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**EVALUATING THE SUSTAINABILITY OF LAND AND
ENVIRONMENTAL RESOURCES UTILIZATION IN THE NEW
JUABEN DISTRICT AND ITS IMMEDIATE ENVIRONS**



**THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA
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This is to certify that the work presented in this thesis was carried out entirely by myself, and all assistance received has been acknowledged. This thesis has never been presented, either in part or in whole, for a degree of any other university.

STUDENT


.....
OPOLO FABI

PRINCIPAL SUPERVISOR


.....
PROFESSOR EMERITUS E. LAING

Feb 2, 2006

SUPERVISOR


.....
PROFESSOR A. A. OTENG YEBOAH

SUPERVISOR


.....
PROFESSOR K. S. AMANOR



To my late parents



QUOTATION

"people are entitled to a healthy and productive life in harmony with nature" (Rio declaration, 1992)

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Timely empirical information on the status of sustainability of land resource use is a critical strategic input for achieving sustainable land-use policy objectives. It is also important for maintaining and improving positive achievements in sustainable resource use. Examining relevant elements of both socio-economic and biophysical factors as findings are referenced to appropriate and recognized standards is the best approach to sustainability evaluation. Land resources of the New Juaben and the neighbouring districts have served as a medium for various land uses over the years. Yet, the sustainable use of these land resources has been questioned. This study, therefore, sought to evaluate the sustainability of land resource use in the area. Four dimensions of sustainable land and environmental resource use were considered: inter-generational equity, protection of water bodies and steep slopes from unsuitable land uses, efficiency in land allocation for suitable land uses and land-user perspectives of the suitability of cropping systems and land types. The investigation involved vegetation study, mapping of cropping systems with GPS, interviews of farmers, satellite data analysis, spatial data modeling and Geographical Information Systems (GIS) applications. The outcome indicated that, land resource utilization has not been sustainable. Per capita land consumption for urban construction has progressively increased from about 0.04 ha to over 0.2 ha. Steep slopes and areas within 100 m of the Densu River have been denuded of forest vegetation and replaced with fallows and annual crop farms. Cocoa has been cultivated in soil types which are naturally unsuitable. Farmer perception of cropping systems has undergone significant changes, with enhanced rating given to the cultivation of food crops, and diminishing emphasis on tree crops such as cocoa. The trends of resource use could be attributed to various remote and proximate factors. Continually monitoring and evaluating the performance of land-resource utilization could provide feedback information necessary for redirecting resource use from the current unsustainable course to one of sustainability.

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| | |
|---------|---|
| CA | Cluster Analysis |
| CHIPS | Copenhagen Image Processing System |
| CSIR | Council For Scientific And Industrial Research (Ghana) |
| DA | Discriminant Function Analysis |
| DEM | Digital Elevation Model |
| ENRECA | Proramme for Enhancement of Research Capacity in Developing Countries |
| EPA | Environmental Protection Agency |
| ESRI | Environmental System Resource Institute |
| GCP | Ground Control Point |
| GERMP | Ghana Environmental Resource Programme |
| GIS | Geographic Information Systems |
| GPS | Geographic Positioning Systems |
| IR | Infra-red |
| ISODATA | Iterative Self-Organizing Data Analysis |
| ISSER | Institute Of Social, Statistical And Economic Research |
| Landsat | Land Satellite |
| RGB | Red-Green-Blue Colour System. |
| RSAL | Remote Sensing Applications Laboratory |
| TIN | Triangulated Irregular Network |
| TM | Thematic Mapper |

INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Land resources can sustain the vital life-supporting roles provided the mode of exploitation guarantees sustained utilization. In the past, human preoccupation has been mainly the struggle to carve out a niche in the biosphere. However, that quest now threatens the very conditions necessary for sustaining human life (Holling and Sanderson, 1996). Sound management of land and environmental resources utilization should be an important feature in land-use strategies if sustainability can be realized.

The importance of sustainable development was endorsed by the Earth Summit in Rio de Janeiro in 1992, which eventually led to the formulation and implementation of national strategies for sustainable development. Internationally, regionally, nationally and locally, this approach to resource use has been acknowledged, and constitutes the subject matter for chapter 10 of Agenda 21 (UN, 1993). The need to sustainably manage land and environmental resources use is a guiding policy for all land-based developments in Ghana (Ministry of Land and Forestry, 1999; EPA, 1994).

Managerial activities such as periodic evaluation of land resource qualities and efficiencies of the performances of land-use strategies, in terms of biophysical impacts and productivity, ensures that implementation leads to achievement of desired results in

the long term. Sustainable land-use management must be informed by timely, real and adequate feedback information on land-use performance and the status of land and environmental resources, rather than speculations. In Ghana, however, such a systematic approach of regular evaluation as a management tool for sustainable land use has not been properly harnessed. Already, this has generated land-use problems with significant implications for long-term use of land and environmental resources in the country (Ministry of Lands and Forestry, 1999).

1.2 Sustainable land use

The concept of sustainable use of land resources is pertinent only against a background of limits to land resource availability and use. If no such limits exist, or they are not perceived to exist, then it is common that resources are overexploited. However, the concept of sustainability becomes increasingly important, as the scarcity of the resource increases due to rising demand and deterioration in resource quality.

The dictionary meaning of sustain/sustenance is 'to keep in existence' or 'to provide for the support of'. It is also defined as 'maintaining the same level of activity or pace of plan, method or system without harming its efficiency and the people affected by it' (University of Cambridge, 1996; BBC World Service, 1992). Inferentially, sustainability essentially means keeping life on earth in existence by maintaining the natural levels of the earth's supportive functions intact, or within reasonable limits of tolerance. Thus, the ultimate goal of sustainable resource use is not to sustain human activity but humans

themselves. Whereas measuring sustainability of human well-being is doubtlessly problematic, sustainable production and consumption is easier to measure, and could be considered as a proxy for the sustainability of human well-being.

Many definitions have been proposed to describe aspects of sustainable development. The multiplicity and variety of definitions reflect the existence of multiple perspectives and their complex inter-relationships. However, this review gives the highest attention and priority to sustainability dimensions that are relevant to the utilization of land and environmental resources.

From an ecological perspective, sustainability in land and environmental resource use can be equated to the concept of resilience. Whereas the concept of resilience as an adaptation to disturbance appears to be first articulated by Holling (1973), Westman (1985) seems to be the first to formally pose the question of whether the degree, if any, of a system to recover after natural disturbance may assist in the process of restoration after man-made disturbance. Westman (1985) defines ecosystem resilience as the degree, manner, and pace of the restoration of initial structure and function in an ecosystem after disturbance. Fox and Fox (1986) illustrate that disturbance-adapted systems appear to display a degree of resilience to human-induced disturbance on a scale relative to the magnitude, duration and type of disturbance.

For managed ecological systems such as agro-ecosystems, sustainability stresses the co-evolution of socioeconomic and natural systems (Reijntjes *et al.*, 1992). Sustainable agriculture is a philosophy based on human goals and on understanding the long-term impact of our activities on the environment and on other species. The philosophy seeks to guide the application of prior experience and the latest scientific advances to create integrated, resource-conserving and equitable farming systems which reduce environmental degradation, maintain agricultural productivity, promote economic viability in both the short and long term, and maintain stable rural communities and quality of life (Francis and Youngberg, 1990).

Sustainable agricultural land use should successfully manage agricultural resources, satisfy changing human needs while managing or enhancing the quality of the environment and conserving natural resources (TAC/CGIAR, 1988). The definite reference to and emphasis on changing human needs confers a dynamic connotation to sustainable utilization/management of land and ecological resources in agricultural sustainability (Serageldin, 1996). The clear allusion to changes in human needs presupposes a periodic monitoring of human needs to determine the relevant use regimes that best respond to prevailing human needs.

The International Union for the Conservation of Nature (IUCN) emphasizes socio-economic and intergenerational equity as an important issue and dimension in sustainable resource use. As a value, it presupposes that in the decision making to allocate resources,



equal weight should be given to the present and future generations. In other words, sustainable development must be a process of social and economic betterment that satisfies the needs and values of all interest groups, while maintaining future options and conserving natural resources and diversity (IUCN, 1980).

Intergenerational equity requires the maintenance of resource stocks - trees, soil, water, etc, and to avoid substantial decline in quality and quantity of resources with time (Markandya and Parce, 1988). In a dynamic system such as human society, sustainability is fundamentally a question of balance maintained over time (Dahl, 1995). Thus, sustainable resource use may be seen as the lack of forces tending to upset equilibrium over time. Accordingly, most indicators of sustainability are, in fact, measures of unsustainability, that is, the amount or extent of imbalances. Intergenerational equity suggests a judicious use of natural resources in a way that ensures that their capacity to support the development of future generation is not compromised (Serageldin, 1996). In this case, sustainable development focuses directly on the population that can be sustained by a given territory, that is, its carrying capacity (FAO, UNFPA and IIASA, 1982; Vitousek *et al.*, 1986). Such capacity depends on the desirable quality of life of the population in the territory, which would have to be defined in terms of essential (minimal) or desirable standards of living.

Compounding practically all the sustainability dimensions, Smyth and Dumanski (1993) define sustainable land resource management as combining technologies, policies and

activities that aim at integrating socioeconomic principles with environmental concerns so as to simultaneously maintain or enhance productivity; reduce the level of production risk; protect the integrity of natural resources and prevent degradation; and be socio-economically viable. Even though this may seem a more comprehensive explanation, it equally complicates assessment of sustainable utilization and management of agro-ecological resources.

1.3 Evaluation of sustainable land use

To move towards the goal of sustainable development, decision-makers at all levels (locally, nationally, regionally and internationally) need information. The primary aim of chapter 40 of Agenda 21 is to help decision-makers at the national level to access information. The information is to assist the understanding of how well we are navigating the road to sustainable development. The concept of sustainable resource use is dynamic in that what is sustainable in one area, may not be in another, and what was sustainable at one time may no longer be sustainable today. Although sustainability cannot be measured directly, assessments of sustainability can be made on the performance and direction of the processes that control the functions of a given system at a specific location (Smyth and Dumanski, 1993).

The problems associated with monitoring and evaluating progress towards sustainable development are highlighted in chapter 40 of Agenda 21. The divergent views on

indicators of sustainable development has necessitated the need to reach consensus on a suitable set of indicators that can adequately reflect the wide range of concerns encompassed by sustainable development, as promoted in Agenda 21. Though several of these indicators have been adopted for use at the international level, these are subjected to national sovereignty considerations (United Nations, 1993).

Change is not, necessarily, undesirable in relation to the requirements of sustainability. The effects of change in one unstable factor may be more than offset, in a positive or negative sense, by change in some other factor. Herein lies the difference between stability (concerned only with the likelihood of change) and sustainability (concerned with the balance between positive and negative change in relation to a particular system). Changes in a land-use system with time reflect instability in one or more individual factors. An understanding of the likely direction and nature of such instability provides a basis for evaluating sustainability.



Given the post implementation assessment of sustainable use of land and environmental resources in the present discussion, it will be appropriate to view 'sustainability' as a measure of the extent to which a form of land use is meeting the pillar requirements of productivity, security, protection, viability and acceptability. Thus, sustainability evaluation refers to a systematic process of post-implementation assessment of real impacts of policy objectives of individuals, institutions and nations in the light of

sustainability dimensions. The prime aim is to identify impacts, such that positive effects may be enhanced, and action taken to counter negative ones, either through selection of appropriate policy alternatives, or through parallel mitigation and enhancement measures

Five years after adopting an agenda for implementing the visions of the 'Earth Summit', it was realized at the Rio +5 forum that there had been little success in translating commitments to realities. The purpose of the summit was to move sustainable development from agenda to action. Before the 2002 Earth Summit, a strong suggestion for a recommitment to the ideals of sustainable development was made by UNEP (2000). But this could be done only after a thorough evaluation of the outcome following the implementation for some time now. To achieve the global, regional and national objectives, it is obvious that aggregation of local and situational developments be made first. That will provide insight into inherent patterns of variations in successes, failures and challenges. Knowledge of real experiences will inform future decision-making processes for any needed adjustments. This will ensure that the trajectory of sustainability in the utilization of agro-ecological resources is maintained on the local level and also provide information on the spectrum of opportunities and challenges to the common national and international sustainability in the utilization of natural resources.

1.4 Problem statement

Land resources are in limited supply, finite, usable and vulnerable to injudicious use (WCED, 1987). The effects of land-use become critical as it progressively intensifies with growing human populations, and expanding multi-purpose use of land aggravates land-use conflicts. Even with the most technologically advanced modes of harnessing land resources, inherent deficiencies constrain achievement of optimally sustained productivity, with minimal degradation of the land resource base. Relative viability of land-use types also undergoes constant changes, and should be regularly assessed for utility from the perspectives of land users. This affords the opportunity to adopt land-use types that offer the opportunity for optimizing land-use benefits.

Among the objectives of Chapter 10 of the United Nations Sustainable Development Agenda, entitled, 'Integrated Approach to the Planning and Management of Land Resources', improving and strengthening ... evaluation system is deemed important for achieving the ideals of sustainable development. Given the intrinsic limitations of land-use strategies, it becomes a prerequisite that land-use management incorporate regular and timely evaluation exercises to yield the needed feedback information on the performance of land-use strategies after implementations.

The deviations of actual efficiency of resource utilization from adopted standards for sustainability furnishes stakeholders with information on current degree of the sustainability of land resources utilization. Having done this, control measures could be applied to re-direct the trajectory of present resource utilization, if found unsustainable.

There is also an opportunity to review and adjust management policies, objectives and criteria for resource utilization for achievable options that reflect prevailing realities. Such feedback information on challenges and opportunities could guide future decision-making processes by ensuring that land-use performance is optimized to achieve sustainable land-use policy objectives.

Land and environmental resources are important media for land-based productive ventures in Ghana. Nationally, high percentage of the population directly depends on land and environmental resources for livelihoods. Between 1984 and 2000, the country experienced demographic growth of 53.8% (Ghana Statistical Service, 2000). Demographic growth would likely continue to be a developmental issue. According to statistics, 49.2% of the work force depended on the agricultural and related sectors from the late 1990s to 2000 (Ghana Statistical Service, 1987). During the same period, the agriculture sector contributed approximately 40.0% of the national GDP, a percentage that was far less than the contribution made in the early 1980s, when 61.1% of the workforce were employed in the sector (Ghana Statistical Service, 1987). In the year 2000, the percentage contribution as reported by the Institute of Statistical and Social Economic Research was 35.5% (ISSER, 2001). Like other developing economies, agriculture and other land-based related sectors are crucial for future economic development.

Increasing population and over-dependence of the economy may have deleterious consequences for land through land-use pressure where there are deficiencies in land management regimes. It is realized that interaction of rapid population and growth could lead to continuing degradation of the environment and diminished resources productivity (Oti-Boateng *et al.*, 1989). Other studies have shown that over-population results in accelerated deforestation (Drigo, 1999; FAO, 1998; Sera, 2000). Obviously, the over all effect of population growth on land could be mediated by other factors such as existence of employment alternatives and adoption of efficient farming systems. For instance, a study by Simmance (1997) indicated that the degree of impact of population on land depends on the intensity of land use and the fragility of existing ecology. According to Boserep theory, however, moderate rather than very low population densities encourages efficient land use through intensive and settled agriculture land use (Schultz, 1990).

Historically, land resources in Ghana have been managed through various legal instruments and customary practices applied through the court system (Ministry of Lands and Forest, 1999). The country has also ratified several environmental and sustainable development-related international and regional agreements. Since 1991, it has adopted and formulated a National Environmental Action Plan to guide sustainable use of land and ecological resources (EPA, 1991).

Despite the institution of management strategies and commitments to sustainable policy objectives, there is concrete evidence to suggest that there is a significant lag of real achievements behind aspirations raised by national policies, formal commitments and published statements.

Investigations on land-use impacts in Ghana (Osman, 2000; Pabi, 1998; Gyasi and Uitto, 1997; Attua, 1996) have revealed serious transformations of the pristine vegetation cover into shades of fallow and degraded lands (Pabi and Attua, 2002). The implications for soil fertility decrease and erosion have been striking (Attua, 1996; Amanor, 1994), most of the good agricultural lands are losing their capacity to support certain agricultural land uses they previously used to (Amanor, 1994). In 2000, an estimated 220,000 km² of land in Ghana was affected by sheet and gully erosion (FAO/AGL, 2000). Nutrition depletion is also prevalent; this is due to reduction in fallow cycle, intensive cropping and inadequate application of fertilizer. This is having a long term effect in crop yield reduction and annual productivity losses of 2.9 percent in all crops and livestock (FAO/AGL, 2000). Impacts on Ghana's economy have been estimated at 2-5 percent of agricultural GDP. It has also affected household food security.



On a local scale, the New Juabeng and the neighboring districts express the above scenario in a pronounced manner. In addition to being the smallest District in Ghana,

New Juabeng has many sensitive and fragile, yet, important ecosystems such as river basins and hilly landscapes. The population size in the 2000 was 136,768, which was an increase of 48.0% over the 1984 figure of 92,482. The population density of approximately 1243 persons/km² in 2000, which is one of the highest in the country, is exceedingly above the 2000 national average of 79.3 persons/km². In the rural communities, the majority of the people directly depend on land through agriculture.

Studies indicate that agriculture and urban land uses are affecting the fragile and sensitive agro-ecological systems (Pabi, 1998; Osman, 2000). Whereas deforestation is a problem in the district, it is pronounced near Koforidua than the comparatively rural settlements. For instance, in a study of vegetation near Koforidua and other rural settlements, it was found that the area around Koforidua was highly deforested compared with the comparatively rural settings. The pattern was the same for species richness reduction (Pabi, 1998). Over the years, Koforidua has rapidly expanded spatially due to constructional activities; however, per capita annual change is unknown. In terms of housing population of the district, the number almost tripled between 1970 and 1995 (Ministry of Local Government, 1996), which obviously, means a corollary consumption of agricultural lands.

Whereas, the above indications raise fundamental questions about the efficacy of land and environmental resource use, they are not suggestive of a definitive unsustainability or otherwise of land resource use. The reason is that the levels of observed resource utilization efficiency is not measured against any recognized and definite sustainable resource utilization policy objectives or standards of performance – locally, regionally or internationally. Thus, without a substantive evaluation programme, no clear feedback

information on the performance of land-use implementation strategies and the degree of achievement of sustainable resource utilization objectives could be identified. This leaves the sustainability of resource utilization question of the districts unanswered, and accordingly, no definite basis for directing future land-use management process. Naturally, without definite information on sustainability of land-use efficiency, management planning decisions will be ineffective.

In the five-year (1996-2000) development plans for the administrative districts in Ghana, post implementation evaluation is identified as an important instrument for achieving land-use and environmental management policy objectives. The need for building capacity to carry out these managerial activities was also emphasized as an important strategic policy (Ministry of Local Government, 1996). Evaluation of sustainable development at the district level provides a basis for establishing aggregated estimates for the nation. Appropriately, the study considered it crucial to investigate relevant sustainability dimensions of land-use in the New Juabeng District in the light of the following issues:

- inter-generational equity in per capita conversion of land resources into urban land-use;
- effectiveness of allocating suitable land (soil) categories to crop types that ensures sustained optimum productivity with minimal land degradation;
- protection of fragile and sensitive but important ecosystems from destructive effects of land use; and

- viability of cropping systems and suitability of land resources from land-user perspective.

