Assessing the effects of land-use/cover change on ecosystem services in Ejisu-Juaben District, Ghana:
The case study of carbon sequestration

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March, 2008

Assessing the effects of land-use/cover change on ecosystem service in Ejisu-Juaben District, Ghana: *The case study of carbon sequestration*

By

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Thesis submitted to the International Institute for Geo-information Science and Earth Observation and Kwame Nkrumah University of Science and Technology in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation, Specialisation: GIS for Natural Resource Management

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Abstract

Land-use/cover change is a direct driver of change to ecosystem services, which occur with a number of consequences such as changes in the atmospheric composition, direct impact on biotic diversity, biological systems and its ability to support human needs and environmental risks such as flooding or water pollution, climatic change. This study focuses on assessing effects of land-use/cover change on ecosystem service and in particular carbon sequestration. Accurate evaluation of carbon stocks and changes in them due to land-use/cover change have been discussed actively since Kyoto protocol but major gap exists in understanding this mechanism and its implications to climatic changes. Despite its importance in the ecosystem carbon cycle no research has been done to estimate emission of CO_2 on land-use/cover basis in Ghana. The objectives of this study are to: identify and map key land-use/cover types between 1986 and 2007 and their ecosystem services, budget carbon stocks in various ecological components in different land-use/cover types, assess how changes in land–use/cover types affect carbon sequestration, explore relationship between spatially-explicit sequestered carbon and selected vegetation indices, estimate relative non-market values of "most ranked harvestable ecosystem service" and "least ranked non-harvestable ranked ecosystem service" and compare the difference in values. Based on satellite imagery for 1986 and 2007, land-use/cover change, their ecosystem services and associated net carbon stocks and changes were estimated in Ejisu-Juaben District, Ghana. Vegetation and soil carbon stocks (standing woody-plant biomass, herbs, litter, and soil) were sampled from forty 498.5m^2 selectively established three-nested circular field plots of radii 12.6m 8m and 4m respectively in different land-use/cover types. Soil in two (2) replicate 30-cm deep pits and separated into two depth strata(0-15cm,15-30cm) under different land-use/cover types were sampled. Carbon stocks of air dried herbaceous plant; litter and sieved soil were determined using Ashing and Walker-Black methods respectively. Standard allometric equations typical of tropical conditions were used to extract carbon stocks in woody-plant biomass. Grid-based analysis of C was done to assess spatial distribution of C using carbon density index. Spectral signature of each field plot were extracted and statistical relationship between selected vegetation indices (NDVI, SR, SAVI, MSAVI and OPSAVI) explored. Contingent valuation method through WTP survey was conducted to elicit comparative non-market values for "carbon sequestration" and "food" ecosystem services. Six (6) land-use/cover types were namely; forest, fallow/bush, agric, bamboo/raffia and built-up/bare. The total area of forest cover was decreased by 37%, whereas grass area increased by 62.7%. The conversion of forests into other land-use/cover types resulted in a remarkable decline in net C stocks. Across the land-use/cover, total mean C densities ranged from 81.30 ± 5 Mg ha^{-1} in grass area to a high of 335 ± 3Mg ha^{-1} in dense forest. The heavily converted areas lost an estimated 47% of their total 1986 C pools, whereas the low-impacted areas lost 8.7%. Changes in land-use/cover released 37.39 Gg C yr^{-1}. Relationship between C and all the vegetation indices was weak. Total WTP bid for "Food" is $4,695/yr, which represent 11.8% of WTP/income ratio compared to $828 (2.1% WTP/Income ratio) for "Carbon Sequestration".

Key words: land-use/cover change, carbon stocks, vegetation indices, willingness-to-pay, grid-based analysis, carbon density index

Acknowledgements

First of all, I wish to express my sincere gratitude to the almighty God for his protection, guidance and benedictions throughout my study and to the Environmental Protection Agency, Ghana for nominating me for this important course. Many thanks also go to the Netherlands Government for awarding me fellowship for my studies in Enschede.

My sincere appreciation goes to my supervisors; Dr Roel Slootweg, Dr. E. Osei Jnr. and Dr. S.K. Oppong for their competent guidance, tolerance and readiness to share their knowledge throughout the thesis period. Many thanks for your encouragements when the going was tough and I enjoyed working with you.

I am thankful to my own friend Dr. Patrick Van Laake for his help in the proposal development and Prof. Dr. Ir. Alfred de Gier, Dr. Michael Weir, Ir. Louise van Leeuween and Dr. David Rossiter for their pieces of advice.

I extend my profound appreciation to GISNATUREM (Kumasi) and ESAM students (Enschede) of 2007 for your diverse contribution to this work.

Lastly, to the entire Benefoh family, I express my gratefulness for the support and encouragements you gave in making this work successful.

Dedication

I happily dedicate this piece of work to my sweet grandmother, Madam Felicia Akua Akyempim, grandma; this is the reward of your hard work over the years.

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List of Abbreviations

MA	Millennium Assessment
FAO	Food and Agriculture Organisation
Pg	Peta gram
C	Carbon
CDM	Clean Development Mechanism
WTP	Willingness-To-Pay
CVM	Contingent Valuation Method
TM	Thematic Mapper
ETM+	Enhanced Thematic Mapper
RMSE	Root Mean Square Error
SOC	Soil Organic Carbon
BD	Bulk Density
NDVI	Normalised Difference Vegetation Index
SR	Simple Ratio
EVI	Enhanced Vegetation Index
SAVI	Soil Adjusted Vegetation Index
OPSAVI	Optimised Soil Adjusted Vegetation Index
MSAVI	Modified Soil Adjusted Vegetation Index

1. Introduction

1.1 Ecosystems and their goods and services

An ecosystem is "an assemblage of living organism that interacts with each other and the chemical and physical environment" (Environment Audit Committee, 2006). The resulting natural processes establish series of complex ecological balances that interrelate at different scales to deliver valuable ecosystem services to man. Curtis (2004) also defined ecosystem services "as the products of the role ecological systems play in providing a sustainable environment for life support, such as clean air, clean water, food, climate regulation, habitat and recreational opportunities". Ecosystem services therefore influence human well-being and thus of value to society (Slootweg *et al.* 2006). The 2003 Millennium Assessment (MA), report grouped ecosystem services into four broad categories:

- **Supporting services**: these underpin the provision of other services, e.g. nutrient cycling, and soil formation.
- **Provisioning services**: harvestable goods such as bush meat, fruits, food, fiber, fuel and water
- **Regulating services**: responsible for maintaining biological diversity itself, including natural purification process and dynamics, such as water purification, biological control mechanisms, carbon sequestration, pollination of commercially valuable crops and;
- **Cultural services**: providing a source of artistic, spiritual, religious, recreational or scientific enrichment or non-material benefits.

De Groot (2002) remarked that ecosystems undergo natural processes to provide goods and services that satisfy human needs directly or indirectly. Therefore, it is the presence of human beings as valuing agents that enables the translation of ecosystem composition, structure and processes into value-laden entities. He further divided ecosystem values, roughly, into three types: ecological, socio-cultural (non-use values) and economic values (use-values). De Groot (2002) again argued that once the functions of ecosystems are known, the nature and magnitude of their value to humans can be evaluated through the goods and services ecosystem they provide and that observed "ecosystem functions" can be reconceptualised as "ecosystem services or goods" when human values are implied.

Turner *et al.* (2003) established a critical distinction between use values and non-use values of ecosystem services to mankind and concluded that the latter component reflects value in addition to that, which arises from usage. Konarska *et al.* (2002) also associated land-use/cover types with specific ecosystem services and concluded that ecosystem value include the aggregate sum of use and non-use ecosystem services provided by specific land-use/cover type at different spatial scales of measurement.

In the past 30 years or so, valuation of ecosystem services has become one of the most significant and fastest evolving areas of research in environmental and ecological economics (Turner *et al.* 2003). One important motivation for ecosystem valuation studies is that, ecosystem services are not fully "captured in commercial market or adequately quantified, they are often given too little weight in decision making Costanza *et al.* (1997).

1.2 Ecosystem service valuation framework

Methodologies for ecosystem services valuation have been developed by, among others, Pearce and Turner (1990), Freeman (1993), Hanley and Spash (1993), Costanza *et al.* (1997), Turner *et al.* (2000), De Groot *et al.* (2002) and Millennium Ecosystem Assessment, (2003). Hein *et al.,* (2006) also developed framework for the valuation of three types of ecosystem services and four types of values based upon Pearce and Turner, (1990), Costanza *et al.* (1997), and (Millennium Ecosystem Assessment, (2003) methods.

Hein *et al.* (2006) remarked that this framework is applicable to all ecosystems, but it will in general be more useful to apply to natural or semi-natural (modified) ecosystems. This is because, specific attention is paid to goods and services provided by regulation and cultural services, which are often higher in natural and semi-natural ecosystems (Pearce and Turner, 1990, De Groot, 1992, and Costanza *et al.* 1997).

Following this framework, Hein *et al.* (2006) grouped valuation of ecosystem services into four steps namely; specification of boundaries of the ecosystem to be valued; assessment of the ecosystem services supplied by the system; valuation of the ecosystem services and; aggregation or comparison of the values of the services (Figure 1). This framework is adopted for the assessment of ecosystem service in this study because it is comprehensive, easy to implement and thorough in literature.

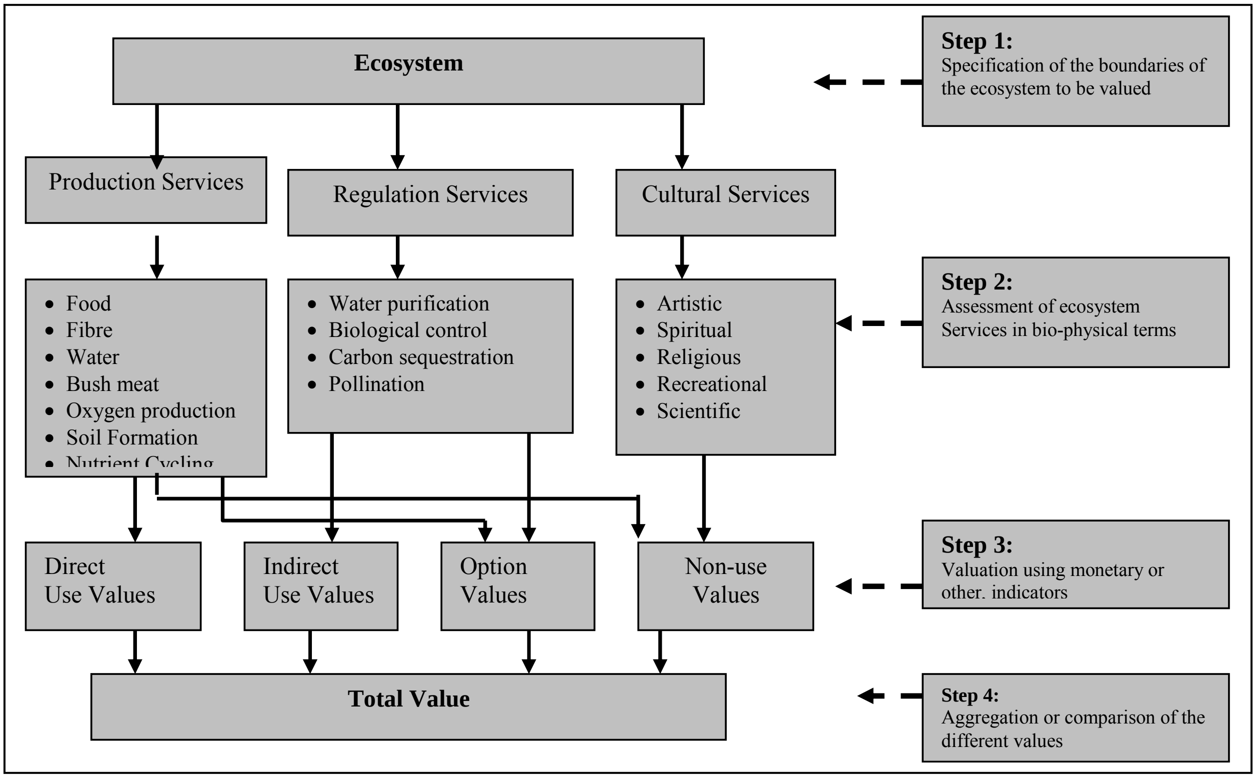

Figure 1: Ecosystem services valuation framework (Hein et al., 2006). The solid arrow represents most important links between the elements of the framework. The dashed arrows indicate the four principal steps in the valuation of ecosystem services

1.3 Threats to ecosystem services

Ecosystems are subjected to many human pressures (e.g., land-use change, resource demands, and population changes) their extent and pattern of distribution is changing. Daily (1997) and Ponting (1998) cited in Curtis (2004) supported the view that ecosystems are being degraded and destroyed worldwide due to human activities at an unprecedented rate in human history. MA (2003) also recognised the indispensable role of mankind in the modification of ecosystems, and remarked that the rate had been more in the last 50 years than in any comparable period. The report also concluded that approximately 61% (15 out 24) of the ecosystem services evaluated are being degraded or used unsustainably.

MA (2003) identified key threats to ecosystem services and categorised them into two drivers of change; indirect socioeconomic drivers (such as policies and legal framework), and direct drivers, which include changes in local land-use/cover as shown in figure 2. This research emphasis on assessing how local land-use/cover as direct driver of change affects ecosystem services in Ejisu-Juaben District of Ghana using (Hein *et al.* 2006) valuation framework(figure 1).

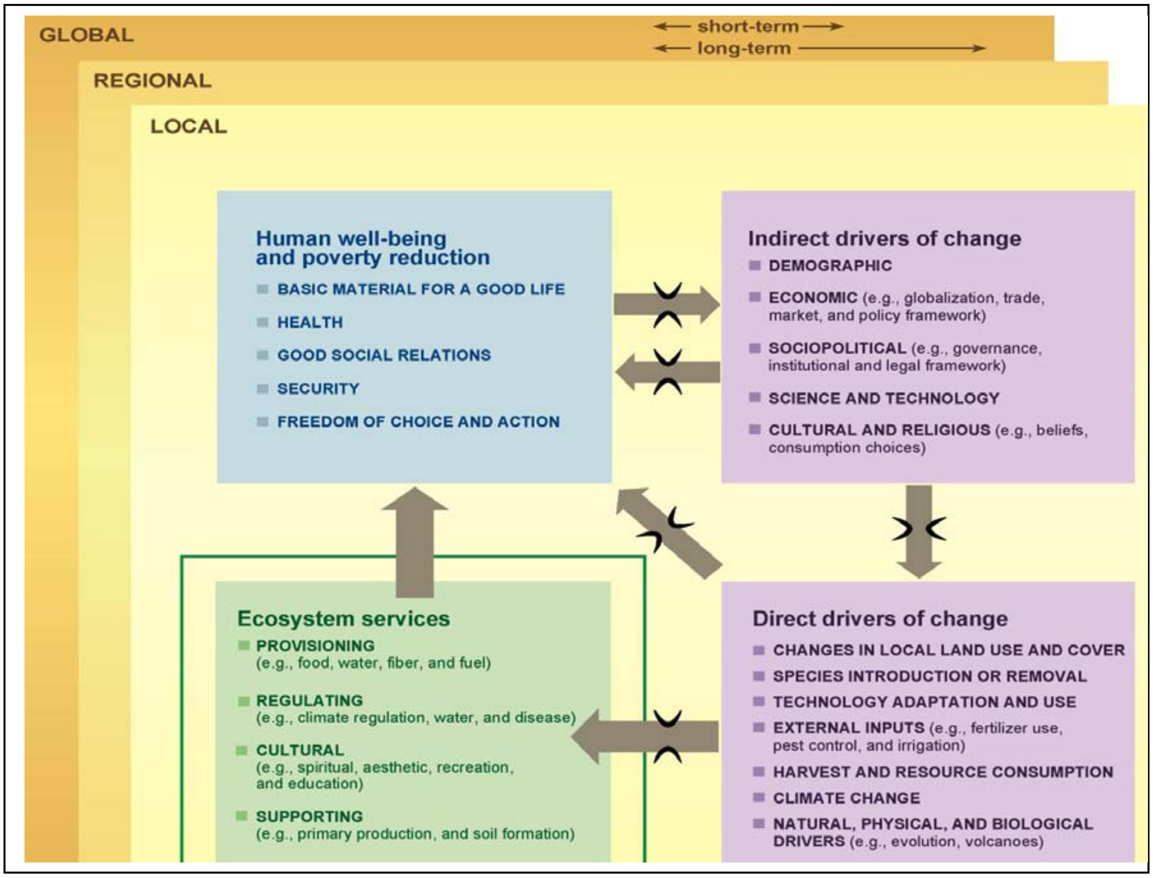

Figure 2: MA Ecosystem Service Framework (Adopted from MA, 2003)

FAO (2001) estimated that the world's forests were converted to other land-use/cover at rate of 0.38 percent (i.e. deforested) annually in the 1990s and more rapidly and diverse in developing tropical countries. Tropical deforestation, rangeland modification, agriculture expansion and urbanisation are the major land-use/cover changes around the globe (Lambin, 2001). In this light, forest cover alone is estimated to have been reduced approximately by 40% in historical times (FAO, 1996). These changes in land-use/cover occur with a number of consequences. Many studies have shown that the changes have had different effects on the environment. For instance, Meyer (1992) remarked that each category of land-use/cover change is associated with a number of environmental consequences, which can affect the global carbon cycle. Lambin, (2001) indicated land-use/cover changes have been identified to be pervasive because when put together, they significantly affect key aspects of the earth system functioning such as changes in the atmospheric composition and extensive modification of the ecosystems.

Sela (2000) also found that changes in land-use/cover directly impact on biotic diversity worldwide. These changes can also contribute to local and regional climate change, as well as to global climate warming due to deforestation (Houghton, 1999). They can also alter ecosystem services, and affect the ability of biological systems to support human needs (Vitousek, 1994) and pose environmental risks such as flooding or water pollution, climatic change (MA, 2003). Kreuter *et al.* (2001) indicated that dramatic land-use/cover changes often have significant negative impact on ecosystems and the goods and services they can provide.

1.4 Changes in land-use/cover in Ghana

Forests play an important role in the economy of Ghana. Timber, fuelwood, medicinal plants, wildlife (bush meat) and fruits are some of the ecosystem goods derived from forest in Ghana. Apart from the abovementioned, forest also provides suitable microclimatic conditions for the production of the country's cash crops, namely cocoa and coffee; and protect watersheds and rivers, which, serve as source of drinking water directly for rural areas and indirectly for urban centres. These services provided by the forest contribute 43% of the Gross Domestic Product and 50% of export earnings in Ghana(Agyarko, 2001).

Ghana's landscape has been categorised into land-use types such as small and large scale farming, forestry, cattle grazing, urbanisation, tree plantations of exotic and indigenous species (cocoa, rubber, timber), and game/park reserves in order to provide the above mentioned goods and services (Agyarko, 2001). However, deforestation stands out as the most prominent change factor within the Ghanaian landscape. Changes in land-use/cover types in Ghana, usually, begins with the gradual degradation of natural forests by excessive logging, slash-and-burn agriculture, mining and quarrying, and fuel wood collection with government policies, predominantly, as the ultimate driver. For instance, in Ghana, the structural adjustment program, which, was prescribed for the country by the World Bank in the 1980s encouraged the expansion of timber companies and increased timber exploitation to raise foreign exchange earnings to service Ghana's debt (Kufuor, 2000).

