.2 pixels.

The 1973 MSS satellite image subsets were geocoded to the rectified TM image subsets. Fifty GCPs were selected for both MSS and TM images of Asukese and Bia Tano. Using a first order transformation eight GCPs were deleted and the resultant transformation yielded an error of 0.2 pixels. Similarly, twelve of the forty GCPs selected for both the Landsat MSS and TM image subsets of Tinte Bepo forest reserve were deleted using a second order transformation. The MSS scene was then geocoded to the TM scene with a transformation matrix that produced an RMS error of 0.3 pixels. The pixel size of the MSS images was resampled from 80 metres to 164.042 feet (50 metres).

To verify co-registration accuracy between corresponding MSS and TM images, the images were displayed on two viewers that were geographically linked. Stable linear features such as roads, were inspected throughout the scenes to assess variation in registration between the two images. As stated earlier different sensor systems do not record energy in identical portions of the electromagnetic spectrum. For example the MSS records energy in four relatively broad multispectral bands (table 2.3) and TM in six relatively narrow bands and one broad thermal band (table 2.4). Ideally the same sensor should be used to acquire multiple date imagery used in change detection analysis. When this is not possible as in the case of this study, bands that approximate each other should be selected for change detection analysis (Jensen 1996). For this study therefore MSS bands 1(green) 2(red) and 4(near-infrared) and TM bands 2(green) 3(red) and 4 (near-infrared) were selected from the rectified images for further analysis.

The selected bands of corresponding MSS and TM scenes were then combined to form two new six channel multi-temporal images. The brightness values of the MSS channels (channel 1-3) were then adjusted in an attempt to match them (approximately) with the TM channels (channels 4 - 6) for both multi-temporal images. The essence of this normalization was to factor out brightness differences between dates resulting from illumination, atmospheric and sensor changes. As stated earlier, when multi-date analysis is being performed it is essential to hold environmental variables as constant as possible between the dates of interest. The use of anniversary or near anniversary dates images helps to ensure general and seasonal agreement between atmospheric conditions but does not guarantee equal overall brightness (Runesson 1992).

A simple radiometric normalization technique was used to adjust the brightness values of the MSS images to the TM images (Runesson 1992; Green *et al.* 1994). The method required the use of pseudoinvariant ground target (i.e. targets that do not change from image to image). The differences between the brightness values of several road intersections for the corresponding green, red and near-infrared channels of the MSS and TM channels were measured and averaged. The overall scene brightness of the MSS channels was then adjusted accordingly by adding the averaged value. Since the objective of this study was to identify excessive spectral changes in the images of different dates, perfectly normalized images were not essential. For the six-channel image of Tinte Bepo channel 1 did not need alteration, a BV of 5 was added to channel 2 and 35 to channel 3. Similarly, 4, 13 and 39 BVs were added to channels 1, 2 and 3 respectively of the six-channel image of Asukese and Bia Tano. The data pre-processing was completed by running a low pass 7X7 filter through the two multi-temporal images to remove any additional noise in the images.

4.2.3 Change Detection Procedures

The change detection procedures involved the use of the multi-temporal dataset to discriminate areas of land cover change between imaging dates. Image Algebra and Spectral-temporal Change Detection procedures were employed for the study. The Image Algebra procedure involved Image Differencing of the MSS and TM bands of the multi-temporal dataset. The TM channels of the multi-temporal images were subtracted from MSS channels as follows:

- Channel 1 - Channel 4;
- Channel 2 - Channel 5 and;
- Channel 3 - Channel 6.

The values of the resultant three-channel files were linearly scaled by two standard deviations. The images were then subjected to an unsupervised classification described in the next sub heading.

Two products were obtained for the Spectral-temporal Change Detection procedure. The first set of products resulted from the traditional classification of all six channels in the two datasets. In the second instance a PCA was performed on the six channel images. Examination of the eigenstructure of the transformed data indicated that the first four components accounted for over 90 % of the spectral variability among the images. Components five and six were attributed to atmospheric and sensor variations. A preliminary classification of the first four components of the PCA showed that adequate change information could be obtained from the first, second and fourth components. The three components were therefore placed in a single image file and reclassified.

4.2.3.1 Image Classification

Supervised classification was considered unsuitable for the study because of the great extent of ground truth information needed for the method. Changes in land cover and subsequent change maps were derived from the differenced, multi-temporal and PCA image files using the unsupervised classification method. ERDAS IMAGINE uses the ISODATA (Iterative Self-Organizing Data Analysis Technique) algorithm to perform unsupervised classification. The method is iterative in that it repeatedly performs an entire classification (outputting a thematic raster layer) and recalculates statistics. The ISODATA clustering method uses the minimum spectral distance formula to form clusters. It begins with either arbitrary cluster means or means of an existing signature set, and each time the clustering repeats, the means of these clusters are shifted. The new cluster means are used for the next iteration. The ISODATA utility repeats the clustering of the image until either a maximum number of iterations have been performed, or a maximum percentage of unchanged pixels has been reached between two subsequent iterations.

Fifty clusters were defined for the differenced, multi-temporal and multi-temporal PCA images, using the ISODATA technique and classified using a Maximum Likelihood decision rule. Twenty-four iterations and a convergence threshold of 95 % were selected. During the processing the number of iterations was adjusted as necessary to achieve the 95 % convergence threshold. The resultant image files were recoded to two classes, namely, ‘change’ and ‘no change’ by visual references to the unclassified differenced images by arranging the images in a screen toggle setup. The recoding process involved determining a threshold among the fifty classes below which classes are coded as areas of change. The "change class" was further grouped into moderate and drastic change classes. The progress maps and the GPS field data (in the case of Tinte Bepo forest reserve) were used to assist the recoding process.

As a final step the recoded images were smoothed with a majority filter. This removed spurious classification of single pixels. The final images were converted to vector format in Arc/Info using the imagegrid and gridpoly commands. The three reserves were then extracted from the coverages with the clip command using their boundaries that has been digitized from the topographic sheets as the clip coverages. The creation of the final maps and subsequent display were accomplished in ArcView.

5.0 RESULTS

The results of the integration of the Arc/info coverages from the various sources exhibited some form of disparity as to the proper co-registration of spatial features when the data were combined into a single database. The product of the image analysis however, demonstrated a great potential of satellite imagery for monitoring changes in the forest reserves of Ghana.

5.1 ARC/INFO COVERAGES

For all three reserves there were discrepancies in the co-registration of their boundaries produced from the progress and the topographic maps. The miss-registrations varied along the boundaries. At some portions however, the boundaries from the two data sources coincided. Figures 5.1a - 5.1b show the overlay of Asukese and Bia Tano reserves' boundaries produced from the progress maps and the topographic sheets. For the Tinte Bepo Forest reserve an overlay of boundary produced from the GPS data with those from the two other sources mentioned earlier exhibited a similar pattern (i.e. various degrees of miss-registration except for localized portions). Of particular interest was the fact that areas of the greatest miss-registrations were common for all three data sources. Figure 5.1c shows the boundary of Tinte Bepo from all three data sources. It would have been simple to determine the source of error had any two of the data sources produced a perfect or near perfect match for most locations.

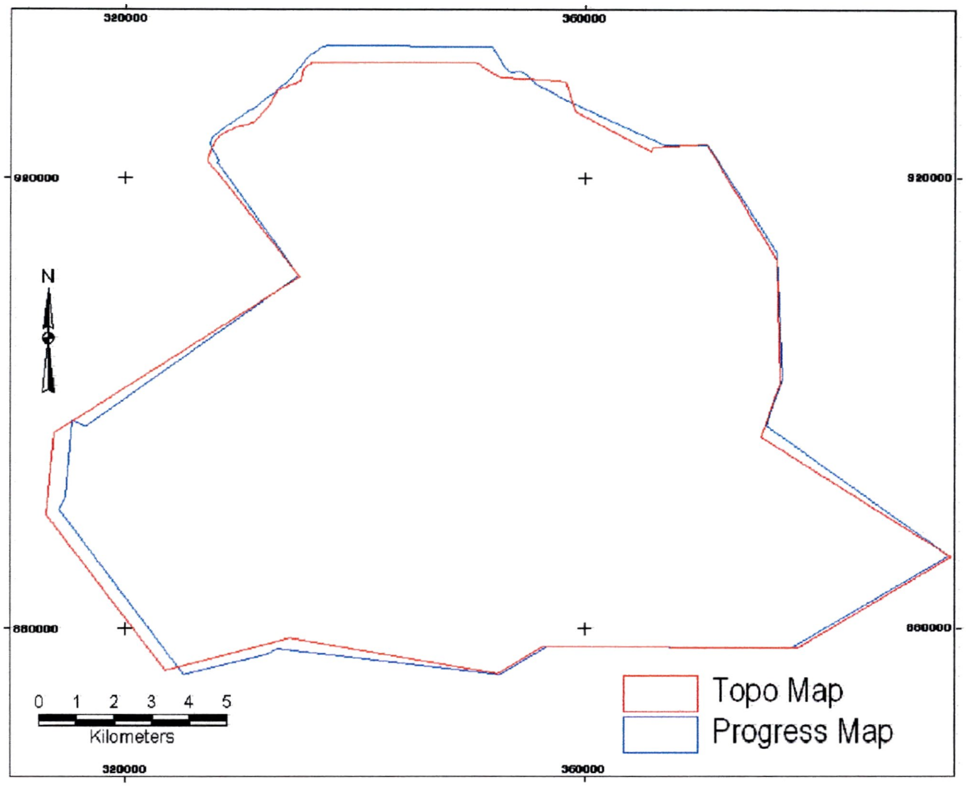


Figure 5. 1 a Overlay of the boundaries of Asukese captured from Topographic and FD progress maps.

