UNIVERSITY OF CAPE COAST

EFFECTS OF ANTHROPOGENIC STRESSORS ON VEGETATION, SO AND WATER QUALITY IN THE UPLAND EVERGREEN TROPICAL FOREST OF ATEWA, GHANA

BY

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A thesis submitted to the Department of Environmental Science, School of Biological Sciences, University of Cape Coast, in partial fulfilment of the requirements for the award of Doctor of Philosophy degree in Botany

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

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Name: Felicity Ghartey-Tagoe

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

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ABSTRACT

Although tropical rain forests are rich in biodiversity and play major roles in vegetation, soil and water quality and socio-economic needs, people have imposed stress on them. The study examined vegetation, soil and water characteristics linked to anthropogenic activities— logging, mining and farming in the Atewa Range Forest Reserve (ARFR) in Ghana. The study sites were categorized into highly stressed vegetation (HSV), moderately stressed vegetation (MSV) and non-stressed vegetation (NSV). Attributes of plant species composition and structure were determined using 50 m x 50 m plots. Tree biomass and carbon stock were determined from allometric equations using tree diameter measurements. Plant diversity was estimated using Shannon Wiener and Simpson diversity indice. The intensity of anthropogenic influence between 1986 and 2016 was analysed using Normalized Differential Vegetation Index techniques. Soil organic carbon was determined using Walkley-Black method. River Birim was sampled and tested for physical, chemical and biological characteristics, as well as heavy metals. The total mean woody plant density was similar and higher for MSV and lower in HSV. Above-ground carbon stock was not significantly different among the three stress levels but below-ground carbon stocks were significantly different at the three stress levels. The forest decreased at the rate of 2 km^2 per annum between 1986 and 2016. Soil pH, bulk density, moisture, organic carbon and nutrients (NPK) differed significantly. Physicochemical properties and heavy metals of the water showed significant variation at the various stress levels. Anthropogenic stressors have negatively impacted the vegetation, soil and water quality of the ARFR, therefore, there is a need for stringent management policies to control human activities.

KEY WORDS

Aboveground Biomass

Anthropogenic Stressors

Belowground Biomass

Biodiversity

Carbon Sequestration

Forest Reserve

Ghana

Water

Intensity Analysis

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DEDICATION

This work is dedicated to my husband, Mr. Kobina Sam Bentsi-Enchill.

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ANOVA	Analysis of Variance
APHA	American Public Health Association
ARFR	Atewa Range Forest Reserve
CO_2	Carbon Dioxide
CWQRB	California Water Quality Resources Board
DBH	Diameter at Breast Height
EC	Electrical Conductivity
EP	Environmental Policy
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
FASDEP	Food and Agriculture Sector Development Policy
FC	Faecal coliform
FIP	Forest Investment Program
FWP	Forest and Wildlife Policy
GDP	Gross Domestic Product
GPS	Global Position System
GSBA	Globally Significant Biodiversity Area
IBA	Important Bird Area
IPCC	Intergovernmental Panel on Climate Change
LPG	Liquefied Petroleum Gas
NDVI	Normalised Differential Vegetation Index
NPLD	Non Pioneer Light Demanders
NRM	Natural Resource Management

REDD+	Reducing Emissions from Deforestation and Forest Degradation
SC	Shifting Cultivation
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
TSS	Total Suspended Solids
UNEP	United Nations Environmental Programme
WHO	World Health Organization

CHAPTER ONE

INTRODUCTION

Background to the Study

Tropical rain forests are high in biodiversity and play major roles in vegetation, soil and water quality. Human activities in tropical rainforests have resulted in exceptional and large-scale changes that trigger loss of biodiversity (Kanninen, et al., 2007; Fischlin, et al., 2009). The increase population growth and the attempt to achieve economic development in many developing countries have culminated in the extensive exploitation of natural resources. As a result, the environment is exposed to multiple stressors. Many stressors affect the functioning and persistence of ecological systems through their impacts on populations of ecologically important organisms. Changes in the species richness, abundance, and composition of an ecosystem might result in changes in the quantum or quality of services provided by that ecosystem (Bunker et al., 2005). A stressor is an environmental factor that detrimentally affects a population or ecosystem property (Folt, Chen, & Moore, 1999; Darling & Cote, 2008). Stressors can be natural environmental factors or they may result from activities of humans (anthropogenic) that can induce adverse effects on individuals, populations, communities or ecosystems. Anthropogenic stressors do affect the ecosystem functioning through changes in biodiversity. Global change and loss of biodiversity have raised concern over the increasing impacts of anthropogenic stressors on ecosystems (Sala et al., 2000; Brönmark & Hansson, 2002; Schindler, 2001). Focusing on major anthropogenic stressors, recent changes being experienced include the degradation and loss of ecosystems as a result of changes in land uses, human impacts on the climate resulting in climate change, and poor management or over-exploitation of the natural resource (Kanninen et al., 2007; Fischlin et al., 2009) leading to deforestation. Stressors, therefore challenge the integrity of the ecosystem and its operations.

In Ghana, like elsewhere, most forests encounter both natural and anthropogenic stressors. McCullough et al. (2007) opined that Atewa Range Forest Reserve (ARFR) is extremely highly important and noted for its numerous global biodiversity conservation. ARFR contains Ghana's last intact stand of Upland Evergreen forest and one of the largest remaining forest blocks in Ghana. Despite this, human occupation of the ARFR is increasingly changing the land-use patterns in the forest's catchment area. The main economic activities that threaten the natural resources at ARFR and its fringes are illegal mining operations, illegal logging and farming. Small scale mining is presently recognized globally as the major source of livelihood for the poor in most emerging economies, and is an important determinant of environmental degradation and resource depletion in such mining areas (Barry, 1996; United Nations, 1996). Clearing of vegetation during mining presents one of the most significant threats to the conservation of biodiversity (Sarma, 2005; Adjei, 2007). It is estimated that, about 40% of the global terrestrial vegetation had been exchanged for mineral exploration and infrastructural developments (Noble et al., 1996) leading to the destruction of key ecological processes and promotion of forest and habitat fragmentation into isolated and smaller habitat patches (Saunders, Hobbs & Margules, 1991).

Logging operations in tropical evergreen forest areas have multiplied in the last ten years as a result of increased mechanization permitted in the exploitation of hitherto inaccessible areas. Thus, the intensity of the stress caused by logging is related to the logging equipment used and the number of trees harvested. Trees such as mahogany *Swietenia macrophylla*, Odum *Milicia excels,* Obeche *Triplochiton scleroxylon* and Emire *Temnalia ivorensis* which were abundant before the 1960s are today locally rare (Amankwah, Komieter, & Mensah, 2003). The number of chainsaw operators has been on the rise since the mid-1980s. Illegal logging has been prevalent in ARFR, especially during the 1990s, leading to increased rates of erosion throughout the catchment area. In 2001, logging escalated so much that the Ghanaian army was called in to help protect the reserve from loggers (Hawthorne & Jongkind, 2006; Hawthorne, 1993). In spite of the above, logging is considered by some researchers to produce marginal effect on forest structure, composition and dynamics (Deckker & de Graaf, 2003) whilst others have indicated that logging leads to changes in species composition (Silva et al., 1995; Luna et al., 1999; Magnusson, de Lima, Reis, Higuchi & Ramos, 1999), forest structure (Silva et al., 1995; Okuda et al., 2003.; Hall , 1988), carbon sequestration and genetic diversity (Jennings, Brown & Sheil, 2001). Exploitation of tropical forest for timber causes canopy opening, leading to changes in microclimatic conditions (Novotny et al., 2010). More important stressors in tropical forest areas are the farming activities and practices of dwellers closer to these sites.

Shifting cultivation (SC) is prevalent mostly in tropical countries. SC is one of the main subsistence activities of small-scale societies and rural populations in tropical forests. This system has been practiced for thousands of years (Altieri 2004; Kammen & Dove, 1997; Harris, 1986) and is based on the ecological processes of forest ecosystems (Altieri, 2004; Long & Zhou, 2001; Vadez et al., 2004; Pedroso-Junior, Murrietta, & Adams, 2008). Estimates of how many people worldwide currently depend on shifting agriculture systems for their subsistence vary from 35 million to 1 billion people (Attiwill, 1994; Brady, 1996; Kleinman, Pimentel, & Bryant, 1996; IFAD, 2001; Sanchez, Palm, Vosti, Tomich, & Kasyoki, 2005). As a result of increasing demand for land, the cycle of cultivation followed by leaving land fallow has reduced from 25–30 years to 2–3 years. The longer fallow period allowed the land to return its natural condition (Patro & Panda, 1994) while the short period results in breakdown of the resilience of ecosystem and increasing soil degradation. Human activities such as felling and burning of forest for agriculture in the natural ecosystems, change the equilibrium between accumulation of organic matters, production of biomass and decomposition and absorption of minerals. The response of terrestrial vegetation to anthropogenic stressors is central to predictions of future levels of atmospheric carbon dioxide (Lewis et al., 2009).

Tropical forest ecosystems occupy 1.8 billion hectares of the total area of 4.2 billion hectares of forest biomes (Lai, 2004). Generally, a distinguishing feature of tropical rain forests is their high biodiversity, major influence on climate and their role in carbon storage. The world's tropical forests are important key carbon sinks for atmospheric carbon dioxide (Goodale et al., 2002; Schimel, House, Hibbard, & Bousquest, 2001) as it serves as a large carbon reservoir (Malhi et al., 2006). Lasco (2002) also posited that the amount of carbon storage in the world's tropical forests which cover 17.6 x 106 km^2 are approximately 4.28 x 10^{11} tonne of carbon is in vegetation and soils.

Mankind has the potential to greatly influence atmospheric carbon dioxide concentrations through the effects of land use change and forest management activities on the terrestrial biomass carbon pool. Facing the increasing carbon dioxide concentration in the atmosphere and its germaneness for the earth's climate system, new and precise information is required on the carbon exchange of forest ecosystems at all latitudes (Grünwald & Bernhofer, 2007). Gorte (2009) has indicated that upland evergreen forests play essential roles in carbon sequestration by seizing much higher quantity than any other biome. Basically, carbon sequestration refers to the transfer of atmospheric carbon dioxide into long-lived pools and storing it securely so it is not directly re-emitted (Kambale & Tripathi, 2010).

The estimation of the amount of forest biomass is very essential for monitoring and estimating the amount of carbon lost or emitted as a result of deforestation and land use change. This is because it gives the researcher an idea of the forest's potential to sequester and store carbon in the forest ecosystem. Terrestrial carbon sequestration is a natural process and a possible strategy for reducing the rate of enrichment of atmospheric carbon dioxide (CO_2). The terrestrial carbon pool in tropical forest ecosystems comprises 120 Mg/ha (tonnes) in vegetation and 123 Mg/ha in soil to a depth of 1 metre (Lai, 2004). Five carbon pools of the terrestrial ecosystem involving biomass have been identified by the Intergovernmental Panel on Climate Change (IPCC), namely the below-ground biomass, above-ground biomass, litter, soil organic and woody debris matter. Among the five pools mentioned, the above-ground biomass comprises the main portion of the carbon pool and is principally the main one which is directly affected by forest degradation and deforestation as a result of logging, mining and farming. Roger (1993) estimated that about 86% of the terrestrial above-ground carbon and 73% of the earth's soil carbon are deposited in the forests. However, changes associated with land use system have a direct impact on the above carbon pool. Thus, forest clearing can lead to soil degradation, erosion, and the leaching of soil nutrients, and may reduce the ability of the ecosystem to act as a carbon sink.