Certainly, the need to enhance the capacity for a managing land resource has been fully acknowledged, yet, practical achievements have not proved encouraging enough (FAO, 1996; FAO, 1993). Increasingly, integrated or systems approach to finding solutions to landscape problems is being recommended (Margerum and Born, 1995). This is due to the complexity and adaptive nature of ecosystems and land-use interactions (Lambin *et al.*, 2001). Clayton and Radcliff (1996) specifically describe a system approach to sustainability studies as offering a basis for liaison between disciplines on philosophical, methodological and technical levels that will allow their diverse modeling to be coupled with one another. It provides the means of linking the subsystems - hard (Hall, 1962) and soft (Checkland, 1981), draws on the interactive and control properties of complex and adaptive systems and then integrate biophysical and socio-economic factors within a common framework.

Agenda 21 makes a strong recommendation for the use of science and technology as an important component of the strategies for achieving sustainable development (WCED, 1987). In this respect, the FAO, among other organizations and individuals recommend the integration of remote sensing and geographic information system (GIS) and geographic positioning system (GPS) technologies in land related studies (Yeh and Li, 1997; Hallet *et al.*, 1996). Particularly, pulling their specific and synergistic advantages

to bear upon research makes possible cross-fertilization of ideas and formulation of methodologies and analysis that was practically impossible hitherto (Eastman *et al.*, 1993; Estes and Star, 1997; Lange and Gilbert, 1999, Star *et al.*, 1997).

Particularly, as sustainability motivates and guides resource management objectives, the direction for development and application of GIS in landscape conservation should be towards the linkage and integration of human and physical environmental systems (Flamm and Turner, 1994; Hobbs *et al.*, 1993). This helps to investigate and reconstruct human-induced transformation spatially and historically on different scales (Skole and Tucker, 1993; Acevedo *et al.*, 1996; Brondizio *et al.*, 1996) an important element of sustainable land resource use evaluation.

Evaluation research is pursued in several venues in a GIS environment. For instance, Talen (1998) applied GIS to examine the equity in distribution of public services to various segments of the community, and to search for areas that have not received adequate planning attention and have not been allocated their fair share of public resources. In an earlier study, Talen (1996) used GIS to assess achievement of open space goals by comparing the planned and implemented projects. Knaap *et al.* (1998) have also used GIS in their evaluation of the relevance and outcomes of planning.

However, remote sensing and GIS techniques alone are incapable of capturing the socio-economic dimensions of sustainable resource use. Of course, many of these socio-economic and cultural factors are the underlying driving forces that control the changes reflected in remote sensing information. Given this limitation, a case has been made to combine the potentials of relevant disciplines in studies involving land use and land cover.

Though, there have been some attempts to use these technologies in land-use studies in Ghana, there has been practically no applications to post-implementation evaluation in relation to planning purposes, applications are generally restricted to land use/cover mapping that do not adequately yield the needed information for the formulation of land-use management strategies. In this study, though, a comprehensive use was made of these technologies to achieve the objectives of the study. Considering the difficulty imposed by the multi-faceted nature of sustainable land use, the study focused on selected aspects of sustainability of land use, which were considered important and relevant.

1.5 Goal and specific objectives.

The main goal of the study was to provide information for decision making to enhance the achievement of sustainable land and environmental resource management objectives in the study area. To this end, it sought to achieve the following specific objectives:

- Find out if land types are allocated to crop systems for which they are potentially suitable.
- To find out the viability of cropping systems and land suitability from land-user perspective.
- To determine whether national land-use directives respecting the protection of steep slopes and flood plains are being complied with.
- Provide information on the degree of inter-generational equity in terms of per capita conversion of potential agriculture lands into urban built-up.
- Determine land-use/cover change between 1991 and 2001.
- Demonstrate how remote sensing and GIS can improve evaluating procedures of land-use performance in the light of sustainability criteria.

THE STUDY AREA

2.1 Location and settlements

The study area is sandwiched between latitude 0° , $10'$ W and 0° . $24'$ W, and longitude 5° . $55'$ N and 6° . $15'$ N. It is located in the upper region of the Densu River Basin. Though the New Juaben District was the primary focus of the study, portions of neighbouring districts - Yilo Krobo, Akuapem North, Suhum Kraboa Coaltar, and East Akim Districts, that interface directly with the New Juaben were considered for a couple of the remote sensing studies and the GIS analyses. The reasons for including parts of the neighbouring districts in the study were due to the irregular shape of New Juaben District, spatial configuration of the settlements in the area and expansion of settlements in New Juaben into the neighbouring districts, the need for investigating specific environmental phenomenon over a wider spatial scale and convenience.

By size, New Juabeng District is the smallest district in Ghana. Of a total land area of 110km square, about 27.0% was built-up, making it one of the most built-up districts in Ghana in 1996 (Ministry of Local Government, 1996). In space, the settlements are made of a centrally positioned conurbation and other minor settlements at different stages of socio-economic development. Koforidua, the most urbanized settlement, forms the central core of the conurbation. Surrounding Koforidua are relatively less urbanized towns including Koforidua Ada, Effiduase, Asokore and Adjeso (Fig.2.1). Structurally,

it is impracticable to differentiate Koforidua *per se* from the other towns; it has grown and physically merged with them to form a single massive built-up conurbation (Fig 2.2). Practically, the conurbation has expanded into the Akuapem North District; a situation that has created administrative and planning challenges.

According to the Medium Term Development Plan publication, there were 52 settlements in 1996 – most of which were villages. The area is heavily urbanized and there is an acute land shortage for other important land uses. Land scarcity is acknowledged as a major developmental constraint in the district (Ministry of Local Government, 1996). In 1996, about 90.0% of the population lived in urban centers.

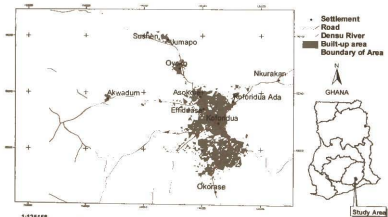


Figure 2.1: Location of the study area

2.2 Demography

Demographically, New Juaben District is multi-ethnic, with the dominant tribe being the Ashanti. Other tribes such as the Akwapems, Krobos, Akims, Ewes and other Northern Ghana tribes from northern Ghana are fairly represented. The population of the New Juabeng District was 52,796 in 1960, increasing to 68,607 in 1970. By 1984, the population was 92,482, of which 77,608 lived in the conurbation. The total population for the district in 2000 was 136,768 (Statistical Service, 2002). In 1984, 82.8% (82,566) lived in urban settlements, whereas the remaining lived in rural areas. The proportion of urban population was 83.4%, which is a slight increase above that of 1984 (Ghana Statistical Service, 1987, 2002). Population density of the district was far higher than the regional average in 1984. It must be stated that the bulk of the population lived in Koforidua.

Comparatively, Koforidua has been undergoing significant demographic growth. In 1960, the population of Koforidua was 34,856; rose to 46,234 in 1970, and reached 58,298 by 1984. In 2000, the population stood at 88,093. The historical population patterns of important settlements in the conurbation are presented in Figure 2.2.

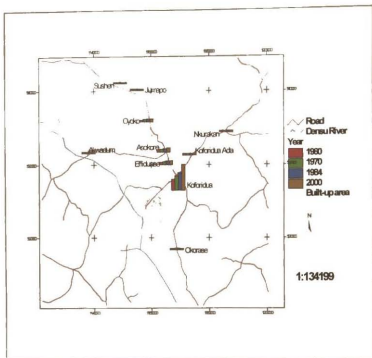


Figure 2.2: Population growth of selected settlements

TABLE 2.1: POPULATION GROWTH OF SELECTED SETTLEMENTS
IN THE KOFORIDUA NEIGHBOURHOOD.

| Settlement | 1960 | 1970 | 1984 | 2000 |
|------------|-------|-------|-------|-------|
| Koforidua | 556 | 773 | 1609 | 2543 |
| Ada | | | | |
| Asokore | 2965 | 4206 | 5892 | 10068 |
| Effiduase | 3907 | 6207 | 7681 | 10063 |
| Koforidua | 34256 | 46235 | 58731 | 87315 |
| Oyoko | - | 4113 | 5061 | 6612 |
| Akwadum | - | 191 | 298 | 2114 |
| Korle | - | - | 251 | 1392 |
| Nkwanta | | | | |

Source: Ghana Statistical Service, Accra.

2.3 Topography, geology and soils

The Voltaian scarp is an important geological feature of the northern section of the region. This consists of chalk and coarse sandstone with some clay shale interstratified (Junner and Hirst, 1946). The Landscape (Figure 2.3) does not show much altitudinal variations; it ranges from about 152 to 200 m above sea level. The plateau overlooking Koforidua and trending a north-west direction forms an imposing feature in the region. It peaks at about 200 m in the Aboabo area. The presence of exposed outcrops is a major characteristic of these highlands. To the southeast lies another prominent plateau range with a relatively low height. Lying between these two is a valley that serves as a passage for Nsukwao (a stream) and the Koforidua-Nkurakan road. From Koforidua towards the western section of the area, the terrain is low-lying and flat with gentle undulations and occasionally low hills rising abruptly above the generally low elevation.

On a broad scale of soil classification, Forest Ochrosol is the dominant soil type in the area, with the Adawso-Bawjiase Association being the commonest (Figure 2.4). Other soil associations such as Koforidua and the Nankese Feric Luvisols (FAO, 1988) that are dissected by streams and the Densu River are restricted to a few localities (Walker, 1962). These are developed from parental rock material of granite. Characteristically, these soils are dark brown, sandy with clay and gravels of quartz, loam and humus components (Adu and Asiamah, 1992). The characteristics and suitability of soil types in the area are summarised in Table 2. 2 (Adu and Asiamah, 1992).

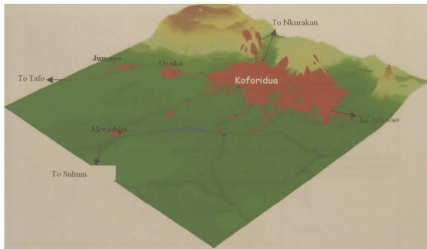


Figure 2.3: Topography of the study area

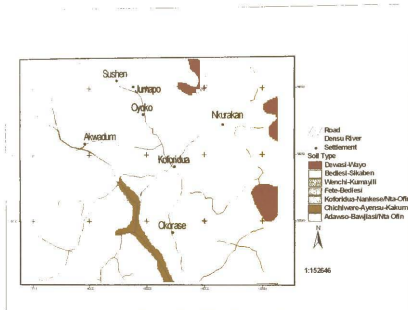


Figure 2.4: Soil types of the study area

TABLE 2. 2: CHARACTERISTICS AND CROP SUITABILITY OF SOIL ASSOCIATIONS IN THE STUDY AREA.

| SOIL ASSOCIATION | CHARACTERISTICS | CROP SUITABILITY |
|---|---|--|
| Koforidua-Nankese/ Nta-Ofin Compound | <p>a. Brown and reddish clay loams developed on summits and upper slopes over weathered biotite? and granodiorite.</p> <p>b. Strong brown loams developed in colluvium on middle slopes</p> | Cocoa, oil palm, coffee, citrus, plantain, maize and cocoyam |
| Fete-Bediesi Complex | <p>c. Brown soils developed over hard quartz.</p> <p>d. Red and brown sandy clays and loams developed in deep piedmond drifts; red concrecretionary clays on upper slopes.</p> <p>e. Yellow -brown and grey-brown alluvial sandy clays on lower slopes and on valley bottoms.</p> | Plantain, maize, cassava, vegetables and rice. |



| | | |
|--|--|---|
| <p>Adawso-Bawjiase/ Nta-Offin Compound</p> | <p>a. Pale yellow brown and redish brown gravely and concrecretionary clay loams and clays developed directly over little weathered biotite granites on summits and upper slopes with areas of red and brown loams derived from peneplain drifts.</p> <p>b. Pale brown and mettle grey alluvial sands and clays on slopes and in valley bottoms.</p> | <p>Cocoa, coffee, oil palm, citrus, maize, cassava, plantain and cocoyam.</p> |
| <p>Source: Adu and Asiamah, 1992.</p> | | |

2.4 Climate and drainage

Being tropical, the temperature is consistently high the whole year round (Figure 2.5). The minimum and maximum temperatures occur in the months of July to August and February to April respectively. The mean temperature is approximately 27 °C, occurring from February to March and 26 °C from July to August (Dickson and Bennet, 1988). Rainfall regime is bi-modal (Figure 2.5). The major rainy season occurs between March/April to July, while the minor season starts from around September to November

(Fig 2.5). Rainfall is normally heavy with associated thunderstorms, with a mean annual rainfall range between 1200-1700mm. Specifically, the mean annual rainfall of Koforidua and Oyoko are 1425 and 1504mm respectively (Adu and Asiama, 1992). Results of analysis of rainfall records from 1966 to 1996 revealed a steady decline in the amount of annual rains in the area, though rainfall days remained practically unchanged (Pabi, 1998).

From December to February, the area comes under the influence of the Harmattan winds that precipitate the onset of the dry season. Humidity is generally high, with the values reducing slightly during the dry season. It is usual for the humidity to approach 100.0% in the night.

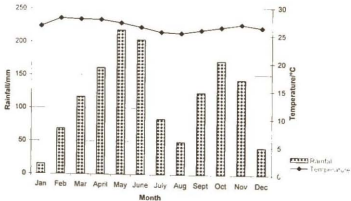


Figure 2.5: Mean monthly temperature and rainfall

The Densu River is the biggest in the area, with Asuoyaa, Kumiabena, Okumi and Nsukwao being its tributaries. The plateau ranges in the northeastern and the southeastern parts of the area serve as recharging sources for the water bodies. The scanty recharging capacity of these highlands is incapable of sustaining these rivers the year round. Human activities such as farming and timber felling and bushfires have destroyed most of the vegetation along the banks of the river. Consequently, they are rendered seasonal, reducing to shallow pools in the dry season while swelling in the rainy season.

2.5 Vegetation

Consistent with the above climatic regime, the area has a semi-deciduous forest of the *Celtis-Triplochiton* Association (Taylor, 1952). However, with progressive intense land-use pressure such as logging and farming, the originally dense vegetation has been completely modified, losing its pristine status. Only patches of the original vegetation exist in the most inaccessible areas such as relatively high elevations (Adu and Asiamah, 1992).

Species richness has reduced in many areas, particularly, around the urban settlements (Pabi, 1998). Most of the tree species remaining of the natural vegetation are *Triplochiton scleroxylon*, *Antiaris africana*, *Ceiba pentandra*, *Cola gigantea*, etc., most of which are characteristic of relic forests. Large tracts of land are covered with food

crop fallows at various stages of maturity, *Panicum maximum* and *Chromolaena odorata* (Adu and Asiamah, 1992).

2.6 Land Use

As already stated, land scarcity is a critical developmental issue in the New Juaben District. Table 2.3 shows the land-use pattern as it existed in 1996 (NDPC, 1996).

| TOWNS/VILLAGE | AREA (km ²) | % OF AREA |
|--|-------------------------|-----------|
| Land available for agriculture and other development | 50 | 45.0 |
| Settlements | 27 | 24.0 |
| Rivers and Forest Belts | 17 | 15.0 |
| Steep slopes | 8 | 7.0 |
| Roads, Railways, and High tension lines | 8 | 7.0 |
| Total Land Area | 110 | 100 |

Source: National Development Planning Commission, 1996

Farming remains an important occupation, especially, in the rural settlements. In 1984, though, the percentage of the labour force engaged in farming was 24.6 %, which was below the regional level of more than fifty percent (Ghana Statistical Service, 1987). A baseline survey conducted in 1996 on occupations in the area indicated that 60.0 % were engaged in farming (Ministry of Local Government, 1996).

Conditions of the soil and climate make the area suitable for the cultivation of cocoa, cola nut, oil palm and other such tree crops (Table 2.2). These crops are still important, especially, around rural towns like Oyoko, Akwadum and Suhyen where forest vegetation persists. Though cocoa used to be very important around Koforidua, replanting after swollen shoot and capsid attacks in the 1950s has seen minimal success. This is principally due to the prevalence of drought, bush fires, deforestation and unsustainable food cropping systems. As usual, cocoa is planted under the canopy of forest trees.

TABLE 2.4: FOOD CROPS AND YIELDS IN THE NEW JUABEN DISTRICT

| Major Crops | Number of farmers | Percentages of farmers | Area (hectares) | Actual Yield (tonnes) |
|-------------|-------------------|------------------------|-----------------|-------------------------|
| Maize | 150 | 12.8 | 900 | 1600 |
| Cassava | 300 | 25.6 | 1600 | 17600 |
| Cocoyam | 200 | 17.0 | 100 | 700 |
| Plantain | 100 | 8.5 | 100 | 800 |
| Tomatoes | 150 | 12.5 | 100 | 2000 |
| Garden eggs | 120 | 10.3 | 100 | 1800 |
| Pepper | 60 | 5.4 | 50 | 1000 |
| Oil Palm | 40 | 3.4 | 100 | - |
| Citrus | 50 | 4.3 | 100 | 1000 |
| Total | 1170 | 100 | 3150 | |

Source, National Development Planning Commission, 1996

Farmers cultivate food crops both for consumption and sale. Essentially, the traditional slash-and-burn method is used in clearing land for farming. Of the major food crops cultivated in the district, cassava and maize are the most popular among the farmers (Table 2.4). In the year 2000, statistics by the Research and Information Directorate of the Ministry of Food and Agriculture indicated that cassava and maize were the most common food crops in terms of size of area cultivated. Vegetables, cocoyam and plantain are also cultivated but on a relatively minor scale (Ministry of Local Government, 1996). A survey showed that majority of the farmers engage in small-scale farming; 61.1 % of the farms were less than 3 hectares (Ministry of local Government, 1996). The problem of land accessibility for large farming is compounded by the existence of poor soils in some areas, outcrops and the uneven nature of the landscape.

Wood-fuel fills the domestic energy needs of most inhabitants of the area. Logging is another important economic activity in the area. The Densu River is the main source of water for all activities. A reservoir constructed on it serves Koforidua and surrounding townships with potable water. Unfortunately, seasonal water shortage has become an annual experience in the towns.



MATERIALS AND METHODS

A typical evaluation study requires a series of standard management procedures, including: (1) adoption of standards of performance for sustainable land resource utilization, (2) data gathering on actual performance of land resource utilization and (3) comparison of the standards and the actual performance (Cole, 1996; Hellriegel and Slocum, 1978). These broad procedures were expanded by incorporating relevant elements of the Bellagio Principles - Guidelines for Practical Assessment of Progress Toward Sustainable Development (IISD, 1996). Among others, the principles make the following recommendations for the assessment procedure: guidance by a clear vision of sustainable development and goals that define the vision; consideration for the well-being of social, ecological, and economic sub-systems, their state as well as the direction and rate of change of the state of their component parts, and the interactions between parts; consideration for equity and disparity within the current population and between present and future generations, dealing with such concerns as resource use, over-consumption, etc., as appropriate; an explicit set of categories or an organizing framework that links vision and goals to indicators and assessment criteria; comparing indicator values to targets; and reference values, ranges, thresholds, or direction of trends, as appropriate.

3.1 DIMENSIONS AND STANDARDS FOR ASSESSING SUSTAINABLE RESOURCE UTILIZATION

Four dimensions were adopted for the concept of sustainability of resource utilization. Corresponding indicators and standards/criteria for sustainability of land and environmental resource utilization for the assessment procedures were adopted by making references to national sustainability policy objectives and recommendations by institutions and individuals on sustainable management for resource utilization.