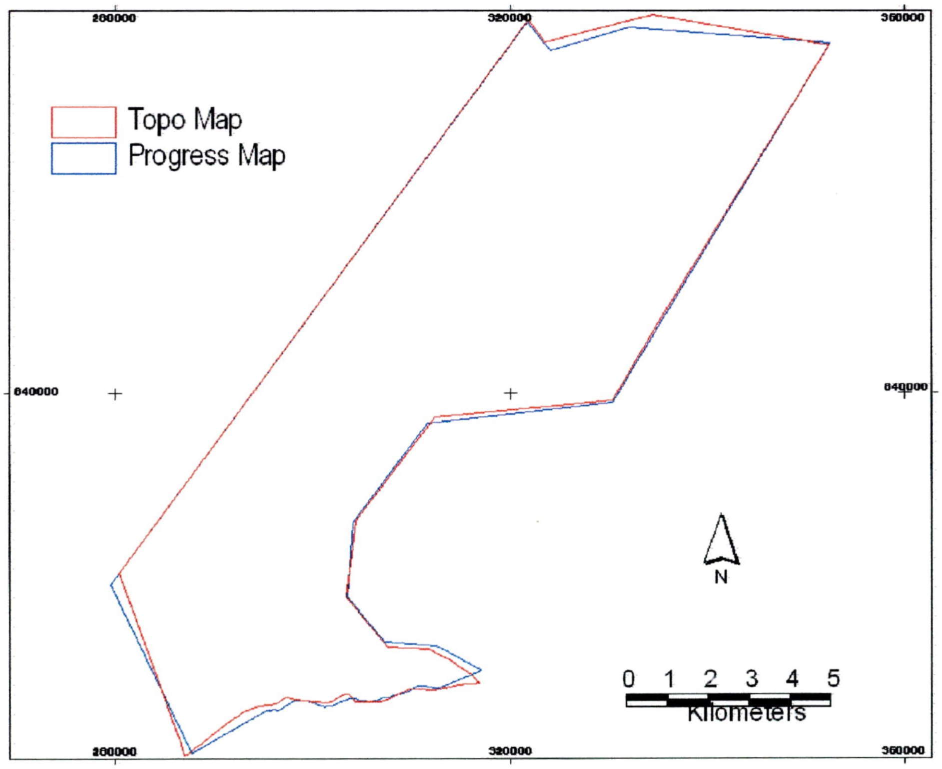


Figure 5.1 b Overlay of the boundaries of Bia Tano captured from Topographic and FD progress maps.

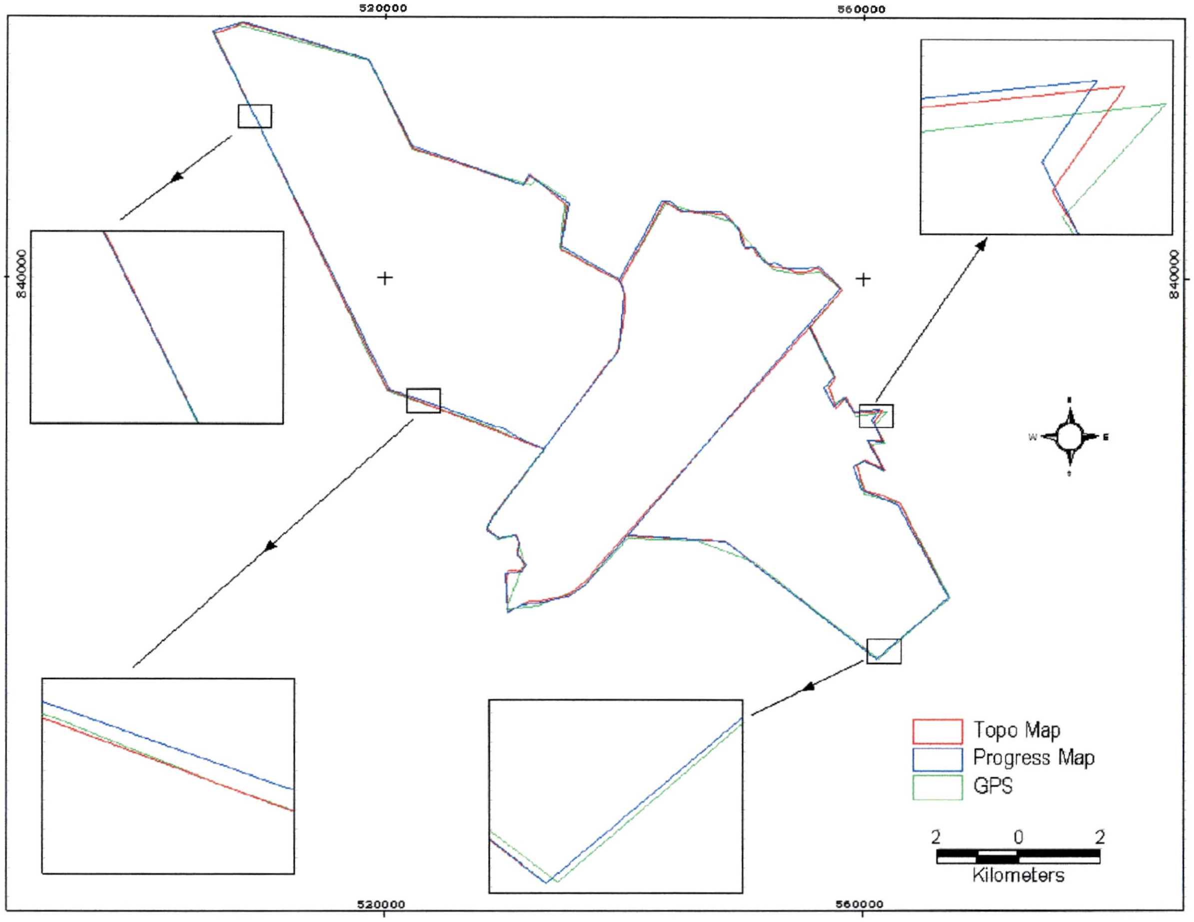


Figure 5.1 c Overlay of the boundaries of Tinte Bepo captured from the three data sources.

However, since this was not the case, it was difficult to ascertain which of the three data sources establish the most accurate boundary location. For the purposes of image rectification the topographic map sheets were assumed to be the most accurate and used. The accuracy of the data was not expected to affect co-registration of the images and subsequent image analysis.

5.2 SATELLITE IMAGE PROCESSING

5.2.1 Image Pre-processing

Aided by the powerful geometric correction tools within the Erdas Imagine software package the corresponding Landsat images were co-registered to each other with a high degree of accuracy. The images showed good agreement with each other and rarely any variation could be observed when displayed on geographically linked viewers and stable linear features (such as roads) were inspected. Figure 5.2 shows the rectified Landsat TM image subset of Asukese and Bia Tano forest reserves. The image is overlaid with the roads and reserve boundary coverages as a means of demonstrating the accuracy of the rectification.

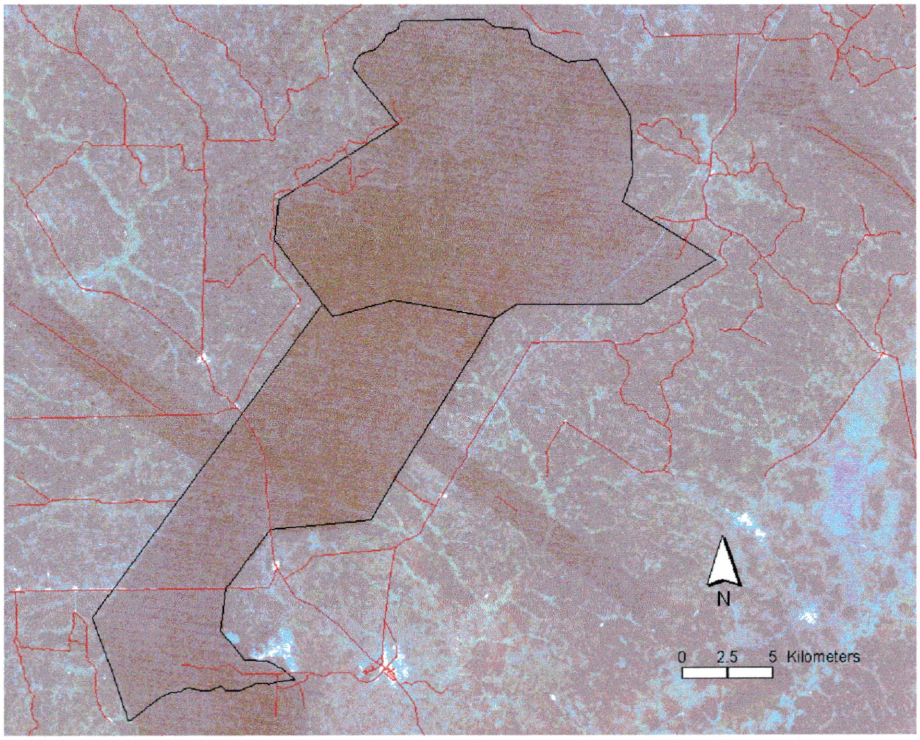


Figure 5. 2 Rectified Landsat TM image of Asukese and Bia Tano.