In support of the aforementioned, Hawthorne (1995) observed that most forest conversion activities that took place in the past were intentional, legal, and necessary for national development. The combined effects of the land-use/cover changes had led to the drastic decline of Ghana's tropical high forest from 8.2 million ha at the beginning the 20th century to 1.7 million ha (Friends of the Earth International, 1999), with an estimated annual forest cover change of 120,000 hectares between 1990 and 2000 (FAO, 2001).

A number of studies on land-use/cover change such as (Hawthorne, 1995) and (Mensah, 2002) had extensively dealt with the major causes and effects of land-use/cover change especially in forest ecosystem in Ghana. More recently, Asubonteng (2007) and Sedego (2007) applied remote sensing techniques to assess causes and implications of land-use/cover change resulting from multiple anthropogenic activities in Ashanti Region of Ghana.

1.5 Research scope

This research focused on investigating effects of land-use/cover change on ecosystem services in a spatial way. Remotely sensed data was used to map out land-use/cover types and it changes between 1986 and 2007. Key ecosystem services associated with the land-use/cover types were identified. In order to relate ecosystem services to the land-use/cover types, carbon sequestration service was adopted as reference ecosystem service. The "reference service" formed the basis for the assessment of changes in ecosystem services with land-use/cover change. It was also the basis relative to which other services were assessed in non-market values terms.

The reason for selecting carbon sequestration as a reference ecosystem service is because; the role of carbon sequestration service in Ghana is gradually assuming prominence, especially, in the climate change research agenda, scientific literature on carbon sequestration is also relatively accessible and lastly, inventory of carbon sequestration, though, time consuming, it is relatively easier to use as an reference service for assessing the effects land-use/cover conversion on ecosystem services. Changes in carbon sequestration ecosystem service as a result of land-use/cover conversion were determined. Finally, interviews were conducted to elicit comparative non-market values of harvestable and non-harvestable ecosystem services from stakeholders using contingency valuation techniques.

It is important to emphasis that, Hein *et al.* (2006) ecosystem services valuation framework was adopted and modified for use in this study (Figure. 3). In relation to the modified Hein *et al.* (2006) valuation framework, the first step was implemented using remote sensing data to define land-use/cover boundaries for 1986 and 2007. In the step two, ecosystem services associated with the land-use/cover types in the step one was identified and the biophysical assessment of carbon sequestration in respect to the land-use/cover types done. The third part constituted valuation of "least ranked non-harvestable" and "most ranked harvestable" services was done using the contingent valuation method. Aggregation and comparison of values of "carbon sequestration" and "food" services was done in the step four to complete the valuation framework.

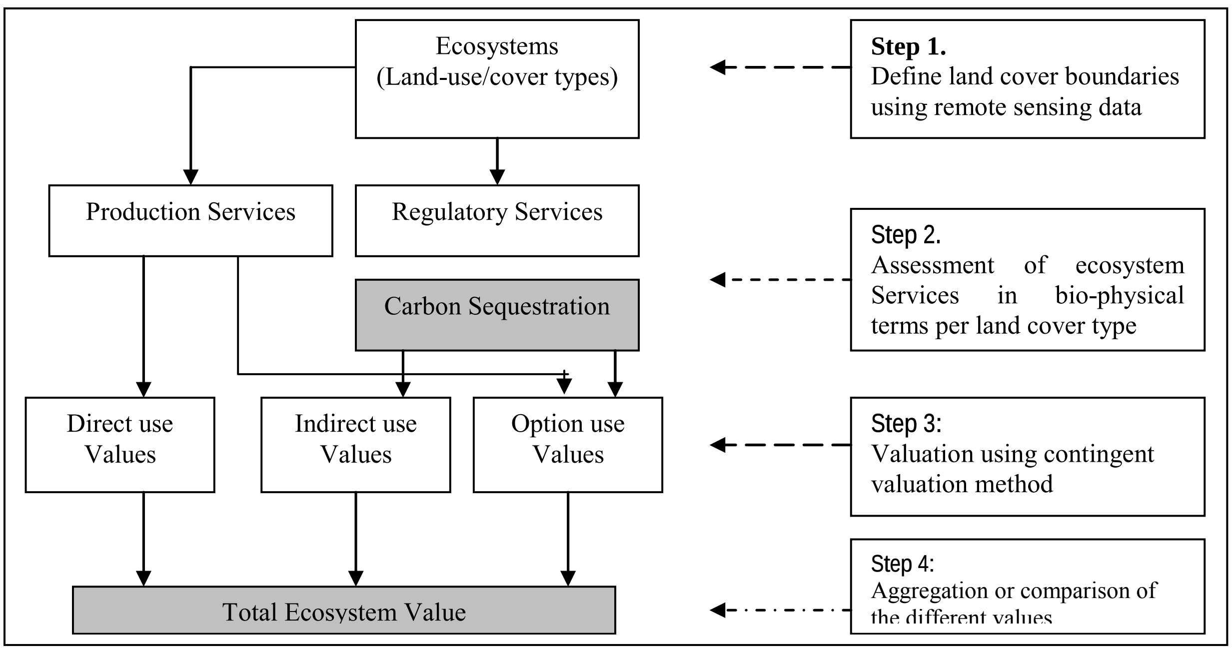

Figure 3: Modified ecosystem services valuation framework by Hein et al. (2006), adopted for this study

1.6 Carbon sequestration service and land-use/cover change

Vegetation, via the process of photosynthesis, transforms atmospheric CO_2 into carbohydrates through primary productivity. The carbohydrates are then stored in various carbon stocks such as plant tissues during growth, some of which may also be transferred to the soil as dead organic matter –secondary productivity (Petenaude *et al.* 2005). The entire process of capturing and up-taking carbon from the atmosphere by vegetation for storage is referred to as carbon sequestration and thus contributes to ensure global carbon balance. Vegetation has been identified as having the potential of up-taking (sink) or releasing (source) carbon at any defined time through its pools. Three (3) major types of carbon pools have been associated with vegetation. These are, aboveground biomass – trees (live or dead); necromass – herbaceous plant, litter and; belowground biomass – soil and roots. The importance of carbon sequestration in maintaining global carbon cannot be over emphasised. Specifically, in Ghana, the first national communication on climate change (EPA, 2000) concluded among other that, carbon dioxide accounts for the largest share of Ghana's greenhouse gas emissions by sources, however, carbon sinks in forested and afforested lands offset the total CO_2 emissions thus making the country a net CO_2 removal by sinks. This is because carbon sinks in the forested and the reforested lands offset total CO_2 equivalent emissions, giving total net CO_2 equivalent removals by sink as -5,411 Gg.

However, land-use/cover change involving deforestation is considered significant global concern due to its associated losses of biomass and leading to remarkable decline in net carbon stocks (Bonino, 2006). Deforestation does not only transfers carbon stocks directly to the atmosphere by combustion and decomposition, but also destroys the valuable mechanism for controlling atmospheric CO_2 (Chambers *et al.* 2001). In Ghana, deforestation has been identified (EPA, 2000) as a major human factor that drives loss of carbon (C) stocks in forest and other land-use/cover types. With the current deforestation rate of 1.7% per annum (Personal Communication), increased carbon loss due to of land-use/cover change is anticipated by the next decade.

1.7 Problem statement and justification

Forest areas in Ejisu-Juaben District (Ghana), are undergoing rapid changes due to increasing pressure from urbanisation and local communities that depend on it for their livelihood, examples include, extractive uses, burning and agriculture intensification with human population growth as the ultimate cause (Backeus, 2006). Human-induced degradation activities are driving changes in land-use/cover types especially in forest ecosystems, once forest lands are replaced with other land-cover types via a change in use.

Asubonteng (2007) looked at the prevalent causes of land-use/cover transfer and the links to socio-economic factors that drive those transfers using hotspot identification procedures in his research. He identified six major land-use/cover types in the study area between 1986 and 2004 and concluded that urbanisation, among others, is the number one driver of change in land-use/cover types over the study period. The rapid conversion of land-use/cover types in the District is having significant negative impact on ecosystems and the goods and services they can provide. Specifically, the conversion from one land-use/cover to another is largely contributing to the loss of net carbon stocks, which is a major source of carbon emissions into the atmosphere leading to local climatic changes. However, carbon stocks in Ghana and Ejisu-Juaben District, in particular, had not been assessed and characterised in a spatio-temporal context. This study will be built on the previous work by Asubonteng (2007) in Ejisu-Juaben District by expanding the scope to address how changes in land-use/cover types affect ecosystem goods and services especially carbon sequestration.

1.8 Research contribution

- Deepen understanding of how land-use/cover change affects vegetation and soil carbon losses to the atmosphere and ecosystem services in general.
- Serves as input into development of "an integrated land management system" for improving carbon sequestration in the study area (CDM opportunities).
- Provide a rapid method for assessing ecosystem services, especially inventory on carbon sequestration in different land-use/cover types.
- Contribute to the building of scientific knowledge in the valuation of ecosystem services in the developing world.

1.9 Research objective

The overall objective of this study is to assess how changes in local land-use/cover as direct driver affect ecosystem services in Ejisu-Juaben District.

1.9.1 Specific objectives

- To identify and map key land-use/cover types between 1986 and 2007 and their ecosystem services.
- To budget carbon stocks in various ecological components in different land-use/cover types.
- To assess how changes in land-use/cover types affect ecosystem services.
- Explore spectral relationship between spatially-explicit sequestered carbon and selected vegetation indices.
- To estimate relative non-market values of "most ranked harvestable ecosystem service" and "least ranked non-harvestable ranked ecosystem service" and compare the difference in values.

1.10 Research questions

- What changes have occurred in land-use/cover types in the study area between 1986 and 2007?
- What are the key harvestable and non-harvestable ecosystem services in the study area?
- What is the concentration of carbon stocks in different land-use/cover types and how is it allocated per pool?
- How do changes in land-use/cover affect carbon stocks in the respective cover types?
- How strong is the relationship between vegetation indices derived from remotely sensed data and sequestered C?
- How much economic value do users or beneficiaries of ecosystem services assign to the “least ranked non-harvestable and “most ranked harvestable” services?

1.11 Research approach

This research commenced with an extensive desktop review (literature review) of existing knowledge in four key areas of the subject of study. These include; land-user/cover classification and change detection techniques, ecosystem services in general but particular consideration to carbon sequestration services and non-market valuation of ecosystem services with contingent valuation methods. The main purpose of the desktop study was to identify existing knowledge gaps and subsequently conceptualise, define and formulate research problem, objective and questions respectively. This was followed by the selection of study area. After the site selection, reconnaissance visits was embarked to the study area to gather more information.

Initial logistical needs were assessed and those required were procured including satellite images, maps, GPS, diameter tape, soil augur, sampling bags, etc. Image pre-processing was done and followed with field validation. The field activities involved validating data from the remotely sensed land-use/cover spectral classes, collecting data on carbon stocks in different land-use/cover types and administering willingness-to-pay (WTP) questionnaires to obtain information on non-market values of "least ranked non-harvestable ranked ecosystem service" and "most ranked harvestable ecosystem service". Data from the field activities were processed and analysed for the discussion and conclusion chapters (Figure 4).

Summary of the research approach is presented in figure 4.

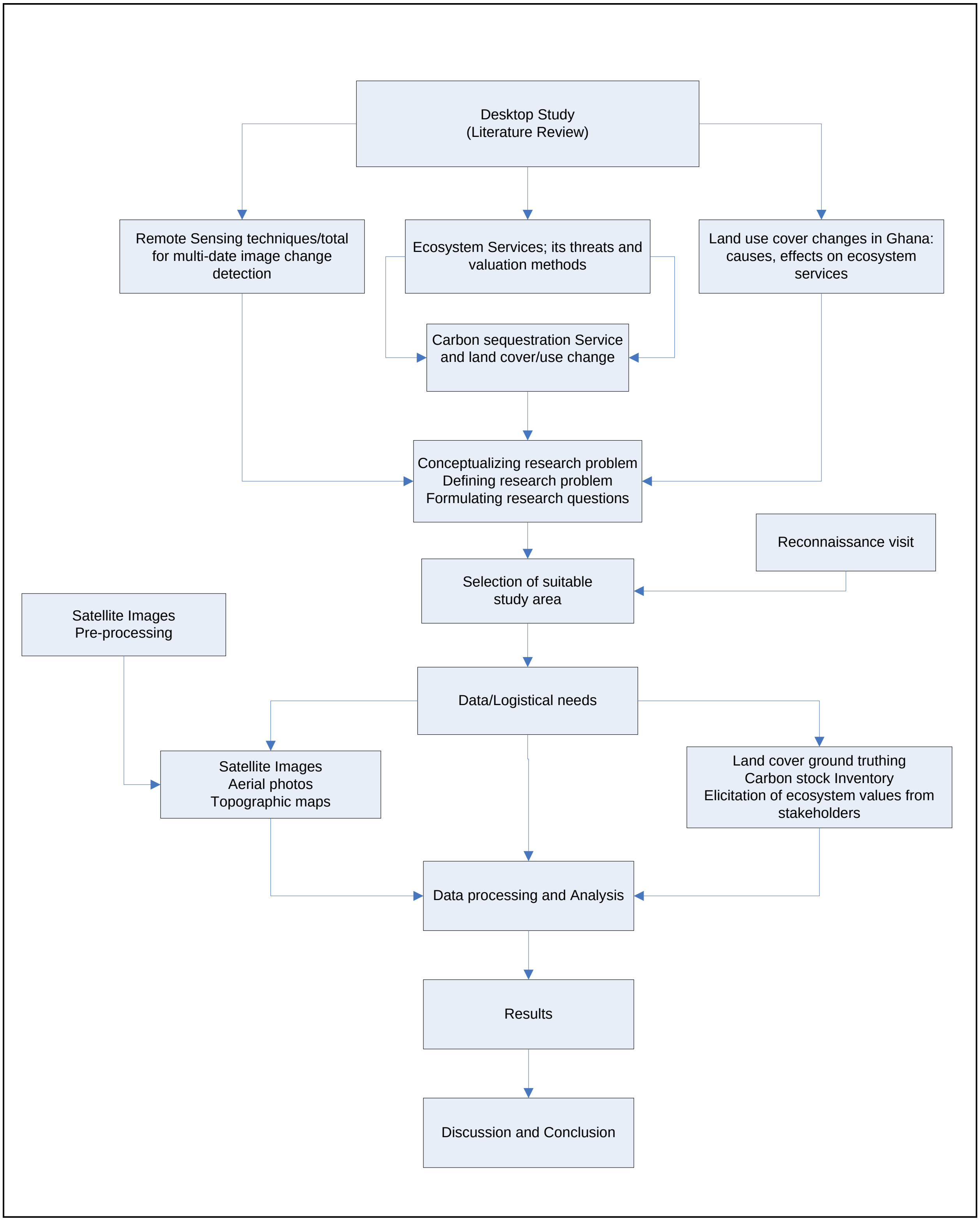

Figure 4: Research Approach

1.12 Thesis outline

This report consists of eight (8) sections namely; introduction, materials and methods, results, discussion and conclusions, recommendation, references and appendices. The introduction section presents an overview of research problem formulation and defining research objectives. Extensive search of scientific of literature in the subject area was done to put the problem in proper perspective.

Following the introductory section, part two (2) of the thesis report deals with the materials and methods employed in the implementation of field activities specific to each objective. This section highlights on description of study area, software and data used and a detailed account of the procedure followed the methods.

The third section presents results obtained subsequent to the implementation of the methods. The results are arranged according to each specific objective. Discussions and conclusions are dealt with in sections four and five respectively. Recommendations, references and appendices addressed in section six, seven and eight.

2. Materials and Methods

2.1 Study area

The research was conducted in the Ejisu-Juaben District in Ashanti Region, Ghana. The study was concentrated in two areas in the district, the north-western portions of the Ejisu-Juaben District, where rapid land-use/cover transformation is more pronounced due to development pressures from more densely populated and expanding Kumasi Metropolis and the south-eastern part of the district, where land-use/cover transformation is relatively less intense because of its distance away from the city.

The study area lies between latitude 6.765N and 6.586N and longitudes 1.419W and 1.385W with a total area of about 363.35km^2. Twenty-two (22) communities are within the study area. The communities are Ejisu, Old Krapa, Atiah, Boamadumasi, Kubease, Juabema, Adokrom, Onwe, Afraku, Yeboah, Besease, Abankro, Kwaso etc. The communities were selected based on the following criterion: communities where land-use/cover change had pervasively taken place due to urban expansion between 1986 and 2007, for example, Old Krapa, Ejisu, Besease, Onwe, Abankro and communities, where changes in land-use/cover had been less intensive including Yeboah, Juabema, Afraku, Adokrom.

This general classification of the study area was done based on the initial visual interpretation of the 1986 and 2007 landsat images. The main purpose for having such a mixture of communities for the study was to optimise representation of the process of land-use/cover conversion across the study area. The study area is presented below in Figure 5.

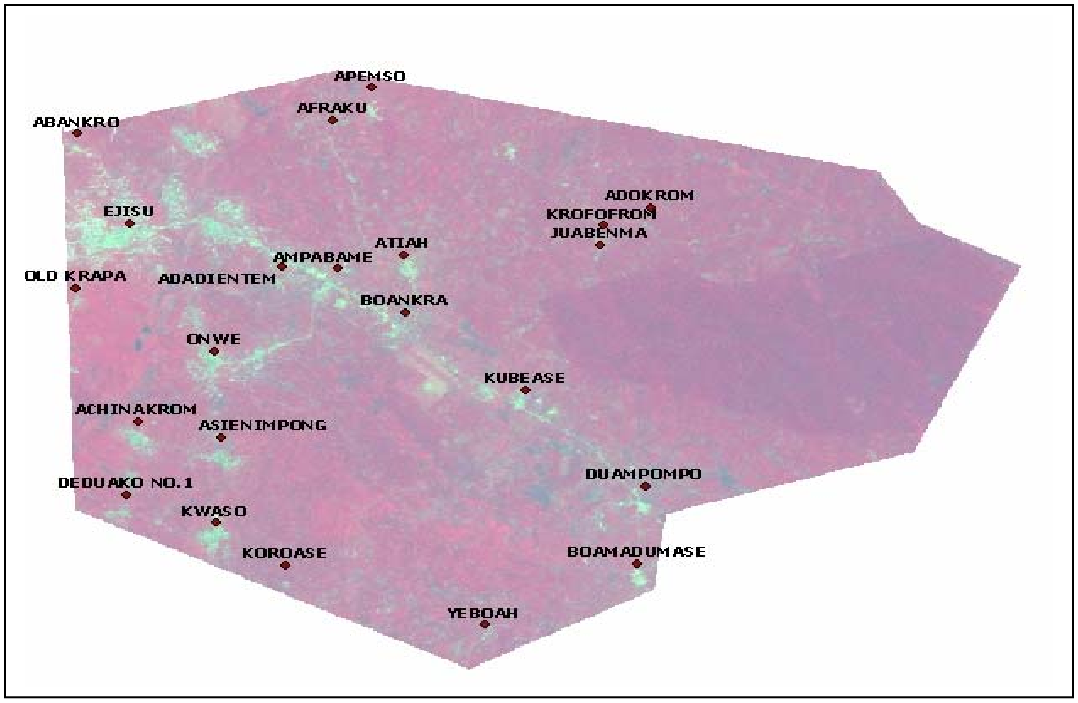

Figure 5: Locations of communities used in the study

2.1.1 Location of Ejisu-Juaben District

The selection of the district for the study was based on the reasons that; it is experiencing rapid urban expansion and agriculture intensification and are acting as catalyst in driving land-use/cover conversion (Asubonteng, 2007). Secondly, increasing population and high incidence of poverty in the study area according to the 2000 population census, undoubtedly, are exerting pressure on the forest ecosystem in the study area.