Below-ground biomass accumulation is linked to the dynamics of above-ground biomass. Eggleston, Buendia, Miwa, Ngara and Tanabe (2006), have indicated that the below-ground biomass is made up of all live roots and this plays an essential role in the carbon cycle by moving and storing carbon in the soil. By definition, below-ground biomass is the entire biomass of all live roots, often excluding fine roots of less than 2 mm diameter since they cannot be empirically distinguished from soil organic matters (Ravindranath & Ostwald, 2008). Below-ground biomass is an essential carbon pool for most land-use systems and vegetation types as it accounts for about 20 –24% of the total biomass whilst the highest proportion of root biomass happens in the top 30 cm of the soil surface (De Deyn, Cornelissen, & Bardgett, 2008). Thus, the concentration of carbon in soil has an effect on the above and below ground forest production. According to Schimel (1995), soils in the forest ecosystem accumulates the largest quantity of soil organic carbon, more than 1500 pg carbon or approximately two times as much as carbon in the air, and more than two and a half times carbon in plant structure.

Soil organic carbon pool plays a vital role in productivity and sustainable use of soils of tropical forest ecosystems through the control of cation exchange capacity, soil structure, water holding capacity, nutrient retention, resistance against erosion and availability and buffering against sudden fluctuations in soil pH. Soil-vegetation carbon pool ratio ranges from 0.9 to 1.2 and increases with increase in latitude (Lai, 2004). Soils contain carbon in both organic (oxidized carbon) and inorganic (non-oxidized carbon) forms. Total carbon is therefore the sum of the two forms of carbon. Soil organic carbon (SOC) is the carbon occurring in the soil organic matter (SOM) while inorganic carbon is present as various minerals and salts from weathered bedrock. On average SOC constitutes about 58 % of SOM mass (Corsi, Friedrich, Kassam, Pisante, & de Moraes Sá, 2012). SOC is an important determinant of soil function.

In the global carbon cycle, CO_2 is exchanged between the atmosphere and terrestrial ecosystems through processes of photosynthesis, respiration, decomposition and changes in the use and cover of the land. Soil respiration has lately received extensive attention in the literature, since it is not only a factor that affects net ecosystem carbon budgets, but also an essential component of global change (Ryan & Law, 2005; Trumbore, 2006). Soil respiration is the main source of CO_2 released by terrestrial ecosystems and is the second largest flux of carbon between the atmosphere and ecosystems (Raich & Schlesinger, 1992).

An estimation shows that soil respiration adds about 75×10^{15} g C year^{-1} to the world carbon budget yearly and second only to oceans in the magnitude of the gross CO_2 flux to the atmosphere (Schlesinger & Andrews, 2000). As a major influx between the atmosphere and biosphere, little changes in its rate may change the annual carbon sink of terrestrial ecosystems leading to a sweeping increase in the atmospheric concentration of carbon dioxide.

Soil respiration can be grouped into two that is, autotrophic respiration which is gotten from plant root production and root-associated organisms, such as mycorrhizae and heterotrophic respiration which comes from the microbial breakdown of organic matter. Both the autotrophic respiration and the heterotrophic respiration are extremely responsive for changes in environmental conditions, such as soil temperature (Rustad et al., 2001), soil water content (Davidson, Verchot, Cattanio, Ackerman, & Carvalho, 2000), soil nutrient availability (Raich & Tufekcioglu, 2000), and plant photosynthetic rates (Högberg et al., 2001). Although many factors influence soil respiration, nevertheless many studies have shown temperature and soil moisture are the two major factors that influences soil respiration (Rayment & Jarvis, 2000). Soil respiration is affected by temperature and soil moisture more strongly than by any other known factors. Overall, soil respiration increases with temperature and varies parabolically with soil moisture (Howard & Howard, 1993). In most ecosystems, soil respiration unswervingly is dependent on the availability of easily degradable carbon compounds and nutrients, yet all ecosystems are potentially vulnerable to the impacts of stressors.

Widespread degradation of the forests as a result of rampant anthropogenic activities threatens the long-term sustainability of water bodies. Watershed ecosystem services are vital for many communities; however, the forest ecosystem is subjected to all kinds of stress with the main stressors emanating from agriculture, mining and logging. Mining either by underground or by opencast methods damages the water regime and consequently causes a decrease in the general availability of water in and around the mining areas. Chemicals such as cyanide and mercury released during the mining process cause water pollution once discharged into water bodies. Aside chemicals, huge quantities of solids are suspended in the water column, particularly in alluvial dredging. Suspended solids may affect biological resources in various ways. ARFR is nationally regarded as an essential area since its hills are headwaters for three rivers, the Ayensu, Densu and Birim Rivers. ARFR is an essential watershed and it holds, clean and discharge freshwater that supports a rich biodiversity and also provides clean water to millions of Ghanaians. In spite of this, ARFR faces serious pollution downstream from water bodies along whose banks mining takes place, as a result of improper mining practices. Most affected is the Birim River which suffers from pervasive sediment loading (Conservation International-Ghana, 2002). Stressors affect hill slope run-off, ground water recharge, stream flow, sediment loads, stream turbidity and general water quality within river systems (Smerdon, Redding, & Beckers, 2009; Keim, Tromp-van Meerveld, & McDonnell, 2006; deVries & Simmers, 2002).

ARFR is an outstandingly important forest for both national and global biodiversity conservation due to its role as a headwaters of major river systems in Ghana and adequately connected to support viable populations of the species in the West Africa sub-region. The national and global significant biodiversity nature of the ARFR shows that there is a need for policy attention to avert the continuous depletion of the forest.

Statement of the Problem

Tropical forest ecosystems play particularly important role in global carbon budget (Dixon et al., 1994; Field, Behrenfeld, Randerson, & Falkowski, 1998). The tropical forests store on average close to 50% more carbon than forest outside the tropics. Large trees characterize an essential proportion of the forest biomass (Martinelli et al., 2000) thus data for generic allometric equations are tilted towards large trees, although many forest stresses affect mostly small trees (Villela, Trindade, Luiz, Aragão & Da Gama, 2006). Presently, the use of the generalized equations for the validity of all tree stands is not very reliable. For example, the generalized equations provided by (Chave et al. (2005) and Brown (2005) are valid for trees up to a diameter at breast height (dbh) of 152 and 148 cm, respectively. The equation cannot account for trees with (dbh) of 152 cm. The tropical evergreen forest consists of a diversity of tree species per unit area, with more than 300 tree species per hectare being found in a tropical forest (Gibbs, Brown, Niles, & Foley, 2007). In evaluating the forest carbon stocks and biomass change, it is essential to reflect on the different ranges of tree species, their distribution, the variation of wood density and volume. For instance, Fearnside (1997) opined that the best situation is to match both density and volume information recognized at species level.

Accurate estimation of forest biomass is crucial for many applications. In spite of this, very few allometric equations exist for sub-Saharan Africa whilst none of the trees used by Chave et al. (2005) to develop generalized allometric equations was from African forests. Zianis and Mencuccini (2004) described 279 allometric equations for all the continents with the exception of Africa. There have been few attempts to estimate tree biomass for sub-Saharan Africa using already existing and incomplete allometric equations. Furthermore, there is paucity of data on carbon stocks in the forests of Ghana.

Currently, experimental partitioning of soil respiration conducted has achieved varied results using different methods. Various reasons have been ascribed to these different results, key among them is that partitioning under experimental treatments is complicated as a result of differential responses of the diverse components to environmental factors which specially related to climate change (Kirschbaum M. U., 1995; Trumbore, Chadwick, & Amundson, 1996; Giardina & Ryan, 2000), and strong co-variations among factors (Davidson, Belk, & Boone, 1998). Other studies have used manipulative field experiments to investigate the effect of climate change and how it interact to alter soil respiration (Wan, Norby, Ledford et al., 2007). These studies have not been able to separate soil respiration into its components without significantly disrupting the soil (Hanson, Edwards, Garten, & Andrews, 2000). Modeling or quantifying changes in soil respiration under different environmental settings is critical for further exploring the mechanisms underlying changes in soil respiration due to climate change.

Soil environments are complex, hence to date, many studies have resorted on empirical models (Subke, Inglima, & Cotrufo, 2006), which are usually based on the strong correlations between temperature (some adding soil moisture) and soil respiration (Janssens & Pilegaard, 2003). Process-based models are needed to advance our quantitative understanding of soil respiration by taking into account additional factors, such as soil water content and root growth (Ryan & Law, 2005; Hibbard, Law, Reichstein, & Sulzman, 2005). On the other hand, soil respiration is composed of respiration from both roots and microbes, and some studies have reported the relationship between soil respiration and the underground environment such as root biomass (Fang, Moncrieff, Gholz, & Clark, 1998; Søe & Buchmann, 2005) and soil microbial biomass (Neergaard, Porter, & Gorissen, 2002). Nevertheless, there are few data on soil respiration and the environment for forests and plantations especially in Ghana (Logah, Safo, Quansah, & Danso, 2010). Understanding the determinant for soil respiration is vital for predicting changes in this variable caused by changes in land use. Despite the numerous studies on soil respiration rates, few studies have compared soil respiration in tropical evergreen forest ecosystems in Ghana, specifically in the Atewa upland forest range.

Harper et al., (2005) stated that nearly 80% reduction of fundamental forests between 1950 and 2000 are credited to the intense pressure from habitat destruction and natural resource extraction, even though fewer studies have focused on understanding stressors because it is particularly challenging when their effect cannot be predicted based on evidence from stressor studies (Breitburg, Seitzinger, & Sanders, 1999; Folt, Chen, Moore, & Burnaford, 1999). Other researchers have suggested that deforestation and forest degradation by over-exploitation are some of the objectives for the establishment of protected areas, however, only 11.5% of the world's natural vegetation is currently protected (Rodrigues et al., 2004). Although there are about 21 protected areas in Ghana, increasing evidence indicates that the rate of environmental degradation has increased in recent times (Gyasi et al., 1995), with previously rich forests being converted to savanna woodland and existing savanna woodlands into near desert (Hawthorne & Abu Juam, Forest protection in Ghana, Forest Conservation Series., 1995). It has been estimated that Ghana's high forest area of 8.2 million hectares at the turn of last century had dwindled to about 1.7 million hectares by the mid-1980s (Hall J. B., Conservation of forest in Ghana., 1987), about one million hectares by the mid-1990s (Forest Services Division, 1996) and it depletes by 65,000 hectares every year.

Purpose of the Study

The purpose of this ecological study is to investigate the carbon sequestration, soil, water and stressors in an upland evergreen tropical forest of ARFR. The study will assess the condition of biological systems to confirm that environmental quality is adequate and also define the existing ecological problem whilst taking into account the existing condition of the plant species in ARFR. In addition, the purpose of the study is to predict the effect of anthropogenic stressors on vegetation in ARFR, provide early warning of conditions which, if left unchecked will result in significant damage to human quality of life as well as detect ecological damage before it is of a magnitude that is unacceptable and avert crises.

This study is much interested in the terrestrial sequestration, since terrestrial sequestration is on how plants capture CO_2 from the atmosphere and then storing it as carbon in the stems and roots of the plants as well as in the soil. Other information that would be garnered includes soil water content, temperature, and the above and below ground biomass. The data collection process would incorporate an in-depth experimental measurement in an effort to ascertain the satus of carbon sequestration, soil and water in an upland evergreen tropical forest of ARFR.

Research Objectives

Main Objective

The main objective of the study was to assess the impacts of anthropogenic activities defined by stressor indicators on the vegetation, soil and water quality in the ARFR.

Specific Objectives

1. Determine the vegetation characteristics in the study area
2. Estimate the above and below ground carbon stock and assess human-induced stress impacts on the vegetation.
3. Estimate the effects of anthropogenic activities on soil and vegetation characteristics in the ARFR.
4. Evaluate the intensity of human induced stress on the vegetation quality through land use changes between 1986 and 2016.

5. Determine the physicochemical, biological and heavy metals impacts of anthropogenic activities on water quality in the Birim River.