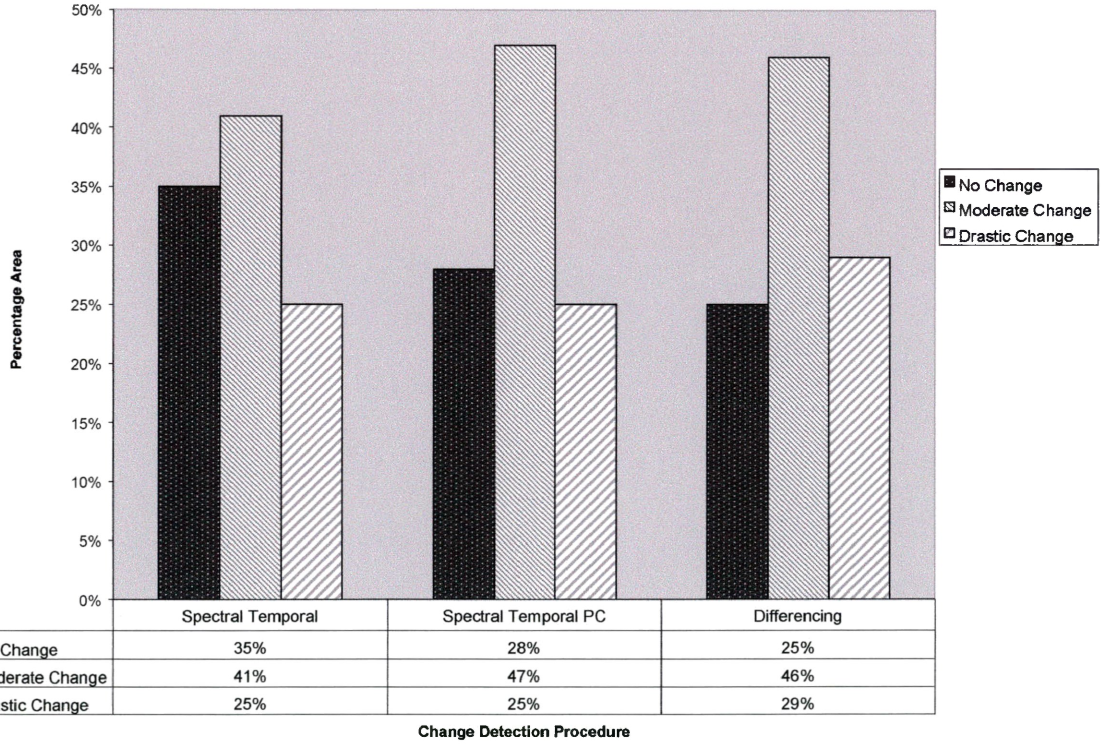
Careful consideration was given to the selection of satellite images available from both the GEMLP program (MSS data) and the Forestry Department of Ghana.

Of major consideration, besides appropriate time interval between imaging dates, was cloud percentage and seasonal variability. As stated earlier, 0 % cloud cover images are ideal for change detection analysis. Though dry season images of Ghana (as used in this study) have the greatest probability of being cloud free it was not possible to obtain images with absolutely no clouds from the available satellite images. A cloud cover of between 5 - 20 % was accepted and used for the study. Further, in spite of the use of near anniversary date imagery, visual observation and subsequent measurements of pseudoinvariant ground targets revealed that MSS image subsets had relatively lower brightness values than the TM image subsets. The BVs of the MSS image subsets were therefore adjusted to match them approximately with the TM image subsets. A preliminary classification of the adjusted multi-temporal images showed that a lot of noise was still evident in the data. This prompted the use of a 7 X 7 low pass filter to remove the remaining noise. Subsequent analysis of the filtered images produced pragmatic results.

5.2.2 Change Detection Procedures

The results of the change detection procedures for each of the three reserves are summarized in Figures 5.3 - 5.5. A greater proportion of the Asukese forest reserve was classified as changed by all three change detection methods. The Spectral temporal change detection (classification of the raw six-channel multi-temporal image) classified 66 % of the reserve as changed between November 1973 and January 1989. Whereas Spectral temporal Principal component analysis (PCA) and image differencing change detection classified 72 % and 76 % of the reserve respectively as changed.

A breakdown of the changed areas into moderate and drastic changes is given in Figure 5.3. The proportion of change for Bia Tano reserve between the same imaging dates as Asukese forest reserve was relatively lower ranging from 43 - 49 percent. The highest percentage of change resulted from the Spectral Temporal change detection method. 49 % of the reserve was classified as changed by this method. The Spectral temporal PC followed closely with 47 % change while Image Differencing resulted in 43 % change. Figure 5.4 shows a breakdown of the change classes to moderate and drastic.

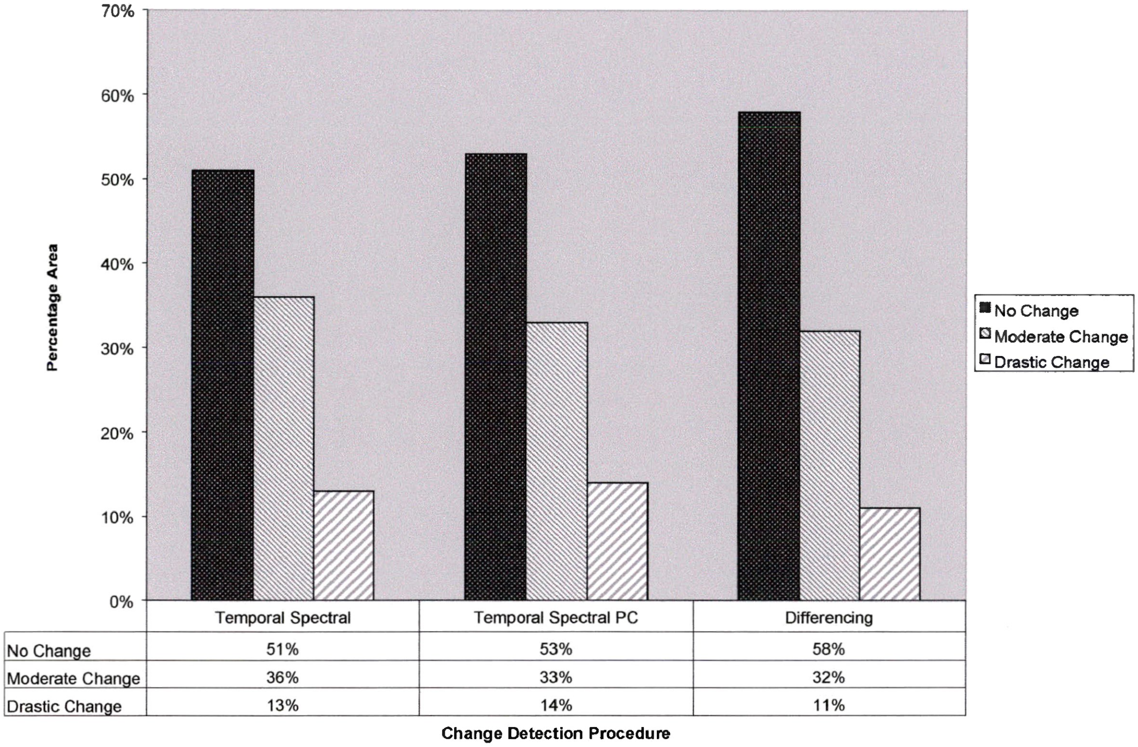


	Spectral Temporal	Spectral Temporal PC	Differencing
No Change	35%	28%	25%
Moderate Change	41%	47%	46%
Drastic Change	25%	25%	29%

Figure 5. 3 Change Classes expressed as percentage of total for Asukese Forest Reserve.

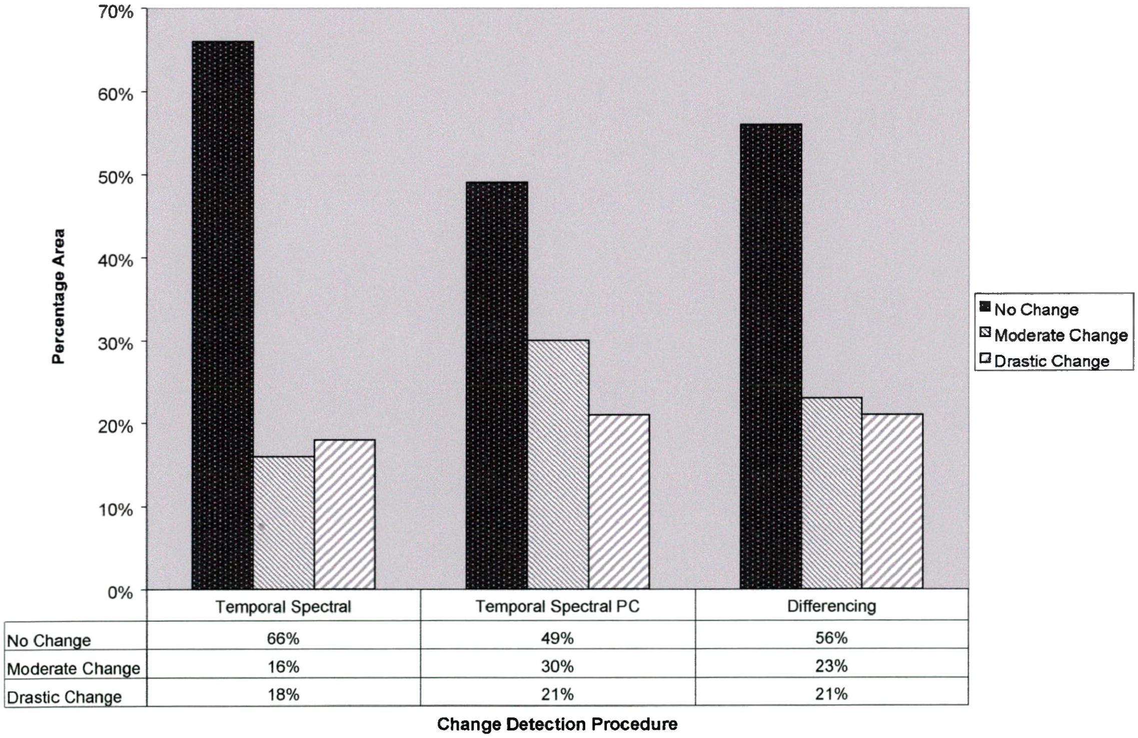
The three change detection methods exhibited the highest variation of the proportions of change for the Tinte Bepo forest reserve with a range of 34 - 51 %. Between the imaging dates of November 1973 and December 1990 34 %, 51 % and 44 % of the reserve was classified as changed by the Temporal Spectral, Spectral Temporal PCA and Image Differencing change detection methods respectively.

Again figure 5.5 gives a breakdown of the change classes.



	Temporal Spectral	Temporal Spectral PC	Differencing
No Change	51%	53%	58%
Moderate Change	36%	33%	32%
Drastic Change	13%	14%	11%

Figure 5. 4 Change Classes expressed as percentage of area for Bia Tano Forest Reserve



	Temporal Spectral	Temporal Spectral PC	Differencing
No Change	66%	49%	56%
Moderate Change	16%	30%	23%
Drastic Change	18%	21%	21%

Figure 5. 5 Change Classes expressed as percentage of area for Tinte Bepo Forest Reserve.