The four dimensions were as follows:

- *Equitable per capita allocation of potential agriculture land resource for urban land use*

This assessment was carried out on the Koforidua Municipality, mainly against the matrix of pronounced scarcity of land and widespread inefficient conversion of prime agriculture lands into urban land uses in the New Juabeng District (Ministry of local Government, 1996). Such a situation necessitates efficient use of land for urban development to ensure inter-generational equity and accessibility of land for other competing land uses such as agriculture. The hypothesis for the evaluation is that differences in per capita land allocated for urban land use (built-up areas) in the Koforidua Municipality should not be significantly different between generations.

- *Allocation of land types to land uses for which they are inherently most suitable for optimum and sustained productivity.*

The logic is that different crops perform differently on different soil types under varied agriculture input regimes. Moreover, sustainable agriculture land use requires

that the natural productive potential of land resource base be maintained or enhanced, and to ensure that the ecological principle of resilience is achieved through the strict observance of complementarity (SCA, 1991). To attain the objectives of this dimension of sustainable land use, suitable lands must be identified for appropriate land uses.

Ecological sustainability

This ensures that land users protect or cause minimal damage to sensitive but vital ecosystems. Protection of ecosystems on steep slopes and the Densu River were the main foci in this context. In assessing the latter, a national environmental policy injunction that forbids farming within 100 m of water bodies (Ministry of Lands and Forestry, 1999) was adopted as a standard. For steep slopes, the same guidelines prohibit the use of slopes $>30^\circ$. However, this investigation adopted the FAO (1985) slope classification scheme that was used for the national agriculture land suitability scheme, since it provides appropriate details for intended analyses in the study. Besides, it has the same unit of measurement (percentage) as the one used in the study. Slope suitabilities for annual crops (cassava and maize) which are extensively cultivated in the area, and whose cultivation may cause greater damage to fragile ecosystems was considered. The slope suitability classes are shown in Table 3.1:

Table 3.1: Slope suitability for maize and cassava

| <i>Maize</i> | <i>Cassava</i> |
|--|-----------------------------|
| 0-8 %: suitable | 0-8 %: suitable |
| 8-16 %: suitable or marginally suitable | 8-16 %: marginally suitable |
| 16-30 %: marginally suitable or not suitable | suitable |
| >30 %: not suitable | >16 %: not suitable |
| Source: SRI (CSIR), Accra | |

- *Land-user perception of sustainable land uses and land types.*

The economic viability of agriculture land-use types from land-user perspective is an important determinant of the sustainability of cropping systems. Essentially, this is informed by experience from years of cultivating crop types on different lands. This significantly influences future decisions on choices of crops and land types that would optimize productivity and utility (SCA, 1991). Accordingly, farmers' opinions of sustainability (suitability) of cropping systems and land types were evaluated.

3.2 DATA SOURCES, ACQUISITION AND MODELING

A good knowledge of the conditions of land and environmental resources and their uses are important for evaluating sustainable utilization (Lillesand and Kiefer, 1994). Collins and Rhind (1997) have argued for a consistent and readily available framework data for scientific monitoring and modeling of resources. Estes *et al.* (1995) have recommended ten relevant core data sets: topography, hydrology,

infrastructure, climatology, demography, land use, land cover, soils, air quality and economy for sustainable development assessment. With due cognizance of constraints of time and data availability, weightier and the most sensitive indicators were selected for the dimensions of sustainable resource utilization considered. Other factors considered were the need for a reasonable balance between accuracy and simplification of data modeling, scale of analysis and usability of output information.

3.3 Slope Modeling

Slope is a critical function of erosion hazard (Desmet and Govers, 1996), and therefore a good indicator of erosive potential for landscapes. In the study, slope is expressed in terms of gradient, the maximum rate of change of altitude (Peucker *et al.*, 1978; Marks *et al.*, 1984). To operationalize the national environmental policies on the protection of land resources such as soil and vegetation for sustained use, slope has been adopted as an indicator to guide identification of areas that require conservation measures (Ministry of Lands and Forestry, 1999). This provided a justifiable basis for examining conflicts between land resource management policy objectives and existing or real land resource utilization patterns.

Elevation sampling

Slope is a derivative of a digital elevation model (DEM). Hence, the construction of a digital elevation model (DEM), which is a 3-dimensional raster representation of terrains, is an important requirement for slope modeling. In the study, elevation was used as the voxel (the volume elements from which DEMs are generated). A 'progressive sampling' method by Makarovic (1984) was adopted and manually

adapted for lack of software for carrying out the, normally, automated tasks. The technique allows for objective sampling of terrain with varying complexity, as is the case in the study area. In this case, highly varied topographic terrains were comprehensively sampled than less varied ones.

First, the boundary of the area of interest was marked out on a topographic map with a scale of 1:50,000, and a contour interval of 50 ft. Lines of varying intervals (depending on the closeness of contours) were drawn parallel to the latitudes across a topographic sheet. Points of intersection between the horizontal and the contour lines were then marked out. Due to practical difficulty of estimating elevation measurements between adjacent contours, sampling of elevation points were restricted to the points of intersections only. A total of 1605 points were marked for the elevation modeling.

The sampled points were digitized on an electronic digitizing board configured to ArcInfo 3.5.1, and the coverage projected and registered to the Ghana topographical map. In ArcView 3.2 environment, the coverage was converted into a point shape file and elevation data entered into an attribute table. The attribute table was converted into an Excel format for subsequent use in the Surfer 7.02 package.

Spatial interpolation by Kriging and variogram techniques for DEM and slope Modeling

Naturally, it is impossible to make exhaustive sampling for environmental phenomena under investigations at every desired location. This necessitated the use of spatial interpolation techniques to estimate values for areas not sampled (Burrough, 1986;

Franke and Nielson, 1991; Watson, 1992). Two broad categories of geo-statistical interpolation techniques can be identified global and the local (Petrie and Kennie, 1990; Oakes and Thrift, 1975). In global interpolation, a function incorporates information from all the samples, thereby suppressing local variations. Therefore, this was considered inappropriate for the study since the scale of analyses required the computation of local variations. The local techniques are based on the assumption that each point influences the resulting surface only up to a certain definite distance. Therefore, two local methods - Kriging (Houlding, 1994) and Triangular tessellation or Triangular Irregular Network-based technique (TIN) (Nielson, 1993) were used in the study. For one thing, these are quantitative interpolating methods, which have been found to be suitable for computer contouring algorithms (Lam, 1990; Burrough, 1986). Also, they can be justifiably used for comparatively small data.

Kriging is a local geo-statistical estimation technique synonymous with "optimal prediction" (Journel and Huijbregts, 1978). The stochastic nature of Kriging interpolation procedure allows for the computation of statistical significance of the surface and uncertainty of the predicted values to be calculated. This is expressed in a variogram that shows how the average difference between values at points change with distance between the points. Semi-variance may be defined as half the expected squared difference between the random variables $Z(x)$ and $Z(x+h)$ at a particular lag h . The variogram defined as a parameter of the random variable, is then the function that relates semi-variance to lag h (1).

$$\gamma(h) = \frac{1}{2} E[Z(x) - Z(x+h)]^2 \quad (1)$$



The sample or experimental variogram - $\gamma(h)$, can be estimated for $p(h)$ pairs of observations, $z(x_i + h)$, $i = 1, 2, 3, \dots, p(h)$ by equation (2)

$$\gamma(h) = \frac{1}{2} p(h) \sum Z(x_i) - Z(x_i - h)^2 \quad (2)$$

The attribute data of elevation and coordinate (feet) were used to generate experimental variogram with forty (40) lags and a total separation distance of 2200 meters in Surfer. Experimental variograms are, invariably, discontinuous and do not meet the conditionality of non-negative variance (Cressie, 1993). To achieve a continuous model of the experimental variogram, the power functional model ($r=0.508$; r is an exponent)(Pannatier, 1996), was fitted to the experimental variogram since they strongly matched. The interpolated elevation surface was gridded to 192.80×192.80 m and used to construct the DEM. Subsequently, a slope surface was constructed as a derivative of the DEM and measured in percentage. It was converted into a line shape file and exported into ArcView where it was interpolated using TIN-base technique into slope surface.

3.2.2 Satellite data processing and analysis

Maps are limiting for ecological analysis since they usually provide data as discrete, sharply bounded and internally homogenous polygons (Aspinall and Pearson, 1995; Goodchild *et al.*, 1992). This type of spatial organizational model imposes a fixed scale on analyses (Stoms, 1992). Satellite imagery, however, provides a varied surface that can be used to investigate generalization and scale effects (Simmons *et al.*, 1992). Additionally, the consistent regularity of covering the same area provides data that

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make for regularly temporal inventorying and monitoring for management of land and ecological resources that undergo various transformations.

The Landsat Thematic Mapper(TM) satellite data used for this study has relatively high spatial, temporal, spectral and radiometric resolutions (SBRC, 1994). The spatial resolution of 30×30 m for the multi-spectral bands, 1-5 and 7 were particularly suitable for the study since they are capable of detecting the typically, small-sized farms prevalent in the area of study. However, this high spatial resolution meant a corresponding high data volume. The thermal-infrared - band 6, has a coarse resolution of 120 × 120 m. It measures the amount of infrared radiant flux emitted from the earth's surface. It was used for mapping out broad temperature patterns of the area using the equation (Anuta *et al.*, 1984):

$$T = -12.5809D - 0.000233D \times D,$$

where T is the temperature in degrees Celsius and D is the relative digital counts for the TM thermal infra-red (IR) band.

The high radiometric and spectral resolutions characteristic of Landsat TM data enable them to discriminate the heterogeneous cover of the tropical landscape effectively. Landsat TM has been used for change detection studies with results comparable to those by aerial photos (Boresjo-Bronge and Thulin, 1985).

Remote sensing data are not received in a perfect state due to errors introduced during the imaging processes (Duggin and Robinove, 1990; Lunnetta *et al.*, 1991). This may affect the accuracy of subsequent image analysis if not corrected (Mayer *et al.*, 1993).

especially for change detection analysis. Therefore, the image analysis was preceded by correction of these distortions (Teillet, 1986). Radiometric and geometric errors - the most common types of random errors, are normally corrected at the user level of processing. All the data for the two periods were secured in a dry season with little cloud cover and haziness, so radiometric correction was not conducted.

Geometric rectification and registration of satellite data

For accurate area, direction and distance measurements, geometric rectification must be performed. Image registration is also a necessary requirement for the detection of changes in land-use/cover from multi-temporal satellite data sets. Since all these were relevant in the study, a hybrid process of simultaneous image-to-image geometric rectification and registration (Jensen *et al.*, 1993) was conducted.

A subscene of 1991 Landsat TM image, which was previously rectified and registered to the national topographic map, was used as a base year image. The registration of the 2000 image to the 1991 image involved the selection of closely matching pairs of ground control points (GCP) in the two images. It is often difficult to locate good ground control points in rural areas, so much use was made of features associated with urban environment such as roads, junctions of and between roads, rivers, etc. In all, 16 GCPs were collected for the registration process. The second power deformation model was used for the registration, as a compromised choice. The basis is that, besides producing a more accurate result, it does not distort the resultant image, as does the third power model. Moreover, it is better to use lower power models for a sub-scene less than half scene. The first power model could have been

more appropriate, but for the profound varied elevational nature of the terrain (Jenson, 1996).

Band selection and image enhancement

Univariate and multivariate statistical analyses were conducted on the satellite data to identify bands with high information content for the enhancement process. Suitable band combination is important for optimizing information extraction. Appropriate band combination is determined by terrain, climate and the nature of project interpretation (Sabins, 1987).

Normally, it is inappropriate to use high correlated bands in a single analysis to avoid information redundancy. The usefulness of a given band-combination may be judged by the correlation between the bands (Epema, 1986). Generally, bands with low correlation coefficients are capable of discriminating between land-use/cover classes (Mulders *et al.*, 1992). Therefore, a correlation matrix of the bands was computed in SPSS 10.0 from the TM digital numbers of the point shape extracted in CHIPS for the vegetation sampling sites. Apart from their comparatively low correlation coefficients between them, bands 3, 4 and 5 that were selected for the enhancement procedure have these vital information values critical for the study:

1. *Band 3 (red)* represents one of the most important bands for vegetation discrimination. It is also useful for soil-and geological-boundary delineation.
2. *Band 4 (reflective infrared)* is responsive to the amount of vegetation biomass present in a scene, emphasizes soil-crop and land-water contrast.
3. *Band 5 (mid-infrared)* is sensitive to the amount of moisture in plants.

Bands 3, 4 and 5 were loaded onto the red-green-blue (RGB) color system in the order of 5,4 and 3 respectively. A contrast-stretch enhancement procedure was applied in the image analysis to optimize information content of the false color image. This was appropriately used since the spectral distribution was Gaussian (Jensen, 1996). In the enhanced image, thicker vegetation appeared dark green, with lighter vegetation cover appearing light green. Young or short fallows/annual crops appeared greenish yellow or yellow, with built-up/exposed or bare ground appearing reddish and purple respectively.

Unsupervised and supervised classifications

The classification process started with initial exploration and identification of possible distinct cover classes using an unsupervised classification algorithm called Iterative Self-Organizing Data Analysis Technique (ISODATA) (Jain, 1989). Coupled with previously acquired *in situ* information, a combined functional and structural (land-use/cover) classification scheme that fits local conditions and the objectives of the study was designed to guide characterization of the land-use/cover types. The adopted land-use/cover classification scheme was made up of following five (5) broad categories:

- Built-up/exposed (exp) areas: constructed features such as buildings and roads;
- Forest-farms(for-farm): patches of dense forest or tree crop farms or a mixture of the two (Plate 2.1);
- Long fallow (longfall): dense and high thicket with a number of trees of different sizes;



- Short fallow (shfall)/annual crop farms(anncrop): young fallows or annual food-crop farms or a mixture of them, usually with widely spaced isolated trees;
- Degraded lands (deg): comparatively short vegetation of grass and other herbs, invariably associated with highlands with a history of intensive cultivation and bush burning.



Plate 2.2: An example of a forest-farm.



Plate 2.2: Pictorial illustration of degraded land

Despite the measures taken to reduce errors in the classification process, the problem of mixed pixel (pixels of different cover types)(Smith *et al.*, 1985) would have introduced some errors. Practical constraints in separating some land-use/cover types necessitated the combinations of some categories of land-use/cover types, which also simplified the scheme. This generalization may have further reduced the accuracy of the output image.

Supervised classification

Prior to designing the classification scheme, the satellite data was examined for the level of normality in the distribution pattern of the reflectance values. This was to ensure that the distribution pattern meets the assumed normality criterion that justifies

the use of the Maximum Likelihood supervised classification algorithm used in the study (Griffith and Amrhein, 1991; Schalkoff, 1992).

Training areas were selected for the various land-use/cover classes. The selection procedure carefully considered homogeneous representative areas for the various land-use/cover categories based on colour, size, shape, and context properties (Richards, 1993; Lam, 1990; Barnsley and Barr, 1997). Previous geo-referenced field information facilitated the selection of the training areas. These were on-screen digitized as polygon shapes.

Training statistics: mean, standard deviation, covariance and correlation matrices of the spectral values were generated for the five land-use/cover classes. The separability matrix of Jeffries-Matusita, which has a continuous scale of 0 - 1.44, was also generated for the training areas to determine the degree of separation or similarity between them. Here, cover classes with separability distance of zero (0) are considered identical classes, with those with a separation distance of 1.44 being totally separated or absolutely different or dissimilar classes. Histogram and scatter plots also facilitated the classification process by progressively indicating the degree of between-class separation prior to the final classification of the entire image. Polygons with multimodal data were not used in the classifier-training process to ensure that each class has only one land-use/cover type.

Maximum Likelihood classifier algorithm was used to classify the image. Though highly reputed for its high accuracy of classification, and hence one of the mostly

used, it relies on the assumption of a multivariate-normality of data distribution. However, this normality condition is not fully met by satellite data, since the values are discrete, with non-negative values; the values range from 0-225 (Mather, 1999).

Field verification and classification accuracy

Verification procedures were designed to balance scientific rigor and defensibility with practical limitations of time, general limitations/challenges associated with the use of remote sensing techniques in the tropics and availability of appropriate historical test reference information. The actual procedure involved the use of a combination of field and limited number of suitable aerial photographic information. Samples collected from the vegetation ground truthing were a valuable source of test reference information since these were randomly collected, photographed, adequately characterized floristically, extensively distributed throughout all the cover types and geo-referenced with GPS. As earlier mentioned, a field verification survey carried out after the unsupervised classification yielded important information that improved the subsequent supervised classification. The pixels used to train the Maximum Likelihood algorithm were not used as test samples. This was to ensure that the reference information was as independent or unbiased as possible.

Statistically, classifications schemes with few categories, such as that adopted for this study do not demand the use of many test samples for error calculation. However, the high importance accorded the vegetated classes, and the appreciable level of within cover variability necessitated the use of a relatively high number of samples (150) for the analysis. The test sample data were converted into a point shape, rasterised and

used for a pixel-by-pixel comparison with the classified image, and accuracy computed using Kappa statistical technique (Carstensen, 1987), which measures the level of agreement between two images captured in different periods.

3.3. VEGETATION COVER AND LAND-USE PATTERNS

3.3.1 *Tree Sampling*

Trees with a diameter of 10.0cm or more, at breast height (1.3 m) were counted in 150 quadrats of 30m x 30m. The quadrats were located at variable distances from footpaths at different intervals apart. The inter-quadrat interval was wider where tree distribution was uniform. The quadrats were geo-referenced using a 12XL Gamin GPS receiver, whose accuracy was previously determined (± 7.6 m). This was computed by using 30 coordinate measurements at a triangulation point that were recorded, at five-minutes intervals. At each of the 150 sampling site, the general state of the vegetation was observed. This was to help with interpretation of images for classification and validation of the classified image. The choice of trees as indicator is based on the assumption that they tend to be more persistent features on landscapes than herbs over time, barring significant natural or anthropologically induced impacts. Though, this is not discounting seasonal climatic variations that affect plant phenology and canopy structure.

3.3.2 *Mapping of cropping systems*

Land use is appropriately described in terms of function rather than physico-chemical properties; it is human use of the land. In this context, cultivated and recently harvested farmlands provided indications for identifying cropping systems.



Cocoa, maize and cassava were identified in the same quadrats in which the trees were counted. Cocoa trees in the quadrats were counted but only the presence or absence of maize and cassava were recorded.

Apart from the graphical and tabular representations, univariate and multivariate analyses were conducted to explore and confirm some relationships. The satellite bands and the number of trees were used as predictor variables to assign the sampling sites of the vegetation ground truthing to pre-determined groups of three (3) levels of cocoa tree densities using discriminant function analysis (DA) (Manly, 1992). The groups were: 1) cocoa farms with normal tree densities, 2) those that have been partially converted into fallow and annual crops (moderate conversion) and 3) those with only remnant cocoa trees or totally converted into fallow and annual food crops (total/extreme conversion). In the case of the last group, farmers were asked of the history of cropping systems at the sites. These were displayed in a canonical plot of the first two canonical functions. The same analysis was carried out using the Landsat TM (2000) but substituting the density of cocoa trees for the density of other tree species, and used to assign the sites to categories or levels of deforestation based on tree densities.

3.4 SOIL AND LAND SUITABILITY

A digital copy of soil association and agriculture land suitability maps prepared under the Ghana Environmental Resources Management Programme (GERMP) by Soil Research Institute, at the scale of 1: 250, 000, were secured and rasterised. The land suitability classification was based on the FAO (1985) scheme. These included the

general agriculture land suitability of crops and land suitability for cocoa under medium input regime. The most extensively occurring soil associations and suitability categories were used. Those included in the investigation were:

Nankese-Koforidua/Nta-Ofin Compound Association (area):

- i. Medium or coarse-textured soils with good structure.
 - ii. Moderately gravely, stony or concretionary.
 - iii. Deep non-gravely soils on lower slopes.
 - iv. Occurs on topography that is undulating with (5-12 %) slopes.
 - v. Has moderate to severe susceptibility to erosion and maintains fairly high moisture retention capacity although surface dryness is common in the dry seasons.
 - vi. Root penetration is easy.
 - vii. It is marginal for mechanized farming with hand tillage recommended.
- Suitable for a wide range of tree and arable crops.