Research Questions

The research which was conducted on the ARFR was underpinned by the following questions:

1. What are the vegetation charcteristics of the study area?
2. How does human-induced stress impact on the above and below ground carbon stock?
3. What are the effects of anthropogenic activities on soil and vegetation characteristics in the ARFR?
4. What is the intensity of human induced stress on vegetation quality through land use changes between 1986 and 2016?
5. How does anthropogenic activities impact on the physicochemical, biological and heavy metals on water quality?

Significance of the Study

The benefits of this research include:

1. An increased understanding of the terrestrial carbon cycle and consequently the global carbon debate.
2. A contribution to the database required for inventories on climate change.
3. Summarisation of Ghana's terrestrial carbon sinks in ARFR to help determine the role of forests in Ghana's carbon balance.

4. Improvement upon the precision and reliability of biomass estimation of individual tree or trees in stands in ARFR.
5. Provision of reference data for the research, teaching and national policy formulation on ecological issues.
6. Filling the gaps in the Ghanaian literature on ecological studies on carbon sequestration, water and stressors.

Study Hypothesis

The hypothesis of the study is presented below as;

For objective one:

Null hypothesis (H_O)

There are no changes in the vegetation characteristics of the ARFR.

Alternative hypothesis (H_1)

There are changes in the vegetation characteristics of the ARFR.

For objective two:

Null hypothesis (H_O)

Above and below ground carbon stock and assess human-induced stress have no impacts on the vegetation in the ARFR.

Alternative hypothesis (H_1)

Above and below ground carbon stock and assess human-induced stress have impacts on the vegetation in the ARFR.

For objective three:

Null hypothesis (H_O)

Anthropogenic activities have no impacts on the soil and vegetation characteristics in the ARFR.

Alternative hypothesis (H_1)

Anthropogenic activities have impacts on the soil and vegetation characteristics in the ARFR.

For objective four:

Null hypothesis (H_O)

The intensity of human induced stress have no impacts on the vegetation quality through land use changes between 1986 and 2016 in the ARFR.

Alternative hypothesis (H_1)

The intensity of human induced stress have impacts on the vegetation quality through land use changes between 1986 and 2016 in the ARFR.

For objective five:

Null hypothesis (H_O)

Physicochemical, biological and heavy metals have no impacts on the on water resource quality in the ARFR.

Alternative hypothesis (H_1)

Physicochemical, biological and heavy metals have impacts on the on water quality in the ARFR.

Delimitation

The study focusses on a tropical forest in Ghana, specifically, the ARFR. The ARFR comprises of two blocks - the Atewa Range and the Atewa Range Extension reserves. The two reserves form a contiguous block between latitudes 5°58' to 6°20' North and longitudes 0°31' to 0°41' West. Atewa Range, covering an area of 23,662 ha, falls within the East Akyem District Assembly under Begoro Forest District, whereas Atewa Range Extension covers an area of 26,312 ha and falls within the West Akyem District Assembly under Kade Forest District. Within the Atewa Forest, the study examined the highly stressed, moderately stressed and the non-stressed part of the ARFR. The study further examined carbon sequestration by measuring the dbh; identification of species in order to estimate above ground biomass; soil analysis to determine carbon stock in the soil; measurement of soil respiration; using Normalised Differential Vegetation Index (NDVI) technique to map the effect of anthropogenic stress; and conducting surface water analysis to measure the conductivity, dissolved oxygen, pH, turbidity, temperature and total dissolved solids.

Limitation

A significant limitation of this study was the measurement of the dbh of the tree with reduced precision. This is because the stems of most trees are not precisely circular in nature or cross-section, hence the measurement of the stem diameter will usually be a biased measurement of the accurate size of the stem. This limitation also arises because of the measurement or estimation technique. The researcher adopted several measures to overcome these limitations. In cases where the tree had climbers around it, the researcher with the help of some research assistants passed the measuring tape underneath the climbers and also cleared any debris. Where the initial method proves impossible then the tape was held up to the climber and the diameter estimated. Additionally, where the tree had a buttress at 1.3 m, the stem was measured at a point 50 cm above the top of the buttress and the point of measurement recorded. Finally, on the field where trees have deformity at 1.3 m height, measurement was taken 2 cm above the deformity and recorded at the point of measurement.

The Alkali Absorption-Method may underestimate actual soil respiration because the CO_2, absorption efficiency of the alkali solution in a dish or jar decreases when the solution is neutralized (Freijer & Bouten, 1991). To reduce the underestimation of soil respiration a smaller beaker containing 25 ml of 5 M NaOH solution was placed under the cylinders and the cylinder was shielded from direct sunlight by covering it with aluminum foil. After 24 hours all beakers were retrieved and refrigerated at 0-3^0C for transport to the laboratory.

Despite the limits to the scope of the research, it could still be argued that this research design is quite ambitious. In addition, deadlines had to be met and to avoid breach of contract and right to privacy, participants' informed consent was sought and contract drawn to avoid disappointment throughout the project. Where possible, the contracts were in the form of an information sheet and signed declaration of consent. Where this was not practically possible or sensible – for example with illiterate participants – the information sheet was communicated verbally by the field assistant and verbal consent was gained. The above processes outlined how anonymity was ensured, the right to withdraw and confidentiality.

Conceptual Framework

The conceptual framework for the study begins with the type of anthropogenic stressors (mining, logging and farming) identified in the study area. These stressors' negatively impact the forest structure and composition, water resource quality and the soil characteristics in the study area as indicated in Figure 1.

These stressors dynamic and changes in climate affect the forest in a negative manner, though few studies have identified some stressors to have a positive impact on the forest especially the soil (von Oheimb, et al., 2014). The research therefore focuses on the negative impact of the stressors on the ecosystem in the Atewa Forest Reserve Range. The impact of these stressors is measurable in both qualitative and quantitative terms hence the focus of this study to examine and investigate quantitatively the impact of the stressors on the forest. Measuring the impact of stressors on the forest considered three effect dynamics, that is, plant diversity, soil characteristics and water quality.

The plant diversity as used in this study was geared towards examination of the impact of the stressors on the variability and dominance of plant species. It was further separated into two main domains, the impacts of stressors on the amount of carbon sequestrated by plant species and the general composition. Under the carbon stock evaluations, the impact of the stressors will be felt in the above ground and below ground carbon stock. The impact on species composition was assessed from the species richness and the species dominance.

Regarding the impact of the stressors on the water quality, physico-chemical characteristic as presented in the conceptual framework were determined. The water assessment was based on the quantity or magnitude of parameters of the water with respect to turbidity, total dissolved solids the conductivity, pH, and temperature etc. Also, heavy metals concentrations were examined for elements including cadmium, iron, copper, zinc, arsenic, lead and mercury.

The last measureable impacts of the stressor was on the soil characteristics. The effects on the soil was categorized into two; the soil respiration impacts and the soil structural effects. The soil respiration impacts focused on the flux of carbon dioxide from the soil whereas the soil structural impacts considered soil texture and nutrient characteristics. In totality, the conceptual framework shows the relationships stressors have on plants, water and the soil found in the study area.

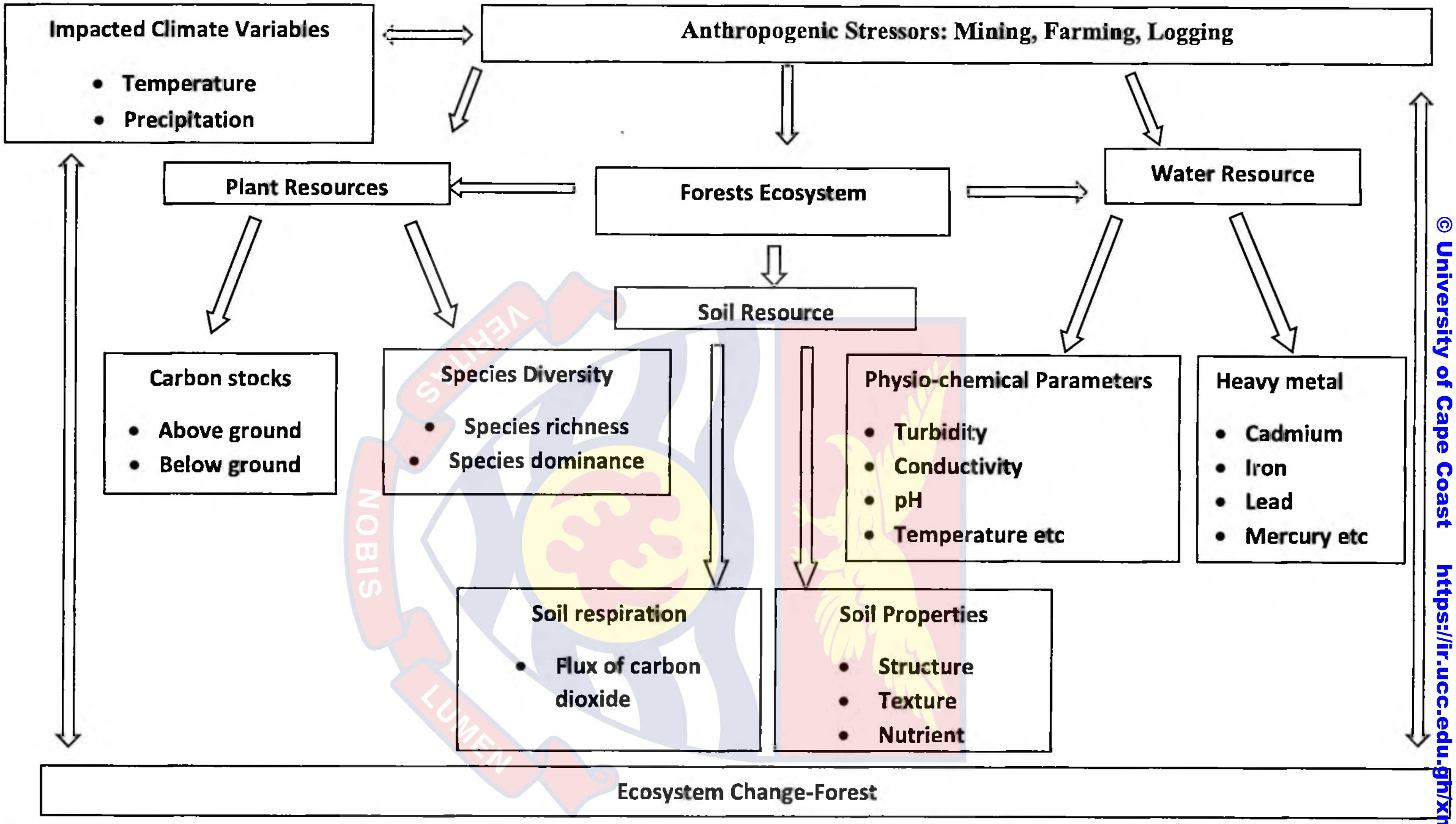

Figure 1: Conceptual Framework for the interaction of Anthropogenic Stressors and Forest Ecosystem

Definitions of Terms

Anthropogenic stressors: Human led activities that causes a change in the original environment.

Aboveground biomass: The aboveground biomass which constitute the amount of organic matter found in living and dead plant materials

Belowground biomass: is made up of all the live roots plays a vital role in the carbon cycle by storing and transferring carbon in the soil

Biodiversity: Constitute variety and variability of plant and animal life in a particular habitat which are considered to be important and valuable.

Carbon sequestration: Carbon sequestration is defined as the process of capturing and the long term storage of the atmospheric carbon dioxide (CO_2)

Forest Reserve: Is an area of forest set asid or designated and preserved by government where human activities are excluded in order to capture element of biodiversity.

Soil respiration: Is a measure of the carbon dioxide released from the soil by microbe decompositing soil organic matter and from the respiration of plant roots.

Vegetation: It is the assemblage of plant species and the ground cover they provide in a particular area.

Water quality: Refers to the chemical, physical and biological charactersitics of water with respect to its suitability for a particular purpose.