A comparative evaluation of the change detection methods was not conducted because a quantitative accuracy assessment was not possible for the procedures. The progress maps obtained from the FD lacked detail and although dated recent seems to be a reproduction of old maps. For example the FD working plans indicated that fire is currently rampant in all three reserves during the dry season. However this was not evident on the progress maps. No burnt areas were indicated on the maps of Asukese and Tinte Bepo and only a small portion of Bia Tano was depicted as burnt. It could be argued that for the Tinte Bepo forest reserve most of the burnt areas were converted to Taungya and therefore the maps may be relatively current. The spatial distribution of Taungya along the boundary of the reserve agreed well with the field data. Unfortunately, the field data was insufficient to determine the accuracy of the progress map as well as to conduct accuracy assessment of the change detection methods. The results were examined to see if some pattern could be observed for the three change detection procedures (Figure 5.6) but there was no particular trend.

Image differencing procedure yielded the highest change in area for Asukese forest reserve. For Bia Tano and Tinte Bepo forest reserves Spectral Temporal and Spectral Temporal PCA methods produced the highest change respectively. On the other hand Spectral Temporal method resulted in the lowest change value for both Asukese and Tinte Bepo while image differencing produced the lowest change value for Bia Tano.

However the final change maps showed that spatial distributions of the changed areas produced by all three methods were similar and that only the extent varied. Figures 5.7a - 5.9c shows the various change maps.

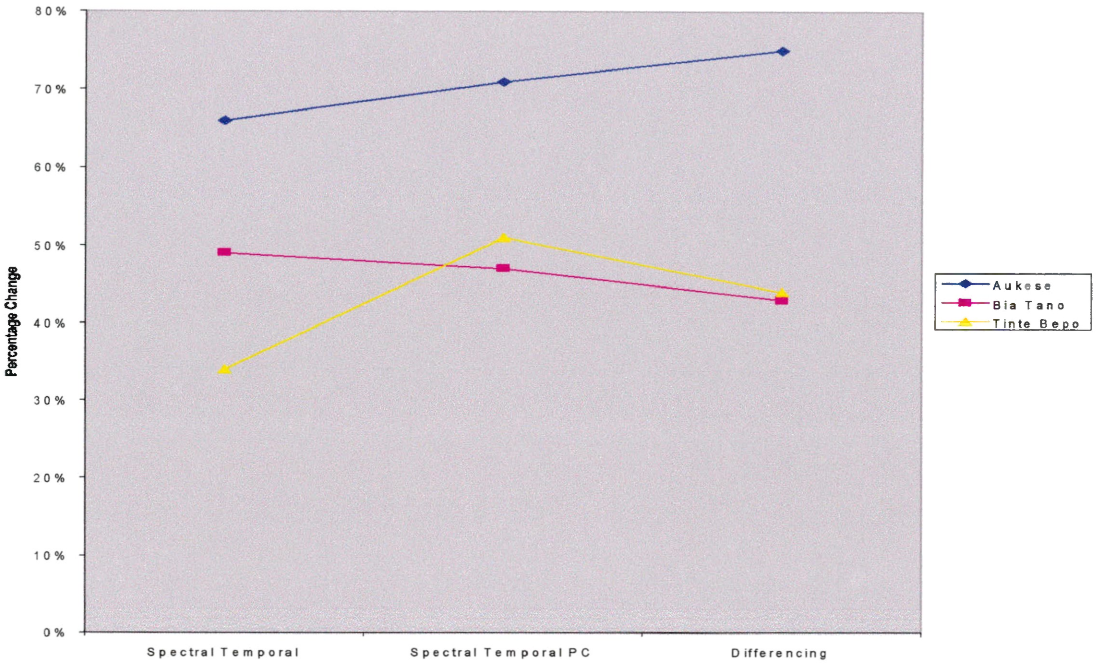


Figure 5. 6 Identification of Trends in Change Detection Methods.

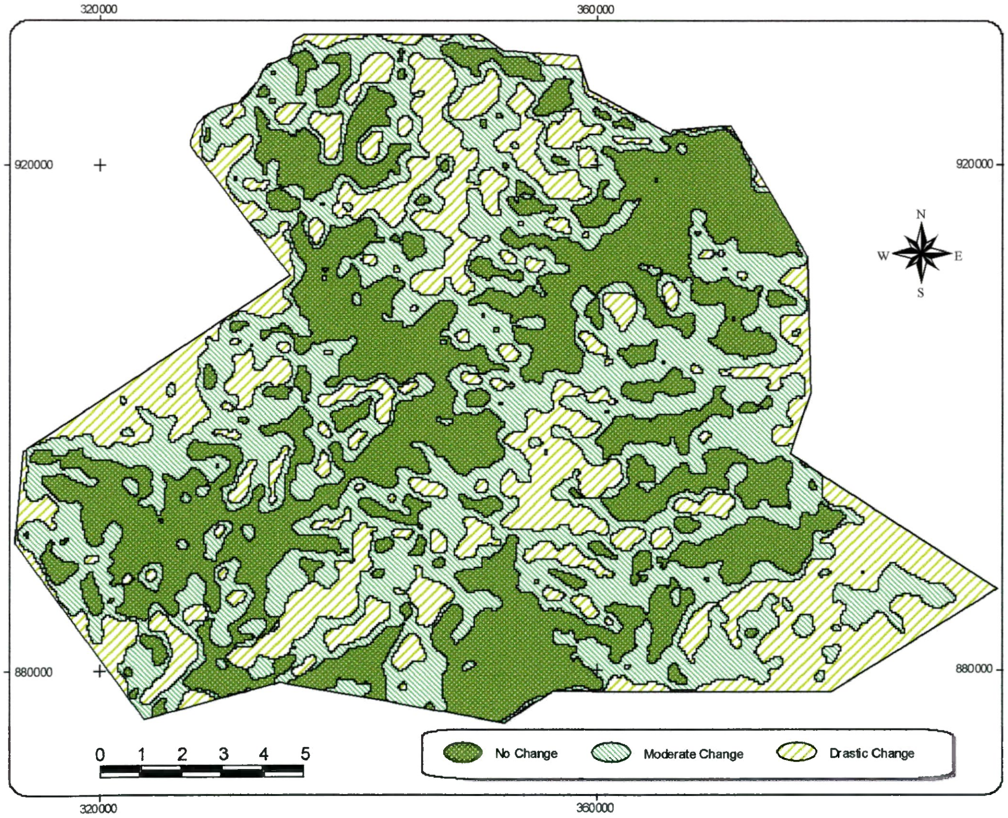


Figure 5.7 a Spectral Temporal Change map of Asukese.

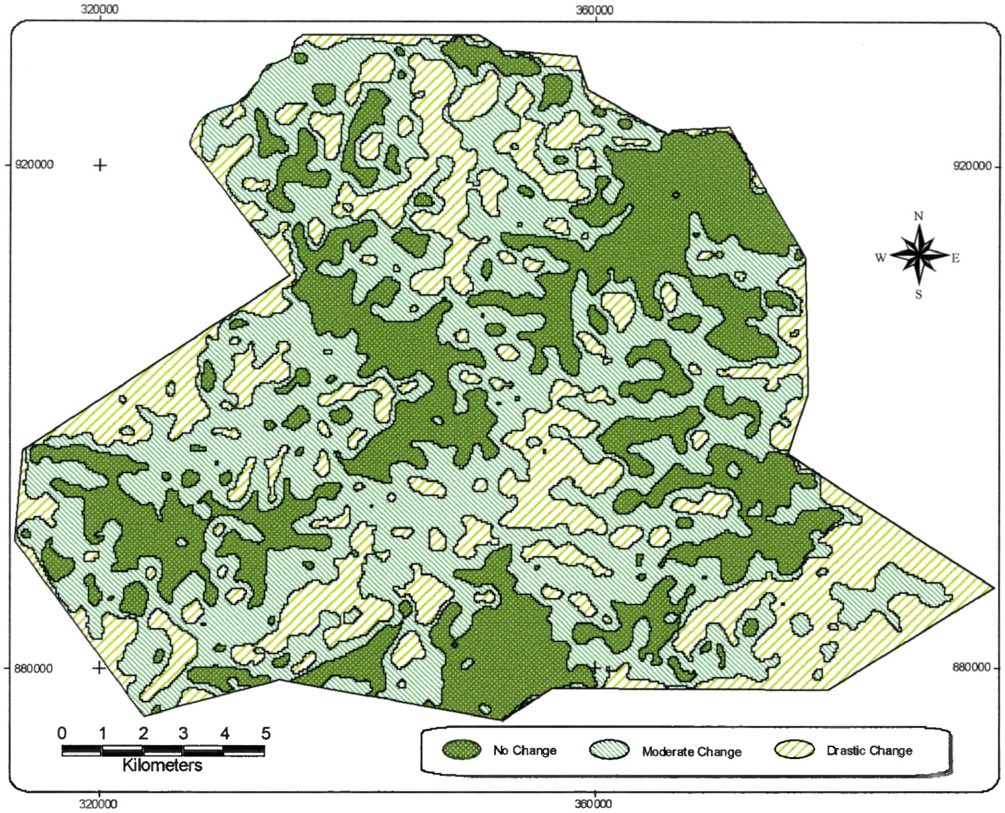


Figure 5.7 b Spectral Temporal PCA Change map of Asukese.