The district stretches over an area of 637.2 km^2 constituting about 10% of the entire Ashanti Region. In terms of political administration, the district is the centre of the Ashanti Region sharing boundaries with Kumasi and Kwabre Districts in the east, Afigya Sekyere and Asante Akim North Districts in the west and Bosumtwe Kwanwoma and Akim south Districts in south. It lies between longitude 1°15' 40.4"W and 1°33' 12.9 " W and latitude 6°25' 20.5"N and 6°48' 54.8" N with its capital Ejisu, located 20m away from Kumasi. A location map of the Ejisu-Juaben District is shown below in figure.6

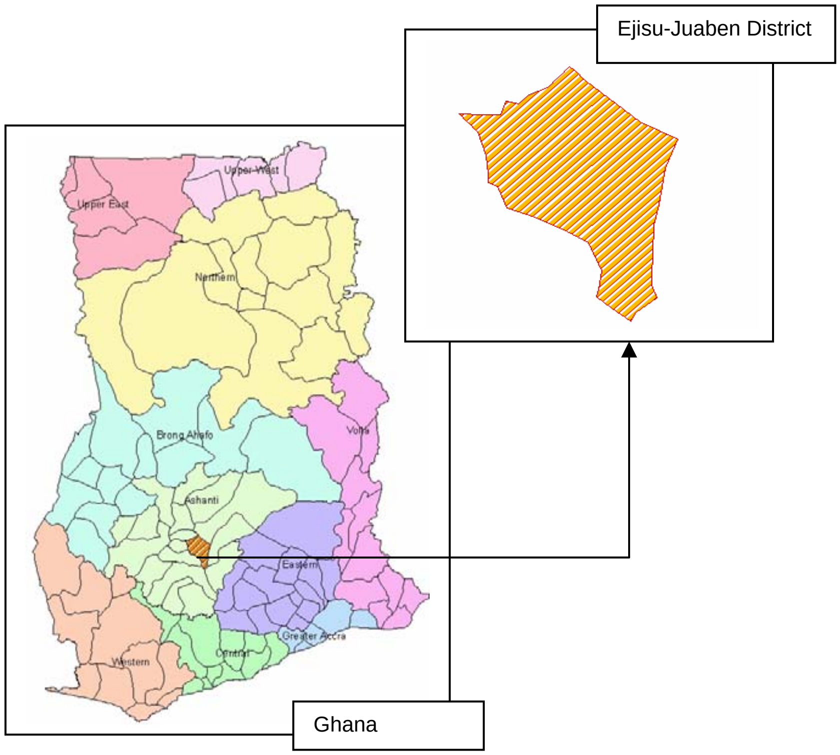

Figure 6: Location map of Ejisu-Juaben District

2.1.2 Topography and drainage

The District falls within the forest dissected plateau terrain region and is underlain by the pre-cambrian rocks of the Birimian and Tarkwaian formations. It rises from about 240 to 300 metres above sea level. The area is generally undulating and is drained by a number of rivers; notable among them are Oda, Anum, Bankro, Hwere and Baffoe. In the rainy season, occasional flooding is experienced in the inland valleys along the river basins (Ejisu-Juaben District Assembly, 2002).

2.1.3 Climate

The rainfall pattern in the district is bimodal in nature with wet semi-equatorial climate. It is characterised by double maxima rainfall lasting from March to July and from September to late November. Mean annual rainfall recorded stands at 1200 mm. Relative humidity is usually fairly moderate but high during the rainy season and early mornings. Lying entirely within the tropical high forest zone of southern Ghana; it experiences annual temperatures ranging from 20°C in August and 32°C in March.

2.1.4 Vegetation and soil

The Ejisu-Juaben District lies in the moist semi-deciduous forest vegetation zone as categorised by (Hall and Swaine, 1976). Bobiri Forest Reserve is found in the district and has a total area of 54.6 km^2 serving production, tourism, research and conservation functions. It is one of the richest in terms of biodiversity in the country. The reserve is floristically diverse and endowed with large quantities of economic timber species which include *Triplochiton screloxylon, Terminalia superba, Nesogodonia papaverifera, Aningeria robusta, Chrysophyllum albidum* and various species of *Entandrophragma* (Bureau of Integrated Rural Development, 2001).

The off-reserve areas mainly consist of annual crops, cash crops, fallow lands, forest patches and riparian vegetation along rivers and streams and grass in abandoned areas. It is important to note that forests outside the reserves are unsustainably logged by illegal and legal loggers. The most predominant plant in the off-reserve is mainly *Chromolena ordorata*. There are eight soil types in the district namely granite based Kumasi-Offin Compound, Bomso-Offin Compound and Swedru-Nsaba Simple Associations; Birrimian rock based Bekwai-Oda Compound, Kobeda-Eschiem-Sobenso-Oda Complex and Atunkrom-Asikuma Association; Tarkwaian based Juaso-Mawso association and lastly the superficial deposits based Boamang-Suko Simple Association (Gaespenu and Associates, 1996). All these soil types can support some form of agriculture ranging from annual crops to cash crops.

2.1.5 Demographic characteristics

The population of the district stood at 124,176 as of the year 2000 (Ghana Statistical Service, 2003) and estimated at 144,272 in 2006. Population of the district continues to increase at a growth rate of 2.5%. Population growth is attributed to the considerable expansion in peri-urban towns in the district. Currently, the district has three sub-urban settlements namely, Ejisu, Juaben, and Besease. These three towns account for 30.2% of the total population in the district with the district capital having 9.2%. The rural settlements are those with their population less than 5,000 and basically their economic activities are agricultural and account for 69.8%.The population growth rate of 2.5% will put pressure on the available natural resources and leading to conversion of agricultural lands into residential uses especially at the peri-urban areas.

2.1.6 Economic situation

Agriculture is the leading employer of the working population employing 68.2% of the people whilst the industrial sector is the least employer of the working population employing 8% of the populace in the district. The service sector also employs 23.8% of the population. The service sector that contributes most to the income (GH ¢56.5 per month) in the district, whiles the agricultural sector is the least (¢45.6 per month) contributor to the economy (Ghana Statistical Service, 2003). Even though most of the people within the district are engaged in agriculture, its contribution to income is very low thus contributing to the low living standards of the people (Ejisu-Juaben District Assembly, 2002).

2.2 Materials

2.2.1 Data

Two (2) multi-date near anniversary, landsat satellite imageries with less than 10% cloud cover- Landsat Thematic Mapper (TM) 1986 and Enhanced Thematic Mapper (ETM+) 2007 (January and February, Level 1 B with path/row 194/55) were acquired for this study. The images were selected from the ITC database based on availability and suitability in terms of seasonal compatibility. The images were used for the classification of land-use/cover types and change detection.

A 1:25000 topographic map (hardcopy), river and road maps were acquired and used in field navigation to pick ground control points for geo-referencing, classification and accuracy assessment. Questionnaires were prepared and administered for willingness-to-pay survey (contingent valuation survey).

2.2.2 Software

ERDAS imagine 9.1; ENVI 4.2; ArcGIS 9.1; SPSS 15.0; KyPlot; and DNR Garmin were the software used in this study. ERDAS imagine 9.1 and ENVI 4.2 were used in the remote sensing image pre-processing, images classification and accuracy assessment. GIS analysis was done in ArcGIS 9.1. SPSS 15.0 and KyPlot software were used for statistical analysis of data. Field coordinates of plots was downloaded using DNR Garmin software.

2.3 Methods

2.3.1 Flow Chart of Methods

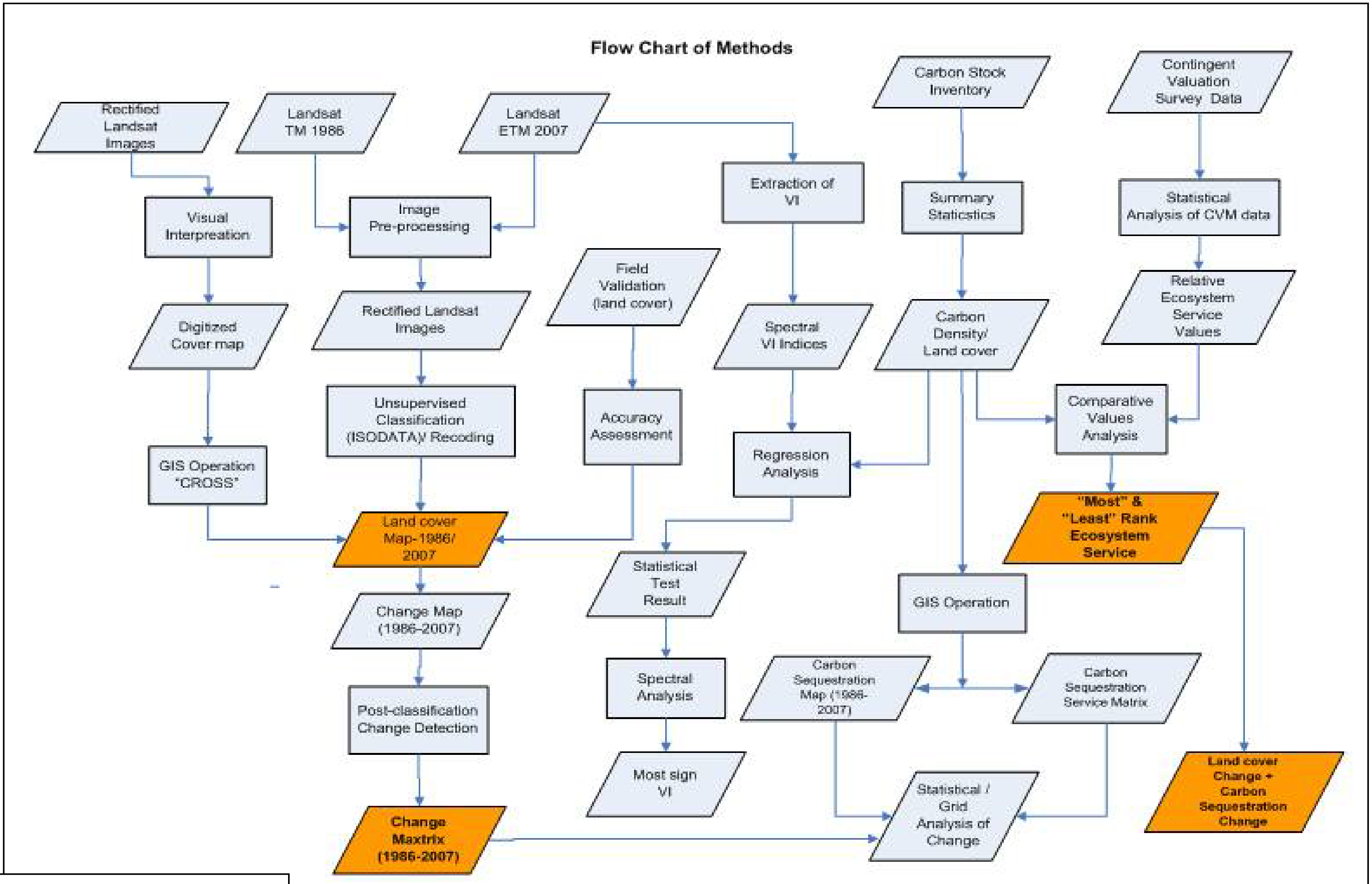

Figure 7: Flow Chart of Method

2.3.2 Image pre-processing

Geometric Correction

Geometric correction procedure is use to register each pixel to real world coordinates. The two (2) images were geometrically corrected to the local coordinate system –Traverse Mercator projection in the Legion datum using ERDAS Imagine 9.1 and ENVI 4.2 versions. The 2007 ETM+ image was georeferenced with forty (40) pairs of well distributed tie points. The tie points were picked at road intersections and river confluence from the road and river digital maps respectively and subsequently co-registered to TM 1986 image using 2nd order polynomial transformation coefficients. Yuan *et al.* (2005) and Attua *et al.* (2001) used 35 and 30 pair of ground control points to georeference landsat TM and Spot images respectively in their respective studies. The forty (40) well distributed points used in this study was purportedly meant to increase the accuracy of the georeferencing.

Root Mean Square Error (RMSE) could be defined as the deviation between ground control points (GCP) and geographic locations as predicted by fitted-polynomial and their actual locations (Shalaby *et al.* 2007). RMSE between the two (2) geo-located images of 0.12 pixel, (equivalent to 3.36m) was recorded and accepted as the positional accuracy of the transformation of this study. This error margin was accepted for the study because it is within 0.5 pixel recommended by Osei (2005). Shalaby *et al.* (2007) and Yuan *et al.* (2005) accepted 0.4 pixel, 0.25 pixel RMSE respectively in their respective studies. It is also instructive to indicate that, different levels of errors were accepted in different studies based on the spatial resolution of the image.

The two (2) landsat images further were resampled to 28.5*28.5m pixel size using the nearest neighbour resampling method to preserve the original image radiometry. Serra *et al.* (2003), Asubonteng (2007) and Yuan *et al.* (2005) used similar resampling methods in their respective studies. The nearest neighbour resampling method assigns the DN value of the closest original pixel to the new pixel without being changed and retaining all spectral information, which makes the resampled image efficient in classification (Kerle *et al.* 2004).

Radiometric Correction

Dealing with multi-date image dataset requires that images obtained by sensors of different times are comparable in terms of radiometric characteristics (Mas, 1998). Radiometric correction techniques such as image enhancement, normalisation, calibration etc are applied to multi-date satellite images in order to increase visual discriminations between features and increase the amount of information to improve interpretability (Bektas *et. al.* 2003). In this study, radiometric correction processes such as haze reduction and band co-linearity analysis were done on the 1986 and 2007 landsat multispectral images to reduce band correlation. The images were further subset to fit the study area using ERDAS IMAGINE 9.1 version.

2.3.3 Image classification

Unsupervised Classification

The major steps of image classification include determination of a suitable classification system which include; selection of training samples, image pre-processing, feature extraction, selection of suitable classification approaches, and accuracy assessment (Lu and Weng, 2005). Land-use/cover mapping could be defined as a process of segmenting images into mosaic of parcels with each parcel assigned to a class (Campbell, 2002). Bektas *et al.* (2003) also stated that the aim of image classification is converting image data to thematic data. Considering the heterogeneity of different land-use/cover types in the study area, of which most are less than the spatial resolution of the image coupled with complex variability in spectral response patterns for individual cover types, unsupervised classification was considered unbiased method to apply (Lillesand and Kiefer, 1994).

Lu and Weng (2005) defined unsupervised classification as clustering-based algorithms used to partition the spectral image into a number of spectral classes based on the statistical information inherent in the image. No prior definitions of the classes are used. The analyst is responsible for merging and labelling the spectral classes into meaningful classes. Attua *et al.* (2001) employed the unsupervised classification method in their work in Ghana because of the difficulties in accurately assigning mixels to its appropriate land-cover class.

Unsupervised classification was performed on the two (2) landsat images using ISODATA algorithms in ERDAS Imagine 9.1 and ENVI 4.2 resulting in fifty-five (55) spectral classes each. This was subsequently recoded into six (6) spectral classes in both the1986 and 2007 images respectively using ground truthing data. "Salt and pepper" appearance in the classified images were smoothen out in the images by applying a 3*3 majority filter (Lillesand and Kiefer, 1994).

Accuracy Assessment

Accuracy assessment was carried out using 156 points purposefully collected from land-use/cover types of the area. The locations of 156 points were chosen using selective sampling method (Nkyi, 2005) in order to ensure adequate representation of different land-use/cover types of the area. Waterlogged and restricted areas were excluded from the sampling because of lack of adequate accessibility. In order to increase the accuracy of land-use/cover mapping of the two images, ancillary data from visual image interpretation were integrated into the initial image classification results using GIS. Visual interpretation of the two images was done using on-screen digitising mode. The resulting polygons of land-use/cover types were raterised in GIS and further incorporated into the classified land cover spectral classes.

Shalaby *et al.* (2007) used 200 points in his studies to assess accuracy of classification because of high variability in vegetation cover in his study area. In addition, he integrated results from visual interpretation of satellite image in the classification and increased accuracy of the classification by 10%.The outcome of the image classification are typologies of land-use/cover types of Ejisu-Juaben District.

2.3.4 Post-classification change detection

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times (Singh, 1989). It involves the use of multi-temporal datasets to discriminate areas of land-use/cover change between dates of imaging. Usually anniversary dates (images taken at almost the same season of the year) are used to minimise sun angle and seasonal differences (Lillesand and Kiefer, 1994).

Post-classification change detection method was used to assess change in the various land-use/cover types over the period of study (1986-2007). This technique was used because it readily provides a change matrix and where different transfers from one land-use/cover types to another can be visually appreciated. Several studies including Sedego (2007), Vasconcelos, *et al.* (2002), Shalaby (2007), and Asubonteng (2007) used post-classification change detection method, which resulted in thematic maps showing transfers between the different images and with a change matrix.

2.3.5 Field data collection

Carbon stock inventory

Carbon stocks for specific carbon pools in different land-use/cover types were measured in 40 field plots of area 498.51m^2 each (Figure 9). The carbon pools considered include; aboveground trees biomass (live or dead wood); necromass – herbaceous plant, litter and; belowground biomass – soil (humus and mineral soils). To avoid double counting, roots of relatively smaller sizes were considered to be part of the humus layer in the soil profile. Carbon stocks in food were excluded from the inventory because of limited time and complexities in its estimation. This is because, cropping systems in the study area is highly variable and thus require detailed inventory of all of them. However, major sources of carbon stocks in agricultural areas were measured from soils, planted or natural trees and occasionally, litter and dead woods that are found on the plot.

Eight (8) plots were selectively established in each land-use/cover type to ensure even distribution of plots among the land-use/cover types. Each sampling site was made of three-nested circular plot of 12.6m, 8m and 4m radii respectively. The purpose of the three nested circular plot design was to ensure highly variable representation of live woody-plants of different ages and also reduce double counting. IPCC (1997) recommend the use of three-nested circular plot design for carbon inventory in tropical ecological conditions where tree-age heterogeneity is dominant. The architecture of the nested circular plot is presented below in figure 8.