Organisation of the Study

The thesis is structured into six chapters. Chapter one of this thesis give an introduction to the study, highlights such relevant aspect as: background to the study, statement of the problem, purpose, objectives of the study, hypothesis and the significance of the study. Chapter two provides the theoretical and empirical underpinning for the study. Chapter three gives a description of the study area and the technique employed in data collection are presented. The research methodology for empirical analysis is also presented in chapter three. The findings of the study are presented in chapter four. Chapter five interprets the findings in relation to the literature reviewed. Chapter six contains summary, conclusions and recommendations based on the empirical results of the study.

CHAPTER TWO

LITERATURE REVIEW

Introduction

This chapter presents the relevant theoretical and empirical literature that are reviewed in the study. The literature was reviewed to address thematic areas of the research which include determination of the vegetation characteristics, carbon sequestration and assessment of anthropogenic stressors (mining, farming, and logging) impacts on the vegetation. In terms of the vegetation review, various types of forest structure, composition, and dynamics were considered. Estimation of the effects of anthropogenic impacts on soil characteristics in relation to vegetation characteristics. The rest are evaluation of the intensity of human induced stress on vegetation quality between 1986 and 2016, whereas with the issue of water quality the physiochemical parameters (turbidity total dissolved solids, pH, conductivity, and temperature), bacteriological quality and heavy metals (Iron, lead, zinc and cadmium) were deliberated on. This chapter concludes with a conceptual framework linking stressors to ecosystem dynamics and vulnerability, and the mechanisms which link these components.

The Concept of Environment and Ecology

The environment may be largely seen as the surrounding of an organism and consists mainly of three components or domains, thus, air (atmosphere), water (hydrosphere) and land (lithosphere) (Cunningham & Cunningham, 2006; Manjunath, 2007). The three components converge at a common platform on the surface of the earth called the biosphere where there are interactions of energy

and matter continuously (Manjunath, 2007). The biosphere which is characterized by plants, animals and non-living constituents including mineral resources have over the years been impacted largely by another component i.e human beings. The assemblage of all the organisms belonging to the biosphere interacting among themselves as well as with the physical environments forms ecological systems or ecosystems.

Ecosystems, however, have three major components namely; abiotic components including the climate; biotic components and the source of energy in the form of light and heat. The abiotic components are made up of both inorganic compounds (carbon dioxide, water, minerals, oxygen etc.) and organic compounds (Carbohydrates, protein, lipids etc) whereas the biotic component is usually comprised of the various species of flora and fauna as well as microbes which aid in many biological and chemical processes within the environment. Usually an equilibrium is observed to exist between the components of the ecosystem, however, recent developments by human kind have resulted in disturbance in the equilibrium affecting the ecological balance which according to Chapman and Reiss (1992) is a kind of stability or persistence observed amongst living organisms and their environment. The study however of the interactions of organisms with their environment which informs their distribution, and abundance and the systems surrounding them is referred to as Ecology.

Classifications of Ecosystems

Ecosystems are largely classified as terrestrial which comprise of forest and grassland ecosystems among others and aquatic ecosystems which comprise of marine, fresh water, estuarine and wetlands ecosystems (Cunningham & Cunningham, 2006; Manjunath, 2007). The classification of ecosystems is largely based on the presence and absence as well as the dominance of specific characteristics including tree populations, water, topography, region as well as the most prevalent climatic conditions experienced in the area. For example, an ecosystem is classified as forest ecosystems based on the population of trees covering the land area which according to the Food and Agriculture Organization (FAO) must be up to 10% or more (FAO, 2012). Further, an ecosystem may merit the status of being aquatic ecosystem based on some degree of water condition cover portions or the whole land area in question.

Vegetation Characteristics

Global Forest Cover and Biodiversity

Numerous forest exists mostly across the equator and other regions of the globe including South and Central America, Africa, Southeast Asia and some Pacific Islands etc. About 422 billion metric tons of above ground forests are known to exist with a quarter of the proportion found in South America (Cunningham & Cunningham, 2006). With about 3.9 billion ha of land area made up of woodlands, thorn scrub, Savanna as well as closed canopy forests, the largest forest areas could be found in Europe including Russia's vast boreal forest. The largest tropical forests however are found in South America's

Amazon basin. Although Africa has a significant percentage of the global forest cover, the highest annual rates of forest disturbance through anthropogenic means occur in there.

Tropical forests usually found where rainfall is abundant and over 200 cm per year and under warm to hot temperatures like other forest types provide great support through ecological services provision, biodiversity sustainability and the control of many climatic and biological cycles. Regarding biodiversity advantages, forests have variabilities in flora and fauna species due to favorable conditions for habitat establishment, food supply systems, nutrient availability and recycling as well as continuous water supply and replenishments etc.

Majority of the world's diversity in terms of flora and fauna is largely found near the equator especially in tropical forests and coral reefs. According to Cunnigham and Cunningham (2006) approximately 10 – 15 % of all biodiversity lives in North America and Europe whereas a significant percentage as well may be found in the tropical forest of Africa. Africa including Ghana is largely losing its biodiversity to anthropogenic activities including mining, farming and logging among others. In Ghana alone, recent activities of mining in forest area for gold and other mineral resources including the study area is on the increase and causing losses to the flora and fauna which in time past provided benefits including food, medicine, habitat for ecosystem survival as well as protection of water bodies such as the Birim and the Densu Rivers.

Forest Ecosystems and Their Significance

Forests are large areas covered mainly by trees and underground growth consisting of living and non-living components with the trees forming the ecological producers and processors through the process of photosynthesis (Manjunath, 2007). According to the FAO of the United Nations, a forest may be defined as an area where trees cover 10 percent or more of the land area (Cunningham & Cunningham, 2006). Forests are among the ecosystems largely disturbed by human activities due to their provision of valuable products including lumber, paper pulp and games that are important for human survival (Cunningham & Cunningham, 2006). Aside their direct benefits to humans, they play significant roles in regulating climate, habitat provision for biodiversity, air purification, water runoff control and a large ecological service (Manjunath, 2007; Cunningham & Cunningham, 2006). The trees form the vital sink for the sequestration of carbon dioxide from the atmosphere and the release of oxygen for other metabolic processes in other organisms. According to Chapman and Reiss (1992), beside the function of producers, trees in forest environment provide shelter for diverse animals, birds and plants which aid in biodiversity sustenance. Usually, areas with moderate-to-high yearly rainfall amounts are sheltered by forest depending on the location and other environmental conditions such as temperature which inform the type of flora. However, based on locations, forests may be classified as tropical, temperate deciduous and coniferous or boreal.

Tropical forests and their Importance

Generally, tropical rainforests are mostly characterized by high tree species diversity, even though large differences are observed at various regions

(Steege, 2000). The structure and species diversity of this type of forests make them the most complex ecosystem as they are made up of evergreen broadleaved trees which flourish in low humidity altitudes between 100 north and 100 south of the equator as well as under high temperature (Yeshitela, 2008). Earlier statistics however indicate that, despite a coverage of merely 6% of Earth's land surface, tropical rainforests harbour approximately half the world's biodiversity (Yeshitela, 2008). They are mostly found in the Southeast Asia, Central and Western Africa and Central and South America with those in Central and West Africa, Southeast Asia and Latin America containing approximately 18%, 25% and 56% respectively of the total world flora and fauna diversities (Whitmore, 1998).

According to Stephens et al. (2007), African tropical rainforests like other forests play essential roles in environmental sustainability and socio-economic development. Amongst the environmental benefits they mentioned included the role as a carbon sink for sequestration of carbon dioxide and provider of ecosystem services including housing of biodiversity. Despite these benefits, tropical rainforests especially those in sub-Saharan Africa has over the years seen significant changes due to land use activities which are destroying remaining standing forest (Laporte et al., 2007; Hansen et al., 2008). This in a way hamper the ability of the resource to be used as a mitigation tool through carbon dioxide sequestration at both regional and global levels (Houghton & Hackler, 2006). Emissions of carbon from Land use change in sub-Saharan Africa, toward climate change and other problems confronting the world today. For example, tropical rainforests in Congo basin which continue westwards into Gabon and Cameroon, which double as the habitat for a large mass of rainforest species (Houghton & Hackler, 2006) in recent times have been faced with numerus anthropogenic threats including farming, logging and construction amongst others.

Forests in Ghana

Ghana has remarkable and important forests of both local and international importance. The country has her west terrain made up of many heavily forested hills with most forest area occupying sections of the Upper Guinea forest ecosystem region of West Africa (Allotey, 2007). The Upper Guinea forest being the 25th biologically richest and most endangered terrestrial eco-regions in the world is made up of remarkably diverse ecological communities providing refuge to copious endemic species (Allotey, 2007). In spite of its importance to conservation and environmental sustainability, human activities within the forest have led to forest fragmentation which is threatening the variability of biodiversity over the years.

Ghana is endowed with rich forest resources which are significant for the country's development and future prosperity, despite increased degradation of these rich resources (Dixon, Perry, Vanderklein, & Hiol Hiol, 1996; Boone, Nadelhoffer, Canary, & Kaye, 1998). According to Siaw (2001) the total forest zone of Ghana account for about 40% of the total land area and occupying some estimated 81,342 km^2. Of this volume, 17,845 km^2 has been identified to be under reservation, 1,980 km^2 under game production reserves, 4,323 km^2 under protection, and 11,590 km^2 under other forms of management systems (Allotey, 2007). Over the years, the area of virgin forests has decreased to less than 25% of its original value in the early 1990s and with current fragmented pieces covering between 20 to 524 km^2 (Allotey, 2007).

Studies have shown that undisturbed forests serve as habitats for abundant biodiversity (Alpert, 1993), protection of fragile soils (FAO, 2012), and as sources of scarce water resources (Glantz & Katz, 1985). In spite of these, it has been observed that, biodiversity in few reserved portions of forests are in very good state whilst that of off-reserves and other portions of the confined area are in deplorable conditions (Brockington, 2007). Bakarr et al. (2001), however, noted that there has been a decline in the density, diversity and species richness in most reserved forest area as a result of anthropogenic land usage which puts a huge pressure on forest biodiversity. Series of human activities including settlement citing, mining, agriculture production systems have been identified as major consequences of pressure on forest biodiversity (De Bie, 2000) following population increases and its corresponding demand for accommodation, food and raw materials leading to serious degradation (Hawthorne & Jongkinds, 2006).

In addition, the misuse of fire, misapplication of chemicals and over-harvesting of genetic resources have over the years led to the misplacement of many forests and their habitats. Forest resources are also being overexploited through logging and the excessive cutting of trees for firewood and energy sources (Agyarko, 2007). As a result, Ghanaian forests areas have been characterised by excessive harvesting of logs resulting in total reduction in the standing volumes of species, species depletion and loss of biodiversity (Agyarko, 2007). This situation, according to Allotey (2007) has resulted in about 14% of the total permanent forest reserves in the country to be reclassified as forests without adequate cover.

The Atewa Range Forest

Significant amongst existing forests in Ghana is the Atewa forest which covers almost 75% of upland evergreen forests (McCullough, Alonso, Naskrecki, Wright, & Osei-Owusu, 2007). Apart from the highly degraded Tano Offin Forest Reserves, the Atewa Forest Reserve is the only upland evergreen forest reserve in Ghana which is a repository of forests, biodiversity wildlife, and water (Abu-Juam et al. 2003). The Atewa holds abundant, widespread and rare species, owing to its unique floristic upland evergreen forest composition which is created by the misty conditions on top of the plateaus which favour usual flora (Swaine, Hall, & Alexander, 1987) Tree population dynamics at Kade, Ghana. A total of seven hundred and sixty-five (765) species of vascular plants including 106 Upper Guinea endemics have been recorded in the Atewa Forest. Specifically, the area houses 323 tree species; 155 liane and climber species; 83 shrub species; 68 herbaceous species; 22 epiphytes; and 5 kind of grasses (Schep et al., 2016). Included in this list is 5 Black Star species (Hawthorne & Jongkind. 2006) as well as over 150 different ferns species of which one (i.e *Cyathea manniana*) is not found in any place in the world (IUCN, 2007).