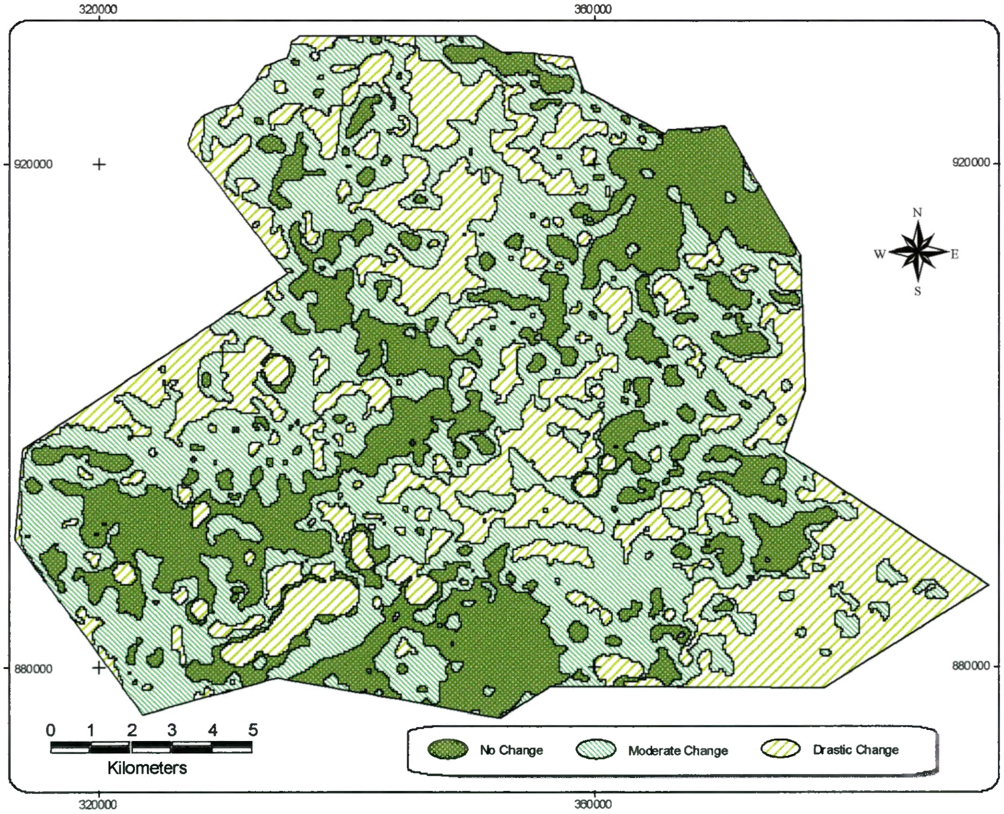


Figure 5.7 c Image Differencing Change map of Asukese Forest Reserve

Figure 5.8 a Spectral Temporal Change map of Bia Tano Forest Reserve.

Figure 5.8 b Spectral Temporal PCA Change map of Bia Tano Forest Reserve.

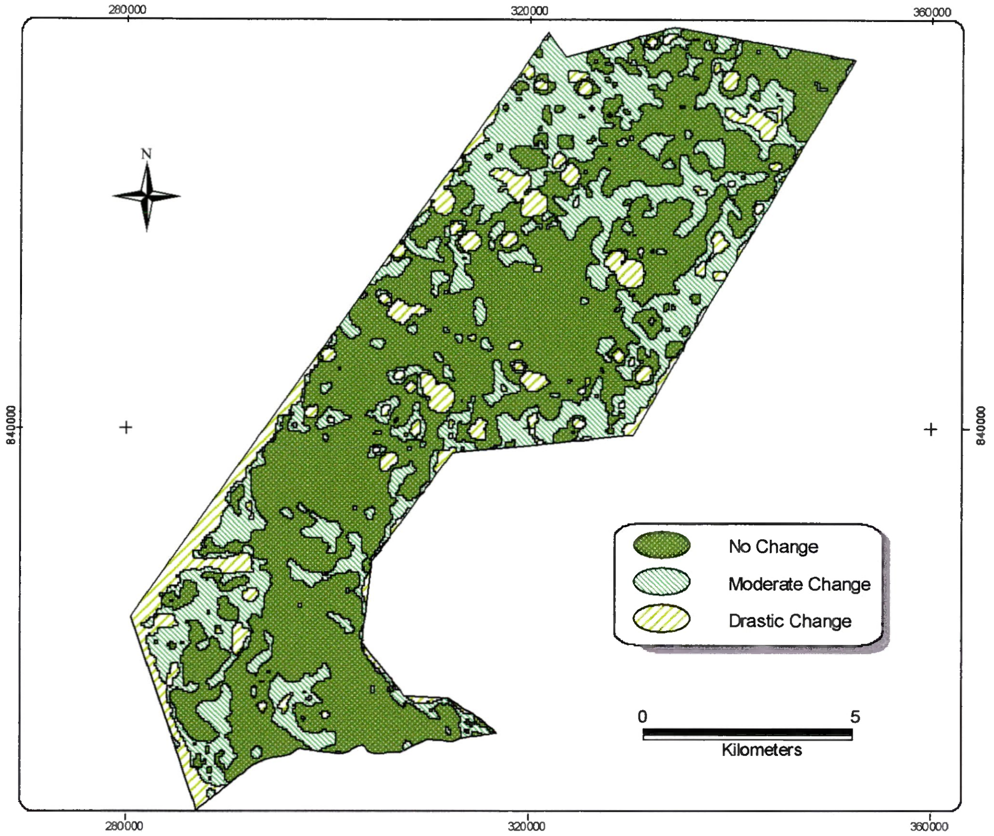


Figure 5.8 c Image Differencing Change map of Bia Tano Forest Reserve.

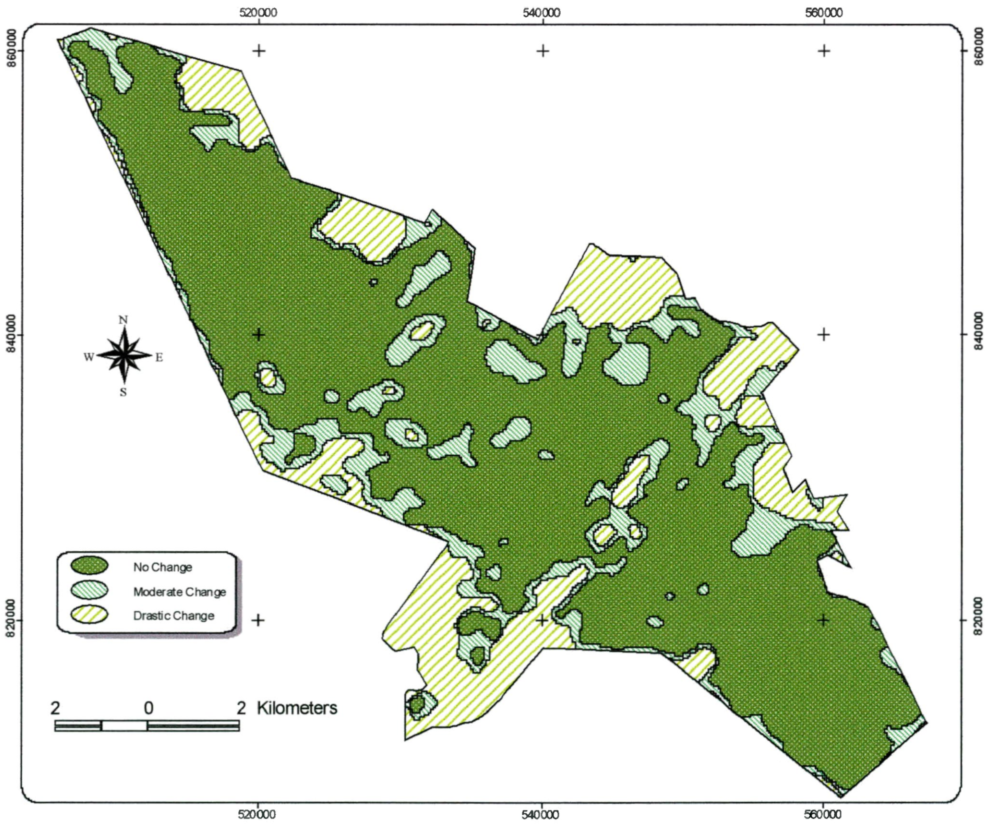


Figure 5.9 a Spectral Temporal Change map of Tinte Bepo Forest Reserve

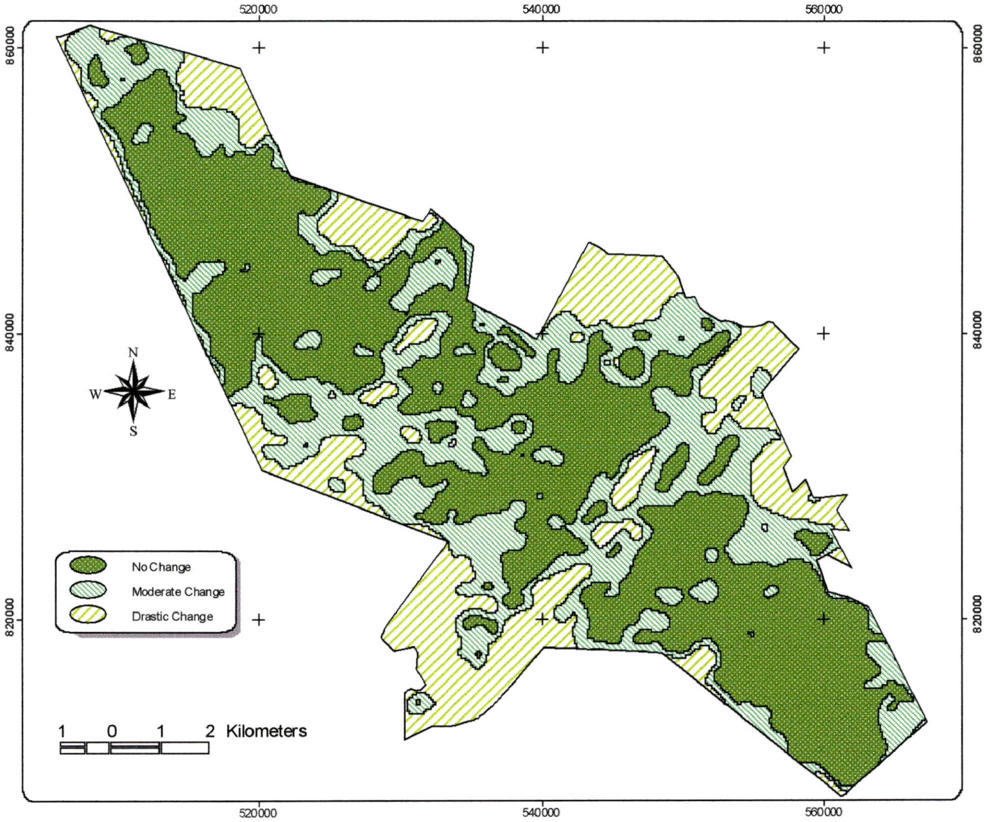


Figure 5.9 b Spectral Temporal PCA Change map of Tinte Bepo Forest Reserve.