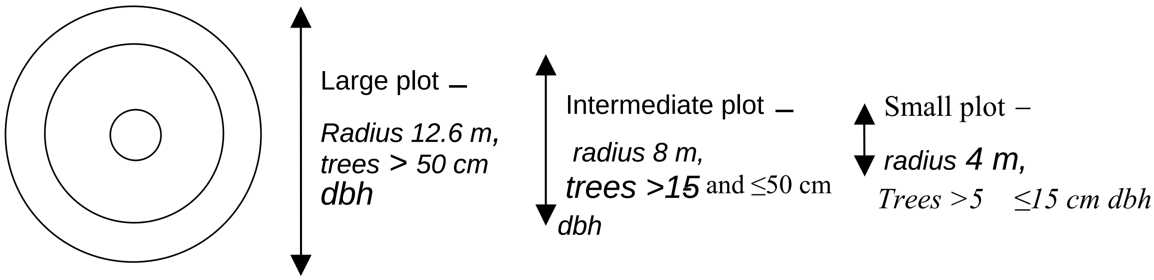

Figure 8: Three (3) nested circular plot sampling design adopted from IPCC, 1997

With the three-nested circular plot sampling design, all trees above 5cm were enumerated and its DBH (Diameter at Breast Height) measured at 1.3m height at each plot location. In the 12.6m radius outer ring plot (large plot), trees of DBH above 50cm were measured. In the intermediate plot – 8m radius, trees of two (2) DBH classes (>15 ≤25 and > 25 ≤50) were enumerated and its DBH measured at 1.3m height. In the small plot, enumeration of trees of DBH >5 and ≤15 were done and DHB measured using the diameter tape. Tree heights (H) of the four most dominant trees species in each sub-ring plot were measured using a clinometer.

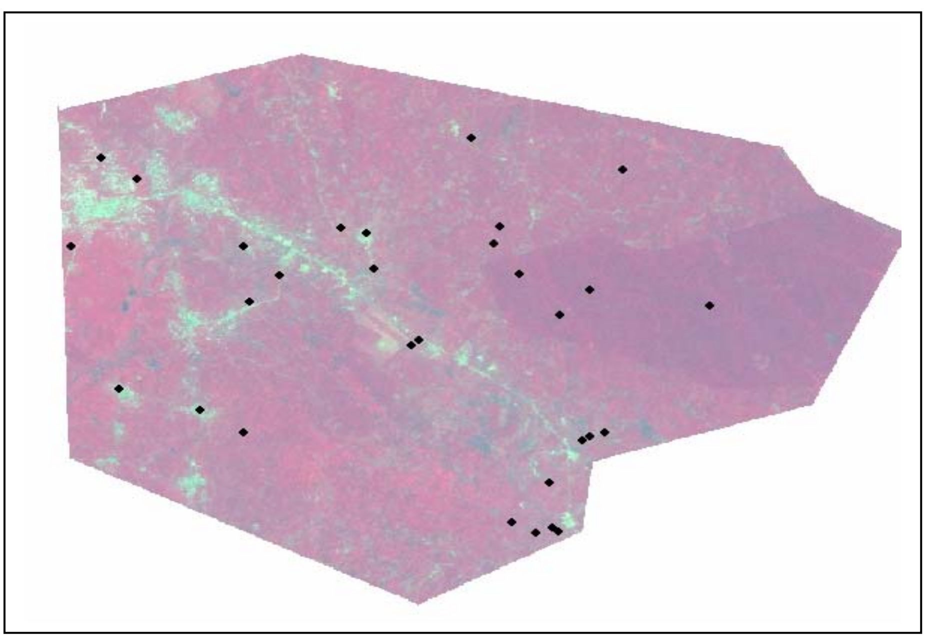

Figure 9: Location of Sampling Plots

In addition, total number of trees, number of trees species and species names were recorded at each plot. Biomass of each enumerated tree was determined using FAO (1997) recommended allometric equations for moist tropical zones (1500-4000mm $^{y-1}$) in Africa:

Aboveground tree biomass (kg tree^{-1}) Y = exp$^{(-2.134 + 2.53 \ln D)}$ (1)
Where Y is the aboveground tree biomass in kg and D is the measured DBH in cm

In order to ascertain results of aboveground tree biomass, other biomass equations developed for specific countries of similar tropical conditions were used to assess the range of uncertainty of estimated biomass. Estimated tree biomass was converted to stocked carbon by a factor of 0.45 recommended by Woomer and Palm (1998) for adjusting tropical woody-plant biomass to carbon.

Approximately, 25m transact walk was taken across the length of each plot location to destructively sample coarse dead wood materials. Herbaceous biomass (plant and litter) was sampled by destructive method using two replicate 30cm x 30cm quadrant. Soil samples were collected in two 30cm deep pits and separated into humus soil (0-15cm) and mineral soil (15-30cm) depth strata. Herbaceous biomass (plants and litter) and soil (0-15cm and 15-30cm) were sampled in 1.4m^2 subplots, dried and weighed in the laboratory and the carbon content determined. Geographic coordinates of the centre of the sampling plot, elevation (m) and plot ID was also recorded (field sampling sheet attached as appendix 1). Dry bulk density of <2mm soil fraction was measured using core method, which similar to the method employed by (Morisada *et al.,* 2004).

2.3.6 Laboratory analysis of organic carbon content in soils and non-woody plants

Analysis of soil samples

Organic carbon in each soil sample (humus 0-15cm and mineral 15-30cm) was determined using the procedure by Walkley – Black (1934). It involves wet combustion of soil specimens with a mixture of Potassium Dichromate. The soil samples were air-dried and sieved through a 2mm sieve. One gram sub-sample was weighed into a 500ml Erlenmeyer flask and 10ml of 1N Potassium Dichromate (K_2CrO_7) added. This was followed by the addition of 20ml 96% concentrated sulphuric acid and the flask shaken for one (1) minute and allowed to stand for 30 minutes to cool. Two hundred millilitre (200ml) distilled water was added followed by 10ml orthophosphoric acid (to aid sharp end-point determination). The solution was titrated against 1N Ferrous Sulphate using 1ml of

Barium diphenyl amine sulphonic acid as indicator until a colour change from purple to green was observed. Another 0.5ml potassium dichromate was added and titrated until a green colour was achieved. A blank titration was done in the same manner without the soil samples in order to standardise the potassium dichromate solution. The percentage organic carbon was calculated using the equation (2) below:

% organic carbon = (Blank x T_1) – (10.50 x T_2) x 3 x 100 (2)

= 0.77 x 100 x Blank x g Soil

Where:

- T_1 – Titer of ferrous sulphate used for Blank
- T_2 – Titer of ferrous sulphate used for soil samples
- 10.5 – Vol. of 1N potassium dichromate used for titration

Soil organic carbon density (SOC_d) (kg/m^2) refers to the soil organic carbon storage at a depth of each soil layer per unit area. For individual profile with the layers, total organic carbon by volume (SOC, C kg/m^2) was calculated using an equation adopted from (Morisada et al., 2004) below:

$$SOCd = \sum_{i=1}^{k} OCi \times BD \times Di \times (1 - Si) \qquad (3)$$

Where SOC_d is the total amount of organic carbon (C kg m^{-2}) above depth *d,* BD_i (Mg m^{-3}) is the dry bulk density of the layer *i,* OC_i is the concentration of organic carbon (C%) in layer, D*i* is the thickness of the layer in the profile and S_i is the volume of fragments > 2mm.

Analysis of Non-woody Plants

Non-woody plant specimens include; dead materials, herbaceous plant, litter, and debris. Samples were oven dried at $80^{O}C$ and milled. Sub-samples of each non-wood plant samples were taken and further dried to $100^{O}C$ to remove all traces of moisture. A gram of each sample was then weighed into a weighed crucible and later placed in muffle furnace and allowed temperature to rise to $450^{O}C$ gradually. The samples were then left at the $450^{O}C$ optimal temperature for four (4) hours. After cooling, samples were removed and the weight of the ashed component recorded using the equations below:

$$\%Ash = \frac{Ashwt}{Samplewt(ovendry)} \times 100 \tag{4}$$

$$\%O.M = 100\% - \%Ash \tag{5}$$

$$\%OC = \frac{O.M}{2} \tag{6}$$

2.3.7 Aggregation and up-scaling of total sequestered carbon

Net carbon stock for each plot was determined by the sum of C stocks calculated for specific pool such as trees, soils, litter and herbaceous plant. Carbon for each land-use/cover type was obtained by the average of C stocks for the common eight plots in each land-use/cover type. Total sequestered carbon (Gg) for each land-use/cover type was determined by the multiplication of the area (ha) of each land-use/cover type by mean C per unit land-cover.

This was used for up-scaling of total sequestered carbon of the entire study area for the two temporal periods (1986 and 2007). Variability in C fluxes between 1986 and 2007 among specific land-use/cover types was considered critical to the analysis of carbon dynamics over time but such data is lacking in Ghana. Therefore, C fluxes variability over the two temporal periods was considered indifferent.

2.3.8 Grid-based analysis of sequestered carbon

Grid-based analysis of sequestered carbon was done in GIS environment. Using interval-method, carbon index of each land-use/cover type was calculated for 1986 and 2007. Averages for the C index between 1986 and 2007 were subsequently obtained, adding up to one. With this index, each raster was spatially assigned a carbon density index depending on land-use/cover type in GIS with 500m grid size. Using the Raster Calculator in ArcGIS, six (6) ratsers, with each containing the value 1 for the pixels that fall into a certain land-use/cover category, and a 0 everywhere else was extracted for years 1986 and 2007. To obtain carbon index for each extracted pixel (Table 1), a multiplication of the land-use/cover selection raster with the individual carbon index was done. The sums of all the individual land-use/cover layers yield the carbon sequestration map.

Table 1: Carbon Density Index (1986-2007)

Carbon density Index			
	Years		
Land-use/Cover	1986	2007	Averages
Forest	0.49	0.35	0.42
Bushfallow	0.19	0.23	0.21
Agriculture	0.15	0.23	0.19
Bamboo/Raffia	0.12	0.09	0.10
Grass	0.05	0.10	0.07
Built-up/Bare	0	0	0

2.3.9 Spectral relationship between Spatially-explicit sequestered C and vegetation indices

Vegetation indices generally depend on forest biomass and the surface area of the green vegetation. However, their reflective signature can be affected by the reflection from the soil surface (Magarura, 2007). NDVI, EVI and SR largely show strength of vegetation greenness, whereas SAVI, MSAVI and OPSAVI incorporate soil correction factor and it is necessary because of large soil exposure in the study area. This actually balances out the relative soil effect while accounting for the amount of vegetation biomass. The contribution of vegetation and soil carbon pools to sequester carbon apparently establishes spectral synergy between the spectral bands. Brief explanation of the vegetation indices are below:

Normalised difference vegetation index (NDVI)

This index explores the difference between absorption of radiation in the red spectral wavelength and the maximum reflection of radiation in the near-infrared (NIR) spectral wavelength (Rouse et al., 1974)

$$NDVI = \frac{NIR - R}{NIR + R} \qquad (7)$$

Simple ratio (SR)

It is calculated as the ratio between NIR and R spectral bands (Jordan, 1969). It has the advantage of minimising shadow effects especially in mountainous areas (Boschetti *et al.* 2007).

$$SR = \frac{NIR}{R} \tag{8}$$

Enhanced vegetation index (EVI)

EVI was proposed by Huete *et al. (*2002) cited in (Nakaji, 2008) as an improvement of NDVI, whose weak point is that it saturates at high biomass and can be an index of folia biomass.

$$EVI = 2.5 * \frac{NIR - R}{NIR + 6 * R - 7.5 * (B + 1)} \tag{9}$$

Soil-adjusted vegetation index (SAVI)

This index incorporate soil adjustment factor and ranges from 0 for very high vegetation cover to 1 for very low vegetation cover cited by (Magura, 2007). A value of L=0.5 was used in this study similar to (Magura, 2007) because it permits the best adjustment by minimising back-scattering effect of canopy-transmitted soil background reflected radiation (Huete, 1988).

$$SAVI = \frac{(1 + L) * (NIR - R)}{(NIR + R + L)} \tag{10}$$

Modified soil-adjusted vegetation index (MSAVI)

SAVI was improved by Qi *et al.* (1994) and subsequently became modified soil adjusted vegetation index (MSAVI). As indicated in (Magura, 2007), this index minimises further effects of soil in places where forest cover has low density, since this could erroneously indicate dense vegetation. This is because soil reflectance increases in both red and infrared channels.

$$MSAVI = \frac{2NIR + 1 - \sqrt{(2NIR + 1)2 - 8(NIR - R)}}{2} \tag{11}$$

Rondeaux *et al.,* (1996) cited in Magura (2007) used optimised soil-adjusted vegetation index (OPSAVI) which, to some extent differ from SAVI because it uses different soil correction factor for achieving better distinction between soil and vegetation.

$$OPSAVI = 1.16 \frac{NIR - R}{NIR + R + 0.16} \qquad (12)$$

Using ENVI 4.2 version, spectral signatures of each plot from the 2007 landsat images was extracted and vegetation indices such as NDVI, SR, EVI SAVI, MSAVI and OPSAVI calculated based on the respective formulae as the independent variables. Total sequestered C for each plot was determined and used as dependent variable.

Normality test for measured C was done using histogram normality curves and normalisation done using log transformation. Parametric linear correlation coefficient, which assumes normality of the data, was done to test strength and direction of the relationship between C (dependant variable) and the vegetation indices (independent variables).

Statistical regression model was fitted for non-soil corrected and soil indices respectively. In order to fit a statistical model to the measured C and the selected vegetation indices, scatter plot was down to visualise the existence of any relationship between the dependent variable (C stocks) and the independent variable (selected vegetation indices). Linear was used to fit the models.

2.3.10 Contingent valuation method (CVM) survey

The CVM has been commonly used as one of the standard and flexible approaches to measure the economic values (Hanemann, 1994). The method uses questionnaire-based approach to estimate socio-economic value of use-ecosystem services (Hanemann *et al.* 1991 and Venkatachalam, 2003) and ecological value of non-use-ecosystem services (Pearce & Moran, 1994). In this study, contingent valuation method (CVM) was employed to estimate non-market value for selected ecosystem service. It is also important to indicate that in this study, CVM is interchangeably used with Willingness-To-Pay (WTP), whereas, ecosystem services and goods are hereinafter referred to as “services”

Multi-stage sampling design was applied in selecting communities for the WTP interviews. Out of the total 22 communities in the study area, six (6) of them were randomly selected at the higher tier of the sampling process. The communities were; Boamadumase, Atia, Adokrom, Yeboah, Ampabame and Deduako no.1. At the community level, respondents such as farmers, hunters, palm-wine tappers were stratified into groups based on their common interest in ecosystem services use and further randomly sampled. This sampling design was adopted and applied because from a social equity perspective, ecosystem services values should be evaluated in manner that involves the fair treatment of competing social groups (Wilson, 2002). Fifty-five respondents were interviewed.

Willingness-to-Pay (WTP) elicitation format and survey structure

Open-ended contingent-valuation elicitation method was used to administer questionnaire on willingness-to-pay (WTP) from respondents in six communities. Draft WTP survey was pre-tested in Boamadumase and Deduako no.1 communities before the final survey was conducted. The WTP elicitation format consisted of an open-ended (OE) questions for obtaining maximum WTP through pebble-bidding game.

The survey sought to use willingness-to-pay (WTP) as an indicator of surrogate values respondent attach to specific ecosystem services of interest. The questionnaire composed non-WTP and WTP questions. Non-WTP questions included; demography, environmental perceptions/attitude, and background information, whiles WTP questions included; elicitation scenario description through visual aids, pebble-bidding game, and payment arrangement (appendix 2). The elicitation scenario was shown to respondents during the interviews followed up by WTP order of questions (Box 1).

The sequence of elicitation of values from respondents followed the use of land-use/cover conversion scenario between 1896 and 2007 as the basis for assigning monetary values to the “least” and “most” ranked ecosystem services. Monetary values for the two “services” were arrived at after respondents had been presented with the elicitation scenario and gone through the order of questions leading to the use of pebble-bidding game for negotiation of their maximum WTP. Focus group discussions were done to validate preliminary results from the household interviews.

Box 1: Willingness-to-pay elicitation scenario

Two classified satellite images were presented to respondents showing trends of land-use/cover conversion between 1986 and 2007

Scenario A : If current trend of land-use/cover conversion continues

Scenario B : If current trends of land-use/cover conversion is halted or managed and a hypothetical conservation project put in place

Data quality assurance and data analysis

Two major rationales were used to justify excluding responses from the WTP questionnaire administration results. First, survey results were rejected especially during the analysis of WTP values if the indicated WTP was unrealistically large, whereby the value for the ratio of WTP to income exceeded 2% compared to 5% ratio used by (FAO Information Division, 2002) and (Ojeda *et al.,* 2007).

Second, survey responses were generally excluded when the interviewer lacked confidence in the sincerity of the respondent's answers (Hadker *et al.* 1997). Valid "protest-zero" (i.e. respondents reject commitment to WTP) responses were excluded from the WTP calculation and respondents asked to explained their choice. An exchange rate of GH ¢ 0.95 to US $ 1 was used in the calculation of maximum WTP using the generic equation below adopted from (Ojeda *et al.* 2007).

$$WTP = \frac{1}{N}\sum_{i=1}^{N} XiYi \qquad (12)$$

Where N is the total number responses (N=50), X*i* is the bid level and Y*i* is the number of "yes" responses of WTP to that bid level. Multiple regression analysis between three independent variables namely; income levels, level of education and occupation and maximum WTP bid was explored to assess the statistical significant between them.

3. Results

3.1 Land-use/cover types between 1986 and 2007 and their ecosystem services

3.1.1 Land-use/cover classification

The unsupervised classification produced two land-use/cover maps from both TM1986 and ETM+ 2007 landsat images of the study area. The classification categorised the area into six (6) main land-use/cover types as elaborated in Table 2 below. The classified land-use/cover maps of the Ejisu-Juaben District are shown in figures 10 and 11 respectively.

Table 2: Description of the main land-use/cover types in the study area

Land-use/cover Type	Description
Forest	Includes the moist semi-deciduous forest. (Bobiri reserve) and other areas high tree cover density (both open and closed canopy) reaching above 15m.
Bushfallow	Areas which have been logged or farmed in the past and now left to recover. It is made up of thickets of shrubs and tree ranging from 2m to about 15m.
Agriculture	Consist of land put under any form of cultivation such as annual cropping, cocoa and oil palm plantations.
Bamboo-raffia	Predominantly *Bambusa vulgaris* and raffia palm mixture usually found along water ways and marshy areas. Such areas harbour non-tree vegetation like ferns and water cocoyam.
Grass	Includes all forms of grasses, ranging from creeping species up to tall elephant grass with sparsely distributed trees.
Build-up/bare	Areas with high intensity of infrastructure and land areas of exposed soil surface resulting from human activities or natural causes.