Adawso-Bawjiasi Association (Area)

- i. This upland association consists of Adawso and Bawjiasi series.
- ii. It is confined to the summits of low hills and lower slopes.
- iii. The soils are gravely and stony.
- iv. May be well, moderately or imperfectly drained, susceptible to drought, and more so to erosion.
- v. They support maize, cassava, yams, pineapples, yet permanent crops such as citrus and mangoes are suitable.

- i. A mixture of good and bad lands, with thin reddish and brown soils overlying massive hard rocks.
- ii. Some lands have clayey pan soils with tightly packed stones.
- iii. Forestry is recommended for these areas.
- iv. The good lands occur on slopes, with soils that are moderately, well or imperfectly drained.
- v. This area is considered suitable for tree and arable crops.

3.5 SPATIO-TEMPORAL DEVELOPMENT OF THE KOFORIDUA MUNICIPALITY

Map data compilation by Town and Country Planning of the New Juabeng District from the 1920s through 1990 were redrawn to a common scale, digitised and geo-referenced to the national topographic map. It was then exported from the ArcInfo environment into ArcView. Area was measured in hectares.

3.6 GIS ANALYSES

Apart from the topographic modeling that was constructed with a Surfer package, all other GIS analyses were carried out in ArcView 3.2 (ESRI) and IDRISI 32 (Clark University) in a grid format. It is computationally easier and faster for a computer to handle overlay analyses in raster than the vector model (Martin, 1996). The analysis carried out included Boolean, map query, area summaries, etc.

3.6.1 Land-use/cover change detection

In any definition of sustainability, the key element is change. This is particularly important in management of natural resource utilization. In determining the land-use/cover change, a method referred to as delta by Nelson (1982), and post classification by Riordan (1981) was adopted. It involved the overlaying and pixel-by-pixel comparison of the classified images of the two periods to determine locations, directions and areas of land-use/cover change. The post-classification technique has advantages of producing from-to image and change detection matrix that makes it easier to detect indefinable changes. This approach has been successfully used by others (Royer and Charboneau, 1988; Pabi and Attua, 2002).

A major drawback of the post-classification method is that errors introduced by classifying the two images separately would be present in the final change-detection map (Rutchev and Velcheck, 1994). Such random and independent errors could mask, especially, areas with limited changes. Hence, this necessitates the need for high classification accuracy (Gordon, 1980; Howarth and Boasson, 1983). This should be of particular concern when images captured at close time interval are being used.

However, the use of images captured in the same season would have reduced this error (Collins and Woodcock, 1994). Rectification of the images and the detailed ground survey may also have further reduced these errors. The degraded land class was further reclassified as short fallow/annual crop to reduce the number of from-to land-use/cover categories to ease comprehension. The two were assigned to one class since they were the most similar categories. Additionally, the degraded land is assumed to develop from short-fallow/annual crop fields.

3.6.2 Intergenerational equity in land allocation for urban land uses

Intergenerational land-use efficiency examined the degree of equity in per capita land allocation among generations. Based on the theory of environmental economics, Tietenberg (1992) has proposed a dynamic efficient allocation model, which can be used to realize efficient land allocation and maintain equity between generations in different time periods. An abridged and simplified form of the model was used in this study. The model allows depletable and non-recyclable resource to be allocated using dynamic efficient criteria. For equity in the use of arable land for urban land use, it is expected that per capita land resource used (Q) be the same for all generations at different times ($t=1,2,3,\dots,n$). That is, $Q_1 = Q_2 = Q_3 \dots Q_n$. If total land resource used by a generation of population (P_t) is Q_t , then per capita land use $Q_t = Q_t/P_t$.

An important assumption for this simplification is that current generation cannot be certain of how future generations may use land resources. It will, therefore, be simplistic to rationalize that future generations will be satisfied with a heritage of capital converted from land resources through inefficient land-use practices.



Population census data of 1970, 1984, 2000 and a few projected ones were obtained from the Ghana statistical Service. Some of the population sizes were estimated by interpolation. Estimates of built-up sections of the settlements were computed in ArcView from historical maps and classified images.

3.6.3 Steep slope protection and land-use conflict

The slope map, was overlaid with a land-use/cover image. This involved initial application of Boolean analysis of the layers. Subsequently, map query analysis was conducted to identify zones where short fallows fell within slopes greater than 15°.

3.6.4 Protection of the Densu Flood Plain and land-use conflict

A layer of series of buffers was constructed around the segment of the Densu River in the study area. Three buffers were constructed at distances of 100 m, 200 m and 300 m from the river. This was followed by Boolean analysis of the buffer and the land-use/cover maps. Map query was conducted on the two maps to identify land-use/cover types that fall within the various buffer corridors. Another map query was also carried out to identify segments within the 100 m buffer that have forest-farms.

3.6.5 Land-use efficiency

This dimension examined whether agricultural land-uses were being carried out on land types for which they are most suitable. To this end, a series of map queries between the soil types and the land suitability map on the one hand, and the land-use/cover map and the cocoa land suitability map on the other were carried out.

3.7 Land-user perceptions of the suitability of land types and cropping systems

Human intentions, decisions and activities constitute the core of management failures or successes of agro-ecological resources. Humans are an important nexus between land use and sustainable utilization of agro-ecological resources. Hence, of all relevant stakeholders in the evaluation of land use for sustainability, land users are very important.

On balance, it is local knowledge informed by experiments that should get highest priority in sustainable evaluation. Local farmers live more closely to real problems, constraints, and opportunities afforded by the environment and land use. Their experience will pick up complex interactions of variables which may be very specific to the local circumstances but which would have been rejected in scientific experimentation because of their local nature and the impossibility of researching every possible permutation of factor values (e.g. rocky, steep slopes; high rainfall; restricted growing season; cereals intercropped with legumes; no fertilizer; hand tools; family labour). Perhaps the most pressing reason to give local knowledge the first consideration is that, in the end, it is the local farmers who suffer from poor advice, failed technologies, and expensive solutions.

Accordingly, a limited discussion with representatives of the district planning committee was carried out. The purpose was to examine their activities on land use and environmental management, the degree of corroboration among them, their current priorities on land use and environmental issues, challenges to policy and planning implementation programmes and how any of these are being confronted.

Since individual landowners and tenants are the ultimate decision-makers of land-use adoption, they were interviewed for their perception of land and crop suitability.

With this, one gains insight into underlying socio-economic and biophysical forces that define current and future trends through spatial inter-connectivity between land resources and activity of farmers. To this end, a questionnaire (Appendix 1) was designed as an instrument to source for information on the past, present and possible future land-use/cover trend. The interviews also examined land-use intensities by changes in the length of fallow cycles, environmentally harmful agricultural land-use practices and ease of acquisition of productive lands for farming. Perceived economic (profitability) and productive suitability of different crops and land types were also determined.

A pre-testing of the draft questionnaires using ten respondents and limited focus group discussions helped to refine some of the questions. Individual farmers were interviewed randomly. The interviews were carried out in areas where the selected crop types were cultivated. Interviews were conducted both at homes and on farms. A total of 126 individuals were interviewed.

The data analyses carried out included both univariate and multivariate statistical techniques. Confirmatory statistical test to compare the rating of the suitability of cropping systems and land types were carried out by the Mann-Whitney technique (Conover, 1980). This was because the variables were independent and the comparisons were made between two or more samples at a time. Cluster analysis (CA) was carried out in SPSS (version 10.0) to explore similarities between crop types based on their land and economic suitability ratings. This was displayed in dendrograms (Hull and Nie, 1981; Manly, 1992).

CHAPTER FOUR

RESULTS

4.1. TOPOGRAPHIC MODELS

The spatial distribution of the elevation samples reflects the nature of the topography in the area. The elevation distribution (Figure 4.1) and model (Figure 4.4a), indicate a broad spectrum of elevation, with a wide range of 527.304m (1730.00ft), and a minimum and maximum elevations of 107.94m (350.00ft) and 318.991m (2080.00ft) respectively. There was a standard deviation of 126.248m (416.00 ft), an indication of extremes in topographic characteristics of the area (Figures 4.1 and 4.2). The distribution of the elevation data appears to be normally distribution (Figure 4.1).

The experimental auto-variogram indicates a strong relationship between change in location and altitudinal variation (Figure 4.3). The variogram showed little variability, for which reason no correction by smoothing was applied. A nugget semivariance of about 1000 was reported. Theoretically, a sample separation or lag of zero is supposed to have a semivariance of zero. There was no definite range (separation distance beyond which semivariance remains the same) and sill (no levelling off of the curve). The fit of the power model to the experimental one was a near perfect one (Figure 4.3). Steep slopes were common in the areas of the mountain range overlooking Koforidua (Figures 4.4a and 4.4b). Figure 4.5 shows the distribution of slope across the landscape.



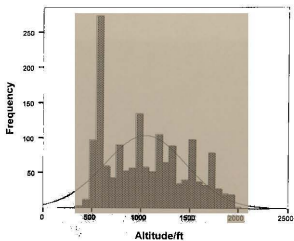


Figure 4.1: Elevation distribution

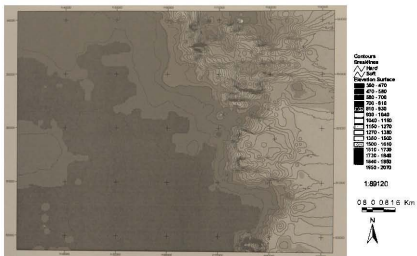


Figure 4.2: Contours and elevation surface

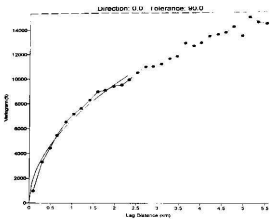


Figure 4.3: Experimental variogram of elevation fitted with a power model variogram

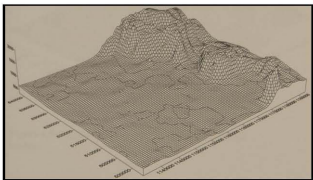


Figure 4.4a: Digital elevation model of the study area

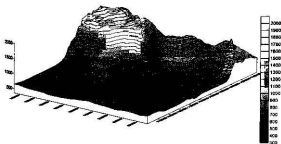


Figure 4.4a: Digital elevation model draped with elevation surface

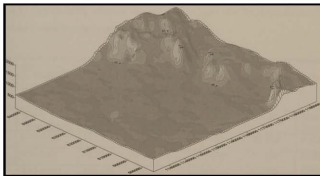


Figure 4.5: Digital elevation Model draped with slope surface

4.2 LAND-USE/COVER DYNAMICS FROM REMOTE SENSING STUDY

4.2.1 Statistics of brightness values for Landsat TM (2000) data at the sampling Sites.

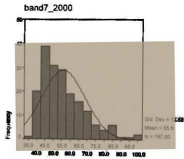
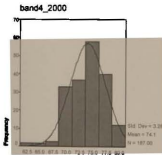
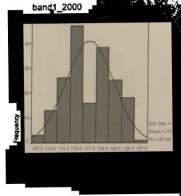
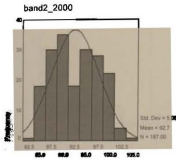
Table 4.1 shows the statistics of brightness values for the Landsat TM bands. Though the visible bands (1 and 3) had the highest minimum and maximum brightness values, they recorded very low standard deviations. The infrared bands (5 and 7) recorded the highest range, lowest minimum brightness values and the highest standard deviations. Practically, the bands expressed appreciable degree of normality in brightness distribution (Figure 4.6). Bands 7 and, especially, 3 were positively skewed whereas Band 4 was also negatively skewed.

There was a significant correlation between the bands ($P < 0.01$), even though some amount of variation in the magnitude of the correlation coefficients existed (Table 4.2 and Figure 4.7). For instance, whereas bands 7 and 5 had correlation coefficient of 0.933, bands 4 and 5 were the least correlated (-0.289).

TABLE 4.1: UNIVARIATE STATISTICS OF BRIGHTNESS VALUES OF LANDSAT TM (2000) OF THE STUDY AREA.

| TM BAND | Wave Length (μm) | Mean | Minimum | Maximum | Range | Standard Deviation |
|---------|-------------------------------|---------|---------|---------|--------|--------------------|
| Band 1 | 0.45-0.52 | 117.518 | 108.000 | 128.000 | 20.000 | 4.57828 |
| Band 2 | 0.52-0.60 | 92.705 | 83.000 | 104.000 | 21.000 | 5.080 |
| Band 3 | 0.63-0.69 | 139.443 | 135.000 | 149.000 | 14.000 | 3.005 |
| Band 4 | 0.76-0.90 | 74.149 | 63.000 | 81.000 | 18.000 | 3.278 |
| Band 5 | 1.55-1.75 | 92.224 | 71.000 | 119.000 | 48.000 | 11.580 |





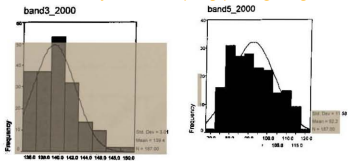


Figure 4.6: Distribution of Brightness Values for Bands 1,2,4, 5 and 7

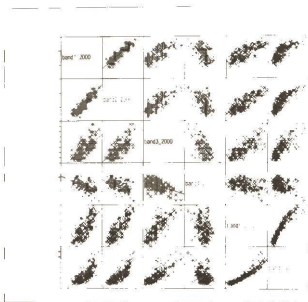


Figure 4.7 Scatter matrixes of spectral values of TM 2000 at vegetation sampling sites

TABLE 4.2 : CORRELATION MATRIX OF THE BRIGHTNESS VALUES OF LANDSAT TM (2000) DATA

| BANDS | Band 1 | Band 2 | Band 3 | Band 4 | Band 5 | Band 7 |
|--------|--------|--------|--------|--------|--------|--------|
| Band 1 | 1.000 | | | | | |
| Band 2 | 0.916 | 1.000 | | | | |
| Band 3 | 0.679 | 0.715 | 1.000 | | | |
| Band 4 | -0.514 | -0.476 | -0.531 | 1.000 | | |
| Band 5 | 0.748 | 0.813 | 0.772 | -0.289 | 1.000 | |
| Band 7 | 0.742 | 0.812 | 0.776 | -0.417 | 0.933 | 1.000 |

4.2.2 Training area statistics for the land-use/cover classes

In the enhanced Landsat TM composite, high vegetation cover zones appeared dark green, with areas of sparse vegetation cover being reddish (Appendices 2 and 3). Land-use/cover types with high and uniform amount of vegetation had low within variations in brightness values. All the land-use/cover types had relatively low standard deviations of brightness values for band 3 in Landsat TM 2000, whereas 5 and 7 had the highest. The forest-farms generally recorded very low standard deviations for all the bands (0.959-4.182), whereas built-up/exposed areas recorded the highest (1.977-13.862) in 2000 (Table 4.3a and Figures 4.8a and 4.8b). The pattern was similar to the 1991 training statistics (Table 4.3b).

Individual bands for both the 2000 and 1991 TM data separated the land-use/cover classes to different degrees (Figures 4.8c and 4.8d). Generally, similarity followed a definite order, with land-use/cover classes displaying high degree of similarity depending on the amount of vegetation cover. Band 3, differentiated the cover categories into two broad groups: the comparatively more vegetated land-use/cover classes (forest-farms and the two fallow categories), occupying regions of low digital numbers and less vegetated lands (degraded and the built-up/exposed areas), occupying a region of high digital numbers. The order of arrangement of land-use/cover classes along the visible red and the infra-red bands was opposite that of near infra-red band. This manner of arrangement was common to both 1991 and 2000. Bands 3 and 5 were very poor at differentiating between the degraded land and the settlements/exposed grounds.

The Jeffries Matisuta separability distance matrix (Table 4.4) indicated a definite trend of land-use/cover transformation from a high-vegetated land-use/cover through low vegetated cover types. This trend showed appreciable level of correspondence to the pattern described in the scatter diagram (Figure 4.8c and 4.8d). In 2000 and 1991, the forest-farm on one the hand and the degraded land and the settlement/exposed land-use/cover classes on the other were totally different (separability distance was 1.41).



TABLE 4.3A: STATISTICS ON TRAINING AREAS OF BRIGHTNESS VALUES OF LANDSAT TM 2000

| | <i>Band 3</i> | <i>Band 4</i> | <i>Band 5</i> | <i>Band 7</i> |
|---------------------------|---------------|---------------|---------------|---------------|
| Degraded land | | | | |
| Min. | 140.000 | 58.000 | 92.000 | 53.000 |
| Max. | 153.000 | 75.000 | 149.000 | 135.000 |
| Mean | 146.321 | 64.777 | 111.644 | 74.088 |
| Std. Dev. | 1.815 | 3.227 | 7.067 | 8.400 |
| Forest-farms | | | | |
| Min. | 134.000 | 60.000 | 58.000 | 31.000 |
| Max. | 141.000 | 83.000 | 103.000 | 74.000 |
| Mean | 136.380 | 73.144 | 76.775 | 42.115 |
| Std. Dev. | 0.959 | 2.510 | 4.182 | 3.168 |
| Long fallow | | | | |
| Min. | 134.000 | 68.000 | 69.000 | 36.000 |
| Max. | 141.000 | 88.000 | 104.000 | 69.000 |
| Mean | 136.517 | 76.992 | 85.052 | 46.774 |
| Std. Dev. | 1.427 | 2.851 | 4.911 | 3.944 |
| Short fallow-annual crops | | | | |
| Min. | 135.000 | 68.000 | 69.000 | 39.000 |
| Max. | 146.000 | 95.000 | 161.000 | 164.000 |
| Mean | 138.715 | 77.669 | 96.859 | 56.897 |
| Std. Dev. | 1.340 | 3.184 | 7.539 | 8.591 |
| Built-up/exposed area | | | | |
| Min. | 138.000 | 60.000 | 83.000 | 50.000 |
| Max. | 152.000 | 83.000 | 198.000 | 234.000 |
| Mean | 144.811 | 69.505 | 110.432 | 83.965 |
| Std. Dev. | 1.977 | 3.616 | 9.342 | 13.862 |

TABLE 4.3B: STATISTICS ON TRAINING AREAS OF BRIGHTNESS VALUES OF LANDSAT TM 1991

| | <i>Band 3</i> | <i>Band 4</i> | <i>Band 5</i> |
|---------------------------|---------------|---------------|---------------|
| Degraded land | | | |
| Min. | 33.000 | 46.000 | 54.000 |
| Max. | 40.000 | 66.000 | 92.000 |
| Mean | 35.958 | 56.743 | 73.027 |
| Std. Dev. | .101 | 2.953 | 4.931 |
| Forest-farms | | | |
| Min. | 28.000 | 38.000 | 27.000 |
| Max. | 35.000 | 66.000 | 71.000 |
| Mean | 31.613 | 54.269 | 47.373 |
| Std. Dev. | 0.839 | 2.978 | 3.808 |
| Long fallow | | | |
| Min. | 31.000 | 54.000 | 43.000 |
| Max. | 38.000 | 71.000 | 69.000 |
| Mean | 33.637 | 61.009 | 54.320 |
| Std. Dev. | 0.849 | 2.622 | 3.828 |
| Short fallow-annual crops | | | |
| Min. | 32.000 | 54.000 | 55.000 |
| Max. | 51.000 | 81.000 | 125.000 |
| Mean | 35.677 | 63.348 | 69.103 |
| Std. Dev. | 1.567 | 3.345 | 5.181 |
| Built-up/exposed areas | | | |
| Min. | 34.000 | 41.000 | 53.000 |
| Max. | 51.000 | 65.000 | 116.000 |
| Mean | 41.671 | 50.416 | 72.016 |
| Std. Dev. | 2.510 | 4.129 | 6.969 |

TABLE 4.4: JEFFRIES-MATUSITA SEPARABILITY DISTANCE BETWEEN LAND USE/COVER TYPES IN THE YEAR 2000

| Region | Degraded land | Forest-farms | Long fallow | Short fallow-annual crop | Built-up/exposed. |
|------------------------|---------------|--------------|-------------|--------------------------|-------------------|
| Degraded land | 0.00 | | | | |
| Forest-farms | 1.41 | 0.00 | | | |
| Long fallows | 1.39 | 0.95 | 0.00 | | |
| Short fallow-ann. crop | 1.37 | 1.30 | 1.07 | 0.00 | |
| Built-up/exposed. | 1.18 | 1.41 | 1.37 | 1.23 | 0.00 |

TABLE 4.5 :JEFFRIES-MATUSITA SEPARABILITY DISTANCE BETWEEN LAND USE/COVER TYPES IN THE YEAR 1991

| Region | Degraded Land | Forest-farms | Long fallows | Short fallow-ann. crop | Built-up/exposed. |
|----------------------------|---------------|--------------|--------------|------------------------|-------------------|
| Degraded land | 0.00 | | | | |
| Forest-farms | 1.36 | 0.00 | | | |
| Long fallows | 1.32 | 0.92 | 0.00 | | |
| Short fallow and ann. crop | 0.90 | 1.31 | 1.06 | 0.00 | |
| Built-up/exposed | 1.11 | 1.36 | 1.35 | 1.12 | 0.00 |

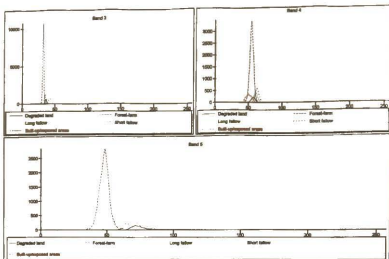


Figure 4.8a: Reflectance distribution for bands of bands 3, 4 and 5 for the training areas in 1990.