Natural (Forest) Resource Management

Forest management involves the planning of sustainable harvesting with regeneration in mind (Cunningham & Saigo, 2005). At the beginning of the twentieth century, the earth had approximately 5 billion hectares (38.5% of the land area) of its surface covered with forest, however current estimation places the occupancy at 2.9 billion hectares (22%) following gaps in management of the resource (Manjunath, 2007). Developing countries have been identified to be losing some 6.5% of their forest per decades following exploitation of forest and minerals resources to address both social and economic problems. As a result, efficient and sustainable management of forests in these areas are critical given the significance of the resource in both local and global climate and environment health. According to Cunningham and Cunningham (2006), about a quarter of the current global forests are under management for wood production through scientific means whereas the rest are not really under strict management. This calls for attention as these may still undermine efforts to regulate exploitation and utilization of forest resource products, the pivot for most exploitations.

To preserve the rich biodiversity that forests contain and to preserve wildlife habitats, it is essential to safeguard the forests through some of the underneath steps; avoid major projects in forest area, avoid laying power transmission lines through forests, avoidance of mining activities in forest, minimization of dependence on timber as raw materials for industries and construction activities, encouragement of the use of liquefied petroleum gas (LPG) rather than fuel woods mostly in rural areas and the establishment of animal husbandry to support domestic animal utilization in food, the planting of tree species around water bodies to avoid evaporation and the proper enforcement of law governing forest resource management and utilization.

Governance Principles for Natural Resource Management

Environmental degradation caused by anthropogenic and natural stressors have increased the debate on the management of natural resource. An essential subset of the sustainability difficulties is frequently defined by the term natural resource management (NRM), which is associated with activities such as forestry, agriculture, and water allocation. NRM is a collective action problem requiring actors such as governments, communities, farmers and nongovernmental organizations whose aim is to integrate their activities so that improvements in the condition of natural resources can be achieved (Head & Ryan, 2004). Attempt to manage forest resources, have been dominated by technical concerns at the detriment of understanding natural resource management issues and its governance holistically.

Governance as used in natural NRM refers to ‘‘the interactions among structures, processes and traditions that determine how power and responsibilities are exercised, how decisions are taken, and how citizens or other stakeholders have their say’’ (Graham, Amos, & Plumptre, 2003). More recently the notion of ‘good governance’ has emerged as a conceptual framework for assessing reforms (Doornbos, 2001). Although there is substantial ambiguity over the term ‘good governance’, there is a widely held view that it is a critical factor in determining the success of resource management and development project. The notion of good governance has been associated with the state-centric system, where the central government plays an essential role in determining how natural resource are allocated. In addition, most academic treatment of governance has somewhat framed the issue as an analysis of formal and informal institutions, usually framed against the relative power of state-market-civil society (Wood, 2001). Although vast swathe of empirical literature exists on good governance, it is easy to overstate the differences in definition (Kaufmann & Kraay, 2008). Furthermore, as Batterbury and Fernando (2006) indicated that “the global, economic and state-centric focus of the governance initiatives has led to a relative neglect of natural resources and local actors in governance reforms". The challenges associated with the concept of good governance have led to the search of more effective approaches to natural resource management.

Privatisation and decentralisation is prominent in the management of many natural resources across the world. The decentralisation debate has been re-invigorated with the introduction of REDD+ (Phelps, Webb, & Agrawal, 2010). Although, privatisation and decentralisation has led to an increase participation of the community in the decision making due to private sector participation, the concept still lacks in certain quarters. The decentralisation and privatisation concept despite being central to donors' good governance agenda, many decentralisation and privatisation reforms have failed to account for corruption, exacerbated sectorial separation, increased the complexity of resource management contexts, complicated debates over land tenure, and have led to an increase of conflicts over resources, particularly at the local level (O'Callaghan, 2010; Forsyth & Sikor, 2013; Ravikumar, Andersson, & Larson, 2013). (Brugha & Varvasovszky, 2000).

The decentralisation and privatisation application to resource management has in many cases resulted in precipitated conflict concerning the relinquishing of central state power to local authorities and private actors, and coinciding entitlements to resources (Yasmi, Anshari, Komarudin, & Alqadri, 2006; Berry, 2004). The diverse approaches to understanding the genealogy of these conflicts and the resolution of these conflicts in the context of natural resource is characterised by the interconnected physical and social systems. Temporal trade-offs, ambiguous property rights and incompatible competing land uses have normally been applied, sometimes indirectly in stakeholder analysis (Yasmi, Anshari, Komarudin, & Alqadri, 2006; Brugha & Varvasovszky, 2000). Notwithstanding the range of approaches, stakeholder analyses are viewed from two approaches, that is, determining which stakeholders are important, and how much influence (power) stakeholders have (Grimble & Wellard, 1997).

In order to achieve a balanced approach, the power, authority and legitimacy concept is pursued in many poises. Weber's dictionary defines power as the probability that one actor within a relationship will be able to carry out his will despite resistance, regardless of the basis on which this probability rests. Authority is normally understood as the 'legitimate power' (Yasmi et al., 2006)

Despite the considerable nuances this conception of power provides, it is also instructive to consider more post-structural notions of power, particularly when considering resource-use debates in the context of climate change and development. The global discourse on sustainable resource management, especially concerning climate change, is dominated by science. Evidently, science cannot be approached using the same analytical frame as the state, community, or other stakeholder groups, and therefore, an appreciation of more Foucauldian conceptions of power is required. The Foucauldian view suggests discourses as the operation of power; struggles over discourses are often simply power struggles (Humphreys, 2009). The scientific discourse over global sustainable development problems has considerable power in influencing resource-use.

It is important, however, not to neglect the power of science to produce knowledge and provide solutions to resource dilemmas, but rather to understand that science itself belongs to the 'circle of actors involved in governance processes', and for both social and natural scientists to 'reflect on their own roles in political decision making' (Görg, 2007). Developing a holistic understanding of natural resource conflicts requires integrating and balancing insights from both natural and social sciences, and reflecting on how these influence governance processes. The final section of this review brings together the themes raised so far and outlines a research agenda for examining mining, forests and governance of land-use conflict in Ghana.

Natural Resource Management and Environmental Regulatory Framework

Many of the sections on the natural resource and environmental regulatory framework were adopted from the "Ghana - Forest Investment Program (FIP) Plan". This comprehensive document focuses on the forest and land use and investment. The forestry sector of Ghana falls under the Ministry of Lands and Natural Resources and the Ministry of Environment, Science and Technology. The legal and policy framework include:

i. The 1994 Forest and Wildlife Policy (FWP) and the 1996 Forestry Development Master Plan: These policies for several years these policies served as guiding policies, in spite of this, it is relatively ineffective in stopping forest resource degradation, illegal logging and controlling illegal chainsaw operations.

ii. The 1994 FWP were reviewed in 2011, to allow for reform in the forestry sector. A section of this reform was directed at maximizing the contribution of the forestry sector, to climate change mitigation and adaptation. The aim of the revision of the policy was to remove the barriers of investments in forestry such as complexities of land ownership, tree tenure, weak infrastructure, forest encroachment, and weak implementation of legislative instruments.

iii. Environmental Policy of 1995: The country's first ever Environmental Policy was enacted in 1995. Like the above policy, the Environmental Policy was ineffective for reducing GHG emission and controlling deforestation, although it was effective in improving the performance of the environment. Notwithstanding the positives, the policy for environmental challenges such as pollution, urban congestion, loss of biodiversity, and climate change worsened.

iv. Revision of the 1995 Environmental Policy in 2000: The revision introduced the social transformation, long-term economic growth, poverty reduction and environmental sustainability. A crucial objective of the revised Environmental Policy was to reduce deforestation via the integration of climate change and Disaster Risk Reduction into National Development Policy formulation and planning processes. Climate change abatement actions included in this policy the operationalisation of the Comprehensive Mitigation Analysis Process (COMPAP) model among others. Tactlessly, the revised Environmental Policy (EP) of 2000 has been effective in achieving major levels of GHGs abatement and decrease in deforestation as a result of inadequate investments in the sector, implementation difficulties, poor attitudes, and ineffective enforcement of the policies, and lack of behaviour change from households, individuals, private and public sector institutions.

v. National Wildfire Policy (NWP) of 2006: This is touted as one of the most successful policies since wildfire is the single threat to the integrity of forests in Ghana. Despite this, an annual average of US$24 million and 3% of Gross Domestic Product is lost from merchantable timber due to wildfire. The NWP was framed with the aim of supporting the Forest and Wildlife policy and it also takes cognizance of the failures of the past interventions, gender sensitive mechanisms, incorporated multi-sectoral and developed the essential structures and systems which will guarantee stakeholder participation in wildfire management.

vi. FASDEP I and FASDEP II: The major causal agent of deforestation in Ghana is agricultural expansion. The first Food and Agriculture Sector Development Policy (FASDEP) was developed in 2002 as strategies to modernise agricultural sector activities in order to increase food and cash crop production. As a result of the challenges associated with FASDEP I, in 2006, FASDEP II was promulgated to encourage environmental sustainability in agricultural production systems.

Legislation

With the aim of strengthening the objectives under the 1994 Forest and Wildlife Policy and 1996 Forestry Development Master Plan, the Timber Resources Management Act, 1997 (Act 547), Timber Resources Management (Amendment) Act, 2002 (Act 617) and Timber Resources Management Regulations, 1997 (LI 1649) were enacted by the Government of Ghana. All this legislation aimed at the proficient resource allocation and avoidance of illegal logging and chainsaw lumbering but have generally been ineffective due to the institutional weaknesses and poor governance structures. This was largely as a result of the weak and the institutional autonomous link to the provisions of the legislation under the Forestry Commission Act, 1999 (Act 571)

Besides, the Timber Resources Management Act, 2002 (Act 617) made it unlawful for farmers and other users of rural land to harvest any forest tree for commercial or domestic reason, even if the tree is growing on their land, and banned logging without erstwhile authorisation from concerned individuals or groups. Consequently, the rural land users are not permitted to profit economically from timber resources growing on their personal land. This created an incentive to keeping high value species on-farm.

Under the Timber Resources Act (Act 547) 1992, farmers and land owners have lawful rights to grow trees. When a Timber Utilisation Contract is granted off-reserve, the holder is mandated to engross in a Social Responsibility Agreement with affected societies in the planned area and the Contract should comprise a proportion of stumpage fees and reimbursement for damaged crops (Timber Resource Management Regulations (L.I. 1649) 1998 and Economic Plants Protection Act (AFRCD 47 1979). Indiscreetly, the implementation mechanisms to back this legislation have been weak.

Carbon Stock

Carbon dynamics in tropical forest

Forest in their pre-agricultural state are estimated to cover about 57 million km^2 (Goldewijk, 2001) and containing *ca.* 500 PgC in living biomass as well as an additional 700 PgC in soil organic matter. Considering various changes in many ecosystems however, Retallack (2001) and Meehl et al. (2007) envisaged the end of the 21th century to observe carbon dioxide concentrations reaching levels which are unprecedented for at least 20 million years. Le Quere et al. (2013) opined that the global forest is changing faster than expected hence an increase in the global carbon cycle of the carbon sink in the terrestrial biosphere. With forest area having carbon usually stored in live biomass with lesser amounts stored in coarse woody debris (Malhi et al., 2009; Sierra et al., 2007), carbon sink reaching approximately 3 Gt by the middle part of the last decade is expected as the carbon uptake over terrestrial land mass in both tropical and extra-tropical latitudes is on the increase (Stephens et al., 2007).