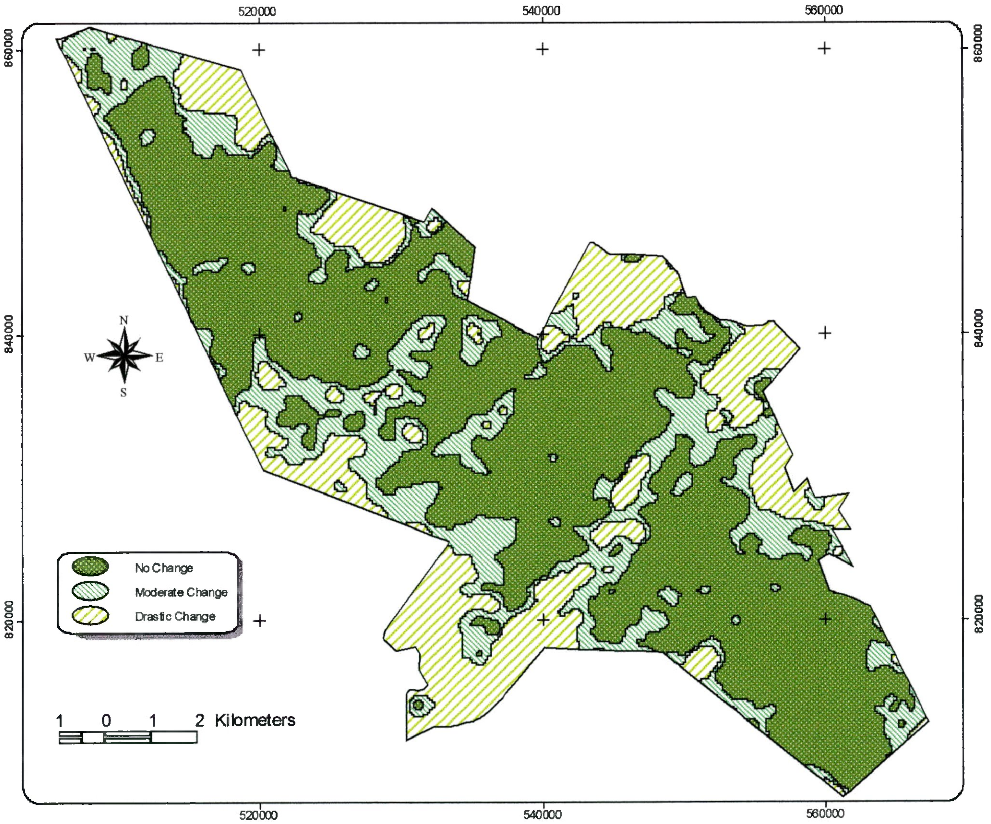


Figure 5.9 c Image Differencing Change map of Tinte Bepo Forest Reserve.

A qualitative assessment of the Change maps of Tinte Bepo by visual comparison with the progress maps and field data disclosed that the spatial distribution of changed areas was reliable. For all three procedures the changed portions coincided with farms, taungya areas and along the reserve boundaries. During the field survey it was observed that most of the taungya areas lacked adequate forest cover having few or no trees with a ground cover of Acheampong weed. On the western boundary of the main block there was the relocation of a couple of boundary pillars probably by farmers in an attempt to extend off reserve farms. Only the central portion of the reserve seems to have intact forest and this pattern was clearly exhibited on the change maps.

The variations in the extent of change for the various change detection methods may be that in some cases spectral change may be easily and directly related to vegetation change, regardless of the change detection approach employed. In other cases, the ability of different change detection approaches to discriminate vegetation changes may be affected by the type of change as well forest stand characteristics such as topography and soils. A field check would be necessary for precise explanation of the variations and also for a quantitative accuracy assessment of the procedures employed in the survey.

On the whole it was encouraging to note that the results confirmed the findings of the field survey as well as what has been documented in literature (FD Working plans) about the condition of the forest reserves studied.

6.0 DISCUSSION

As pressure on the Ghanaian forest resources continues to mount, there is the need for much greater efficiency in forest management practices. A one-time inventory of forest cover is often limited in value. Rapid and accurate appraisal of forest cover by means of a series of inventories and the detection of change provide significant information on resources at risk and in some cases may be used to identify the agents of change (Jensen 1996). Deficiencies associated with conventional methods of field survey such as high cost, subjectivity, low spatial and temporal coverage limit the effectiveness of decision making and subsequent implementation of management practises. New techniques of monitoring and mapping changes in forest cover must therefore be employed in conjunction with conventional methods. This study demonstrated the use of GIS, a limited field survey and satellite image processing, as an effective means of monitoring changes in the Ghanaian forest reserves.

Prah (1994) presents several problems that hamper the work and impede the Forestry Department's ability to satisfactorily manage forest reserves. Among others, he mentions lack of implementation, monitoring and evaluation of operational methods. This discussion focuses on findings of the study and how the procedures outlined in the study can help alleviate some of these problems.

6.1 GEOGRAPHIC INFORMATION SYSTEM

GIS was effective in the generation of the database for the study. The initial database, from the 1:50,000 scale Ghana topographic map sheets were used for rectification of the Landsat TM images. With the exception of coverages captured from one map sheet, these initial coverages were transformed with fairly good RMS errors. Investigation of the high error associated with sheet number 0703D4 suggested that the error may be due to distortions in the map sheet. Further all the map sheets were outdated having been produced from aerial photographs taken between 1972 and 1973. However, this did not present a major problem with co-registration of Landsat images.

GIS was also used to capture information from the progress maps and the GPS data were also converted to Arc/info GIS coverages. The database produced from the various sources was easily integrated in a GIS environment. The data retrieval and displaying capabilities of GIS were used to compare the various coverages. Finally the data conversion ability of GIS was employed in the production of output maps from the products of image analysis. In a GIS environment the data was queried to determine the proportions of change and unchanged classes.

The applicability of GIS in monitoring the Ghanaian forest reserves is broad. Forest management requires various forms of information from biotic to abiotic. The need to develop a GIS is therefore inevitable for the integration of the many sources of data. Besides as data collected by conventional methods accumulate there is the tendency of the data to be redundant, lost altogether or retrieval may be cumbersome. At the inception of the Forest Inventory Project in Ghana, no GIS programs existed in Ghana and it was anticipated that conventional spreadsheets might not be adequate for compiling the voluminous amount of data. A computer base model GHAFOSIM (Ghana Forest Simulation Model) was therefore developed (Wong 1989). The model basically outputs tables and pie charts of stand or plot characteristics. Unfortunately, data entry into the model seized in 1989. As such the data collected for the project has not been fully exploited and there is danger of their being lost (Flint and Hardcastle 1992). Within GIS software packages such as Arc/Info large volumes of spatial data can be stored indefinitely and be retrieved readily as and when needed. In addition in the dynamic forest environment information needs to be always updated. Site specific data can continually be added as attributes in a GIS irrespective of the data source.

The GIS then allows the collation of the separately collected data. Overlaying or cartographic modelling can be employed across layers of information outputting maps that express the spatial relationship among variables. This study illustrated the map production ability of GIS through the reproduction of both the topographic and progress maps as well as the creation of change maps derived from image analysis. Being in the same geographic space the old maps can be overlaid with the change maps in one of several ways to produce different maps with new information. Maps are a very important component of forest management. The forest map is usually the point of departure in preparing management plans and provides a base document for assessing the success of management practices and monitoring trends. All forest operations from planting to harvesting are best planned and monitored using maps. In a GIS database (provided the initial source is accurate) the problem of paper distortion is eliminated and accurate maps can be promptly reproduced.

The modelling capability of GIS extends far beyond this study. Forest management as indicated earlier, is a holistic and integrated approach to managing resources. Keeping forest data in a GIS therefore offer the advantage of performing complex analysis using a number of spatial data to address complex ecological issues. Various management strategies can be designed and tested with computer models prior to implementation (Lachowski *et al.* 1994). Historic data can also be employed with predictive modelling to estimate the future impact of development activities such as land-use conversion on the forest environment (Sader and Joyce 1988).

Of particular importance is the ability to model biophysical and socio-cultural information to identify the complex interaction between people and the environment. Forestry plays a broad and profound role in society and vice versa. Among the current forestry reforms in Ghana is the incorporation of participatory forest management into forestry practices. Information such as local community needs, markets and population growth that are vital to management decision can be integrated and analysed in a GIS environment.

6.2 GLOBAL POSITIONING SYSTEM

In spite of the localized discrepancies in co-registration with other data sources the GPS data was able to show clearly an area where the local people had relocated boundary pillars. This observation had been noted earlier during the limited field survey. The confirmation of this earlier observation demonstrated the feasibility of keeping track of the condition of the reserve boundary particularly the boundary pillars. The GPS could also be used to demarcate the extent of admitted farms in the forest reserves. These measures when put in place will greatly minimise encroachment along both the reserves' boundaries and the admitted farms. Similarly, the extent of forest fires could be monitored for effective management decisions.