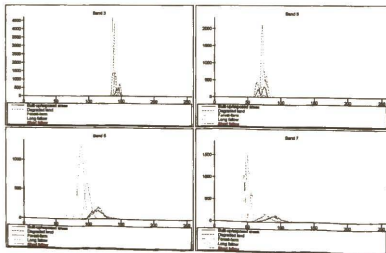


Figure 4.8b: Reflectance distribution for bands of bands 3, 4, 5 and 7 for the training areas in 2000.

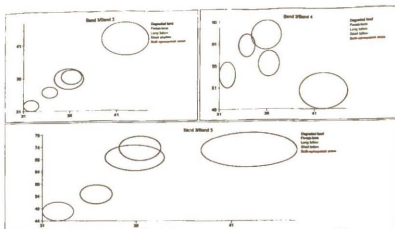


Figure 4.8c: Scatter diagrams of bands of bands 3, 4 and 5 for the training areas in 1990.

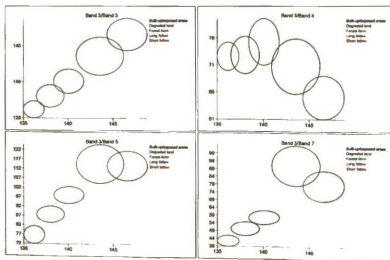


Figure 4.8d: Scatter diagrams of bands 3, 4, 5 and 7 for the training areas in 2000.

991

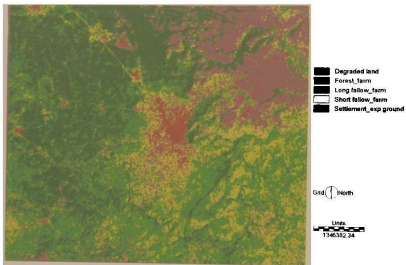


Figure 4.9a: Land-use/cover pattern in 1991

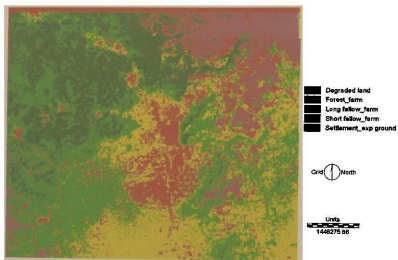


Figure 4. 9b: Land-use/cover pattern in 2000

4.2.3 Land-use/cover patterns

The five land-use/cover classes for 1991 and 2000 are showed in figures 4.9a and 4.9b. The amount and proportion of the cover types are also shown in table 4.6 and figure 4.10. In the periods investigated, the forest-farms were restricted to the north-western sections of the area, with the fallow dominating the southern sections. However, some appreciable amount of dense vegetation was found in the south-eastern and western sections. During the period considered, the Koforidua Municipality significantly expanded in the direction of the Akwapem North District. The municipality has practically merged with Okorase in the Akwapem North District. The distribution of vegetation cover pattern showed a negative spatial correspondence with temperature intensity (Appendix 4).

| Land Use/Cover | Area (Ha) 2000 | Area (Ha) – 1991 |
|-------------------|----------------|------------------|
| Degrad/Exp grd. | 29082.000 | 94519.982 |
| Forest-farms | 129333.500 | 220764.392 |
| Longfall-farms | 272901.500 | 219501.573 |
| Shortfall/Annrcps | 252294.000 | 112323.988 |
| Settlements | 38991.000 | 13572.120 |

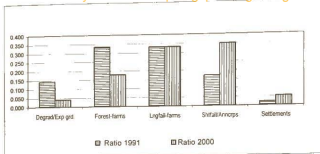


Figure 4.10: Land-use/cover ratios of 1991 and 2000

4.3 DISTRIBUTION OF VEGETATION AND CROPS

4.3.1 Distribution of trees and fallows

There were six hundred and eighteen (618) trees in all the 150 quadrats (13.5 ha), which constituted an average of 48 trees per ha. Abundance-class distribution (Figure 4.11) was positively skewed, presupposing a high degree of rarity. There was a mean of 4 trees per quadrat. A significant inverse relationship ($ETA = 0.294$, $P < 0.01$) existed between tree density and fallow occurrence. That is, low tree densities normally occurred where fallow dominated (Figure 4.12).

The first discriminant function (1) was a measure of the amount of tree cover; it contributed 99.2% of the total explained variance among the samples. It predicted group memberships of the samples for the 3 levels of deforestation categories: no/incipient, moderate and total/extreme to different extent (figure 4.13). The second function (2) contributed only 0.8%. Wilks' lambda (Λ) test confirmed the first

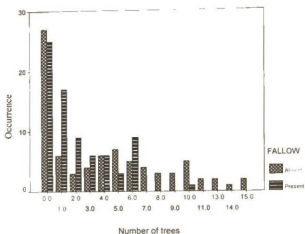


Figure 4. 12: Relationship between fallow occurrence and tree density

| TABLE 4. 7: COEFFICIENTS OF THE FIRST TWO STANDARDISED CANONICAL DISCRIMINANT FUNCTIONS OF DEFORESTATION | | |
|--|-------------------|-------------------|
| <i>Band and No. of trees</i> | <i>Function 1</i> | <i>Function 2</i> |
| Band 2 | -0.664 | 0.409 |
| Band 3 | 0.136 | 1.050 |
| Band 4 | 0.109 | 1.134 |
| Band 5 | -0.015 | -2.077 |
| Band 7 | 0.102 | 0.840 |
| Number of Trees | 0.795 | -0.322 |

TABLE 4.8:STRUCTURAL MATRIX OF THE STANDARDISED CANONICAL DISCRIMINANT FUNCTIONS OF DEFORESTATION

| Band and No. of trees | Function 1 | Function 2 |
|-----------------------|------------|------------|
| Band 2 | -0.637 | -0.361 |
| Band 3 | -0.463 | -0.212 |
| Band 4 | 0.279 | 0.534 |
| Band 5 | -0.535 | -0.492 |
| Band 7 | -0.488 | -0.420 |
| Tree number | 0.820 | 0.294 |

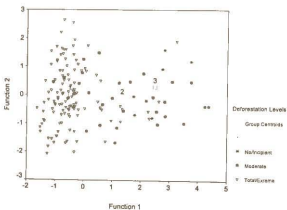


Figure 4.13:Group memberships of deforestation levels by the first two canonical functions

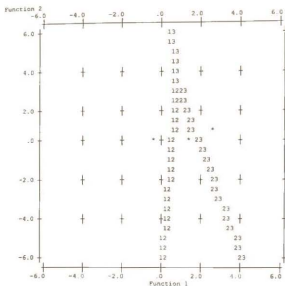


Figure 4.14: Territorial map of deforestation classes

| Symbol | Levels of deforestation |
|--------|-----------------------------|
| 1 | Extreme/total deforestation |
| 2 | Moderate deforestation |
| 3 | Normal vegetation cover |
| * | Group centroid |

$$F_i = 0.936C - 0.460b5 - 0.452b3 - 0.420b2 - 0.382b7 + 0.130b4 \dots\dots\dots(1)$$

$$F_{ii} = -120C + 0.262b5 + 0.096b3 + 0.691b2 + 0.430b7 + 0.190b4 \dots\dots\dots(2)$$

The annual food crops - cassava and maize, and cocoa (perennial cash crop) were distributed with high spatial variability. There were 2,527 cocoa trees in the 150 quadrats, with a mean of 19 cocoa trees per quadrat. This was equivalent to 133 cocoa trees per ha. Cocoa tree abundance distribution was heavily skewed towards the least abundance classes, with 58.0% of the quadrats recording zero(0) cocoa trees and 65.3% of the quadrats containing from 0-5 cocoa trees. This may indicate a conversion of cocoa farms into either fallow or annual crop farms.

There was also a strong positive relation between the distribution of natural vegetation cover and crop types. Generally, cocoa tree density was high where the number of trees was also high and vice versa (Figure 4.15). The correlation was a highly significant one ($P < 0.01$). The uncertainty coefficient also indicates that tree density is a significant ($P < 0.01$) predictor of cocoa density in the area. In contrast, an inverse relation was found between cocoa densities and fallow occurrence. Also, there was a high frequency of occurrence of annual food crops in the low-tree density areas than the high tree-density zones (Figure 4.16).

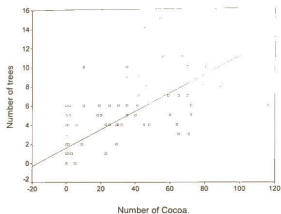


Figure 4.15: Association between tree and cocoa densities

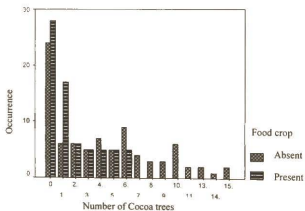


Figure 4.16: Distribution pattern of food crops and trees

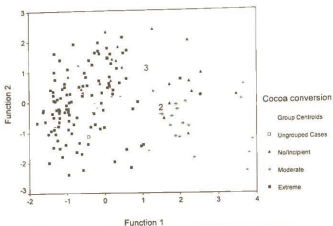


Figure 4.17: Group membership of conversion levels from normal cocoa farms.

Annual crops were invariably associated with fallows. Of the 77 fallow sites, 51 (66.23%) were found in association with annual crops; an association that was found to be significant ($P < 0.01$) by chi-square statistics.

Based on multivariate analysis of satellite and tree densities, the two canonical functions predicted group memberships for the sites and discriminated between the three levels of cocoa farm conversions (Figures 4.17 and 4.18). The eigenvalues of the first and the second functions were 0.786 (86.1%) and 0.127 (13.9%). The Wilks' lambda test indicated that the means of the conversion classes were significantly ($P < 0.01$) different for the two discriminant functions.

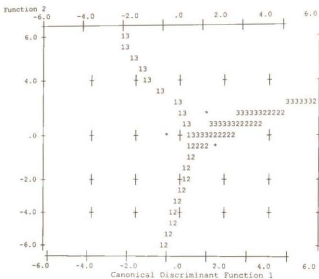


Figure 4.18: Territorial map for levels of cocoa conversion

Symbol Group Levels of conversion

- | | |
|---|----------------|
| 1 | Extreme |
| 2 | Moderate |
| 3 | Non/Incipient |
| * | Group centroid |

Soil

Altogether, the soil associations of the study area covered a total area of 563635.83 hectares. Adawso-Bawjiasi/Nta-Ofin and Koforidua-Nankese/Nta-Ofin constituted the major and most important soil associations used in the analysis in terms of size and location (Table 4.9). Equal amounts and location of soil associations and suitability were used. The soil maps show the existence of close spatial relationship between the associations and the suitability categories.

| Soil type | Area/ha |
|----------------------------|-------------|
| Adawso-Bawjiasi/Nta-Ofin | 174918.9820 |
| Bediesi-Sikaben | 125598.2320 |
| Chichiwere-Ayensu-Kakum | 23022.8580 |
| Dewasi-Wayo | 11526.3610 |
| Fete-Bediesi | 64715.8970 |
| Koforidua-Nankese/Nta-Ofin | 126748.8500 |
| Wenchi-Kumayili | 31214.5370 |
| Yaya | 5890.1120 |
| Total | 563635.829 |

4.4.1 Land-use/cover change

Three typological changes in land-use/cover have occurred in the area. These were locational: quality or type of transformation in different areas, character (condition: transformation from one category to another or direction of change) and magnitude (amount of change of land-use cover) (Figures 4.19, 4.20 and Table 4.10). Koforidua Municipality has significantly expanded outward, especially, in a southward direction across the boundary between New Juabeng and the Akuapem North Districts. It has also expanded in the direction of Oyoko, but not as extensive as in the direction of Adawso.

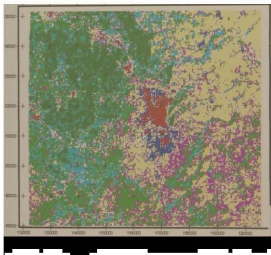


Figure 4.19: Land-use/cover change pattern from 1991 to 2000



Figure 4.20: Amount of land-use/cover change between 1991- 2000

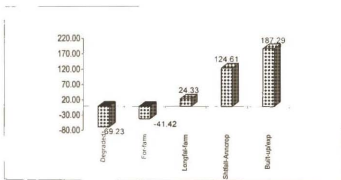


Figure 4.21: Percentage land-use/cover change

TABLE 4.10: LAND-USE/COVER CHANGE MATRIX FOR 1991 TO 2000

| Land-use/cover 1991 | Land-use/cover 2000 | | | |
|--|---------------------|-------------|--|---------------------------|
| | Forest-farm | Long fallow | Short fallow-annual crops/Degraded land | Built-up/exposed areas |
| Form-farm | 92764.326 | 11581.836 | 747.536 | 0.000 |
| Long fallow-farm | 69700.326 | 97628.299 | 25615.592 | 308.981 |
| Short fallow-annual crop/exposed- degraded | 13056.975 | 64158.587 | 133500.096 | 1933.628 |
| Built-up/exposed areas | 498.357 | 2641.296 | 16455.775 | 10465.514 |
| Total | 176019.984 | 176010.018 | 176318.999 | 12708.123 |
| Values are in square meters | | | | |

In character or condition, all the original land-use/cover types have undergone transformations into one or more other land-cover/use types from 1991 to 2000. Change in character was essentially an expression of vegetation cover change. There was a definite trend of change from high to low vegetation cover in this order: forest farms – long fallow/farms – short fallow-annual crop farms – degraded lands – built-up/exposed lands. Yet, it must be pointed out that in many locations, there was a reverse of the general trend. Thus, a change in vegetation was not a unidirectional phenomenon, but multi-directional inter-conversions between the cover types (Table 4.10). In absolute terms, short fallow-annual crop underwent the greatest increase, with forest farms experiencing the highest reduction (Figure 4.19). Proportionately, however, the built-up/exposed areas experienced the highest growth (187.29%), whereas the forest-farms shrunk by 41.0%. The degraded land also experienced extensive restoration (Figure 4.20).

Land-use/cover changes that have occurred in the different soil types also differed. In the poorest (N2 and S1a) soils that had little forest cover by the early 1990s, the dominant transformation was long fallow to short/annual crops. In contrast, lands that

had wider coverage of forest farms (e.g. S3b and S3c in 1993) even though a high proportion of forest-farms converted into long fallows. Of all the soils, the most suitable agriculture soil type in the area, S3b, underwent the greatest conversion into built-up/exposed areas (Figure 4.22)

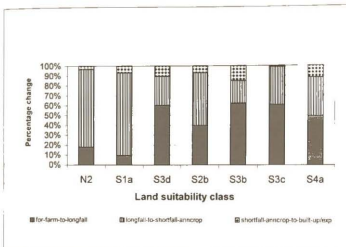


Figure 4.22: Land-use/cover change and land suitability

4.4.2 Equity in per capita land resource allocated for urban land use in the Koforidua Municipality

Koforidua Municipality has undergone a steady physical growth since the 1920s. With gradual increase from the 1920s, the quantum of change levelled off from the mid 1970s till the early 1990s. Particularly, in the past decade (1990-2000) there has been a rapid surge in the physical expansion of the municipality than any time in the past. However, the growth has been relatively less compact, especially, at the fringes of the municipality where sprawling is already apparent (Figures 4.23-4.25).

Characteristically, population has increased over the years, though with variable rate of increase for specific periods (Figure 4.26). Yet, there have not been dramatic periodic changes like that associated with physical growth of the Municipality in the past decade. Apparently, the proportional change in population growth has been less dramatic. Therefore, though per capita land-resource allocation for urban land use in the municipality has risen steadily over the years, the rate has risen over the years (Figure 4.27). Specifically, per capita land allocated in the 1990s has been quite dramatic. For instance, per capita urban land consumed for the 1990s through the year 2000 was about five (5) times that of the 1980s.

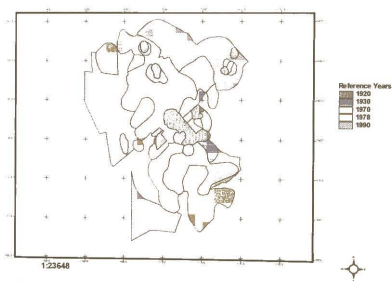


Figure 4.23: Historical Map of Koforidua Municipality

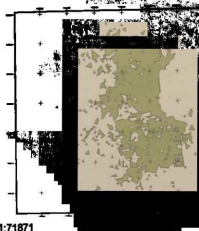


Figure 4.24: Koforidua Municipality in 2000

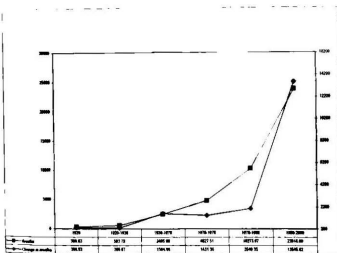


Figure 4.25: Physical growth of the Koforidua Municipality from 1920-2000

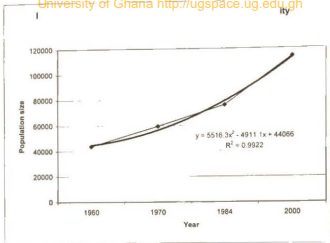


Figure 4.26: Population changes in the Koforidua Municipality from 1960 to 2000

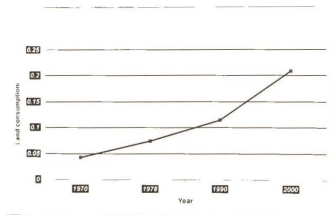


Figure 4.27: Per capita land consumption of arable land by urban land use in the Koforidua Municipality

4.4.3 Sustainable use of land resources within ecologically

sensitive zones.