In view of the above observations, Dixon et al. (1994) posited that about 50 % of the total carbon obtained in terrestrial systems are stored in aboveground biomass whilst 50 % is stored in the top 1 m of the soil in the tropical rainforest. That notwithstanding, difference have been recorded among sites, for which the tropical forest in African has been identified to have thrice as much carbon in the aboveground biomass as in soil to 1 m depth (Djomo, Knohl, & Gravenhorst, 2011). The Peruvian montane forest for example, also has twice as much carbon in soil as in aboveground biomass (Gibbon et al., 2010). The story isn't different in China with the tropical seasonal forests (Lu et al., 2010) and a selectively logged lowland dipterocarp forest in Sabah and Malaysia (Huang, et al., 2012). A secondary forest in the Philippines had 50 % more carbon in the aboveground biomass than in the soil (Lasco, 2002).

The differences observed in carbon storage among tropical forests are an indication of the variation in a number of factors, such as tree community composition, successional stage, stressors history, climate, and soil fertility (Wei et al., 2013). Secondary forests are of specific importance, assuming that the proportion of tropical forests that are secondary is predictable to continue to rise due to increasing anthropogenic pressure and the movement of populations towards urban centres (Thomlinson, Serrano, Lopez, Aide, & Zimmerman, 1996; Wright, 2005). This however implies that carbon stocks and uptake in secondary forests may be increasingly important for global tropical forest carbon budgets.

Forests as a Tool for Carbon Sequestration

Carbon sequestration is defined as the process of capturing and the long-term storage of the atmospheric carbon dioxide (CO_2) (Sedjo & Sohngen, 2012). According to Lal (2004), carbon sequestration may refer to the transfer of atmospheric CO_2 into long-lived pools and securely storing it for future remittance. The sequestration of carbon may refer also to the artificial or natural process through which carbon dioxide is either taken or removed from the atmosphere and stored in a liquid or solid form (Hongqun, 2008). In terms of soils, carbon sequestration is associated with increasing soil inorganic and organic carbon stock through careful land use and recommended management practices. With reference to forest area, Malhi et al. (2006) indicated that, carbon is predominantly stored in the soil and in live biomass, with lesser quantities stored in coarse woody debris. Further, earlier study by Dixon et al. (1994) showed that in tropical forests, an equal percentage (about 50 %) of the total carbon is stored in the top one (1) meter of the soil and in the aboveground biomass (50 %). In spite of this, there are differences in carbon sequestration among the various sites based on numerous factors. For instance, the moist tropical forest of Africa having three times carbon quantities in the aboveground biomass (Djomo et al., 2011) compared to the Peruvian montane forest which has twice (Gibbon et al., 2010) may be attributed to factors including topographic and number of trees available. The differences in the carbon storage between the various tropical forests is a reflection of the variation in the number of factors including tree composition, successional stage, stressors of the history, soil fertility and climate amongst others (Malhi, Baldocchi, & Jarvis, The carbon balance of tropical, temperate and boreal forests., 1999).

The estimation of the aboveground biomass of the total carbon stocks in most tropical forest are underestimated (Sierra et al., 2007). A more specific and accurate estimation of the carbon stored in the aboveground and belowground part of the tree, including the litter and fallen leaves enhance the comprehension of the carbon dynamic as well as the total carbon stock estimation (Sierra et al., 2007). Furthermore, the striking biomass accumulation within the tropical rain forest may possibly result in the expectation that the ecosystem carries on to accumulate carbon, which might be the case for individual trees located within the forest but not true for the entire forest. Schlesinger and Melack (1981) indicated that in mature rainforests, the decomposition rates of carbon are nearly the same as the carbon fixation rates. The only exception is the cases of the exportation of organic acids and the precipitation in estuaries (Brown et al., 1993). Researching into the carbon fixation rates, Nabuurs et al. (2008) designed a model (CO_2Fix) to predict the carbon budget of forest ecosystems as a standard for the quantification of carbon sequestration in afforestation projects, and sustainable forest management, including agroforestry systems. They projected that a 5-year-old coffee plantation with *E. poeppigiana* and *C. alliodora* could sequester 5.3$MgCha^{-1}$. The model projected that this agroforestry system would sequester C steadily, reaching 183.5$MgCha^{-1}$ in its 100th year.

According to Watson et al. (2000), carbon stocks for smallholder agroforestry systems in the tropics sequester C ranging from 1.5 to 3.5MgCha^{-1} year^{-1} with a tripling of C stocks in 20-year-period to about 70 MgCha^{-1} year^{-1}. Such potential of agroforestry systems is largely observed in terms of the trees and in the soil. Tropical forests have also been documented for their potential to store carbon in biomass and aid improve the rising level of CO_2. Comparing Ghana's forest carbon sequestration to that of the entire continent, the forest in Ghana is observed to contain a biomass of about 1,132 megatonnes of carbon (1 MtC = 10^6 tonnes) against 60 gigatonnes of carbon for Africa forest (1 GtC = 10^9 tonnes) (FAO, 2005). Carbon mapping statistics of Ghana further indicates that, the country's terrestrial carbon stocks may be projected to 2.04Gt in totality. This according to the Forestry Commission is made up of 1.7Gt carbon in above- and below-ground biomass and approximately 0.34Gt in soils to 1m depth. That notwithstanding, Ghana has an uneven distribution of both biomass and soil carbon with high biomass carbon density cover of 6% in approximately 2% of the nation's total land area.

Biomass in Forest Systems

Biomass refers to the weight or total quantity of organisms in a given area or volume (Field, Behrenfeld, Randerson, & Falkowski, 1998) including forest ecosystems. According to Grace (2004) the responses of the tropical forest to changes in the anthropogenic or natural environment are an important subject in ecology. More essentially, Houghton (2003) also suggests that the long-term forest inventories are very beneficial and appropriated means of evaluating the magnitude of carbon fluxes between the atmosphere and the aboveground forest ecosystems. The establishment of guidelines and principles for setting up permanent plots, censuring trees properly (Condit, 1998), and for estimating aboveground biomass stocks (Chave et al., 2005) are however crucial. The IPCC in that respect has identified five carbon pools of terrestrial ecosystem which are of significance in ecological study as much as biomass are concerned. The carbon pools include the above-ground biomass, below-ground biomass, woody debris, dead mass of litter and soil organic matter (Eggleston, Buendia, Miwa, Ngara & Tanabe, 2006). All these pools may be linked to a common process of photosynthesis from plants.

Carbon dioxide fixed by plants through photosynthesis is transported across the various major carbon pools with majority carbon component constituted in the above-ground biomass of trees forming associated with the terrestrial forest ecosystem (Ravindranath & Ostwald, 2008). Changes however in forest ecosystem as a result of deforestation and degradation directly affect the above-ground biomass which plays essential roles in the carbon cycle by transporting and storing carbon in the soil. Although the woody debris and dead mass of litter are not a vital component of the carbon pool, they contribute some fractions of forest carbon stocks worth mentioning (Ravindranath & Ostwald, 2008). Aside these, soil organic matter may be considered as essential contributor to the total forest carbon stocks (Lai, 2004).

Categorization of Biomass

Biomass may be categorized based on the position from where they are obtained. By this, they are classified as Aboveground (biomass found above the soil surface) or Belowground (biomass found underneath the soil surface). The aboveground biomass, which constitutes the amount of organic matter found in living and dead plant materials are an essential part of the carbon cycle found in the forest ecosystems since it aids in the provision of both long and short-term carbon sequestration. Studies have indicated that secondary forest and primary forest alike have quick rates of aboveground biomass production particular during the early stages of successions. According to Geider et al. (Geider, Delucia, Falkowski, & Woodward, 2001) tropical forests are key portions of the terrestrial carbon cycle contributing 26% of global carbon storage in biomass and soils although estimations of the values of the carbon sequestration in tropical forests are lacking in many areas. Chave et al. (2005) partly attribute this lacking estimated value of carbon sequestration to the scarcity of suitable allometric models for predicting biomass in a species-rich tropical ecosystem. In spite of the above, the greatest challenges in the measure of carbon stock in many tropical forests are the lack of standard modelling converting tree measurements to aboveground biomass estimates. Earlier studies however by Golley & Lieth (1972) have shown that terrestrial carbon cycling circulation principally depends on the contribution of tropical forests, whilst the measurement and quantification of these contributions have proven to be very difficult in spite of the over four decades of active research in these areas.

Regarding the Belowground Biomass, a total global carbon in soils ranging from 1500 and 2000 Gtons is documented (Scharlemann, Tanner, Hiederer, & Kapos, 2014) with the bulk of it in terrestrial pools stored in soil (Janzen, 2004). Belowground biomass largely made up of all the live roots in the soil plays vital roles in carbon cycle by storing and transferring carbon in the soil from one place to another (Eggleston, Buendia, Miwa, Ngara & Tanabe, 2006). According to Ravindranath and Ostwald (2008) however, dead mass of litter and woody debris do not constitute a major carbon pool since they are simply a smaller fraction of the carbon stocks of forests. Soil organic matter may also be considered a vital contributor to the total carbon stocks of most forests (Lal, 2003), after the above-ground biomass (Ravindranath & Ostwald, 2008). In all, empirical studies on the estimation of carbon stock in tropical forest show wide variation attributable to the uncertainty associated with the estimation of carbon flux (Saatchi et al., 2011)

Biomass Estimation in Forest Ecosystems

Allometric equations are arguably the most extensively used technique for estimating forest biomass. The purposes of allometric equations are to assess the biomass and possibly the carbon stocks of forests by applying it to the forest inventory data (Vargas-Larreta et al., 2017). However, the generalized biomass predictions of Allometric equations have been extensively applied to varied tree species and forest type globally (Chung-Wang & Ceulemans, 2004; Navár, 2009). Over the years, allometric equations have helped in the establishment of relationship between diverse physical parameters of trees such as the height of the tree trunk, diameter at breast height, total height of trees, tree species, and crown diameter etc (Shrestha & Wynne, 2012).

The past decade has witnessed increasing interest among researchers on not merely the quantification of the biomass of forest ecosystems using allometric equations but the potential carbon fixation as well (Schulp et al., 2008). For example, Schulp et al. (2008) and Federici et al. (2007) used allometric equations to show that traditional carbon estimation methodologies tend to under estimate or overestimate the real carbon stocks in different forest types. Brown, Gillespie and Lugo (1989) used allometric regression equations to estimate the above-ground biomass for individual trees in tropical forests as a function of the total height, diameter at breast height and wood density (Brown, Gillespie, & Lugo, 1989).

In comparing some available allometric equations on biomass and carbon stock estimations, Brown & Gurevitch (2005) biomass equation may be said to have accounted for only the live trees excluding standing dead trees and fallen litter whilst Nelson et al. (1999) using the Amazon forest develop mixed-species and species-specific allometric relationships for estimating total above-ground dry weight using eight abundant secondary forest tree species. Chave et al. (2005) on the other hand developed generalised allometric equations using 2410 globally pan tropical trees which excludes tress from Africa (Djomo, Knohl & Gravenhorst, 2011). Studies using the allometric equations have been seen to yield different results according to Henry (2010) who indicated that, incorrect choice of equations may be a major factor in arriving at results with errors margin of more than 40% when estimating above ground biomass. Maniatis (2010) also suggested that the varied results in most cases have led to the persistence of debates among scientific communities over the best and accurate technique for estimating biomass.

Impact of stressors on vegetation and soil characteristics

Environmental and Ecological Impacts of Human Activities (Stressors)

By definition, a stressor may be considered as an environmental factor that detrimentally affects a population or ecosystem property (Darling & Cote, 2008). An ecological stressor however, describes any physical, chemical and biological constraints on the productivity of species and development of ecosystems (Orcutt & Nilsen, 2000) Stressors occur naturally through environmental factors or as a result of activities of humans which negatively affect individuals, populations, communities or ecosystems and are believed to be the reason for species variation within tropical forests (Laidlaw, Kitching, Small, & Stork, 2007).