Adopted and Modified from Asubonteng, (2007)

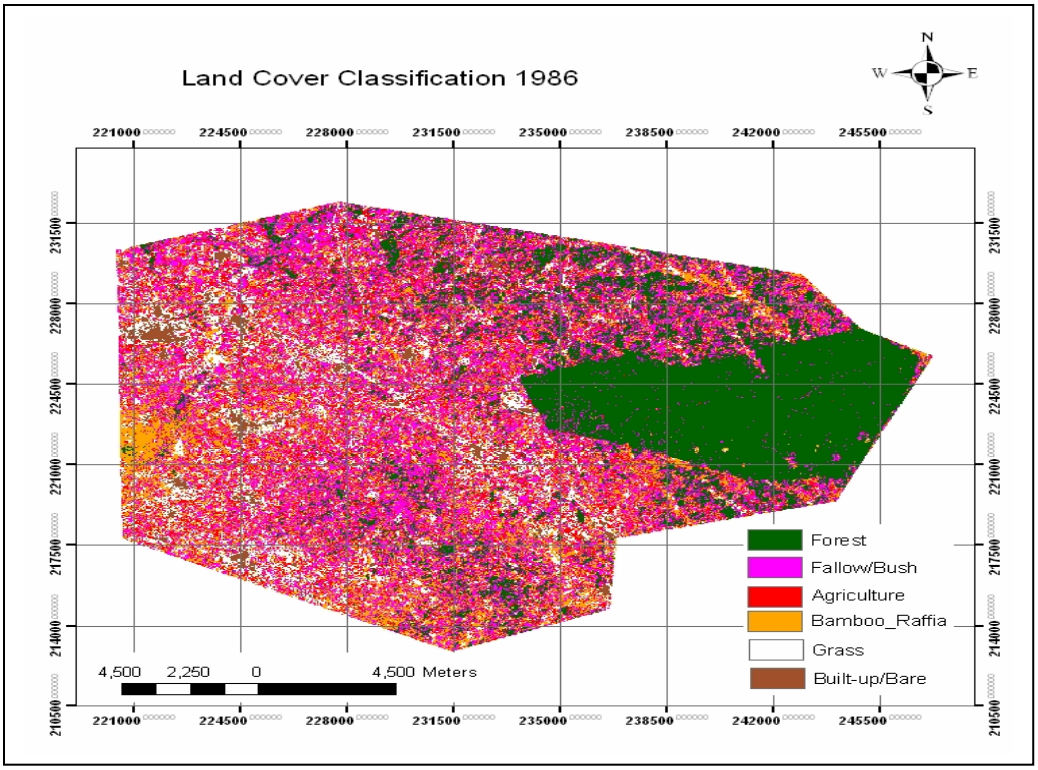

Figure 10: Land-use/cover map of portions of Ejisu-Juaben District in 1986

According to the 1986 land-use/cover thematic map (Figure 10), forest are predominantly found at the north-eastern portion of the study area where human activities are relatively less intense, whilst bushfallow occurs as patches across the landscape. Grass is common in western part and around towns and frequently associated with built-up/bare areas, while agriculture like bushfallow is scattered across the landscape but not in the east. Bamboo-raffia restricted to marshy areas and along river courses.

The 2007 land-use/cover map (Figure 11) showed forest mainly in the north-eastern portion of the study area, where Bobiri Forest Reserve appears as a large homogenous patch. Agriculture and bushfallow spread across the entire landscape except the middle and some southern portions that have been taken over by grassland. Build-up/bare is predominant in the north-western corner. Bamboo-raffia exists as strips along waterways.

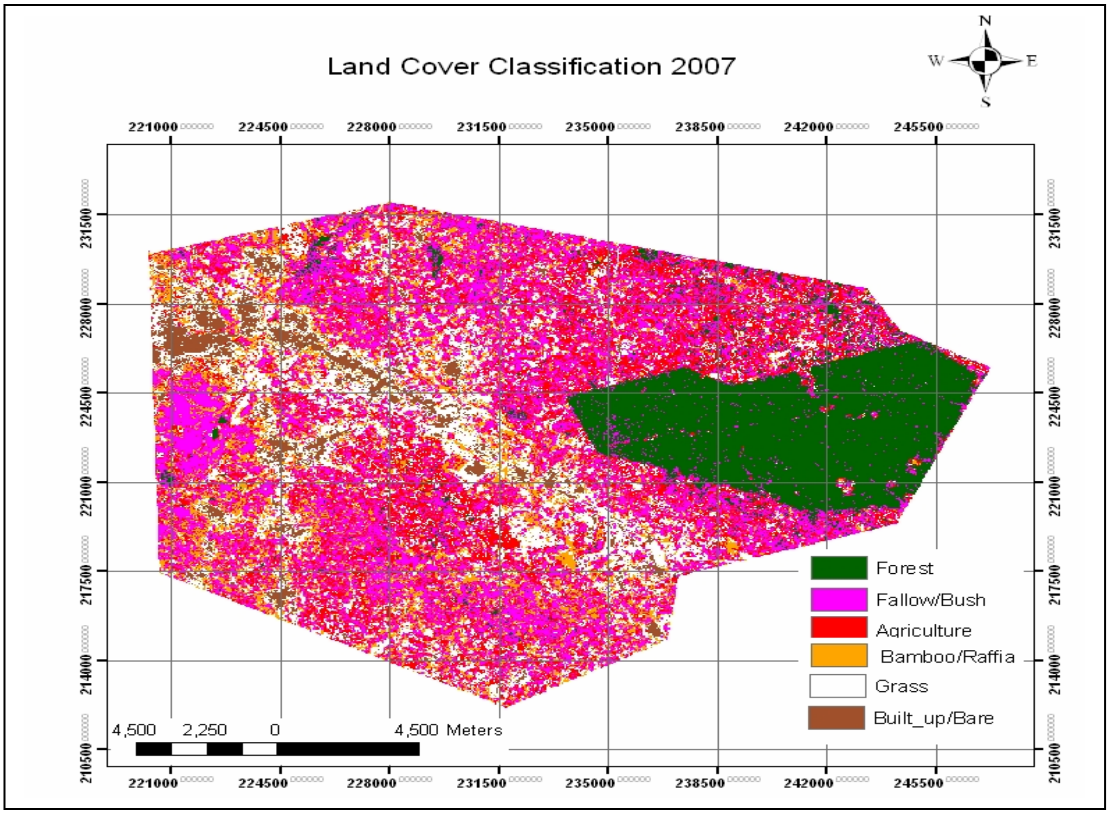

Figure 11: Classified land-use/cover map of portions of Ejisu-Juaben District in 2007

Table 3 revealed that forest, bushfallow and bamboo/raffia formed the major land-use/cover occupying 25.9%, 26.0% and 18.6% of the area respectively in 1986. It is followed by agriculture (15.7%), grass (10.9%), and lastly build-up/bare (2.9%). In 2007, the area experienced considerable change in land-use/cover as shown in table 3. Bushfallow, agriculture, and grass formed the major land-use/cover occupying 28.3%, 20.7% and 17.8% of the area, respectively. Forest, bamboo/raffia and build-up/bare accounted for 16.3%, 12.9% and 4.3% respectively (Figure. 12).

Table 3: Land-use/cover change matrix

	1986		2007		Difference	
Land Cover Class	(ha)	%	(ha)	%	ha	%
Forest	9432.3	25.9	5938.8	16.32	-3493.6	-37.0
Bushfallow	9467.1	26.0	10296.3	28.30	829.2	8.8
Agric	5709.5	15.7	7514.0	20.65	1804.4	31.6
Bamboo/Raffia	6764.0	18.6	4614.8	12.68	-2149.2	-31.8
Grass	3970.7	10.9	6458.4	17.75	2487.7	62.7
Built-up/Bare	1037.9	2.9	1559.4	4.29	521.5	50.2
Total Area	36381.6	100.0	36381.6	100		

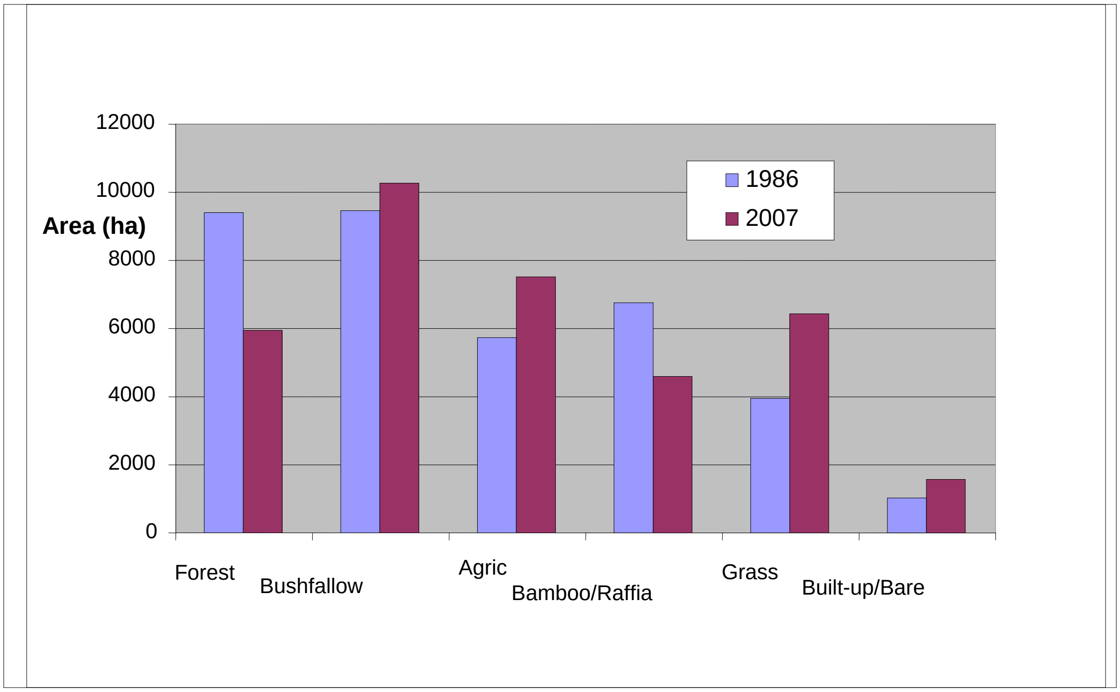

Figure 12: Changes in land-use/cover types in 1986 and 2007

3.1.2 Classification accuracy assessment

The accuracy of the classified ETM+ 2007 image was assessed using 156 reference points to obtain error matrix and kappa statistics of 75.2% and 0.73 respectively. The integrating of the classified images with ancillary GIS data (visual interpretation data) increased the accuracy of the classification to 86% and a kappa of 0.85 (appendix 3). However, accuracy of the TM 1986 image could not be statistically assessed but was ascertained with the use of local knowledge and validated with information on "no change areas" in the ETM+ 2007 and TM, 1986 images."

3.1.3 Land-use/cover change (1986-2007)

Comparison of 1986 and 2007 land-use/cover maps (Figure 10 and Figure 11) showed different levels of change in the cover types due to conversions between land-use/cover types. Figure 13 indicates the extent of change among land-use/cover types. Generally, all the six (6) land-use/cover types experienced change in size from 1986 to 2007.

Table 3 shows that forest and bamboo-raffia decreased in size whereas build-up/bare, agriculture, and bushfallow and grass increased over the 21 years. Forest and grass experienced the most negative and positive changes respectively. Whiles forest lost a substantial area of 3493.6 ha, which is about 37% of the previous extent of forest, grass increased by gaining 2487.7 ha representing 62.7% of the existing grass cover in1986. A total of 2149.2 ha of bamboo-raffia were lost accounting for 18.6% and 12.7% of the entire area in 1986 and 2007 respectively. Agricultural area increased from 5709.5 ha in 1986 to 7514 ha in 2007. Bushfallow areas increased by 828.2 ha from 9467.1 ha in 1986 to 10296.3 ha in 2007. Build-up/bare increased from 1037.9 ha in 1986 to 1559.4 ha in 2007.

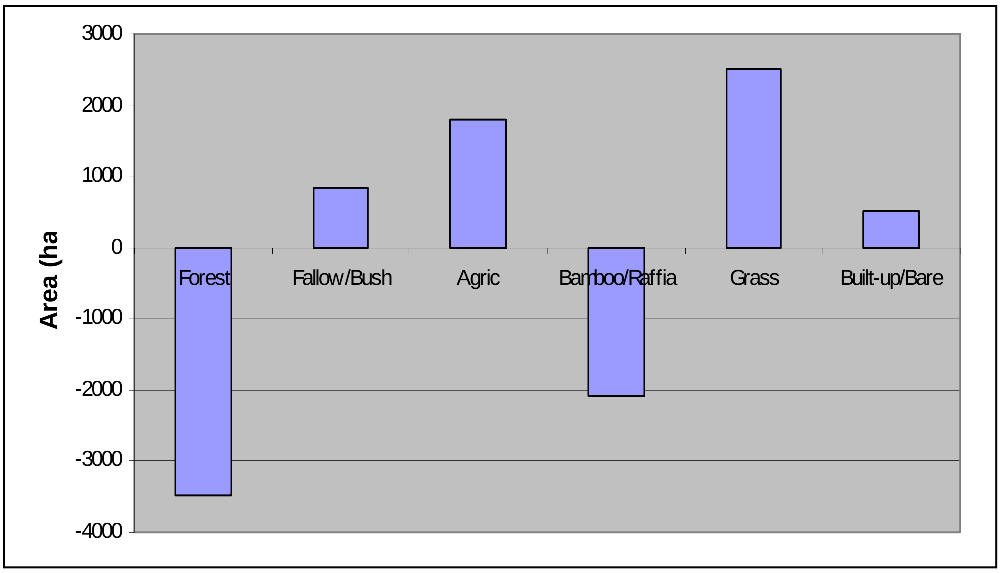

Figure 13: Land-use/cover changes matrix from 1986 to 2007

The diagonal of table 4 shows proportions of the landscape that remained unchanged and forms 35.9% of the total area. A total of 1697ha of forest were transferred to bushfallow during the study period. Considerable area under bushfallow (2257 ha) were transferred to cultivated lands; however, 33.2% of the previous bushfallow areas in 1986 remained unchanged as at 2007 and 474 ha were allowed to fallow to attain forest status. With agricultural areas, 1293ha remained under cultivation in 2007, 1043ha were converted to grass, and whiles 1794 are under bushfallow. Also 15.5% (1009 ha) bamboo-raffia areas remained undisturbed, whilst 34.2% and 23% were transferred to bushfallow and agricultural areas respectively in 2007.

Table 4: Land-use/cover conversion matrix

Land cover types	Forest	Bushfallow	Agriculture	Bamboo/Raffia	Grass	Built-Bare	Total Area, 1986
Forest	**4949.4**	1697.6	1355.0	422.7	649.4	52.3	9126.4
Bushfallow	474.0	**2996.6**	2256.9	1292.2	1739.4	320.7	9079.7
Agriculture	-	1794.7	**1293.0**	1116.1	1043.0	278.0	5524.7
Bamboo/Raffia	-	2221.0	1497.1	**1009.6**	1289.8	484.8	6502.4
Grass	-	1035.1	735.6	680.8	**1003.2**	430.2	3885.0
Built-up/Bare	-	-	134.7	-	307.1	**1821.6**	2263.4
Total Area, 2007	5423.4	9745.0	7272.3	4521.4	6031.8	3387.6	**36381.5**

3.1.4 Identification of harvestable and non-harvestable ecosystem services

Results from five (5) respondents were excluded from the WTP analysis based on the criteria set under quality assurance. This reduced the total sample to fifty (50) for further analysis.

Demographic characteristics of respondents

Males constituted 74% of the respondents with the remaining 26% being females. In terms of levels of education, 33% are literates (respondents have had at least 10 years of formal education), 29% are illiterates (respondents with no formal education), 13% have had six (6) years of primary education, and whiles 21% have had post-secondary education. 32.4% of the male respondents are illiterates compared to 30.7% of females. Twenty nine (29) of the fifty (50) respondents are farmers, of which nineteen (19) are male and ten (10) being females. Ten (10) are teachers; whiles six (6) are herbalist and hunter five (5) respectively (Table 5).

Table 5: Demography of respondents

Age Class	Gender	Occupation of respondent: Farmer	Hunter	Teacher	Herbalist	Total
0-25	Male	6				6
	Male	1	2	3		6
25-35	Female	5	0	1		6
	Male	2	2	2	1	7
35-50	Female	2	0	1	1	4
	Male	10	1	3	4	18
Above 50	Female	3	0	0	0	3

Gender	Level of Education: Illiterate	Primary	Literate(MSLC, JSS)	Secondary	Tertiary
Male	12	4	11	2	8
Female	4	2	5	0	2

Identification of harvestable ecosystem services

Five (5) major harvestable ecosystem “services” were identified by respondents and are obtainable from five (5) main land-use/cover types namely; forest, bushfallow, grass, agricultural and bamboo-raffia areas. The “services” include; fuel wood (FW), food (FD), bush meat (MP), medicinal plants (MP) and palm-wine (PW); (Table 6).

Table 6: Harvestable ecosystem services identified by respondents in the study area

Ecosystem services items collected		
Harvestable “services”	Frequency	Percent (%)
BM[1], FD	3	6
BM, FW, FD,	4	8
FD[2]	5	10
FD, MP	8	16
FW[3], FD	10	20
FW, FD, PW[5], BM, MP	1	2
MP[4]	3	6
MP, FD, BM	3	6
MP, FW, BM, FD	6	12
MP, FW, FD	7	14

[1] Bush meat; [2]Food; [3] Fuelwood; [4] Medicinal Plants [5] Palm wine

Food (FD) and fuel wood (FW) were the most patronised ecosystem services by respondents. They accounted for 20% of the total harvestable “services" (Table 6) identified by respondents. This is followed by collection of food (FD) and medicinal plants (MP) – 16%. About 62% of the harvestable ecosystem “services” identified by respondents are obtainable from agricultural lands, followed by forest (16%), bamboo-raffia (12%) and grassland (10%) in that order. Table 7 shows that 86% of the respondents travel maximum of 10km to collect the ecosystem items identified above as compared to 14% that travel distance more than 10km.

Table 7: Factors that affect collection of harvestable ecosystem services

Factors that affect collection of ecosystem “Services”		
Ecosystem Service Collection Points	Frequency	Percent
Forest	8	16
Agricultural	31	62
Grass	5	10
Bamboo/Raffia	6	12
Distance traveled to collect items from home		
1-10km	43	86
10-20km	7	14

Identification of non-harvestable services

Respondents identified six (6) non-harvestable ecosystem services provided by forest, grass, fallow-bush, bamboo-raffia and agricultural cover types. The six (6) services are: shade (SD); soil protection (SP); climate regulation (CL); carbon sequestration (CS); habitat (Hb); and catchment protection (CP). Respondents defined the “services” as presented in table 8:

Table 8: Definition of non-harvestable services by respondents

Ecosystem Services	Definition
Shade (SD)	Provision of shade (relatively favorable temperature) necessary for plant growth and human habitation.
Soil Protection (SP)	Maintenance of arable lands; Prevention of damage from erosion
Climate Regulation (CL)	Maintenance of favorable climate – precipitation, wind, temperature
Carbon Sequestration (CS)	Net gas exchange (source-sink balance) through photosynthesis
Habitat (Hb)	Providing suitable living space for wild plants and animals
Catchment Protection (CP).	Flood prevention, controls hyper transpiration

Table 9 shows that "climate regulation and soil protection" (18%) was the most identified "services" and followed by climate regulation only (16%), "shade and soil protection" (14%) in that order and lastly, carbon sequestration (4%).