Land-use/cover categories of 2000 within the flood plains of the Densu River

There was no appreciable difference in the relative compositions of land-use/cover in the series of buffers created at the various distances from the Densu River in the year 2000 (Figures 4.28 and 4.29). Within the buffers, long fallow constituted the highest proportion of the land-use/cover types, with forest-farms and short fallow/annual crops following the order. Some amount of built-up/exposed areas was located within all the buffers (Figure 4.30).

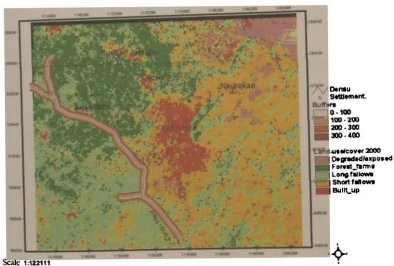


Figure 4.28: Buffers around the Densu River in the 2000 land cover

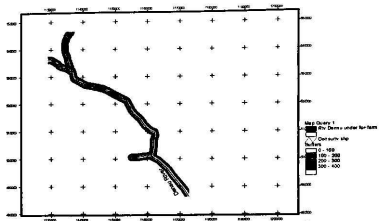


Figure 4.29: Segments of Densu River covered with Forest-farms



Plate 4.2: A narrow patch of forest remnant on the bank of the river Densu near Koforidua. For most part, land within 100 m of the river is totally deforested.



Plate 4.2: Siltation of the reservoir at Koforidua. The sandy materials may have originated from the exposed surfaces in Densu Basin

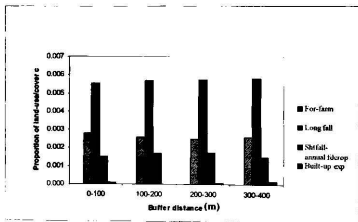


Figure 4.30: Land-use/cover categories of 2000 within the four buffers around the Densu River

The soil associations have a strong spatial relationship with elevation (Figure 4:31a).

Kofofidua-Nankese/Nta-Ofin, Adawso-Bawjiase/Nta-Ofin and Chichiwere-Ayensu-Kakum occupy lower elevations. Fete-Bediesi, Bediesi-Sikaben and Wenchi-Kumayili are located on slopes and mountain summits.

Of the total land surface for which slope was generated, about 80.0% of the area were within the slope categories of 0-2% and 2-5% (Figures 4.30 and 4.31). Only 4.59% of the area was found in the relatively steep range of 16 and 45%. The steep slopes were located in the mountainous areas, with the less steep slopes found in the flat and undulating zone.

Different proportions of the 2000 land-use/cover types were located within the various slope classes (Figure 4.32). Forest-farms, short fallow- and long fallow farms dominated the less steep slope (flat and undulating) classes. However, at the steeper slopes, the proportion of long fallow and the short fallow-annual crop farms largely prevailed, with a decrease in the amount of forest-farms. Short fallow-annual crops dominated the steepest slopes (Figure 4.33). Some built-up/exposed zones were also found in the steep slopes (>16%)





Figure 4.31a: Soil Associations draped over elevation model

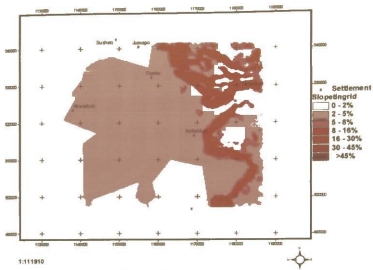


Figure 4.31: Slope surface

| TABLE 4.11: PROPORTION OF SLOPE CLASSES | |
|---|---------------------|
| Slope class (%) | Percentage of class |
| 0-2 | 22.321 |
| 2-5 | 58.208 |
| 5-8 | 6.871 |
| 8-16 | 9.765 |
| 16-30 | 2.638 |
| 30-45 | 1.960 |
| >45 | 0.000 |

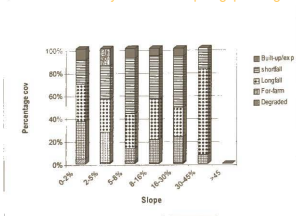


Figure 4.32: Land-cover classes within slope classes

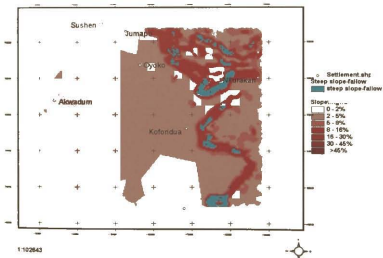


Figure 4.33: Steep slopes under short fallow/annual crop

4.4.4 Land-use/cover, cropping systems and soil potential or suitability

Settlements have been established in almost all the soil associations/suitability categories (Figures 4.34 and 4.35). However, two soil associations have been widely used for constructional activities, particularly, in the Koforidua Municipality. These were the Adawso-Bawjiase and Nankese-Koforidua Associations. The latter is rated good for agriculture, and was the most extensively cultivated with cocoa and also the most densely forested (Figures 4.34 and 4.36). There was a remarkable relationship between the soil types/ land suitability for cocoa cultivation (Figures 4.37). A more striking parallel relationship was apparent between the zone designated as good for cocoa cultivation and the prevailing spatial distribution of cocoa farms (Figures 4.38). The areas with the most extensive cocoa coverage were those designated as suitable by the land suitability scheme for cocoa production (Figure 4.39). Again, forest cover has a strong positive relationship with the distribution of cocoa. Obviously, both forest cover and land suitability seemed to have influenced cocoa distribution in the area.

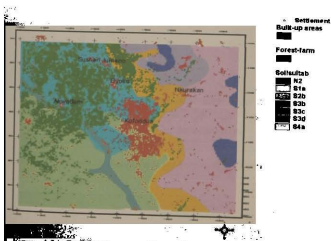


Figure 4.34: Build-up areas and forest-farms in land-suitability classes

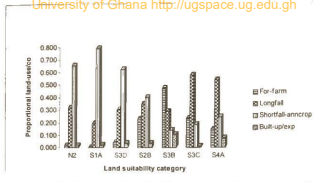


Figure 4.35: Proportion of land-use/cover categories in each agriculture land suitability class in 2000

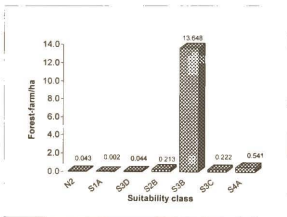


Figure 4.36: Forest-farm per hectare in land suitability classes

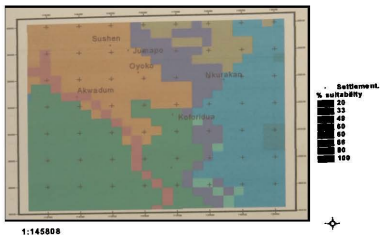


Figure 4.37: Percentage land suitability for cocoa production

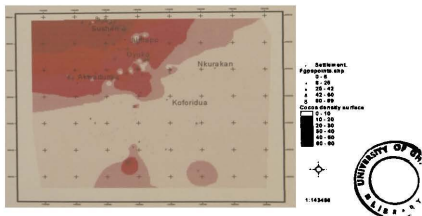


Figure 4.38: Surface of cocoa trees per 90m² in 2000

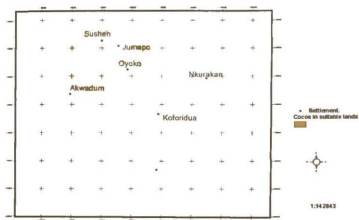


Figure 4.39: The highest cocoa tree density occurred in the most suitable soil and forest-farms

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4.5 Perceptions of land use and land-cover dynamics and sustainable resource use

Ethnically, the farming community was diverse, with Ashantis, Ewes and the Akwapems constituting the dominant tribes (Figure 4.40). Land-owning farmers were more than tenant farmers, though some locational variations existed (Figure 4.41) For instance, most Akwapems have farms in Obourtumpan whereas Ashantis have farms in almost all the localities considered, with the exception of Obourtumpan. Again, the majority of Ashantis and Akwapems farmers were landowners. In contrast, a greater proportion of Ewes were tenant farmers (Figure 4.40).

4.5.1 Land use pressure

Ease of accessibility to good farm lands, preference for bigger farmlands and the length of fallow cycles were good indicators of the degree of land-use pressure. On the basis of ease of land accessibility, 62.8% of the respondents said they were facing difficulty in securing fertile farmlands. A high proportion of the farmers cultivated annual crops at reduced intervals of six months to two years. Fallow cycles of three or more years were exceptional events (Figure 4.42). Approximately, 80.0% of the respondents wished they could have bigger farmlands than they were using for farming.

Majority of the people (80.4%) thought the trend in the difficulty of land acquisition would be more pronounced in future. This perception had no relationship with land-ownership status: high proportions of both land owners (83.8%) and tenant farmers (94.8%) shared the same view (Figure 4.43). Locationally, there was a similar trend, with between 81.0% and 100.0% of respondents from each of the settlements saying there would be unrelenting surge in the difficulty of land accessibility.

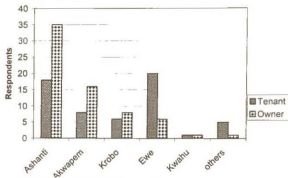


Figure 4.40: Tribal affiliation and land ownership

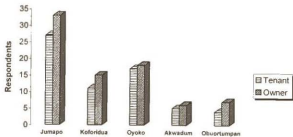


Figure 4.41: Location and ownership of farmlands

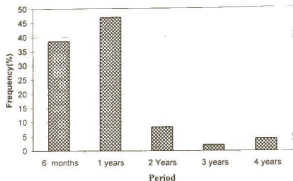


Figure 4.42: Length of fallow period

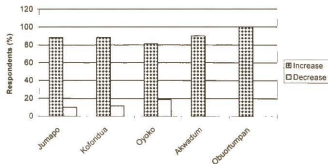


Figure 4.43: Perception of difficulty in farmland accessibility to farmland in future

4.5.2 Dynamics and economic suitability valuation of cropping systems

Crop types cultivated in the area have undergone steady changes over the years (Figures 4.44a and 4.44b). This trend has not only been progressive in the past, but may continue for some years to come. Significantly (Cramer's $V = 0.294$, $P < 0.01$), different cropping systems have been adopted in the past couple of decades or more. In the past, cocoa used to be the major cultivated crop as indicated by 101 (71.6%) of the respondents. Most of the annual and perennial food or cash crops were only marginally cultivated. These included maize, 5(3.5%); palm, 8(5.7%); plantain, 11(7.8%); cassava, 7(5.0%); vegetable, 1(0.7%); cocoyam, 3(2.1%); and cola, 5(3.5%). This was a widespread phenomenon in the study area (Figure 4.44a).

However, a reversal of the past trend prevailed at the time of study; there was a popular preference for annual crop cultivation to tree crops (Figure 4.44a). Yet, some farmers still have substantial cocoa farms, especially around Oyoko, Sushen, Akwadum and other areas where the land is naturally suitable and trees were available. Most of the localities have only patches of cocoa farms (Figure 4.38). Active cultivation of new cocoa farms was rare. Some 65.5% of the cocoa farmers no longer cultivated cocoa. Of those who owned cocoa farms, 65.4% replaced dead cocoa trees with new ones, whereas 34.6% replaced cocoa with food crops. In an extreme situation, some farmers were deliberately cutting live and healthy cocoa trees to make way for food crops and constructional purposes, a development that could continue in future.

The economic suitability rating status of the crops reflected of the trend above. For crop economic suitability, most farmers ranked palm as 'very suitable'. However, this high rating did not reflect on the scale of actual cultivation at the time of study. In contrast, very few perceived cocoa as 'very suitable' (Figure 4.45). Multivariate analysis of economic suitability rating identified cassava and plantain as similar whereas palm and corn belonged to a similar rating group.

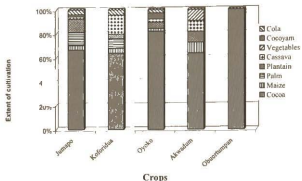


Figure 4.44a :Past commonly cultivated crops

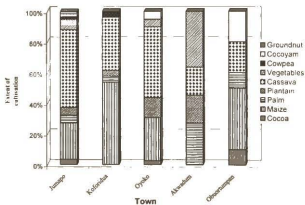


Figure 4.44b :Current commonly cultivated crops

For crop economic suitability, most farmers ranked palm as 'very suitable'. However, this high rating did not reflect on the scale of actual cultivation at the time of study. In contrast, very few perceived cocoa as 'very suitable' (Figure 4.45). Multivariate analysis of economic suitability rating identified cassava and plantain as similar whereas palm and maize belonged to a similar rating group. However, the degree of similarity between crops of the two groups was the same; individual crops were separated or joined at the same distance. Cocoa, though, was an odd one (Figure 4.46). In future, it is more likely that the shift from tree crop, especially cocoa to annual food crops will intensify as indicated by figure 4.47. Maize and cassava may continue to dominate as the most dominant cultivated food crop in the area. Other small-scale intensively farmed crops such as vegetable were also cultivated.

Of the crops that were commonly cultivated, maize and cassava were rated the most suitable economically (Figure 4.45), though their level of dominance did not match that enjoyed by cocoa in the past. A confirmatory test by Mann-Whitney indicated a high significant difference ($P < 0.01$) between perceived economic suitability ratings in the past and the present of the selected crops.

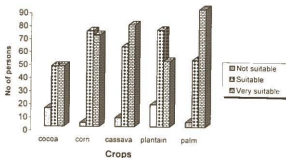


Figure 4.45: Economic suitability rating of crops by respondents

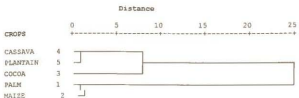


Figure 4.46: Dendrogram of hierarchical cluster analysis of crop economic suitability ratings

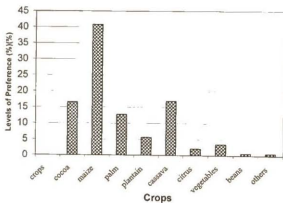


Figure 4.47: Future crop preference

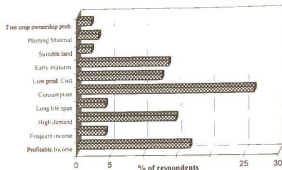


Figure 4.48 :Factors influencing recent crop cultivation by percentage of repondents

Many factors have informed the decision making process for selecting suitable crops for optimum yield and economic returns (Figure 4.48). Largely, several direct or indirect financial/economic considerations have influenced the choice of crop cultivation. These factors may have dictated the trend of agriculture land-use dynamics in the area. Farmers were deeply concerned about household consumption. Frequent or year round income flow, crop marketability, low crop production cost, stable crop pricing, etc. (Figure 4.48) were some of the economic related factors that have driven crop suitability decisions. These factors have been accorded different importance over the years.

Indeed, no singular factor could account for the steady shift from cocoa to annual food crop cultivation. Apparently, several factors of different nature have contributed to the decline of cocoa cultivation. This phenomenon may be assigned to two broad reasons: economic/financial and ecological/biophysical. The economic related factors were: non-profitability, irregularity of income flow, high production cost and low pricing of cocoa produce. Ecological or biophysical factors were unsuitable soils, bush fires and diseases. Multiple uses, short maturing period, home consumption, easy management

In future, it is more likely that the shift from tree crop, especially cocoa to annual food crops will intensify as indicated by figure 4.47. Maize and cassava may continue to dominate as the most dominant cultivated food crop in the area. Other small-scale intensively farmed crops such as vegetables were also cultivated.

Of the crops that were commonly cultivated, maize and cassava were rated the most suitable economically (Figure 4.45), though their level of dominance did not match that enjoyed by cocoa in the past. A confirmatory test using the Mann-Whitney indicated a high significant difference ($P < 0.01$) between perceived economic suitability ratings in the past and the present of the selected crops.

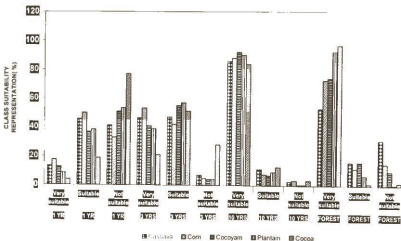


Figure 4.49: Views of land suitability (crop productivity) based on years of fallow

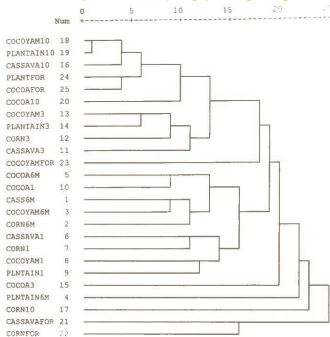


FIGURE 4.50: Dendrogram of hierarchical cluster analysis of crop suitability for vegetation cover types at different ages

Symbol definition of Figure 4.50

Number attached to crop names are years of fallow

6M represents six (6) months of fallow

FOR represents forests

DISCUSSION

5.1 Slope Surface model

The normally distributed nature of the elevation data (Figure 4.2) justified the use of kriging interpolation technique for creating the DEM and the slope surface since it is a necessary condition for kriging. The high magnitudes of both the standard deviation and the range of the data set reflect the extremes in heterogeneity of the topography of the terrain: these reflect the comparatively low-lying terrain in the southwestern section of the area and the mountainous landscape to the northeastern regions (Figure 4.4).

Enhanced fit between an experimental variogram and a power model, as obtained in the study (Figure 4.3) suggests a better predictive capability of elevation by the experimental model. However, it appears the predictive capacity may be higher at higher than lower elevations. Non-stationarity may also exist between elevation and distance at certain localities due to the presence of valleys in the area.

Theoretically, variograms are supposed to have zero semivariance at a lag distance of zero (Cornford, 1999). Therefore, the non-zero semivariance or nugget variance/effect found in the study implies that more than spatial variability accounts for the total variability in elevation. Possibly, random errors might have been introduced during the processing of the aerial photographs for the topographic maps. Also, digitising of the maps may have contributed some amount of random variability in slope. Local variations inherent in the topography of the area may also explain the presence of the

nugget effect. There could have been a sill if more samples were collected or the experimental variogram estimated beyond 5.5 km range. Topographic variability has been studied using variograms (Isaaks and Srivastava, 1989; Curran and Atkinson, 1998). Curran and Dungan (1989) have shown that the square root of the nugget variation can be a useful estimate of standard deviation of terrain elevation.

5.2 Remote sensing study

The use of statistical classification algorithm such as the maximum likelihood, a parametric technique, must obey the relevant assumptions for its usage. So, beside the fact that the satellite data used was of high level of measurement, it was ensured that it was normally distributed (Figure 4.6). The large training samples extracted for each land-use/cover type guaranteed that it was more representative of the sub-scene analysed. It is also recommended that the minimum training set size be 10-30 times the number of discriminating variables (Mather, 1999; Piper, 1992). Maximum likelihood classification is computationally demanding, hence, relatively slow. The comparatively small sub-scene used for the study made the classification process reasonably fast.

Remote sensing technology has been an important tool for effective monitoring and inventorying natural resources. Information derived from satellite data is essential for developing policies on change in land use and land cover as a result of human activity, thereby indicating whether the activity is sustainable, from a biophysical perspective. The characterised land-use/cover information derived from the satellite data provided insight into the nature of land-use/cover dynamics in the terrain. Effectively, the data discriminated between identifiable land-use/cover types, and thus confirms the

recommendation for the use of the technology in the investigation of land-use/cover dynamics (Foresman *et al.*, 1997; NASA, 1998).