Earlier research have shown that the structure, co-existence of species and composition of forests are influenced by numerous factors (Barlow, Peres, Lagan, & Haugaasen, 2003). Four vital theories used to explain this coexistence is the Janzen-Connell hypothesis, recruitment limitation, niche differentiation, and the intermediate stressors (stressor) hypothesis (Ricklefs & Schluter, 1993). Other theories such as the regeneration and gap dynamics are important components of the four other theories (Barlow et al., 2003). It is hypothesized that one of the main causes of biodiversity loss in forest ecosystems is the changes observed in the environment at large. Owing to this, plants and animals known to be sensitive to fluctuations in environmental factors or stressors originating on global scale but manifesting on a local scale may exist based on conditions in their localities. These conditions may further be classified as Physical stressors including extreme conditions of temperature and hydrologic changes as well as habitat alteration or destruction. Physical stressors may also be associated with changes in climate as may be seen currently in the release of 70 million tons of carbon dioxide (CO_2) per day resulting in atmosphere changes (Kannan et al., 1997). Chemical stressors include a variety of inorganic and organic substances mostly chemicals in nature which usually may result in secondary stressors conditions. Also known are biological and anthropogenic stressors which usually affect ecosystem functioning through changes in biodiversity especially when ecosystem processes (e.g., primary production) are maintained by only a few species (Tilman, 1999). As a result of biological stressors through accelerating rate of biological impoverishment, many ecosystems may be rendered incapable of compensating for the loss of biodiversity and thereby reducing resilience to environmental change (Scheffer, 1998). Stressors may alter the successional pattern (Doyle, 1981), composition, diversity and the structure of forests (Busing, 1995). However, Stressors in some ecosystems may help regulate the diversity, production and drives evolution.

In the wake of the ever increasing stressors of ecosystems by human activities, the transformation of the natural forests to agriculture has led to a reduction in ecosystem function including carbon sequestration and storage due to removal of tree populations (Arets, 2005). Ghana has lost roughly 80% of its forest trees and habitat since the 1920s (Cleaver, 1992) with Atewa currently representing one-third of the remaining closed forest in the Eastern Region (Mayaux, Bartholomé, Fritz, & Belward, 2004) due to anthropogenic stressors. Dixon et al. (1996) indicated that between 1970 and 1990, an estimated 1.3% of the Ghanaian forest was lost each year as a result of harvesting and degradation.

Natural and Anthropogenic Stressors

Stressors may occur naturally or may be induced by anthropogenic activities in the form of hurricanes, droughts, floods, fires, mining, logging and farming etc. However, the suppression of natural stressors such as fires and floods may usually affect biological systems including forests also some species have some form of adaptation to periodic stressors. In some cases, seeds may germinate only after exposure to the high temperatures from fires which influences the vegetation composition and structure in most forests' vegetation. According to Wright and Bailey (1982) the structure and composition of the forest are largely influenced by fire regimes characterised by six components namely; frequency, size, intensity, seasonality, type and severity.

Fire frequency affects ecosystems through terminating individuals' life cycles whilst fire size determines landscape patchiness and the distance for regeneration (Veblen, Baker, Montenegro, & Swetnam, 2003). Fire intensity referring to the amount of energy released during a fire, vary greatly depending on the fuel type and loading, topography, meteorological influences and characteristics of previous stressors (Veblen, Baker, Montenegro & Swetnam, 2003). Usually, seasons of the year in which fire occur are dependent on successional trajectories on which ecosystems embark after fire (Veblen, Baker, Montenegro & Swetnam, 2003). The time of year further affects the fire intensity through differences in surface and crown fuel moisture contents (Veblen, Baker, Montenegro & Swetnam, 2003). That notwithstanding, the seasonal phenological state of plants which are burned during fire events determine the characteristics of vegetative and the eventual effect on the structure of post-fire ecosystems and landscapes (Littell, Peterson, Riley, Liu, & Luce, 2016). With regards to Fire type, references are made with respect to crown, surface and ground fires, which are largely controlled by fire intensity and fuel characteristics structure, load and moisture (Littell, Peterson, Riley & Luce, 2016).

Since the early 1980s, there have been concerns over the loss of species as a result of human activities (Wilson, 1988; Dobkin, 1992). Loss of species is usually documented as a global phenomenon. However, the negative impact of human activities on species has been revealed mainly on much smaller spatial scales (Wickham, Wu, & Bradford, 1995). Anthropogenic changes to the biosphere and the atmospheric system implies that all ecosystems on earth are currently being affected by the activities of humans. Whereas absolute deforestation is physically palpable, other understated processes, such as surface fires and hunting, also affect forests in ways that are less evident to the casual observer (Malhi & Phillips, 2004).

With Stressors generally inducing tolerance in species, Steffen et al. (2004) indicated that, manifold anthropogenic stressors have aggregated impact on changes taking place in ecosystem and biodiversity function. According to Kneitel and Chase (2004), stressors in particular may be anticipated to exert complex interactive effect on ecosystem given the ubiquitous nature of ecological trade-offs. The interactions among diverse stressors inconsiderately may not easily be accounted for and/or modelled since they produce net impacts that either fall below or exceed their predictable additive effects (Folt et al., 1999).

Anthropogenic stressors in forest ecosystems are numerous, pervasive throughout and reduce the diversity across forest ecosystems (Nowacki & Abrams, 2008). Largely amongst human-induced stressors or anthropogenic stressors in forest ecosystems are farming (agriculture), mining of mineral resources, logging of timber species and settlement establishments etc.

Mining as a Form of Anthropogenic Stressor

Mining is an essential source of income to the economies of many nations, most especially the Ghanaian economy. It is an essential contributor to the Gross Domestic Product (GDP) of many nations. In spite of the above, mining is a vital anthropogenic stressor in many forest areas in Ghana as it is gradually leading to the destruction of the vegetation cover of the land. Its activities lead to the destruction of habitats of fauna and flora, changes in hydrology, topography and landscape stability (Boateng, 2009). Mining activities adversely affect land use and land cover as extraction methods employed in the sector i.e open-cast mining and surface mining over the centuries have negatively impacted ecosystem services and functions.

The major mining technique adopted by miners in Africa and the study area (ARFR) is the open cast mining method. This method has over the years negatively impacted the physical, biological and hydrological environments (Schep et al., 2016) and gradually degrading most forest vegetation. The major difficulty in addressing this form of stress caused by mining activities lays on local and national unwillingness and conditions of poverty and poor resource management practices. The open cast mining as practiced in the Atewa Forest Reserve and most areas removes the top layer of the soil in order to get to ores underneath the earth and hence resulting in soil erosion as well as pollution from the dumping of mining waste on soil surfaces and water bodies. Further, erosions from these sources have the potential of significantly loading sediments in water bodies during severe storm and rainfall. Also mining activities can eliminate both above and below ground biomass of the entire forest ecosystem if not managed properly (Schep et al., 2016). In all, the total removal of the forested areas forms the utmost ecologically destruction established through the open cast type of mining approach especially in tropical forests. According to Bansah, Yalley, & Dumakor-Dupey (2016), the open-cast mining method is the most environmental destructive method although it is the most inexpensive mining method. The method is extensively used because the mineral seams are closer to the surface, making it easier to dig the mineral directly out of the ground (Bansah, Yalley & Dumakor-Dupey, 2016).

As most mining activities leave vegetation areas bare after clearing, the activitiy recognised as a significant threat to conservation of biodiversity (Adjei, 2007). Earlier studies by Noble et al. (1996) estimates that about 40% of global terrestrial vegetation have been substituted for mineral exploration, exploitation, and infrastructural developments. An estimated 22,000 hectares of existing tropical forest cover in Ghana, however, are annually lost due to mining and other anthropogenic stressors (Hawthorne & Abu Juam, Forest protection in Ghana, Forest Conservation Series, 1995). Apart from mining activities exposing the top soil to high temperatures, the soil nutrients needed for vegetation growth are depleted as a result of the clearing of the land (Lu, Moran, & Mausel, 2002). This results in the destruction of essential ecological processes and promoting forest and habitat fragmentation as well as the formation of smaller habitat patches (Saunders et al., 1991).

Farming (Agriculture) as a Form of Anthropogenic Stressor

A decrease of global forest cover is directly linked to human history and the dawn of agricultural revolution about 8000 years ago (Malhi, Meir, & Brown, 2002). By this, approximately 17% of global forest area had been lost by 1700 coupled with industrial revolution leading to the intensification of human alteration to biosphere which resulted in some 30% loss of original forest area (Goldewijk, 2001). The loss of these vegetation types had also contributed to some 45% increase in atmospheric CO_2 the year 1850 following the conversion (Goldewijk, 2001). In recent times also, the increases in rates of crop production and grasslands expansion as a result of higher crop productivity and grain yield (Tubiello, et al., 1999) have caused the conversion of forest zones to production fields. Projections however foresee global agroforestry increases in the near future.

The cultivation of forest areas for agricultural purposes dates back to several thousands of years which brought about the domestication of plant and animal (Williams et al., 2008). Current practices in the sector according to Solomon et al. (2007) point to a desire for the cultivation of virgin forests with very fertile soils which as a result leads to the loss of soil organic carbon and other important nutrients. The soil organic carbon losses in cultivated tropical forests is mostly 1 meter in depth and increases from 15 to 40% within 2–3 years of cultivation (Ingram & Fernandes, 2001). Since the 1980s, more forest lands have been cleared for both cash crop and food crop production for export and domestic use while the past four or more decades have seen millions of hectares of virgin forest cleared and burnt for various forms of agricultural endeavours (Pearce & Watford, 1993).

Numerous diversities of flora and fauna in forest reserves have been lost through the activities of smallholder farming in most parts of the world (Water Resources Commission, 2012). This has been the result of most smallholder farmers using limited resources for the cultivation of food crop than plant trees which usually take longer to yield and hence affecting farmers' investments. Although this source of forest degradation is large, it is not seen because of the smaller sizes of land usage, a collection of them causes great depletion of forest trees and their corresponding soil carbon pool. The soil degradation and erosion in most cleared forest vegetation greatly affect the flux and long-term storage of C in the terrestrial biosphere (Dixon et al., 1996). It is, however, envisaged that agro-forestry approach which keeps some of the forest trees on farms as an ecological system play an essential role in the global carbon cycle as it contributes approximately 12% of the world terrestrial carbon (Dixon et al., 1996). The incessant harvest of crops and other products in agroforestry systems, notwithstanding the deterioration in the fertility of the soil may be insignificant in this type of systems. This may be attributed to abundant pruning and litter biomass which replenish the soil in addition to decayed roots which contribute to the improvement of soil physical and chemical properties as well.

The combination of trees on farms affects the carbon stocks differently than in forest land management system or typical cropland (Zhang et al., 2012). Trees in agroforestry systems make available a close-fitting coupling of nutrients and maintenance of the soil carbon pool compared to sole cropped areas (Zhang et al., 2012). Nonetheless, trees are more frequently harvested in these systems in comparison with a typical forest management program (Watson et al., 2000). Sánchez (2000) in that respect speculated that agroforestry systems could be superior to other land-uses at the farm, watershed, regional and global level due to the optimizing trade-offs between three variables; increased food production, poverty alleviation and environmental conservation. The systems could also be inferior to other land-use systems due to the inappropriateness of technologies, and the inability of accompanying policies to enable farmers establish the system as a carbon offset project (Sánchez, 2000).

Logging as a Form of Anthropogenic Stressor

Approximately 3 to 7 million animal and plant species are found in the tropical forest, making the resource the highest variety of life occurring anywhere else on earth (Wilson, 1988). Despite this important property, logging activities destroying the habitat of diverse butterflies, birds and mammals cannot be ruled out in most forests. In the absence of serious conservation processes, the population of these butterflies, birds and mammals might become extinct leading to a reduction in flora and fauna diversity in forest areas.