Table 9: Non-harvestable ecosystem services

Non-harvestable ecosystem services		
Ecosystem services	Frequency	%
CS[1]	2	4
CL[2]	8	16
CL, CP[4]	4	8
CL, SP	9	18
CL, SP,CS	2	4
SD[3]	4	8
SD, CL, CP	2	4
SD, CL, SP	4	8
SD, SP	7	14
SP	2	4
SP, CL, SD	3	6
SP, CS, CL, Hb[5]	3	6

[1] Carbon Sequestration [2]Climate Regulation [3]shade [4] Catchment Protection [5]Habitat

3.2 Carbon stocks budget in various ecological components for different land-use/cover types

3.2.1 Distribution of sequestered carbon in different land-use/cover types

An estimated mean of 160.9± 8 Mg/ha C was recorded in this study area. Carbon in different land-use/cover types ranges from 335 ± 3 Mg/ha C in forest to 81.3 ± 5 Mg/ha C in grass. Agriculture, bushfallow and bamboo/raffia areas recorded 171.2 ± 6 Mg/ha, 122.2 ± 9 Mg/ha and 110.4 ±1 Mg/ha carbon respectively (Table 10).

Table 10: Land-use/cover allocation of mean sequestered carbon

	Allocation of carbon sequestered (Mg/ha)				
	BGB* (Soil)		AGB^	Necromass	% Total Sequestered Carbon
Land Cover Types	0-15cm	15-30cm	Live + Dead Trees	Litter + Herbaceous	
Forest	74.91	29.14	231.03	3.44	40.08
Fallow/Bush	58.76	26.09	42.88	3.42	15.53
Agriculture	60.02	23.43	90.55	3.18	20.98
Grass	56.44	19.85	6.32	3.69	10.22
Raffia/Bamboo	76.02	28.82	2.68	3.88	13.19

** Belowground Biomass ^ Aboveground Biomass*

In the forest areas, 68.2% of C is stored in woody-plant biomass compared to 30.7% of C in soils. Apart from the forest areas, aboveground carbon stocks in agricultural areas are also higher (51.1%) than C in Soils (47.1%). However, carbon storage in the remaining land-use/cover types (i.e. bushfallow, grass and bamboo/raffia) is relatively higher in soils (64.7%, 88.4% and 94.1% respectively) than woody-vegetation (32.3%, 7.3% and 2.4% respectively). Carbon stocks in non-woody vegetation pools in all the land-use/cover types ranged from 1% in forest areas to 4.3% in grass (Figure. 14).

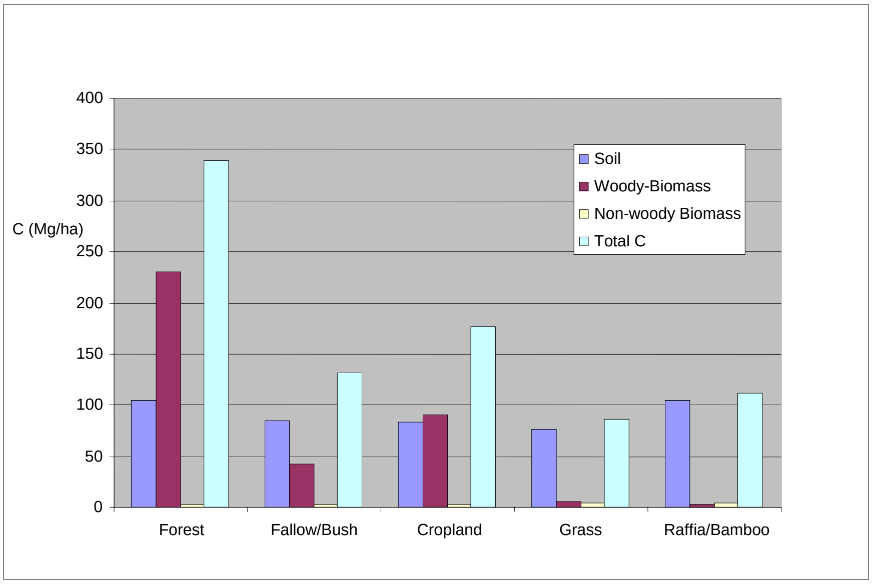

Figure 14: Distribution of C share among carbon pools in different land-use/cover types

Mean aboveground biomass carbon in forest is significantly higher at 201 ± 30 Mg/ha C compared to the other land-use/cover types. Carbon in woody-plant vegetation in agricultural areas are moderately high (85.6 ± 6 Mg/ha C) compared to a relatively lower net carbon stocks in bushfallow areas (40.9 ± 2 Mg/ha C). Woody-vegetation in grass and bamboo/raffia areas recorded comparatively low carbon of 5.3 ± 1Mg/ha C and 2.1 ± 0.67 Mg/ha C respectively.

From table 10, mean soil carbon concentration at 30-cm depth in different land-use/cover types ranges from 76.3 Mg/ha in grass to maximum of 104.8 Mg/ha C in bamboo/raffia areas. Soil carbon in forest is close to that of bamboo/raffia (104.1 Mg/ha) compared to bushfallow (84.9 Mg/ha) and agriculture (83.5%). Generally, soil carbon decreased with increasing depth. Variations in non-woody vegetation (necromass) carbon storage among land-use/cover are not significant. It ranges from a highest of 3.9 Mg/ha in bamboo/raffia to the lowest of 3.2 Mg/ha in agricultural areas.

3.3 Changes in land–use/cover types and carbon sequestration

3.3.1 Total carbon sequestration with land-use/cover types

In 1986, a total of 6562.8 Gg C was sequestered in the study area as compared 5777.5 Gg C in 2007 (Table 11). Forest areas recorded the highest carbon storage of 3193 Gg C and 2010.4 Gg C in 1986 and 2007 respectively, representing 48.7% and 34.8% of the total ecosystem carbon. This is followed by bushfallow, which stored about 1241.70 Gg C (18.9% of total carbon) and 1350.5 Gg C (23.4% of total carbon) in 1986 and 2007 respectively.

Carbon pools in agricultural areas also sequestered 11011.6 Gg C (15.4% of total carbon) and 1331.3 Gg C (23% of total carbon) in years 1986 and 2007 accordingly. Also 11.8% and 9.1% of the total ecosystem carbon in 1986 and 2007 respectively are stored in bamboo/raffia areas with lowest of 342.7 Gg C in 1986 and 557 Gg in 2007 in grass areas (Table 11 below).

Table 11: Total Carbon Allocation per Land-Use /Cover Type (1986-2007)

Total Carbon Per Cover Type							
	Area(ha)		Per unit	Gg		%	
Class name	1986	2007	TC (Gg/ha)	1986	2007	1986	2007
Forest	9432.33	5938.77	0.34	3193.03	2010.39	48.65	34.80
Bushfallow	9467.10	10296.34	0.13	1241.70	1350.47	18.92	23.38
Agriculture	5709.55	7513.96	0.18	1011.56	1331.25	15.41	23.04
Bamboo/Raffia	6764.04	4614.80	0.11	773.81	527.93	11.79	9.14
Grass	3970.69	6458.36	0.09	342.67	557.36	5.22	9.65
Built-up/Bare	1037.89	1559.41	-	-	-	-	-
Total study area	36381.61	36381.65		6562.78	5777.40	100	100

3.3.2 Grid-based analysis of total carbon sequestration in land-use/cover types

The grid-based analysis in figure 15 revealed that more areas to the eastern part of the study area, where forest is relatively least disturbed sequestered more carbon in both 1986 and 2007. However, the white dotted grids are areas under built-up/bare, and carbon uptake is considered insignificant. The high carbon sequestered (green grids) are more dominant in 1986 than in 2007 (Figure 15)

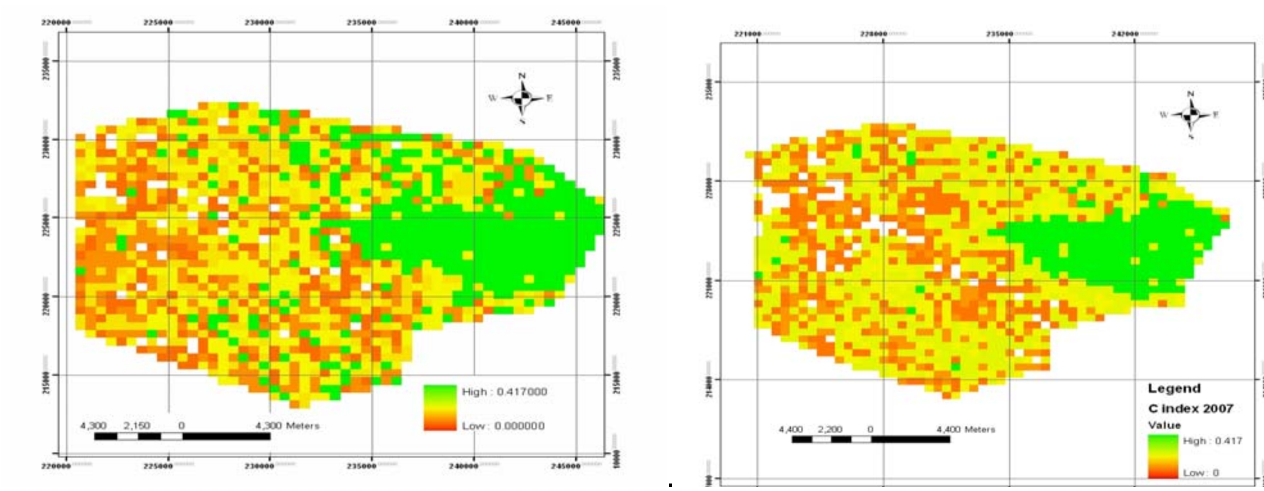

Figure 15: Distribution of sequestered carbon in 1986 and 2007

3.3.3 Changes in carbon sequestration

An average of 785.4 Gg of C (equivalent to 37.4 Gg C yr^{-1}) was loss between 1986 and 2007 due to changes in land-use/cover types. The study area is, however, considered as a net source of Carbon. From table 12, forest and bamboo/raffia are considered key carbon emission sources compared to fallow/bush, agric and grass, which served as emission reduction sinks between 1986 and 2007. Forest had the highest loss of 1182.6 Gg C (56.3 Gg C yr^{-1}) followed by bamboo/raffia with 245.9 Gg C (equivalent to 11.7 Gg C yr^{-1}) emissions. In 2007, agricultural areas sequestered 319.7 Gg C more relative to 1986. Similarly, grass and bushfallow areas in 2007 sunk more C than in 1986 - i.e. 214.7Gg C and 108.7Gg C respectively (Table 12).

Table 12: Changes in Carbon Sequestration with land-use/Cover types

	Area (ha)		(Gg/ha)	Gg		
Land-use/cover	1986	2007	Per unit TC	1986	2007	Change(Gg)
Forest	9432.33	5938.77	0.34	3193.03	2010.39	-1182.64
Bushfallow	9467.10	1029.34	0.13	1241.70	1350.47	108.76
Agric	5709.55	7513.96	0.18	1011.56	1331.25	319.69
Bamboo/Raffia	6764.04	4614.80	0.11	773.81	527.93	-245.87
Grass	3970.69	6458.36	0.09	342.67	557.36	214.69
Built-up/Bare	1037.89	1559.41	0	0	0	0
Totals Area	36381.61	36381.65		6562.78	5777.40	-785.38

3.4 Spectral relationship between sequestered C and selected vegetation indices

Histogram normality test of measured C showed skew distribution of C but was subsequently normalised by log transformation to ensure its normal distribution (figure 16).

a. Untransformed of measured C

b. Log-transformed of measured C

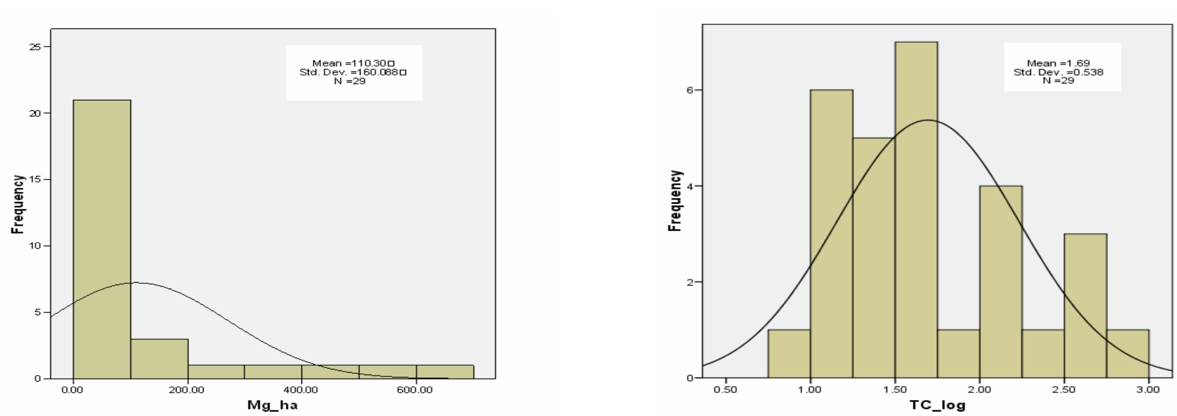

Figure 16: Untransformed and Log-transformed Histogram Plot of Measured C

Table 13: Parametric Linear Correlation of C and selected vegetation indices

Parametric Linear Correlation Summary							
	NDVI	SR	EVI	SAVI	MSAVI	OPSAVI	TC_Log
NDVI	1						
SR	0.995744	1					
EVI	0.7673692	0.7839047	1				
SAVI	0.998766	0.9943894	0.7678764	1			
MSAVI	0.9945175	0.9843226	0.7551265	0.9974016	1		
OPSAVI	0.9987672	0.9943727	0.7675341	0.9999998	0.9974111	1	
TC_Log	0.2928361	0.2874219	0.0749874	0.2705953	0.258328	0.2707709	1

*R^2 *Correlation Coefficient not significant at 0.95 confident level*

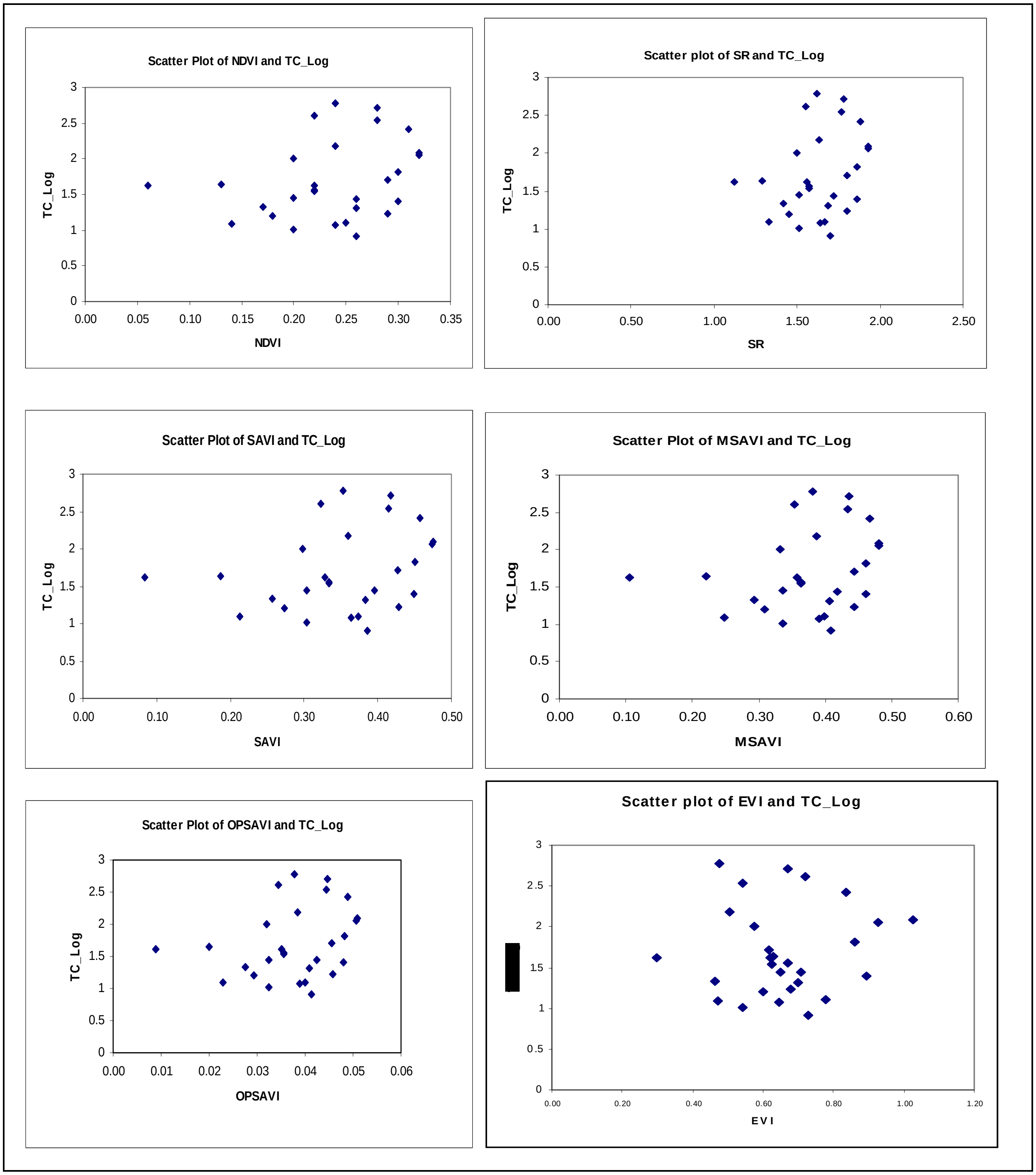

Figure 17: Scatter Plot of Measured C and Selected Vegetation Indices

The scatter (Figure 17) plot did not visually indicate any distinguishing statistical relationship between the vegetation indices and the sequestered C.

Linear correlation coefficient test showed weak and directionless relationship between dependent variable (measured C) and independent variables (selected vegetation indices) at 0.95 significant level (Table 14). However, R correlation coefficient of SR suggests high correlation relative to the others. EVI correlation is very weak with sequestered C (Table 14).

Table 14: Linear Regression Model of C and selected vegetation indices

Independent Variable	R	R square	Sig
NDVI	0.238	0.057*	0.214
SR	0.250	0.062*	1.798
EVI	0.075	0.006*	0.148
SAVI	0.221	0.049*	1.385
MSAVI	0.259	0.067*	1.877
OPSAVI	0.279	0.078*	2.186

* *Regression is not significant*

Generally, the amount of variance indicated by the R square values explained by the linear regression models for all the independent variables was weak.

3.5 Comparative non-market values of "most" and "least" ranked ecosystem services

3.5.1 Ranking of ecosystem services

Respondents ranked six (6) harvestable and non-harvestable ecosystem services according to their livelihood sources and preference. About 60% of the respondents ranked food collection (FD) as the most preferred ecosystem services, followed by soil protection (SP) and medicinal plant collection (MP) with 14% each, bush meat collection (BM) and climate regulation (CL) with 6% and 4% respectively, whereas 2% ranked carbon sequestration (CS) as the least (Table 15).