Different land-use/cover categories may be capable of withstanding transformation pressures to different extents (Table 4.5, Figure 4.8). The study indicated that whereas some cover types have been totally transformed and appeared distinct from other classes, others were similar. The pattern of the conversions suggests that the cover types with high similarity levels, particularly the fallows, are more likely to be transformed from one type to the other. This will depend on the level and direction of the dynamics in prevailing environmental conditions and land-use pressure. The multi-spectral nature of Landsat TM data may have improved or optimised information extraction from the floristically, topographically and pedologically heterogeneous terrain.

5.3 Land-use/cover changes and sustainability of land resource utilization

The importance of examining land-use/cover change is to highlight changes in the productive or protective uses of the land resource to facilitate sustainable land use planning and policy development. Such information is useful in identifying opportunities to protect land resources or promote future allocation that ensures the greatest sustainable benefits for people. Land-use and cover dynamics have been identified as an important challenge for environmental change (NRC, 2001). Previous studies conducted in the major ecological zones in Ghana have established appreciable changes in land-use/cover (CSIR, 1975; Nsiah-Gyabaah, 1994; Gyasi *et al.*, 1995; Attua, 1996; Agyepong and Kufogbe, 1996). As has been indicated in the results, the nature of changes that have occurred in the area is a complex inter-

conversion among various cover types (Table 4.9 and Figures 4.19 -21). Yet, a reduction in dense forest cover to fallow fields and annual crops was an important land use/cover change. Contrary to this, reverse trend of change from sparse to dense woody vegetation has also been observed in some localities in a study of the Northern Forest-Savanna transition (Pabi and Attua, 2002). Such situational observations contradict the perception that land-use/cover change follows a simple linear direction of forest conversion into fallows and annual crop fields. Invariably, the question of possible complex land-use/cover inter-conversions is begged off or ignored.

The definite loss of high to low vegetation cover in this study fits the dominant pattern of conversion - forest-farms to fallow and annual crop fields, observed by others (Figure 4.4 and Table 4.4). There was no significant close canopy forest in the area (Hawthorne and Abu-Juam, 1995; Ministry of Local Government, 1996). Studies in other parts of Ghana agree with this pattern of land-use/cover change, except that the quantum of change differed (Nsiah-Gyabaah, 1994; Pabi and Attua, 2002). There is a definite evidence of the trend globally (Brown, 2001).

The spatial differentiation in land-use/cover pattern and temporal changes was quite significant (Figures 4.9a, 4.9b and 4.2). Generally, different land types respond differently to the same land management or natural events, which is a manifestation of spatial variability in resilience/stability and sensitivity of landscapes (Simmanee, 1987; Black, 1994). Whole landscapes are now becoming increasingly recognised for their differences in sensitivity (Thomas and Allison, 1993). In this respect, Koforidua-Nankese/Nta-Ofin association seems to be quite resilient to disturbances of land use.

The level of variation in the amount of forest vegetation associated with the various soil types could scarcely be explained by chance occurrence (Figure 4.36).

This study revealed that land-cover in most part of the fragile hilly region beyond Nkurakan was degraded (Figure 4.4) (Sombroek and Antoine, 1995). It is an area that is widely cultivated with food crops such as cassava and maize by intensive farming. In the land suitability scheme of Ghana, this area is described as a mixture of good and bad soils, and recommended for forestry. In other words, they are supposed to be marginal lands with high sensitivity and fragility to land use, and limited land-use options (Adu and Asiamah, 1994).

Substantive information on land-use/cover change is an important indication of the need for effective management for sustainable land resource use. Turner *et al.* (1990) have made excellent documentation of historical changes in land cover. A few local studies in the West African sub-region include that of Guyer and Lambin (1993) and Nsiah-Gyabaah (1994).

Complex interactions of many different factors could account for the general transformation/conversion of forest-farms into fallows and annual crops. Though it may not be a simple reflex to demographic growth, studies have noted a strong correlation between demographic growth and agriculture land-use intensification and deforestation (Bilsborrow and Okoth-Ogendo, 1992; Cropper and Griffiths, 1994; Langston, 1998; Verheye, 1998). Turner *et al.* (1995) believe this cannot be confirmed at a regional and local scale. The dominance of short fallows and annual crop fields

around population centres such as the Koforidua Municipality as compared to forest-farms in the comparatively rural areas could confirm this. Bush burning which is now an important ecological factor in the area could be exerting ecological pressure that may have accelerated the transformation of forest-farms into fallows around the population centres (Korem, 1985; Hawthorne, 1990).

The degraded section around Nkurakan area has a history of intensive cultivation of annual food crops. Fox and Fox (1986) have illustrated that disturbance-adapted systems display a degree of resilience to human-induced disturbance on a scale relative to the magnitude, duration and type of disturbance. Possibly, scarcity of suitable lands for farming has forced farmers in the area to persistently intensively cultivate the same land to the extent where both edaphic and micro-climatic conditions may have significantly changed, which in turn, have affected the original course of succession.

As long as human land-based developments continue, land use will generate unavoidable consequential changes in land cover. Different areas will exhibit responses reflecting situational land use strategies. Much as land cover change should be seen as a normal product of land-use for development, forms and pace of changes that defy the fundamental principles of sustainability of land resource utilization should be effectively controlled. The indications from the study reflect that such a process has been ongoing in the area, and hence necessitating a proper management of land-use/cover change to ensure sustainability.



5.4 Tree cover and sustainability of cropping systems

The pattern of land-use/cover derived from the satellite data strongly corresponds to the field patterns of crops, trees, and fallow. Persistent opening of tree canopies encourages the proliferation of herbs (Hawthorne and Abu-Juam, 1995; Hall *et al.*, 1972). This process of transformation is widespread in the area. Studies have confirmed this pattern of vegetation in most parts of Ghana, including the Densu River Basin (Adu and Asiamah, 1992; Pabi, 1998). This supports the inverse relationship between fallow and tree cover observed in the area (Figure 4.12). Persistent canopy fragmentation or deforestation due to intensive human activities promotes the invasion and establishment of species such as *Chromolaena odorata* and *Panicum maximum* (Hall *et al.*, 1972; Hawthorne and Abu-Juam, 1995).

In the traditional system of farming, matured trees are usually left on cocoa farms to provide humid conditions, shade and protection, especially, to the young cocoa plants. Therefore, matured fallow or forest formations with trees are perceived as most suitable land types for cocoa cultivation (Figure, 4.49). This practice is still common among farming communities in the area. However, in areas where practically all trees are felled or burnt, annual food crops are dominant. This explains why annual food crops were mostly associated with fallow fields and little tree cover, whereas cocoa was found in association with high tree numbers.

If the transformation of vegetation from forest to fallows in the area progresses, most people may perceive the land as suitable for annual food crops rather than tree crops. This may partly explain the proliferation of annual cropping in the area. Similar

observations have been made by Attua (1996), Agyepong and Kufogbe (1996) and Amanor (1994). Given the prevailing scenario, one could deduce that cocoa cultivation may not be sustained unless trees are either protected or replanted. Possibly, annual food crops will continue to dominate the agriculture land use system in the area in future (Clayton, 1958).

Reduction in the percentage of vegetation cover in the form of forest-farms and an increase in fallow and annual crops may threaten the sustainability of some agriculture land uses by modifying the general biophysical conditions necessary for their existence (Amanor, 1994). Specifically, it may undermine land suitability potential to support the production of forest tree crops like cocoa that needs some amount of tree cover for establishment. To some extent, this study lends credence to this claim since cocoa farms were generally confined to areas of high tree density (Pabi, 1998).

5.5 Equity in per capita conversion of good agriculture lands into built-up areas

The International Union for the Conservation of Nature (IUCN) emphasises inter-generational equity as an important issue and dimension in sustainable resource use. As a value, it presupposes that in the decision making to allocate resources, equal weight should be given to the present and future generations. In other words, sustainable development must be a process of social and economic betterment that satisfies the needs and values of all interest groups, while maintaining future options and conserving natural resources and diversity (IUCN, 1980). It requires the maintenance of resource stocks: trees, soil, water, and to avoid substantial decline in quality of resources with use over time (Markandya and Parce, 1988).

The conversion of arable lands to built-up areas could be considered an irreversible process. It presupposes that the conversion process in the Koforidua Municipality should be as efficient as possible to avoid wastage. The principle should also be followed by all generations so as to achieve intergenerational equity. Thus, it was expected that per capita inter-generational allocation of arable land for constructional purposes be reasonably equal. However, it is clear that recent generations are using more land than the earlier generations (Figure 4.27). It appears that from the early 1990s, people began a rush to build more houses, and in the process scattered them over a wider landscape without due attention to efficient use of land. If the trend continues, it is clear that future generations will face acute shortage of land.

This trend has been observed on a global scale. In both developed and developing countries, there has been increasing per capita consumption of resources (UNEP, 1998). Possibly, local situations such as observed in the New Juabeng is feeding into the global context. In dynamic systems such as human society, sustainability is fundamentally a question of balance maintained over time (Dahl, 1995). The intergenerational imbalances in the conversion of land may be due to inefficient urban land use that is usually manifested in urban sprawl (Figure 4.24). Regarding this, Agenda 21(UNCED, 1993) and WHO (1992) have made a recommendation for the development of synergies between urban and rural land uses to ensure that settlements and industrial areas and peri-urban infrastructure is prevented from unduly pre-empting prime agricultural lands through effective market controls.

Again, sustainable development focuses directly on the population that can be sustained by a given territory, that is, its carrying capacity (FAO, UNFPA and IIASA, 1982; Vitousek *et al.*, 1986). However, population size alone is not the only relevant determining factor. Such capacity depends on the desirable quality of life of the population in the territory, which would have to be defined in terms of essential (minimal) or desirable standards of living. Possibly, historical differentiation in the quality of life may explain the observed disparity in per-capita consumption in land for constructional purposes. Thus, even though population has increased over the years in the Municipality, temporal differences in efficiency in land-use may be a force driving inequity in land allocation.

Intergenerational equity suggests a judicious use of natural resources in a way that ensures that their capacity to support the development of future generation is not compromised (Serageldin, 1996). Considering the trend in the conversion of agricultural lands into built-up areas, it is possible that future generations may have to experience severe shortage of land for farming. This trend has been observed in other countries where urban development has consumed much of the highly productive agriculture land (Bowers, 1997; Bernard, 2000).

5.6 Sustainable utilization of sensitive ecosystems

Ecological compatibility of land utilization is an important characteristic of a sustainable system. Sensitive and vulnerable but important natural ecological systems must be protected if they are to continually provide needed ecological services.

Internationally, this principle has been advocated for implementation through various strategies to ensure sustainability in the use of environmental resources (WCED, 1987).

5.6.1 Sustainable use of steep landscapes

Slope is a critical determinant of terrain vulnerability to erosive agents (Price, 1993), hence its inclusion in land-use sustainability equations. For its practical sustainability diagnostic importance, Ghana uses slope as an important indicator to determine the degree of vulnerability of terrain to erosion and a measure of unsustainability to land use (Ministry of Lands and Forestry, 1999).

Though a greater proportion of the area investigated was gentle rolling, appreciable amount fell within the slope range considered unsuitable for various forms of land-use activities (Figure 4.33). As a measure for sustainably managing these marginal lands, Lal, R (1986) have recommended that steep and rocky terrains are better left as 'protected forest reserves'. Clearing of vegetation creates favourable conditions for water and wind erosion (Jankauskas, 1994; Lobb *et al.*, 1995). For croplands, they recommended the use of gentle slopes (<5%) with deep good soils, which are input responsive.

Contrary to such suggestions, steep terrains in the mountainous regions of the New Juaben and neighbouring districts were heavily deforested through farming, bush burning and to a limited extent, constructional purposes. Mainly, these areas were either left bare or covered with fallows capable of limited protection of the soil against erosion, for most part of the year. Contrary to the recommendation for employing

effective farming practices that minimize erosion hazards on steep and rolling terrains, these areas were used for intensive annual cropping with no appropriate erosion-mitigating measures. Apparently, land resource utilization is not being carried out in a manner that promotes sustainable use of environmental resources. Sustainable management of land and environmental resources utilization in topographically marginal terrains should be seen in the context of their vulnerability to land degradative processes, and their roles in ecological processes.

5.6.2 Sustainable use of flood plains

Disturbances of vegetation cover over watersheds cause disruptions of hydrological regimes (Gash and Stedard, 1977). For their importance and sensitivity to disturbances, watersheds and flood plains are considered very important resources that must be protected through sound ecological measures (Golly, 1993; Hedin and Likens, 1996).

Along extensive segment of the floodplains of the Densu River, vegetation disturbance is a common phenomenon (Plate 4-1). Land-use/cover characteristics of the segment of the floodplain of Densu evaluated for its sustainable use typifies the general condition along a significant portion of the river. This is more pronounced in areas such as Nsawam. Existence of patches of isolated clusters of trees as portrayed in the satellite images (Figure 4.29), as well as responses from interviews on the past conditions of the basin confirmed that there used to be relatively dense tree cover along the river. Obviously, the requirements for sustainable use of the basin have not been totally complied with.

The transformation of the forest cover into fallows and progressive adoption of intensive annual cropping systems on the flood plains may have contributed to the persistent flush floods and drying-ups during the rainy and dry seasons, respectively, of the Densu River in recent years. Erosion of bare grounds of the watershed may have been responsible for siltation of the reservoir on the river at Koforidua (Plate 4.2).

Prior to the formulation of the national land-use policy strategies that prohibits land use within 100m of water bodies, there were local and traditional arrangements that sought to protect vegetation in the immediate vicinity of rivers and streams. Somehow, these protective frameworks appeared to have outlived their usefulness. Certainly, current status of land-use and the vegetation cover in the Densu Basin can scarcely promote sustained water flow of the river, and the provision of water for both human use and aquatic communities.

Having noticed the negative effect of deforestation on the Densu River, its negative impacts on sustaining water flow and subsequent sustained water provision, the District Assembly has initiated a programme to re-afforest sections of the floodplain of the Densu River in the New Juabeng District. Yet, the coverage is not extensive enough to be effective in protecting the entire river. A more comprehensive inter-district measure could be an effective and a better option.

5.7 Efficient allocation of suitable land to land-use types for sustainability.

The concept of sustainability is dynamic in that what is sustainable in one area, may not be in another, and what was sustainable at one time may no longer be sustainable.

Thus, sustainability demands that effort is made to identify suitable land types for land uses that generate optimum output. To ensure sustained productivity of cropping systems, the integrity of biophysical characteristics of the agro-ecological supporting systems are maintained. The use of land resources in the long-term basis should meet the present needs without jeopardizing future potential, and enhance per capita productivity, maintain/enhance environmental quality and restore productivity and capacity of degraded and impoverished systems (Lal, 1995).

The investigation shows that it has not been a standard or normal practice for farmers to determine soils that are suitable for newly introduced crops. In most cases, this is learnt through use over time. This may have been the case with cocoa, as was revealed by the study. At the time of introducing cocoa in the area, it is apparent that the farmers had no previous experience of the long-term performance of cocoa on various land types. They established cocoa farms wherever forested land was available. In a study of the Western Region, an important cocoa frontier in Ghana, Benneh (1988) has indicated that most cocoa farms failed since they were cultivated on soils that were unsuitable for cocoa. A similar development has been found in a study at the Many Krobo District – one of the pioneer cocoa growing areas in Ghana (Amanor, 1994). It is obvious that the overriding attraction for cultivate cocoa was the high price offered, especially, in the 1950s. There may have been little concern for sustainable production of cocoa.

Evidently, some of the soils cultivated in the study area are similarly unsuitable for cocoa (Figure 4.37). For instance, soils such as Adawso-Bawjiasi/Nta-Ofin

Association that were cultivated in the past are susceptible to drought and erosion (Adu and Asiamah, 1992). According to some farmers, their effort to re-cultivate Obourtumpian area has not been successful. The seedlings wither and die as soon as they are planted. Conversely, crops, such as cassava and maize that are recommended as suitable in these areas were successfully being cultivated.

By and large, the Koforidua-Nankese/Nta-Ofin association that is evaluated as good: with high soil moisture retention capacity and suitable for a wide range of tree and arable crops has continued to sustain a good number of cocoa farms and other food crops. It must, however, be noted that some localities within this area were also devoid of cocoa (Figure 4.39). This was especially true of areas with heavy fragmented canopies. Naturally, soil associations are not totally homogeneous. Thus, it may be that patches of unsuitable soils that were originally cultivated with cocoa were unable to support them, in the long term. However, a simple causal relation between soil types and the distribution of cocoa farms is not being suggested, though, since important factors such as socio-economic and other biophysical elements could be operating in a complex fashion to influence growth and cocoa productivity.

Even though tree crop plantation may be successful and ecologically sustainable in areas considered theoretically suitable, successful production can be sustained provided there are high scientific based inputs (Fearnside, 1987b; Harwood, 1987). This management regime is currently lacking in the area, and may have affected the long-term sustainability of cocoa on some good lands. The implementation of the Economic Recovery Programme since the early 1980s, in Ghana, has made it



impossible for the country to continue supporting programmes that ensure sustainable production of cocoa.

Landscapes are not uniformly resilient to disturbances associated with farming systems. Therefore lands characterised by steep slopes, shallow soils, rocky and uneven terrains are recommended for forestry (Adu and Asiamah, 1992; Lal, 1995). That is, they are better left in their natural or undisturbed state. For annual crops, the land should be low lying, gentle to flat with slight sloping ($< 5\%$), deep soil and good fertility (Lal, 1995). Apparently, these recommendations have not been fully heeded, in practice. Food crops have been cultivated in hilly terrains. Frequent Slash-and-burn practice, bush burning in dry seasons and crop harvesting that render lands bare predispose these vulnerable areas to erosive agents. That may account for the degradation of the land in the mountainous regions of Nkurakan and others (Figures 4.9a and 4.9b).

There are two major types of land suitability – urban suitability and agriculture suitability. A piece of land will be favourable for urban development if it is close to a built-up area or linked by a road. Agriculture, however, is related to soil fertility and topography. Conflicts that usually arise between urban and agricultural land uses should be settled to achieve efficient allocation of land resources close to fast developing areas. For efficient land use, it is suggested that the best agriculture lands should be reserved; land use conflicts should be resolved properly. Land use should not also be carried out in a fragmented pattern.

Considering the limited size of the New Juabeng District, it is vital that lands, which are suitable for agriculture are allocated or reserved for such. As much as possible, agriculturally suitable lands should not be used for constructional purposes. Any conflicting development should be considered counterproductive to achieving sustainable land resource use. However, agriculturally prime lands in the Koforidua Municipality were being used for constructional purposes in the area towards Oyoko where good agriculture lands exist (Figure 4.34). Generally, many towns have been established in fertile lands (Harrison, 1992). The tendency is that prime agriculture lands are pre-empted as townships develop spatially (WRI, 1992; Mike, 1983). Although the direct transformation of rural land through outward urban expansion affects relatively small areas of land, the impact is great where it is in short supply such as the New Juabeng Municipality (Satterthwaite, 1991). Land allocation at the periphery of Koforidua municipality is inefficient. It is more fragmented, and thus lacks the compactness that is an index of efficiency in land allocation.

5.8 Perceptions Of Land-Use And Land Suitability And Sustainability

5.8.1 Land-use pressure and sustainable land utilization

Poor accessibility to farmlands becomes an issue of sustainability if land scarcity is caused by degradation of existing arable lands due to inefficient use. There was an obvious positive relationship between the outcome of the land-use/cover change analysis and farmers' accessibility to good farmlands. The fact that even landowners have problem accessing good farmlands is an indication of how serious the problem of land-use pressure might be in the area. The existence of vast fallow fields and degraded lands may have been due to continuous cropping over the years. With little

or no application of fertilizer or manure, the soils in the area may now be significantly exhausted (Pabi, 1998).