Other areas in the effective management of the Ghanaian forests where the use of GPS will be handy include dynamic (enumeration) surveys, stock surveys, and subsequent creation of stock maps. The dynamic inventory described earlier, involves a five yearly interval measurements of specific trees in permanent sample plots in order to monitor the growth and dynamics of the forest reserves. According to Blackett (1989) a major problem encountered in this survey is the difficulty in re-locating trees during subsequent measurements. The preparation of a tree location map was therefore introduced during the 1989 National Inventory to overcome this difficulty. The use of GPS and subsequent incorporation of measurement in a GIS database would not only alleviate the problem of tree re-location but also enhance the accuracy of the tree location maps. The ability to accurately and easily relocate trees would ensure adequate monitoring of the trees. It would indicate which trees have been logged, which ones died and how well the others are growing. Such information will go along way to assist in the calculation of volume increments (MAI) for adequate prescription of annual allowable cuts. Furthermore, the incorporation of the GPS data into a GIS would allow for easy and accurate reproduction of the tree maps as and when needed. Similar advantages would be obtained if GPS technology were introduced in stock survey and stock mapping for the purpose of harvesting. In this regard, the GPS would aid in the location of trees to be removed during harvesting, monitor restocking, and assess the damage caused to forest in addition to timber removal.

6.3 CHANGE DETECTION IMAGE ANALYSIS

It is a well-established fact that the underlying factor of forest management problems in Ghana is the cost or logistics involved (Prah 1994; Flint and Hardcastle 1992). Financial constraints led to the abandoning of regular field surveys (enumeration surveys) initiated in the sixties (Prah 1994). In addition even though the need for a national inventory was long realised similar constraints delayed it until financial assistance was forth coming from the ODA (Francois 1989). The field work alone for the national inventory (FIP as it was called) when it was finally conducted lasted 4480 man months at a total cost of 1.1 million pounds sterling to the ODA and 59 million cedis to the Ghana Government. A latter ODA evaluation of the FIP indicated that much time was accumulated laying out plots in severely degraded forests (Flint and Hardcastle 1992). The analysis of Satellite data to detect changes in forest cover as illustrated by this research could have served as an appropriate reconnaissance survey. This would have provided some form of stratification of the country's forests. The stratification in turn would have reduced the time spent in the field and consequently the cost incurred. Further area estimates of the various strata, which can readily be accomplished through the analysis of satellite data, would have gone a long way to increase the accuracy of subsequent volume estimates.

Another instance where satellite image analysis could serve as a form of reconnaissance survey would be in the area of pre-survey compartment inspection. Recall that a pre-survey compartment inspection is carried out prior to the stock survey in order to avoid the expense of time and money on a compartment that may be unsuitable for harvesting (FD 1995).

Remote sensing satellites orbiting the earth continually collect data at various time intervals. The costs and time involved in acquiring satellite data are thus confined to ordering from the organisations controlling the satellites. A full scene of Landsat TM data from EOSAT covering an area of 185 X 170 km costs between US $ 3 600.00(raw) and US $ 4 900.00 (geocoded). Eight such scenes cover the entire High Forest Zone. Besides the issue of data acquisition in Ghana is partially solved. Landsat TM data has already been acquired for southern Ghana. There is the need to acquire more data such as historical data for change analysis and even more current data obtained from recent sensors with improved resolution.

Perhaps, more important is the greater cost associated with initial set-up of computer hardware and software for the processing or the extraction of useful information from the satellite data. Fortunately over the last few decades the cost performance ratio of both computer hardware and software has continued to decline (Johnston *et al.* 1997). In the case of Ghana, delays in the analysis and reporting of the FIP as a result of inadequate and faulty computer wares led to purchasing and setting up adequate computer equipment in the Forest Inventory unit of the Forestry Department (Flint and Hardcastle 1992). For example the unit is equipped with the image processing software ERMapper and Arc/Info GIS. With the existence of appropriate hardware and software and once satellite data has been acquired, the processing steps outlined here should be broadly applicable throughout the forest reserves of Ghana and adequate results can be obtained in a shorter time.

The use of change detection image analysis could also assist in monitoring and evaluation of management decisions. In view of the results of the FIP, it has been suggested that forests with extensive degraded patches should not be logged.

Over the years, Ghana has been noted for declaring and documenting sound forest management decisions. Unfortunately, the FD as the leading executing and operational agency has not been able to effectively implement these management decisions mainly due to staffing problems. Staffing problems of the FD has earlier been estimated at 63 % under strength in professional grades (WB 1988). Almost a decade after this estimate the problem has not been resolved. According to Prah (1994) insufficient number of professional and technical staff as well as low moral of those at post have serious implications for supervision and monitoring of forest management practices. The issue has initiated a plan that makes concession holders responsible for stock surveys. This places a considerable responsibility on the District Forest Officers for stock checking. Evidence show that while some companies are reliable and appear to be prudent in their surveys others exhibit substantial inconsistencies (Flint and Hardcastle 1992). There is therefore the risk of harvesting degraded forests.

The extraction of change information from digital satellite data as demonstrated by the study is highly automated and unlike a detailed field survey does not require a crew. Further, the automated nature of the process minimises analyst bias. The only instance of analyst bias is in the definition of threshold values for recoding the classified images (Runesson 1992). However the overall reduction of analyst bias allows different analysts to readily reproduce the results. As such different personnel at various levels in the FD (as a means of cross checking) can to a high degree of accuracy determine the condition of a compartment in a forest reserve prior to passing it for harvesting.

6.4 STUDY LIMITATIONS

The main limitation of the study was insufficient ground truthing to quantitatively assess the accuracy of the classifications and evaluate the change detection methods employed. As indicated earlier the progress maps obtained from the FD were outdated and lacked detail. The maps did not reflect the condition of the reserves documented in the FD's working plans.

The second source of ground truthing, the GPS location data was limited to only one of the three reserves. Even though the spatial distribution of taungya and farms along the boundary of the reserve obtained from the GPS data coincided with that on the Tinte Bepo progress map the data was insufficient to determine the accuracy of the map. Besides the limited number of locations taken, most of the GPS data concentrated along the reserve boundary and as such was not representative enough to be used to conduct a quantitative accuracy assessment of the change detection methods.

Another limitation of this study, which happens to be a major intricacy of utilizing Landsat imagery is the existence of frequent cloud cover in Ghana that obscure spectral characteristics of target phenomena on the earth surface. For this study dry season images were selected because they have the greatest probability of being cloud free. Yet it was not possible to obtain images with absolutely no clouds from the available satellite images. Active microwave sensors such as Synthetic Aperture Radar (SAR) that penetrate clouds cover may be useful for acquiring valuable satellite imagery all year round. A passive sensor that may also be useful is the Panchromatic scanner of the IRS-1C and IRS-1D satellites that offer a temporal resolution of 5 days. The frequent revisits greatly increases the ability to acquire cloud free images. Utilizing both SAR and IRS PAN images could be of additional benefit. The use of SAR data may have the added advantage of the possibility to derive information about the forest structure (height, stem diameter and frequency, basal area, canopy characteristics and above ground biomass) from backscatter measurements (Sader *et al* 1990). The IRS PAN in turn with its 5-meters spatial resolution is currently the best of any civilian remote sensing satellites. It is worth noting that the scope of digital image processing in monitoring forest cover well extends beyond this study. The study has demonstrated that analysis of Landsat images is efficient in identifying abrupt changes (such as fires and land use changes) in forest cover. More often, however, forest responses to disturbances are highly variable and occur in patches. Thus, the ability to discriminate local areas of change will be related to patch sizes and sensor resolution (Townshend 1981). Further, the heterogeneous nature of Ghanaian forests may complicate the classification of Landsat data. The improved resolution of current and proposed sensors therefore will offer more valuable information for monitoring the Ghanaian forests. To add to this, image processing software packages are becoming more powerful. However, as the art and science of Remote sensing continues to evolve the ability to rapidly benefit from the new development is dependent on current applications (Runesson 1992). The automated nature of extracting valuable information from digital images also means that training of analysts requires shorter periods.

7.0 CONCLUSION AND RECOMMENDATIONS

7.1 CONCLUSION

This study illustrates the feasibility for using satellite data and GIS to map changes in the Ghanaian forest reserves. Several data sources were integrated in a GIS environment and the resultant change detection techniques presented could help address some of the lingering problems in managing the Ghanaian forest reserves.

Of particular interest was the demonstration of the synergistic relation between Remote Sensing and GIS through the outline of the research. GIS was used to create the initial database for the study. The remote sensing image analysis required the information stored in the GIS database for rectification and for the assessment of the classification procedure. The new layers generated from the image analysis - Landcover Change Classes - were displayed and stored in the GIS. The Landsat data therefore become a GIS information source.

The importance of the outlined procedures in the management of Ghanaian forest and the limitations of the study were discussed in detail. The fact that the compatibility of image processing and GIS extends beyond this study: i.e. beyond the need to maintain information in a geographic format in order to compare different date images or summary analysis was also mentioned. Emphasis was placed on the advantages of the modelling/analytic capability of GIS. However the full range of benefits from a GIS cannot be obtained without a regular source of accurate data. Satellite imagery provides a synoptic view and locational precision and spatial resolution to satisfy a large number of forest resources mapping requirements. Further, the improved resolution of current and proposed sensors as well as advancements in image processing software have much more to offer in providing valuable information for mapping and subsequent monitoring of the Ghanaian forests.

Satellite imagery is not a panacea though and the need for detailed ground base information to aid classification and subsequent accuracy assessment in addition to information required for site specific management cannot be overemphasised. GPS has recently become an important survey tool to supplement and in some cases replace conventional techniques of field data collection. The impact of the technology is due to cost and time savings as well as accuracy improvements over traditional mapping and surveying methods. The limited GPS data collected for this study was able to adequately display the boundary of the Tinte Bepo reserve, the spatial distribution of Taungya and farms along the boundary as well as the relocation of boundary pillars. This shows that GPS can be readily incorporated into operational survey such as monitoring encroachment along the boundary of reserves, demarcating permanent and temporary sample plots, demarcating burnt areas, and recording the location of trees measured during enumerations to mention a few. Once such information has been acquired, it can be entered as attributes of specific sites into GIS database for adequate storage, visualization and easy retrieval.