Table 15: Respondents ranking of ecosystem services

Ranking of Ecosystem Services		
Ecosystem Services	**Frequency**	**Percent**
Food collection	30	60
Soil Protection	7	14
Climate Regulation	2	4
Bush-meat	4	6
Medicinal Plant	7	14
Carbon Sequestration	1	2

Analysis of respondents preferred WTP scenarios

Table 16 shows that, 96% of the respondents preferred scenario B, where current trends of land-use/cover conversion is halted and a hypothetical conservation project put in place, whereas 4% preferred scenario A, where the current rate and trend of land-use/cover conversion continues. About 64% of the respondents prefer conservation of forest, if a hypothetical conservation project is to be implemented. Out of the 64%, 38.7% of them are farmers, 25.8% are teachers, 19.4% are herbalist whereas 16.1% are hunters (Table 17).

Table 16: Respondents preferred WTP scenarios

Land-use/cover conversion scenarios		
Preferred conversation path	**Frequency**	**Percent**
* Scenario A	2	4
+Scenario B	48	96
Conservation of cover type		
Forest	31	64
Bushfallow	2	4
Agric	8	16
Bamboo/Raffia	2	4
Grassland	6	12
Why A or B		
Food Production	38	76
Climate Regulation	7	14
Soil Protection	3	6
Carbon Sequestration	2	4

* *Scenario A* : *If current trend of land-use/cover conversion continues*

\+ *Scenario B* : *If current trends of land-use/cover conversion is halted or managed and a hypothetical conservation project put in place*

Sixteen percent (16%) and 12% of the respondents prefer that the hypothetical conservation project be focused on maintaining agricultural and grass areas respectively (Table 16). Especially for the agricultural areas, tables 17 shows that some farmers prefer that agricultural lands are maintained rather than other cover types. For bushfallow, bamboo/raffia lands, 4% of the respondents prefer its conservation.

Table 17: Most preferred conservation area

Occupation	Forest	Bushfallow	Agric	Bamboo/Raffia	Grassland	Total
Farmer	12	2	9	2	4	29
Hunter	5	0	0	0	0	5
Teacher	8	0	0	0	2	10
Herbalist	6	0	0	0	0	6
Total	31	2	9	2	6	50

Out of the 94% respondents who prefer scenario B, 76% of them want forest areas to be conserved so that it continues to provide and support good conditions for food production. Fourteen percent (14%) and 6% of the respondents indicated that the conservation of forest should be paramount so that it continues to provide “climate regulation” and “soil protection” services respectively. Only 4% of the respondents who preferred scenario B wanted conservation of forest to continue to serve as sequester of carbon through photosynthesis.

3.5.2 Comparative WTP bids for "food collection" and "carbon sequestration" services

Twenty-eight percent (28%) "protest zero" responses were recorded compared to 72% positive WTP bid for "food collection service". Out of the 28% "protest zero" responses, 8% assigned payment or funding responsibility to national government whiles the remaining 20% did not expressed interest in payment toward forest conservation for continued food collection (Table 18). WTP toward forest conservation for carbon sequestration, 70% "protest zero" responses were recorded compared to 30% positive WTP responses. Twelve percent (12%) of the "protest zero" responses put payment task to the national government whereas 58% refused payment.

Table 18: WTP for food collection and carbon sequestration services

	WTP			Maximum WTP Bid ($/annum)		Maximum WTP Bid ($/month)		Income	% WTP/Income Ratio
Ecosystem Service	No	Yes	Gov't	Sum	mean	sum	mean	$/annum	
FD[1]	10	36	4	4,695	94	391	7.8	39,868	11.78
CS[2]	29	15	6	828	17	69	1.4	39,868	2.08

FD[1]: Food CS[2]: Carbon Sequestration

With a total income of $39,868 per annum, $4,695/yr representing 11.8% WTP/income ratio was recorded as the maximum WTP bid for forest conservation for food collection (FD) service whereas $828 (2.1% WTP/Income ratio) maximum WTP bid was obtained for forest conservation for carbon sequestration.

Table 19 shows maximum WTP bid in terms of social demography. From the table, FD maximum WTP bid for males ($ 4,011) is almost a double of the females ($684) in terms of WTP/Income ratio whereas for CS, though in nominal terms, the bid for the males is higher ($ 565) than WTP bid for females ($263) with respect to WTP/Income ratio, females marginally offered more bid than males.

The highest WTP bid ($1,337) for FD was obtained from "illiterates" followed by $1,242 from respondents with tertiary education. Whiles CS, the highest WTP bid of $526.3 was obtained from respondents with tertiary education (Table 19).

Table 19: Maximum WTP bid for “food collection” and “carbon sequestration” services by demography

	WTP_FD			WTP_CS			Income/annum	WTP($)/yr		% WTP/Income Ratio	
Demography	No	Yes	Gov't	No	Yes	Gov't	$	FD	CS	FD	CS
Gender											
Male	4	25	4	15	12	6	30,221	4,011	565	13.27	1.87
Female	6	11		14	3		9,653	684	263	7.09	2.73
Education											
Illiterate	3	9	1	0	1	3	5,800	1,337	100	23.05	1.72
Primary	4	4	2	10	1	2	5,153	279	0	5.41	0.00
Literate	3	10	1	10			7,737	1,047	52.6	13.53	1.29
Secondary		7		9	1	3	9,021	790	149.5	8.75	0.10
Tertiary		6			1		12,158	1,242	526.3	10.22	4.33
Occupation											
Farmer	8	18	4	25	2	3	15,311	1,789	105	11.68	0.69
Hunter	1	4		3	1	1	3,368	842	105	25.00	3.12
Palm-wine Taper	1			1			211				
Teacher/Civil Servant		12			1		12,042	2,000	632	97.94	30.93
Herbalist		2				3	632	105		16.67	

In terms of occupation, the maximum WTP bid for FD and CS of $2000 and $632 respectively was obtained from teachers and civil servants. Palm-wine tappers offered zero bids for both FD and CS. Figures 18 below shows that maximum WTP bid for FD and CS increased proportionally with incomes but for CS, some respondents bided “zero” even as their income increases.

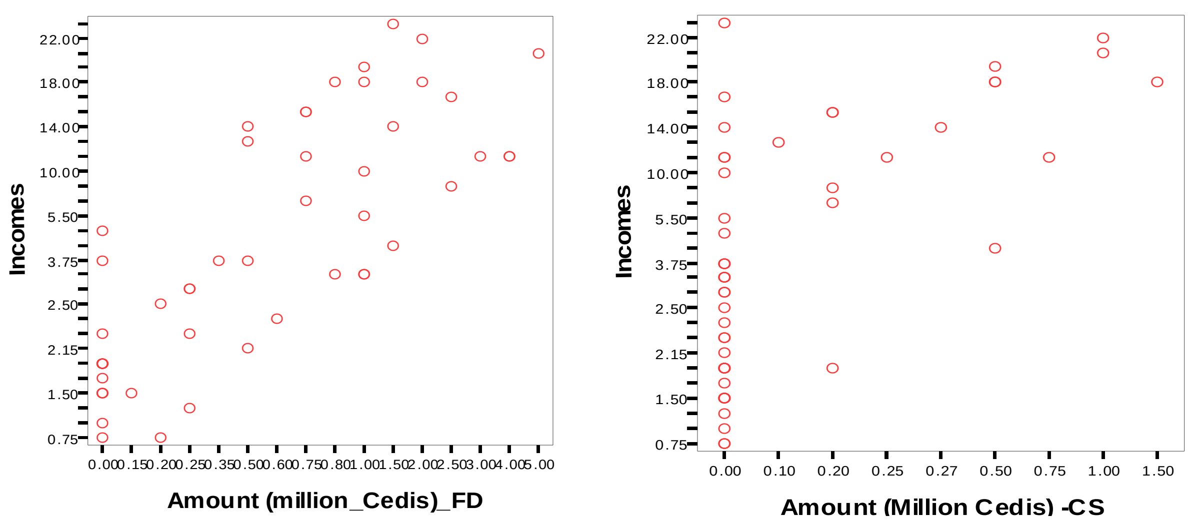

Figure 18: Scatter plot of maximum WTP bid with Income

Multiple regression analysis of maximum WTP bid for food collection (FD) and carbon sequestration (CS) against three (3) independent variables, namely; level of education, incomes and occupation is presented in table 20. From the table, none of the independent variables can neither significantly relate to WTP for FD and CS. However, level of education and income of (R^2 =0.41) relate to individual WTP bid for FD more than incomes (R^2 = 0.37) and level of education (R^2 = 0.05) only.

Table 20: Multiple regression analysis of FD and CS maximum WTP bid and three independent variables

Multiple Regression Model Summary for FD				
Model	R	R^2	Adjusted R^2	Std. Error of the Estimate
1	0.64	0.41	0.38	0.90
a	*Predictors: (Constant), Level of Education, Incomes*			
2	0.63	0.40	0.37	0.91
b	*Predictors: (Constant), Occupation of respondent, Incomes, Level of Education*			
3	0.24	0.06	0.04	1.13
c	*Predictors: (Constant), Level of Education*			
4	0.61	0.38	0.36	0.92
d	*Predictors: (Constant), Incomes*			

Multiple Regression Model Summary for CS				
Model	R	R^2	Adjusted R^2	Std. Error of the Estimate
1	0.22	0.04	0.02	0.90
a	*Predictors: (Constant), Level of Education, Incomes*			
2	0.11	0.02	0.01	0.87
b	*Predictors: (Constant), Occupation of respondent, Incomes, Level of Education*			
3	0.25	0.23	0.02	0.91
c	*Predictors: (Constant), Level of Education*			
4	0.10	0.01	0.01	0.82
d	*Predictors: (Constant), Incomes*			

R^2 multiple regression is not significant at 0.95 significant level

4. Discussion

4.1 Land-use/cover types between 1986 and 2007 and their ecosystem services

4.1.1 Accuracy assessment and land-use/cover classification

The overall land-use/cover classification accuracy of the 2007 landsat image was 86% and kappa statistic of 85%. These results generally suggest good conformity between the classification and the actual land-use/cover categories with few misclassifications of pixels occurring across nearly all the categories. The accuracy level is within the 85% and 90% classification accuracy standards used by Campbell (2002) and Lins & Kleckner (1996) respectively. The accuracy is also consistent with the results obtained by Kiage (2007), Braimoh (2006) and (Yuan *et al.* 2005) with respect to the standards used in Campbell, (2002) and Lins & Kleckner, (1996) and about 10% improvement of the previous studies by Asubonteng (2007) and Sedego (2007).

The general improvement in accuracy level and kappa statistics could be attributed to the incorporation of GIS ancillary data into the initial spectral clustering of the 2007 landsat image. In addition, the large number and evenly distributed nature of the field validation points coupled with the fact that these points were collected the same year as when the 2007 landsat image was taken could contributed to the improvement of classification accuracy. The classification accuracy of the 1986 image could not be statistically assessed due to unavailability of reference data. However, views gathered from the local people on the historical land-use/cover of the study area coupled with information derived from “unchanged” areas in the 1986 and 2007 landsat images helped in the rough assessment of the classification accuracy.

4.1.2 Land-use/cover change

Over the 21 years (1986-2007) study period, the study area experienced land-use/cover conversions of multifaceted nature, mainly attributable to urban and agricultural expansion. Human activities related to urban expansion prevailed more prominently in areas associated with existing settlements and roads, whereas significantly, agricultural-expansion activities featured more in influencing conversion in areas distant from the city. Two distinct land-use/cover conversion pathways with varied direct and proximate causes were observed in the study areas. The first land-use/cover conversion pathway (pathway 1) starts with gradual modification and eventual conversion of forest to agriculture and depending on the intensity and type of human activities involved, agriculture areas are either allowed to be converted to bushfallow and subsequently regenerated to forest or permanently converted to grass. This trail of land-use/cover conversion is commonly found in the eastern portion of the study area where physical expansion is relatively minimal compared to agricultural expansion. This underlying mechanism of land-use/cover change reflected in the loss of forest areas by 37% and the resultant increase in grass, bushfallow and agricultural areas (Figure. 13). In view of this, agricultural and bushfallow areas served as intermediary land-use/cover that drive the conversion loop depending on the factor at play.

The second pathway (pathway 2) involves complete and permanent transformation of natural vegetation (forest, bamboo/raffia in particular) to non-vegetated built-up/bare areas with grass and bushfallow usually at the start-up end. It is generally observed close to existing settlements especially at the western portion of the study area close Kumasi. This observation confirmed the land-use/cover conversion pattern recognised by Lambin *et al.* (2003) and Braimoh (2006) in Ghana.

4.1.3 Land-use/cover types and their ecosystem services

With exception of built-up/bare areas, eleven harvestable (food, bushmeat, medicinal plants, fuelwood and palm-wine) and non-harvestable (shade, climate regulation, habitat provision, catchment protection and carbon sequestration) ecosystem services were identified and associated with the five (5) land-use/cover typologies namely; forest, bushfallow, grass, agriculture and bamboo/raffia.

Previous studies by De Groot *et al.* (2002) and Boumans *et al.* (2002) resulted in a similar characterisation of ecosystem service typologies. For harvestable services, collectable items were mainly obtained from cultivated and forested areas since most of the local people are mostly farmers (Table 6) whose livelihoods depend on them. Collectors, especially, some farmers, and in particular, hunters and herbalist, travel a maximum of 10km from their homes to obtain these harvestable items apparently for selling and/or domestic purpose. This is largely due to the fact that human activities had degraded natural conditions favorable for occurrence of certain collectable items over time.

Climate regulation and soil protection was considered most vital non-harvestable ecosystem services provided largely by forest and bushfallow areas. This is because the local people who are practically farmers consider these two services as important in the provision of conductive conditions for cultivation. Carbon sequestration, though, was identified and associated with forest areas more than the other land-use/cover types; its relative importance to farmers was minimal compare to teachers. The reason could probably be that teachers comprehend the ecological values of carbon sequestration to life-support more than farmers whose interest is more of direct economic benefits from harvestable services for supporting their livelihoods.

4.2 Carbon stock budget in different land-use/cover types

Differences in net carbon stocks for various land-use/covers support the hypothesis cited by Sharma *et al.* (2007) that, land-use/cover transformation from forest to agriculture and other usage causes tremendous loss of carbon stocks. The relatively high amount of C stocks in forest compared to other land-use/cover types confirmed Houghton (1990) assertion that forests contain 20 to 100 times more biomass C per unit area that agriculture and other types.

The estimate of 335 ± 3 Mg/ha C for forest in this study is among the largest recorded in tropical regions including those values reported by Sharma *et al.* (2007), Sierra *et al.* (2007), Glenday (2006) and Woomer (2007). The result indicates that natural forest significantly sequesters more C compared to other land-use/cover types. This is because tropical forest is perceived to contain remarkably diverse and high density of active vegetation and soil carbon pools. These active pools also facilitate high net primary productivity (NPP) in forest more than other land-use/cover types. This is consistent to the high NPP value (1000gC/m^2/year) reported for tropical seasonal forest by (Klein *et al.* 1994) relative to other vegetation types.

Total sequestered C in agricultural areas is half almost of that of the forest. The main reason for this difference could be due to relatively high NPP fixed in forest areas compared to agricultural area. In addition, decomposition and subsequent release of C to the atmosphere are suspected to be high in agricultural areas probably due to its favorable temperature and relative humidity conditions. This condition facilitates reduction in conversion of litter C to stable C in soils.

Sharma *et al.* (2007) reported similar low carbon in agriculture areas but the difference is in 100 folds. In the study area, perennial cropping is most common farming system. However, the perennials are usually interspersed with trees, primarily, to provide shade and fertile soil necessary for growth. This practice is believed to have accounted for the relatively higher vegetation C in agricultural areas in this study compared to the results reported by Sharma *et al.* (2007).

Grass areas (i.e. areas considered as degraded and uncultivated) sequestered 81.30 ± 5 Mg/ha C. This observation, though, is the least recorded in this study, it is significantly high compared to previous results obtained by Woomer *et al.* (2007) in the Senegal's transition zone of Africa, particularly because of differences in climatic conditions. Soil carbon accounts for more than 50% of the total C in the grassland and could be attributable to the high foliaging nature of chromoleana ordorata and elephant grass common in the study area. The nature of the grass could also facilitate litter C transfer through the root systems and decomposition.

Bamboo/raffia areas showed promising C sequestering potential especially from the soil. This may be attributed to the underground biomass pools like the roots, which serve as an active conduit for sequestering. Conversion of litter C to stable C is suspected to be high due to the low temperature conditions in bamboo/raffia areas. Remarks from other studies in tropical Africa regions on C sequestering in bamboo/raffia is difficult to come by because of lack of adequate research in this regard. However, a study by Hu *et al.* (2006) in China reported 14.56 Mg/ha which is significantly low compared to results from this study.

Total woody-vegetation C (live and dead trees biomass) in forested and non-forest areas ranged between 2.68 to 231.03 Mg/ha. This value falls within the range reported by Sierra *et al.* (2007), Woomer (2007) and Glenday (2006) and consistent with the potential aboveground biomass limits modeled for African lowland moist forest by Brown and Gaston (1995). However, various authors like Sharma *et al.* (2007), Bonino (2005), and Houghton (1999) had reported considerably lower results in other tropical regions in Asia. Although, the general expectation of aboveground biomass C was comparatively large, the natural intactness of Bobiri Forest Reserve coupled with high undergrowth of weedy-biomass justifies this observation.

In this study, total woody-vegetation C recorded in natural forest is significantly higher than soil C. This figure contradicts what had been widely reported by various authors including Sierra *et al.* (2007), Woomer (2007) and Glenday (2006) which suggest soil as the largest C pool. This result, though, unexpected and further research for deeper understanding of the underlying driving mechanism would be appropriate. For agricultural areas, soil and vegetation C is almost the same. However, soil C in bushfallow, grass and bamboo/raffia areas are higher than vegetation C for the obvious reason that, soil contains more belowground biomass pool in these land-use/cover types than forest and agriculture. This is certainly in conformity with the previous studies by Sierra *et al,* (2007), Woomer (2007) and (Glenday, 2006).

Soil carbon stocks reported in this study is generally consistent with the results from De Wit, (2006) and Sharma *et al.* (2007). Higher C was recorded in the first 15cm of soils in all the land-use/cover types compared the 15-30cm layer. This observation confirms results reported by De Wit, (2006) with the reason that the 0-15cm soil layer contains more active C pool than the mineral layer. Decomposition and litter C transfer to stable C normally take in the humus layer. Soil C stock in bamboo/raffia is strikingly higher compared to other land-use/cover. This observation is anew revelation to this study and in Ghana and therefore requires further detailed research, specifically toward the search for more cost-efficient emission reduction opportunities under the CDM arrangements.

4.3 Changes in carbon stocks and land-use/cover types

The conversion of forest and bamboo/raffia area between 1986 and 2007 to other land-use/cover types contributed to the loss of 785.38 Gg C at an annual of 37.4 Gg C year $^{-1}$. This figure is similar to the recent results obtained by Li *et al.* (2008) in the China Xishuangbanna region. The decrease in total C is also consistent to the rate of land-use/cover change, similar to what Sharma *et al,* (2007) reported. The highest change in C stocks resulted from the conversion of forest to agricultural areas and subsequently allowed to go fallow over a period of time (pathway 2 conversion process). This facilitated the replacement of vegetation and soil biomass C from forest to either fallow or agriculture.