The conversion of substantial amount of dense vegetated land into fallows may be likely due to reduced fallow period. Gyasi *et al.* (1995) have made a similar observation in their study within a comparable agro-ecological zone in a neighbouring locality. The length of fallow cycle found in their study ranged from 1-2 years. Associated with this reduced fallow period was declining soil fertility (Gyasi *et al.*, 1995).

Studies have indicated that with the current reduced range of fallow cycle, soils could scarcely regain fertility, unless accompanied by fertilizer application, mulching, manuring, agro-forestry practices or other soil fertility improvement techniques (Nye and Greenland, 1960; Foggie and Piasecti, 1962; Wills, 1962). Lal (1986) has also pointed out that land degradation is a function of clearing, duration of fallow, mode of agriculture and the choice of crops. Without application of fertilizer and careful tillage and management practices, progressive reduction in fallow period reduces the productive capacity of farmlands (Grigg, 1987).

Removal of forest vegetation coupled with continuous cropping, with practically no agricultural input may have been responsible for poor accessibility to good farmland in the area. Certainly, the widespread poor accessibility to fertile farmlands is an important issue since it may constrain future agriculture land-use programmes. Much as the limited size of the district is relevant in this regard, inefficient land-use could

aggravate pressure on land resources, thereby compounding inaccessibility to fertile farmlands.

5.8.2 Socio-economic and biophysical dynamics and the perception of sustainability of cropping systems and land types

Like other land users, farmers in the area make decisions that are socio-economically rational. They function within a varying socio-economic environment and make decisions on the basis of experience, information and technology available to them and in the light of what they feel is the most efficient way of utilizing their soil, water, skill, labour, and capital to achieve their goals. In a generic sense, their decision making process involves identifying a range of possible crop alternatives or land uses which are suited to existing (or modifiable) biophysical environment, deciding which of them would be possible to produce, sold; and finally which of these best support their objectives. This continuous and iterative process is carried out seasonally.

Land-use sequences express change in the use of land, particularly for agriculture production as a result of change in technology, socio-economic and biophysical environment. Socio-economic induced change occurs as changes in demand and price respond to a range of policies. Deteriorating environmental conditions arising from natural causes, such as decrease in soil fertility may lead to changes in land use. Studies have established distinct patterns of land-use dynamics in the West African forest zone (Ahn, 1958; Clayton, 1958). From his study in Nigeria, Clayton (1958) observed these trends: normal crop rotation where thicket develops into secondary forest, and then re-cultivated; degeneration as a result of repeated cultivation; decline

of cocoa plantations as the canopy opens by die-back as inter-cultivation commences. In his study, Ahn (1958) observed that abandoned farmlands were re-cultivated with cocoa after some 25 years when it has turned into secondary forest. Naturally, the significantly reduced period of fallow in the area makes this later option an impossibility.

Obviously, changes have occurred in the cropping systems in the area investigated. Even though several factors, socio-economic/financial and biophysical were mentioned by the farmers as possible driving forces, they seemed to be interested in satisfying their basic needs on a sufficiently regular basis. Apparently, they may not be able to support or sustain costly investment in farming inputs.

Among the principles for designing sustainable farming systems in Tropical Africa, one of the few objectives is to render farming systems sufficiently flexible to manage risks associated with the vagaries of climate and markets (SCA, 1991). Thus, due consideration should be given to prevailing conditions in choosing the commodities to be produced, varieties to be produced and the sequences of operations and nature of operations to be performed. It is easy to appreciate that applying this principle will be difficult, particularly where farmers have cultivated practically all their prime agriculture lands with perennial crops such as cocoa. For one thing, flexibility will be lacking in the face of severe scarcity of land. If one has already cultivated available land with one type of crop such as cocoa, only a marginal proportion of land will be available for other crops that may be in great demand in future.

Besides current frequent bush fires (Korem, 1985) and drought, there has been a steady reduction in the amount of rains in the area (Pabi, 1998). These events increase the risk of cultivating crops that take years to mature. Likely, farmers may have cultivated cocoa for its attractiveness due to past government policies that subsidised agricultural inputs and better pricing regimes. Accordingly, cocoa was widely cultivated in all manner of soils without prior determination of its performance on these soils in the long-term. Forested lands were erroneously assumed to be good for cocoa, irrespective of the land suitability of the area. This possibility is seen in the farmers' suitability evaluation of land-use/cover types for crop types (Figure 4. 45). But, these national agriculture-subsidizing regimes have changed. Farmers will have to pay for high cost of these inputs, if they can afford at all.

Even where cocoa is considered suitable, patches of annual crops have replaced cocoa farms. Generally, soil types do not naturally occur spatially in homogeneous patterns: a mixture of both bad and poor soils may occur in an area (Adu and Asiamah, 1992). It is therefore conceivable that the areas without cocoa at the time of study may have soils that are unsuitable for cocoa. It is also probable that farmers replaced dead cocoa trees with annual food crops due to poor land accessibility. Moreover it may be that, to some farmers, cocoa is no longer profitable and would prefer to replace it with more productive alternatives (Figure 4.45).

5.8.3 Views of cropping systems and land types and sustainable land use

The choice of land-use is fundamentally a product of rational use of available information from personal experience and other sources under prevailing socio-

economic and biophysical contexts. In the past, the decision to cultivate particular crops may have been greatly influenced by government policies, normally determined by the need for cash crops for foreign exchange. In the past, population size of the area was comparatively low (Engmann, 1986; Ghana Statistical Service, 2002). Thus, farmers had enough fertile land to conveniently cultivate both perennial cash crops and annual food crops.

With increasing population and the resultant progressive fractionalising of fixed inherited lands - several times over, for ever-expanding families (Table, 2.2), there may not be enough land for food crops and perennial tree crops at the same time. It has been found that areas dominated by cocoa production usually have insufficient food supplies since there is a scarcity of land (Engmann, 1986). Results from sample census of agriculture in the 1970s indicate that cocoa is averagely cultivated on bigger lands than annual crops such as maize and cassava (Engmann, 1986). It seems that cocoa, being essentially a cash crop imposes a strict minimum size of the economically viable unit, whereas, food crop farming may not. Therefore, food cropping may be amenable to extreme sub-divisions of land.

In the face of real and challenging circumstances, farmers in the area make decisions based on some real and perceived factors. Evaluation of these factors would be based, primarily on previous experience and prevailing socio- economic and land/environmental resources conditions. It is obvious that avoidance of production risk (Wolgin, 1975; Upton, 1997) as expressed in preference for short term and regular income flow, land-suitability, food for the household, seemed to weigh heavily and



ultimately determine the choice of crops to be cultivated on the types of land cover in the area. Naturally, perennial crops may not be a popular choice on a sustainable basis (Figure 4.46) considering the prevailing biophysical and socio-economic conditions and poor accessibility to good lands.

Prevailing trend in annual food cropping and intensification of farming will likely continue in the future. Possibly, fallow cycle may progressively reduce further; this will lead to further erosion of biomass and subsequent soil deterioration.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Some major findings from the examined perspectives of sustainability of land resource utilization in the New Juabeng and parts of the neighbouring Districts could be captured in brief itemised summaries. A few logically deductive conclusions are drawn, either directly or inferentially from the findings and the discussions. These are stated in the most probable sequence in which the observed events may have occurred as a result of past and present land resource usage. It must be noted, however, that in drawing the conclusions, strict and definitive causal relations between various findings or events are not suggested. This is due to the complexity of interactions between a multiplicity of factors that may have occurred.

SUMMARY

The most important land-use/cover change that has occurred in the area is the conversion of denser and matured woody vegetation into fallow and annual crop fields. However, notable features of the land-use/cover changes that have occurred included inter-conversion among the various cover types and local-specific changes related to soil differentiation.

Per capita arable land conversion into built-up areas in the New Juabeng District has progressively increased over the years: this is a form of intergenerational inequity. Increasingly, this has occurred at the expense of good farmlands.

There was a high positive correlation between tree crops and tree density; in contrast, there was a negative correlation between the distribution of annual crops and tree density.

Steep slopes and areas within 100m of the Densu River were heavily deforested and replaced with short fallows and annual crops that are less protective land-covers against erosion and high water loss.

Farmers have cultivated all manner crops in various soil types irrespective of their suitability status. Apparently, little or no effort was made to identify suitable soils for different crop types prior to large-scale cultivation. Cocoa cultivation is a typical case. Soils, which are potentially suitable for cocoa and a wide range of crop types were extensively cultivated, whereas unsuitable soils were supporting only isolated remnants of cocoa farms and extensive annual crops and/or fallow fields.

Poor accessibility to good farmlands was widespread among both tenant and land-owning farmers. Fallow cycles have shortened significantly. Typically, it ranged from six (6) months to 2 years. Fallow periods of 3 and 4 years were unusual events.

Farmer perception of the suitability of cropping systems has appreciably changed. Evidently, the high suitability rating formerly accorded cocoa has significantly declined; in practice annual food crops have emerged as the most preferred cultivated crops.

The type, number, relative importance and the mix of factors that have informed farmer decisions in the choice of crops have undergone significant changes over time. Apparently, cropping systems with short turnover time frame and have regular returns are the most preferred.

CONCLUSIONS

The application of GIS and remote sensing techniques in modelling some features of the land resources for the evaluation process evidently manifests the possibilities of applying these tools in land-based investigations and sustainable management of land utilization. This strengthens the case for further application of these technologies in similar land-use/cover studies in both national and local contexts.

Largely, it is obvious that unsustainable land use has occurred in practically all the sustainability dimensions investigated. Most of the findings may have been triggered by remote factors, namely - demographic, socio-economic, cultural, political, etc. and immediate ones, such as inefficient land-use practices and wrongful use of land. In most cases, the correspondence between unsustainable land utilization and the current biophysical state of the land resources and on the community perception of the suitability of cropping systems.

Whereas the contribution of population growth to the issue of unsustainable land use may be ill defined, it may have fuelled demand for good farmlands. With poor accessibility to farmlands, farmers may have been forced to intensify the use of their limited lands by re-cultivating the same piece of land for extended periods with attendant declining following periods. Thus, the traditional bush fallow system, which

incorporates an important element of shifting cultivation, may be undermined for sustainability under the prevailing mounting scarcity for good farmlands. It is apparent that the traditional farming system can only be sustained if only far-reaching adaptations are made to it in the environment of rapidly changing socio-economic, demographic, cultural and biophysical conditions.

Denudation of vegetation from the sensitive ecosystems and marginal lands such as river banks and steep slopes of the highlands clearly indicates that the long-term capacity of these natural systems to sustain the provision of ecological services is being undermined. Seemingly, the principle of complementarity which is a necessary condition for sustainable land resource use is not being duly considered in land resource utilization in the area.

The progressive increase in per capita land conversion of potential agriculture lands into urban land uses may have contributed to the pressure on land resources in the New Juabeng Municipality. This reflects intergenerational inequity that portrays a form of unsustainability in land resource utilization. Obviously, future generations may face acute land shortage if the current trend in land use continues.

The removal of trees and reduction in fallow cycles with no appreciable fertilizer application could have resulted in soil fertility exhaustion. Transformation of the vegetation to bush fallow may increase the vulnerability of the landscape to fires. The above conditions could continue to suppress the recovery of the original vegetation by

changing the normal course of secondary succession to produce derived savannah and scrubland.

As the mix of factors driving farmer decision-making processes undergo significant changes: diminishing size in land holdings; decreasing vegetation cover, with attendant enhanced solar insolation; soil fertility decreases; removal of government subsidies for agriculture inputs, farmers are increasingly being forced to rethink their concept of land and crop suitability. This has dynamically influenced the decisions and choices made by farmers as to the cropping systems that are economically suitable. What is perceived or rated as highly suitable cropping systems will be adopted by farmers on sustained basis, whereas those perceived as unsuitable will be unsustainable or de-emphasised, in the long term. Thus, as the landscape progressively becomes more fallow, annual crops that are relatively good on fallow lands - with little agriculture input would likely be considered suitable, and dominate the area. Perennial cropping systems may, however, be unsustainable.

In the past, soils that are naturally unsuitable were cultivated with cocoa since all forested lands may have been wrongly perceived as suitable for all crop types in the long term. These soils might have lost their capacity to sustain cocoa production on a sustainable basis. Having learnt through experience to differentiate between soils of different suitabilities, farmers are in the position to determine soils that are suitable for cocoa and make informed choices accordingly.

RECOMMENDATIONS

The District Assembly and Sectoral Agencies

- i. Within the national land policy framework for sustainable land resource utilization management scheme, the New Juabeng District Assembly, in consultation with appropriate government agencies and other relevant local and external stakeholders should develop land and environmental resource use policies with goals, objectives and strategies suitable and targeted to the scale of their operations, present ecological nature of available resources and peculiar socio-economic matrix of prevailing land-use status. Such management regime could facilitate land resource allocation that reflects the cardinal principles of resource utilization sustainability and yields optimum benefits.
- ii. Effective monitoring and evaluation elements should be incorporated into any formulated land and environmental management scheme. These instruments should have clear visions, distinct land-use sustainability indicators and standards of land-use performance that are capable of guiding resource use for sustainable development.
- iii. Relevant authorities – both traditional and governmental, should review existing regulatory framework - laws, regulations and enforcement procedures, etc., in order to eliminate weaknesses and identify improvements needed to support sustainable land use and management of land resources. Where

appropriate new and enforceable byelaws that ensure the achievement of policy objectives should be enacted.

- iv. The District Planning Department should be technically strengthened and well resourced to plan ahead of development so as to avoid haphazard and inefficient use of land currently prevailing. Additionally, its coordinating capacity should be improved to facilitate integration of sectoral concerns and strategies for land-use and resources management. The use of GIS and remote sensing techniques and a form of an information system unit (Appendix 5) could facilitate the operations of the Planning Department.
- v. Effective trade-offs that enhance the resolution of land-use conflicts and improves the delivery of environmental objectives should be made integral part of resource management strategies. In this respect, farming communities along the Densu River should be encouraged to adopt agro-forestry along the banks of the river. This way, they will be motivated to avoid total devegetation of the flood plain. Currently, the specified across-the-board distance of 100m from rivers within which farming is forbidden as stated in the National Land Policy document is unrealistic. A range of distance categories based on flood plain sizes will be more practical and workable.
- vi. In the true sense of the word, land is not only finite, but is also an extremely scarce resource in the New Juabeng District. In view of this, land that is most suitable for agriculture should not be used for constructional purposes. The

Assembly should also encourage the construction of story buildings so as to optimise the use of land resources. It must be fully acknowledged that land resources are used for a variety of purposes, which interact and may compete with one another; therefore, it is desirable to plan and manage all uses in an integrated manner.

- vii. Economic instruments, institutional mechanisms and incentives to encourage the best possible land use and sustainable management of land resources should be instituted and encouraged.
- viii. Education on sustainable resource use should be intensified.

Researchers, NGOs and Agriculture Extension Services

- ix. Researchers in Ghana should replicate the methodological approach or adopt modified forms to evaluate sustainability of land and environmental resource utilization in similar and other agro-ecological zones in the country to provide information that guides the course of sustainable resource utilization.
- x. Researchers should seek to integrate remote sensing, GIS and GPS in land-based investigations to enhance the quality of output and build the capacity for the application of these research tools.
- xi. Research institutions, extension services and NGOs should educate farmers on land and crop suitability based on all relevant production factors. As much as possible, newly introduced crops should be tested on small-scale experimental

basis for their production levels and ecological impacts on different soil types before recommendation are made for large-scale adoption. Already introduced crops such as cocoa, which have already been cultivated on a large scale, should also be comprehensively assessed for sustainability based on current biophysical conditions and socio-economic factors.

APPENDIX 1: QUESTIONNAIRE ON THE PERCEPTION OF LAND-USE PRESSURE, LAND-USE COVER CHANGE, CROP AND LAND SUITABILITY.

- 1 Are you a landowner or tenant?
- 2 What is the location of the land?
- 3 What is your tribe?

Pressure on land

- 4 How frequent do you crop the same land?
- 5 Are you satisfied with the size of your current farm land?
6. How accessible are good farmlands in your area?
7. Give reasons for the difficulty in accessing new fertile lands?
8. How do you see the future trend in land accessibility?

Suitability of cropping system

Evaluate these factors in your consideration for the choice of crops (Scale: 1 – 3)

- i. Soil fertility
 - ii. Tree cover
 - iii. Land size
 - iv. Proximity to settlement
 - v. Cost of production
 - vi. Economic viability
 - vii. Demand for crop/ marketability
 - viii. Length of maturity
 - ix. Others
9. Name two crops that were dominant among the crops you cultivated in the past. Why did you cultivate them?
 10. Presently, what are the dominant crops you cultivate? Why do you cultivate them?
 11. What two crops are you likely to cultivate in future? Why?
 12. What crops are you no longer cultivating in recent times? Provided reasons?
 13. Have you ever cultivated cocoa?
 14. Are you now cultivating cocoa?
 15. What do you replace dead cocoa trees with?

Economic suitability of crops

16. Evaluate economic suitability of following crops (scale: Not suitable, suitable, very suitable)
- i. Palm
 - ii. Cocoa
 - iii. Cassava
 - iv. Maize
 - v. Plantain
17. Evaluate the of suitability of crops these crops: cocoa, cassava, plantain, palm, maize and cocoyam, for these land types
- i. 6 months fallow
 - ii. 1 yr fallow
 - iii. 3yr fallow
 - iv. 10 yr fallow
 - v. Forest

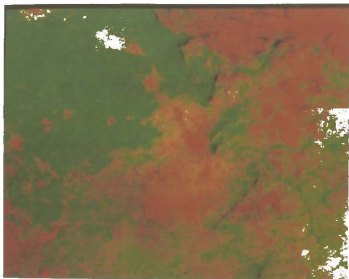
(Scale: Not suitable, suitable, very suitable)

18. Do you practice slash and burn? Yes/No
19. Do you have forested land? Yes/No
20. Describe the type of soil suitable for cocoa?

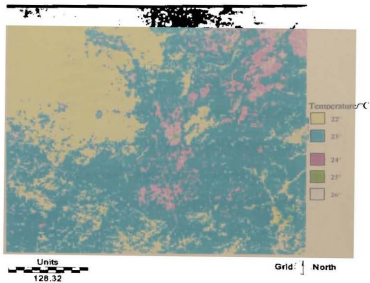
APPENDIX 2: ENHANCED LANDSAT TM IMAGE OF 1990



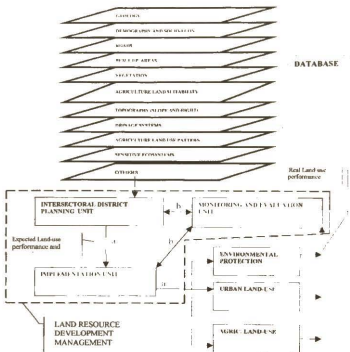
APPENDIX 3: ENHANCED LANDSAT TM IMAGE OF 2000



**APPENDIX 4: TEMPERATURE DISTRIBUTION PATTERN
DERIVED FROM THE THERMAL BAND OF LANDSAT TM
2000**



APPENDIX 5: RECOMMENDED INFORMATION SYSTEMS FRAMEWORK



- a. Expected standards for performance policy objectives of land use development
- b. → Expected standards for performance policy objectives of land-use development
- ← Level of agreement between expected and real land-use performances

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