In summary the study has demonstrated the potential of image analysis in a GIS environment to map out changes in vegetation cover of forest reserves over a period of time. This capability if administered on a regular basis, offers significant potential for increasing our knowledge and understanding of the effects of both naturally occurring forest disturbances (eg. fires) as well as human activities.

7.2 RECOMMENDATIONS

The effectiveness of alternative change detection approaches for detecting changes the Ghanaian forest reserves is rarely evaluated within the context of a single study. The following areas are therefore suggested for future research initiatives.

- Conduct a quantitative accuracy of this study and perform an evaluation comparison of the change detection methods employed.
- Develop a forest cover classification pertinent to the forest reserves of Ghana. Such a classification can then be used as a base for post classification change detection methods.
- Verify the accuracy of the Ghana Topographic sheets.

Meanwhile it is high time the science of Remote Sensing and the technologies of GIS and GPS are incorporated into on going forest monitoring in Ghana. The processing steps outlined here should be broadly applicable throughout the forest reserves of Ghana. It may be necessary to acquire both historic as well as data acquired by recent and improved sensors such as SPOT, SAR and IRS.

A factor not addressed in this research, however of great importance is the human element of these evolving disciplines. As powerful as they may be these disciplines are merely tools and require competent analysts to be effective. Increased training is essential for the application of these powerful tools to resource management. On going training programmes are in the right direction. For example the Ghana Environmental Management Literacy Project (GEMLP) funded by the Canadian International Development Agency (CIDA) program has set-up workshops for training resource managers and faculty members in GIS, GPS and remote sensing technologies at the Institute of Renewable Natural Resources, Kwame Nkrumah University of Science and Technology in Kumasi (Rudy 1997). In addition as part of the World Bank Co-ordinated Action Plan for Ghana, NRSC has a training arrangement with the Remote Sensing Applications Unit of the University of Ghana, Legon to provide focused training and institutional development consultancy for a period of five years. The NRSC also designed and delivered a series of GIS and image analysis training programs. Such training programs need to be on a continuous basis as remote sensing, GIS and GPS technologies continue to evolve.

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APPENDICES

APPENDIX I

COMPARTMENT INSPECTION FORM

Form FD50

Pre-stock survey compartment inspection Date:

District:

Forest Reserve: Compartment:

Concessionaire:

Date of last harvesting operation:

Has compartment been burnt: Yes/No Date last burnt:

Observations from field visit to three areas within the compartment (circle most appropriate description under each heading):

Topography	Stocking of Class I species	Forest canopy	Forest Understorey
Area 1			
Flat Rolling Steep	High Average Low	Closed Patchy Open	Mixed shrubs Pioneers Grass/ Chrom. odorata
Area 2			
Flat Rolling Steep	High Average Low	Closed Patchy Open	Mixed shrubs Pioneers Grass/ Chrom. odorata
Area 3			
Flat Rolling Steep	High Average Low	Closed Patchy Open	Mixed shrubs Pioneers Grass/ Chrom. odorata

General comments

The compartment is recommended/not recommended for stock survey (delete one).

Signed:
District Forest Officer

IF THE COMPARETMENT IS RECOMMENDED FOR STOCK SURVEY:

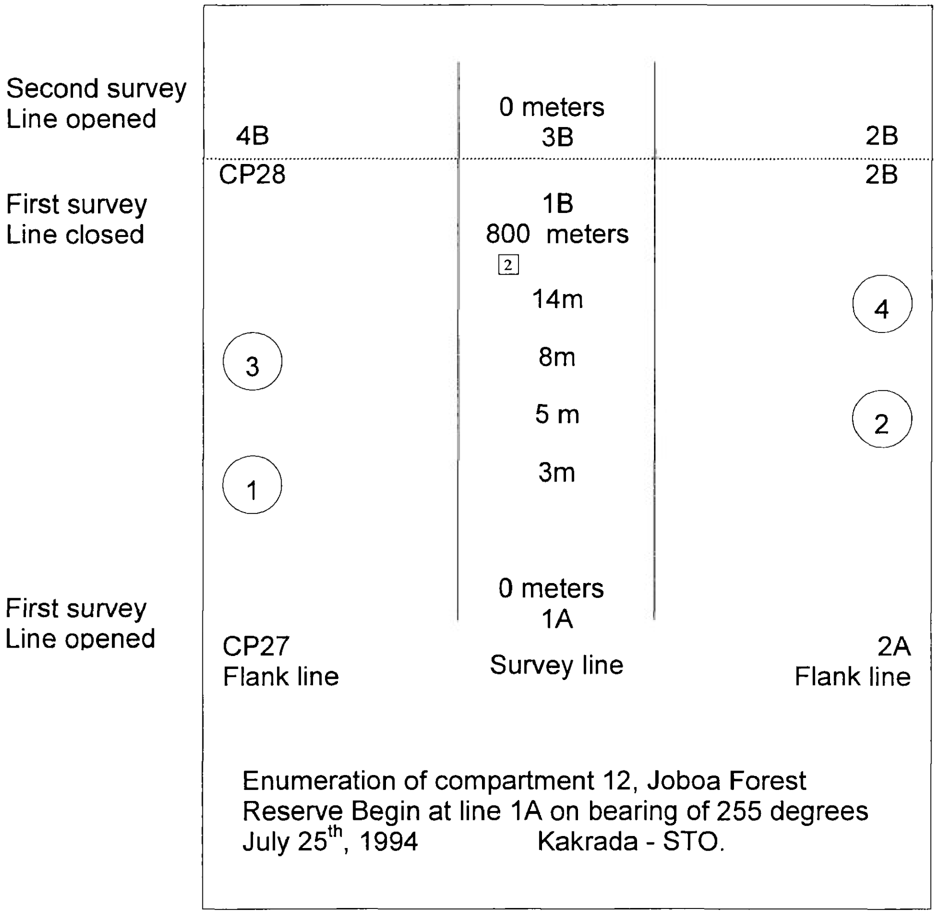
I request that the commerce stock survey operations for which I will pay in advance/I will carry out a stock survey of the compartment (delete one).

I understand that should the stock survey operations indicate that the compartment is not suitable for harvesting the cost associated with the stock survey cannot be reimbursed. I have read and understood the Forestry Department Logging Manual and handbook of harvesting rules and agree to comply with their request.

Concessionaire

APPENDIX II

SAMPLE STOCK SURVEY FIELD BOOK



Enumeration of compartment 12, Joboa Forest
Reserve Begin at line 1A on bearing of 255 degrees
July 25th, 1994 Kakrada - STO.

APPENDIX III

AML USED TO PROJECT TICS OF TOPOGRAPHIC MAPS FROM LATITUDE/LONGITUDE TO GHANA TRANSVERSE MERCATOR CORDINATE SYSTEM

```
input
projection geographic
units dd
parameters
output
Projection Transverse
Units feet
Parameters
0.99975
-01 00 00
04 40 00
274320
0.00000
end
```

APPENDIX IV

AN EXAMPLE OF RAW GPS DATA FILE

;>PR010819.FLD			19-Aug-97	11:22:27	2849												
H	R	DATUM	IDX	DA	DF	DX	DY	DZ									
M	G	WGS	84	100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00								
H	IDNT	LATITUDE	LONGITUDE	DATE	TIME	ALT	ATTRIBUTE	DESCRIPTION	#PTS	SIGMA							
W	BASE	6.6701861	-1.5797141	19-Mar-98	23:03:54	276		BASE	STATION	0	0						
H	LATITUDE	LONGITUDE	DATE	TIME	ALT	D	EPE	HPE	VPE	PDOP	HDOP	VDOP	SAT	PRN	&	SNR	
N	6.9813729	-1.9427673	19-Aug-97	11:22:42	276	2	57.8	57.8		2.5	2.5		3		14		29
N	6.9815197	-1.942645	19-Aug-97	11:22:43	276	2	57.8	57.8		2.5	2.5		3		14		29
N	6.981402	-1.9425935	19-Aug-97	11:22:44	276	2	57.8	57.8		2.5	2.5		3		14		29
N	6.9813575	-1.9425455	19-Aug-97	11:22:45	276	2	57.8	57.8		2.5	2.5		3		14		29
N	6.9814599	-1.9424787	19-Aug-97	11:22:46	276	2	57.8	57.8		2.5	2.5		3		14		29
N	6.9813493	-1.9425696	19-Aug-97	11:22:47	276	2	57.8	57.8		2.5	2.5		3		14		29
N	6.9813582	-1.9426562	19-Aug-97	11:22:48	276	2	57.8	57.8		2.5	2.5		3		14		29
N	6.9814023	-1.9426778	19-Aug-97	11:22:49	276	2	57.8	57.8		2.5	2.5		3		14		29
N	6.9813721	-1.9427152	19-Aug-97	11:22:50	276	2	57.8	57.8		2.5	2.5		3		14		29
N	6.9813895	-1.9426894	19-Aug-97	11:22:51	276	2	57.8	57.8		2.5	2.5		3		14		29
N	6.9813957	-1.9426207	19-Aug-97	11:22:52	276	2	57.8	57.8		2.5	2.5		3		14		29
N	6.9814237	-1.9425605	19-Aug-97	11:22:54	276	2	57.7	57.7		2.5	2.5		3		14		29
N	6.981391	-1.9425689	19-Aug-97	11:22:55	276	2	57.7	57.7		2.5	2.5		3		14		29
N	6.9813976	-1.9425279	19-Aug-97	11:22:56	276	2	57.7	57.7		2.5	2.5		3		14		29

APPENDIX V

AML USED TO PROJECT GPS DATA FROM LATITUDE/LONGITUDE TO GHANA TRANSVERSE MERCATOR CORDINATE SYSTEM

```
input
projection geographic
units dd
datum WGS84
parameters
output
Projection Transverse
Units feet
Datum LEH
Parameters
0.99975
-01 00 00
04 40 00
274320
0.00000
end
```