Though, agricultural areas could maintain certain levels of sequestered C after conversion from forest but because such areas are allowed to fallow and in the process accumulates some level of active vegetation and soil biomass which sequester more C in a relatively large area. This accounted for the high C stocks in bushfallow areas in 2007 relative to 1986. Apart from the loss of vegetation and soil carbon pools in forest and bamboo/raffia areas, the 33% average conversion of forest and bamboo/raffia to other land-use/cover types remarkably influenced the decrease in C stocks in the study area.

It is also important to note that, the pathway 1 conversion, which include permanent transfer of bushfallow or grass to built-up/bare contributed greatly to C loss as emission source. This is considered to have contributed to an average of 12.8% C emission of 1986 and 2007 total sequestered C from the study area.

4.4 Spectral relationship between selected vegetation indices and sequestered C

In this study, the relationship between sequestered C and selected vegetation indices was poor as indicated by the correlation and regression analysis (Table 13 and 14) and thus no reliable spatial variability analysis of sequestered C and selected vegetation indices could not be done. This result was not anticipated, especially for NDVI, SR and EVI which has been widely reported in literature to measure photosynthetic activities in woody-vegetations. Specific reasons for the weak relationship could not be readily found in the study and coupled with the fact that research in this is lacking in Africa. Perhaps, the low photosynthetic activity during the dry season led to minimal reflectance abilities in the study area.

Correlation between sequestered C and soil corrected vegetation indices such as SAVI, MSAVI and OPSAVI is weak. Though, this result was expected, especially in close-canopy forest areas where background reflectance from soil is minimal, explanations for the extremely low correlation coefficient between the dependent (sequestered C) and the independent (vegetation indices) variables is difficult and incoherent. Further studies are required for gathering extensive baseline data for the development of specific algorithms between sequestered C and selected vegetation indices.

4.5 Comparative non-market values of "least" and "most" ranked ecosystem services

The payment vehicle for eliciting WTP bids for the "least ranked" non-harvestable (carbon sequestration) and "most" ranked harvestable (food collection) service is based on the hypothetical conservation scenario below:

"The study area between 1986 and 2007 had experienced forest conversion to other land-use/cover types at varying rates, would respondents prefer, scenario A, (where the rate of conservation continued) or scenario B, (where the forest conservation is halted or managed and hypothetical conservation project put in place) and why".

Similar but different content of WTP elicitation scenarios had been used by other authors including Gürlük (2006), Amirnejad (2006), Cho (2005) and Zhongmin (2003) to elicit WTP bids. Others studies by Wilson (2006), Kreuter (2001), Zhao (2004) used adjusted ecosystem services benefits transfer values originally developed by Costanza (1997) to determine specific values of different ecosystem services.

Generally, "the 28% zero" WTP bids for FD appears close to the 20-25% reported in literature and justifiably acceptable in developing world where WTP has not been extensively implemented over years as intimated by Whittington (1998). However, the "70% zero bid" for CS is extremely high because majority of respondents lacks the necessary understanding of the ecological values of carbon sequestration to mankind. Even, those with certain level of understanding of ecological values of carbon sequestration, shifted payment to national government.

The general mean WTP bid for FD and CS is $7.8 and $1.4 respectively. Other studies by Guo et al. (2001) and Gürlük (2006), Amirnejad (2006); had reported relatively high bids for carbon sequestration and other services. The difference in the bids for FD and CS was expectedly high considering income level of respondents. The bids of different interest groups for both services were perceived to be influenced by three key factors, namely level of income, educational level and occupation.

For instance, with relatively low income for “respondents with no formal education (illiterates)” compared to their “tertiary” counterparts (Table 19), their FD WTP was higher than the latter. This perhaps clarifies why illiterates gives high priority to food collection because it is their major livelihood source. CS WTP bids are certainly influenced by level of education (Table 19) to the extent that, local people with tertiary education are likely to bid more for CS than those with secondary and primary education in that preferred order. However, their WTP bid for FD is always more than a double high of CS bids.

For income, figure 18, confirmed that the expected increase in income level of respondents would yield subsequent rise in WTP bid for FD and CS. However, for CS, in some cases income could increase yet WTP bids remained unchanged. This concept is largely consistent with the economy demand theory explained by Urama and Hodge (2006) and validated by (Ojeda, 2007). The weak significance of the multiple regression analysis between dependent variables (FD and CS) and independent variables (income, education and occupation) vary with what was report by Carson and Mitchell (1993) but the R^2 for incomes and level of education confirmed the linear and logit model by (Ojeda, 2007).

5. Conclusions

5.1 What changes have occurred in land-use/cover types in the study area between 1986 and 2007?

- Six (6) dominant land-use/cover types (i.e. forest, bushfallow, agric grass, bamboo/raffia and built-up/bare) exist in the study area.
- Forest and bamboo-raffia decreased in size whereas build-up/bare, agric, and bushfallow and grass increased over 21 years.
- Forest and grass experienced most negative and positive changes respectively.
- 3493.6 ha forest area was lost, which is equivalent to 37% of forest areas in 1986.
- Grass increased by gaining 2487.7ha representing 62.7% of the existing grass cover in 1986.
- 2149.2 ha of bamboo-raffia were lost. This represented 18.6% and 12.7% of the entire area in 1986 and 2007 respectively.
- Agriculture areas increased from 5709.5 ha in 1986 to 7514.0ha in 2007 whereas bushfallow areas increased by 828.2ha from 9467.1 ha in 1986 to 10296.3 ha in 2007.
- Build -up/bare increased from 1037.9 ha in 1986 to 1559.4 ha in 2007.

5.2 What are the major harvestable and non-harvestable ecosystem services in the study area?

- Five harvestable (**f**uel **w**ood, **f**ood, **b**ush **m**eat, **m**edicinal **p**lants, and **p**alm-**w**ine **t**apping) and six non-harvestable (**s**hade, **s**oil **p**rotection, **c**limate **r**egulation, **c**arbon **s**equestration, habitat and **c**atchment **p**rotection) were identified as major ecosystem services associated with forest, bushfallow, agric grass and bamboo/raffia**.**

5.3 What is the distribution of carbon stocks in different land-use/cover types?

- Forest recorded the highest of 335 ± 3 Mg/ha whereas 81.3 ± 5 Mg/ha C in grass. C in agricultural, bushfallow, bamboo/raffia areas were 171.2 ± 6 Mg/ha, 122.2 ± 9 Mg/ha and 110.4 ±1 Mg/ha respectively.
- In the forest areas, 68.2% of C is stored in woody-plant biomass compared to 30.7% of C in soils. In agricultural areas vegetation is also higher (51.11%) than soil C (47.10%).
- However, soil C in bushfallow, grass and bamboo/raffia is higher (64.7%, 88.4% and 94.1% respectively) than woody-vegetation (32.3%, 7.3% and 2.4% respectively).

- Carbon storage in non-woody vegetation pools in all the land-use/cover types ranged from 1% in forest areas to 4.2% in grass.

5.4 How do changes in land-use/cover affect carbon stocks in the respective cover types?

- 785.38 Gg C (equivalent to 37.4 Gg C yr^{-1}) was loss between 1986 and 2007 due to changes in land-use/cover types.
- Forest had the highest loss of 1182.6 Gg C (56.3 Gg C yr^{-1}) followed by Bamboo/Raffia with 245.97 Gg C (equivalent of 11.71 Gg C yr^{-1}) emissions. However, agricultural areas sequestered 319.69 Gg C more relative to 1986. Similarly, grass and bushfallow areas in 2007 sunk more C than in 1986 - i.e. 214.69 Gg C and 108.76 Gg C respectively.
- It is therefore concluded that the rate of land-use/use cover change over two the temporal scales cause commensurate loss of carbon stocks. However, the rate of C loss becomes emission source if the conversion is from vegetated to non-vegetated areas. Though conversion within different vegetation types releases C to the atmosphere, it is reasonably compensated in the new land-use/cover type over time.

5.5 How strong is the relationship vegetation indices (VIs) derived from remotely sensed data and sequestered C?

- The relationship between sequestered C and the selected vegetation indices in the study area has proven to be weak and directionless. However, the relationship between SR and sequestered was comparatively promising which requires further study.
- Therefore, it can be concluded that even though its may be inappropriate to use vegetation indices to accurately predict sequestered C at the study area, the results provide useful and practical information for further research in the application of remote sensing data for carbon accounting.

5.6 How much economic value do users or beneficiaries of ecosystem services assign to the "least ranked non-harvestable and "most ranked harvestable" services?

- "Food" is ranked as the most harvestable ecosystem service whereas "carbon sequestration" is "least" ranked non-harvestable ecosystem service.
- Total WTP bid for "Food" is \$4,695/yr, which represent 11.8% of WTP/income ratio compared to \$828 (2.1% WTP/Income ratio) for "Carbon Sequestration".

- FD maximum WTP bid for males ($ 4,011) is more than double of the females ($684) in terms of WTP/Income ratio whereas for CS, though in nominal terms, the bid for the males is higher ($ 565) than WTP bid for females ($263) with respect to WTP/Income ratio, females marginally offered more bid than males.
- The highest WTP bid ($1,337) for FD was obtained from "illiterates" followed by $1,242 from respondents with tertiary education. Whiles CS, the highest WTP bid of $526.3 was obtained from respondents with tertiary education.
- Palm-wine tappers offered zero for FD and CS.

6. Recommendations

6.1 Land-use/cover classification and change detection

- The concept of combining ancillary data from visual interpretation of satellite images with unsupervised classification has been demonstrated in this study to improve accuracy of land-use/cover classification. It is therefore recommended for application in areas where mixed pixel conditions are problematic for effective land-use/cover classification.

- A further detailed statistical study is recommended for the development of suitable method of validating classification accuracy of old satellite images. The current practice of using local knowledge and “unchanged areas” in satellite images for validation is apparently unaccountable and subjective.

6.2 Carbon stock inventory and land-use/cover change

- The absence of country specific allometric equation and C adjusted factors introduced uncertainties in the determination of aboveground biomass for C in this study. Future studies in this regard must consider development of biomass equation for the different metro-ecological zones of Ghana. This will improve accuracy of aboveground biomass estimation especially with respect to C accounting.

- Further studies must also consider investigating variability in C fluxes over time, which is considered most critical in fully understanding dynamics of carbon sequestration. This is one of the limitations of this study.

- It also recommended that future studies could be focused on assessing how different resource management practices affect sequestered C levels. For instance, comparative C stocks assessment could be done for managed and natural forest areas or agricultural lands under different agronomic practices.

- Specific reasons could not be readily found for the outstanding soil C stocks in Bamboo/Raffia area. Additional studies in this regard would be appropriate, particularly because, success in this effort could immensely contribute to the development of country-specific strategies for effective management of Bamboo/Raffia areas to serve the dual purpose of catchment protection and sequestering C.

- With respect to C stocks and land-use/cover change, it is recommended that future studies be looked at creating alternative future scenarios of C stocks based on forecast different land-use/cover regimes. This will certainly assist in the assessment of the consequences on C stocks under different development strategies.

- Regional C stocks assessment in Ghana could employ the grid-based analysis method used in this study. The method when properly implemented could provide accurate, reliable and practical information on C stocks over large area.

6.3 Relationship between vegetation indices and sequestered C

- In the future, if remote sensing data is to be used with sequestered C measured from the field seasonal compatibility must be recognised as important.

- The reasons for the weak and directionless relationship between vegetation indices and sequestered C could not be found in this study. However, more research focusing on developing appropriate algorithms or indices specific for predicting sequestered C based on remote sensing data is necessary in the future. Efforts in that direction must take due cognisance of back-scattering effects from soils, saturation effects from green vegetation and difference in ecological conditions in Ghana.

6.4 Willingness-to-Pay (WTP) survey for eliciting non-market values of ecosystem services

- Further studies in WTP surveys in Ghana, could consider assessment of the extent to which variables such as income levels, levels of education and occupation of individual can influence their WTP bids for different natural resource commodities. Other factors such as household size, environmental consciousness of an individual and gender could also be explored.

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8. Appendix

Appendix 1: Field Sampling Sheet

Inventory of Carbon Stocks – Field Data Collection Sheet								
1	**General Information**							
1.1	Recorder		1.2	Date		1.3	Town name	Kubease
2	**Plot Information**							
2.1	Plot ID		Distance to next plot (m)			Plot Radius		12.6
2.1	Plot Centre Geographic Coordinate		N:			2.2	Land use/cover type	
			W:			Forest		Crops	
2.3	Elevation (m)	242	Slope (%)		Aspect	Fallow/Bush		Bare	
	Comments					Grass		Others	
3	**Enumeration of Above Ground Biomass Stocks**							
3.1	Standing Woody Biomass (Tree)							

Tree no.	Tree Species		Plot radius (m)			DBH(cm)				Tree Ht(m)	Stand Density	Comments
	Local Name	Scientific Name	12.6	8	4	12.6r	8r		4r			
						≥50	≥25-50	15-25	5-15			
1												
2												
3												
4												
5												

3.2	Herbaceous Plants and Debris							
Herbaceous Plants and Debris	Plot ID (4m sub-plot)			Sample ID		Q1.	Q2.	
3.3	Dead wood (25.2m transect)							
4.	**Enumeration of Below Ground Biomass Stocks**							
4.1	Roots (>2cm diameter)				**Description**			
4.2	Soil (1.4M sub-plot) Bulk density	Sample ID	0-15cm		Colour		Texture	
			15-30cm					

Appendix 2: Questionnaire on WTP Survey

ITC, Enschede, Netherlands
Kwame Nkrumah University and Technology, Kumasi
(College of Agric and Natural Resources)
MSc. GISNATUREM

Structured Questionnaire for Open-Ended
(Willingness-to-Pay) Face-to-Face Survey
Key Informant Interviews

Introduction
This exercise forms part of the data collection activities towards my MSc. research on the topic *"Spatial Analysis of Ecosystem Values with Land Cover/ Use Changes"* This questionnaire aims to elicit reliable information from stakeholders like you on the economic value of services provided by different ecosystem units such as forest, riparian, grassland, farmland in this study area. The outcome of this survey will be used as input in the estimation of key indicator ecosystem services as per different land cover types.

Thank you in advance for your assistance. Daniel Tutu Benefoh (MSc. Student)

General Information

Field Enumerator		1.3	Date		Village Name		

Respondent's Personal Information

Respondent's Age	0-25		25-35		35-50		Above 50		2.2	Education Level
Respondent's Name										
Gender	M		F		2.4	Occupation	Farmer		Hunter	
Household Size		Palm wine Tapper			Teacher / Civil Servant					
No. of Children		Other (Specify)								
No. of Dependents		2.6	Income Level	Annual		Monthly				
Family Size		Daily		Other (Specify)						

Education Level	
Illiterate	
Literate	
Primary	
Secondary	
Tertiary	

Respondent's Environmental Perception/Attitude

Pair-wise Comparison of Services

	MP	FC	FD	BM	PW	SH	SP	C S
MP	1							
FS		1						
FD			1					
BM				1				
PW					1			
SH						1		
SP							1	
CS								1

3.1	Which of the following items do you usually collect?			3.2	Where do you usually collect these Items?		
Medicinal Plants		Fish		Forest		Fallow Lands/ Secondary Forest	
Fuel wood		Food		Grassland		Farmland	
Palm wine		Bush meat		Bamboo/Raffia			
3.3	Do you know these land cover units provide other services? Y[ ] N[ ]			Others (Specify)			
3.4	If yes, specify below			4			
1				5			
2				6			
3				7			

How far do you walk/ travel to collect these items					3.8	Do you collect these items for your family use or sell it? Y [ ] N[ ]		If Y, how many people make use of these items		
Miles/km	1-10		10-20		30-40		If N, how much do you earn when you sell your items in Cedis (Daily, Weekly, Monthly)	1-5		5-10
40-50		Above 50						Above 10		

4.0	**Current State of Land cover Units and Rank**									
4.1	Between 1986 and 2007, lots of forest areas have been converted to other cover types and degradation is on-going (respondents look at images and answer the following)									
4.1.1	Are you aware of this change?	Y		N		4.1.2	Do you know the key causes of the changes?	Y		N
4.1.3	Can you mention some of the effects of the forest change?						If **Y,** list them			

4.2	Pair-Wise Comparison of Land Cover types using livelihood Supports							4.3	Do you know of any other goods/services that these land cover unit provide? Y [ ] N [ ]
		NL	FLL	GRL	FL	BB/RF	BRL	Score	4.4 If Y mention them in order of importance
	NF	1							1
	FLL		1						2
	GRL			1					3
	FL				1				4
	BB/RF					1			5
	BRL						1		

5.0 **Ecosystem Service Value Elicitation Scenario (Using hypothetical costed-pebbles)**
Two Images will be presented to respondents indicating the trend of land cover conversation.
Scenario A : current trend of land cover conversion from forest to others units
Scenario B: current trend would be halted with a hypothetical conservation project

5.1	How severe is the conversion of each cover type?				
	Very Severe	5.2 Which of the Scenarios do you prefer		5.4 If A, which of the cover units would you want converted and to which	
	Moderately Severe	Scenario A		Primary/Secondary Forest	5.5 Are you willing to pay certain amount of your income for your choice?
	Severe	Scenario B:		Grassland	Yes
	Slightly Severe	5.3 If B, which of the cover units do you want it to be conserved in order of preference?		Farmland	No
				Riparian Area	No Response
	Insignificant	Primary/Secondary Forest			Gov't/User Business
5.5	Why A or B	Grassland		5.7 What is maximum amount you are willing to pay for implementing your choice in Cedis('000)	
		Farmland		10-500	500-1,000 / 1,000- 5,000
		Riparian Area		Above 5,000	Other (Specify)
5.6	Why do you want to contribute certain amount of your income for implementing your Choice?			Recreation	
	Continuous collection of food, NTPS, medicinal plant etc.			Cultural Values	
	Future Use				
	The use of other				

6.1	Do you have a place set aside as Sacred Groove/Heritage Site Y[ ] N [ ]	6.3	What is the history behind the establishment of the site?
6.2	6.0 **Case Study Carbon Sequestration or NPP or Food Production (Indicator of CS OR NPP)**		
6.4	Do you know how nature helps to produce the food/ plants/medicine you collect? Y [ ] N [ ]		
If yes, how		6.5	How much are you willing to contribute for continuing maintenance of the support nature provides and why?

6.6 How do you know you about how tree produces its food from the sun? None [ ] Little [ ] Enough [ ] More [ ]

Appendix 3: Accuracy Assessment

Class name	Reference Totals	Classified Totals	Number Correct		Producers Accuracy	Users Accuracy	Kappa
Forest	16	16	14		87.50%	87.50%	0.82
Bushfallow	11	10	9		81.18%	90.00%	0.84
Agriculture	20	16	16		80.00%	100.00%	0.81
Bamboo-raffia	5	5	5		100.00%	100.00%	1
Grass	11	14	9		81.82%	64.29%	0.73
Build-up/bare	7	9	7		100.00%	77.78%	0.89
Totals	70	70	60				
Overall Accuracy	**86.0%**						
Overall kappa	**0.85**						