Logging activities may cause decreasing species diversity and eventual disappearance of forests (Abdullhadi & Sukardjo, 1981). As unrestrained logging has substantially influenced biodiversity conservation, species composition, forest structure, and the loss and fragmentation of forests (Foahom & Jonkers, 1992), numerous studies have recounted declines in large tree species after logging (Schep, et al., 2016) in recent times. In situations of minimum level of mechanization and relatively little incidental damage during extraction (Ganzhom, Ganzhorn, Abraham, Andriamanario, & Ramanajatov, 1990), there have been observations of deteriorations in over storey tree size, increased small-stemmed species, and a reduction in larger commercial species after logging events. In some cases, the overall number of tree species remains the same but species composition have changed in favour of pioneer species (Schep, et al., 2016). Usually, logging decreases the canopy cover and produces huge amounts of dead phytomass and litter fall providing fuel material which is susceptible to human-induced forest burning (Nepstad et al., 1999). In most instances, ignition sources from cattle pastures, commercial crops and slash-and-burn plots (Gascon, Williamson & Da Fonseca, 2000) are the common source for forest fires. In general, logging may be said to have prompt and unwavering effects on the composition and structure as it causes canopy openings which might lead regeneration problems (Parthasarathy, 2001).

Logging has over the years resulted in many environmental and ecosystem challenges in the area including the loss of forest products, erosion, flooding, pollution, loss of biological diversity, increasing rate of siltation, and the acceleration of extinction of flora and Fauna (Fuwape, 2001). Although the last official logging in the Atewa Forest Reserve was recorded in 1991, illegal logging still continues in restricted areas of the reserve. A recent estimate of logging activities in the reserve, however showed that there are as many as 500 chainsaw operators and approximately 2,500 young men working as operators and lumber carriers (Owusu, Jiagge, Adom, & Amponsah, 2013).

Other Anthropogenic Stressors and their Effects on Forest Ecosystems and Climate

One of the most essential question of the 21st century in ecology refers to how multiple stressors interact with the climate and the cumulative impact on the ecosystems (Crain, Kroeker, & Halpern, 2008). Climate has both direct and indirect effect on the forest ecosystems. Directly the climate may change the frequency and intensity associated with forest disturbance through agents such as, storms, insect outbreak, wildfires, and the occurrence of invasive species (Aber, et al., 2001). Precipitation, Temperature change, and the amount of carbon dioxide are major climate factors that affect the distribution and productivity of forest ecosystems. Furthermore, most predictions have indicated that climate would negatively affect future forest conditions by altering forest processes including plant photosynthesis and respiration (Aber, et al., 2001).

According to Schilling, Chan, Liu, and Zhang (2010) changes in climate together with anthropogenic stressors prevalence may cause changes in forest productivity, forest water resources sustainability, carbon sequestration and the way people relate to the forests through recreation.

Since stressors are integral and natural parts of forest ecosystems, they aid in the process of forest succession and the existence of some specific forest species which benefit from disturbed sites. In spite of these, when stressors exceed their natural level, they cause extreme changes in the structure and function of the forest (Ayres & Lombardero, 2000). In addition, the size, intensity, frequency, duration, seasonality and type of stressors usually depend on the climate (Schilling, Chan, Liu, & Zhang, 2010) prevailing in any forest environment. For example, an earlier empirical study by Renkin and Despain (1992) showed that the Yellowstone fire of 1988 in the United State of America which burned over 250 000 hectares of forest was linked to prolonged drought and high wind activity. In Ghana for instant, the dry seasons which are usually associated with bush and forest fires have resulted in the destruction of many forest vegetation and farm lands especially in the northern part of the country which records higher temperatures annually (Allotey, 2007).

Wildfires in most cases have been linked to climatic variability and the type of forests (Fauria & Johnson, 2008). Forests affect the climate in many ways since predicted climate changes are largely associated with increasing concentrations of atmospheric CO_2 emissions from deforestation (Houghton, Jenkins, & Ephraums, 1996). An estimated 25% of the increases in atmospheric CO_2 are linked with deforestation, indicating a strong relationship between forests vegetation and global climate change (Houghton et al., 1996) as the distribution of trees can affect precipitation patterns and the rate of carbon stored in trees or dead wood (Foley, et al., 1996).

Stressors and Their Effects on Soil Quality and Functions

Anthropogenic and natural stressors are historically a common feature in most tropical forest ecosystems affecting both floristic composition and soil quality as they leave lasting legacies or imprints that continue for generation in ecosystems (Foster et al., 2003). They alter the landscape structure, vegetation and soil properties as the usage of forest lands significantly change the soil composition and characteristics (Lauber, Strickland, Bradford, & Fierer, 2008). Forest land usage is largely noted as the main factor altering the plant species diversity and productivity as well as nitrogen (N) and carbon (C) cycling in forest areas (Cusack, Chadwick, Ladefoged, & Vitousek, 2013). According to von Oheimb et al., (2014) land-use intensification and land-use change are among the most significant stressors affecting forest diversity, community structure, and forest dynamics in many parts of the world.

Stressors in forest systems may negatively affect microbial structure and functionalities which may consequently affect the nutrient cycling rates (Potthast, Hamer, & Makeschin, 2012). For instance, clear cutting vegetation of forest areas may lead to soil carbon loss as a result of faster decomposition whereas nitrogen may be lost through nitrate leaching (Mo, et al., 2008). Also, greater amount of woody biomass is removed by clearing forest vegetation compared to forest damages due to natural fire events (Tinker & Knight, 2000) Usually, during burning through wildfire, soil temperatures reaching 100^{0}C result in the loss of soil organic carbon, after which decomposition is accelerated at the expense of carbon inputs (Osei-Owusu, 2016). According to Osei-Owusu

(2016) the losses observed in carbon through these means may have lasted for a period, between 17 and 50 years. Wildfires are known to negatively impact soil pH through base cations introduction. Agricultural stressors on the other hand affect the soil in three ways i.e through plowing, soil amendments, and crop removal. Plowing mostly get rid of re-sprouting shrubs (Motzkin, Patterson, & Foster, 1999) and reduces the organic matter as well as alter the spatial distribution of soil nutrients (Sauer & Meek, 2003). Soil amendments on the other hand may offset nitrogen losses, and increase soil phosphorus which may not persist for decades (Falkengren-Grerup, Brink, & Brunet, 2006).

Some studies have found some stressors such as fires, to have some positive and beneficial long-tern effect on soils in forest ecosystems in other regions. For example, von Oheimb et al., (2014) empirically found fire usage during farming in temperate climate to increase phosphorus content although the practice lowers soil carbon and nitrogen contents. According to Wallenstein and Hall (2012), the above observation may be explained by microbial adaptation and recovery under that condition which may play a vital role in the ecosystem responses. Sun et al. (2011) further indicated that the long-term effect of previous land-use decisions on soil microbial communities are essential for forecasting changes in ecosystem operations and services as re-growing of vegetation from clear cutting may reconstruct soil organic matter with the passage of time (Kim & Byrne, 2006).

Soil Organic Carbon and Soil Respiration in Forest Environments

Most empirical researches indicate a large proportion of terrestrial carbon pool to be found in soils (Spijker, Mol, & Van der Veen, 2011). According to Eswaran et al. (1993) global soil organic carbon pool is made up of 1500 Pg carbon, which is twice or thrice the quantity of carbon stock in vegetation. It is the main tank in nearly all ecosystems, as it helps in the interaction with the atmosphere although vegetation stores significantly less carbon (Oelbermanna, Voroney, & Gordon, 2004). Fluxes between soil organic carbon and the atmosphere is however negative (emission of CO_2) or positive (sequestration of CO_2) depending on the management practices adopted in the terrestrial ecosystem (Oelbermanna, Voroney & Gordon, 2004).

With regards to soil respiration (also known as soil carbon dioxide efflux), a key pathway when it comes to the global carbon cycling, there are indications of relationships between stressor conditions and the rate of soil respiration. According to Raich and Schlesinger (1992) the flux of carbon from soils to the atmosphere in the form of carbon dioxide may be estimated to have a magnitude of 68–100 Pg C/yr. Recent issues of soil respiration have been receiving widespread attention (Schimel, House, Hibbard, & Bousquest, 2001) as the process accounts for between 60 and 90% of the total ecosystem carbon emissions, compared to the anthropogenic CO_2 releases from burning fossil fuels and land-use change (Marlon, et al., 2008). According to Raich and Schlesinger (1992), soil respiration varies among diverse vegetation type as well as among major biome types since vegetation types are essential determinant of the respiration rate. They further explained that vegetation type and their environmental changes are more likely to lead to the modification of soil responses. Soil respiration or carbon dioxide efflux emanated from the soils is usually greater in all terrestrial-atmospheric carbon exchanges except in the case of gross photosynthesis (Raich & Schlesinger, 1992). Nearly 10% of the atmosphere's CO_2 goes through soils each year which may be equated to 10 times the CO_2 released from fossil fuel combustion (Raich, Potter, & Bhawagati, 2002).

Measurement of Soil Respiration

Soil respiration is considered a good estimator of overall biological activity since it has been proposed as a descriptor of soil quality (Doran & Parkin, 1996). Measuring soil CO_2 flux is important to accurately evaluate the effect of soil management practices on global warming and carbon cycling. Soil carbon modellers generally consider soil efflux as a function of soil temperature or a combination of soil temperature and moisture (Raich and Schlesinger, 1992; Davidson et al., 2006). However, there is no consensus in functional forms and parameterization in these models. The uncertainty is partly due to instrumentation and methods used to measure soil CO_2 production and efflux (Livingston & Hutchinson, 1995; Davidson et al., 2002). Although accurate prediction of soil CO_2 efflux is important for models of global carbon cycle, uncertainties in estimates exist due partly to methodological differences (Raich & Schlesinger, 1992) and variation in substrate availability, soil temperature and moisture (Xu & Qi, 2001; Davidson, Belk, & Boone, 1998). Despite these challenges a variety of methods exist to measure soil CO_2 efflux (Sullivan, et al., 2010). The alkali absorption method (AA-method) involve Carbon dioxide evolved from soil in a closed chamber as absorbed in a caustic solution (Bekku Y. , Koizumi, Oikawa, & Iwaki, 1997)

The AA-method has been used by many researchers because of its convenience and the ability to measure many points (Bekku Y. , Koizumi, Oikawa, & Iwaki, 1997). However, it has been suggested that the AA-method may underestimate actual soil respiration because the CO_2, absorption efficiency of the alkali solution in a dish or jar decreases when the solution is neutralized (Zhao & Wells, 1995). Bekku et al. (1997) modified this method, and proposed to use an alkali-soaked sponge disc instead of a dish to increase the surface area of the trapping solution and the CO_2 absorption efficiency. The open flow infra-red gas method (OF-method) whereby ambient air flows through a chamber, and CO_2 flux is calculated from the concentration difference between inlet- and outlet-air (Burba, et al., 2012). The closed chamber method (CC-method) involved CO_2 in a closed chamber which is sampled periodically and the efflux is computed from the rate of increase of CO_2, concentration in chamber (Bekku Y. S., Koizumi, Nakadai, & Iwaki, 1995)

Two of the most widely used techniques for the measurement of soil CO_2 efflux are those known as the closed dynamic chamber technique (Rochette, Desjardins, & Pattey, 1991) and closed static chamber technique (Smith & Stitt, 2007). Their difference lies in the presence or absence of air circulation. In dynamic closed chamber systems, air is circulated from the chamber to an IRGA and returned to the chamber, while the operation of closed static chambers consists of sealing a certain volume of atmosphere above the soil surface for a period of time to allow the gas to accumulate to a concentration that can be determined by gas chromatographic or infrared analysis (Conen & Smith, 1998).

The use of dynamic closed chambers is more recent and this method often requires the placement of collars in the soil and the area covered is usually very small: from 0.005 m^2 (Janssens et al., 2001) to 0.019 m^2 (Rochette et al., 1991). The method can also be subject to error from effects of stressors due to "edge effects". There are a number of so-called "chamber effects", that have an impact on the flux measurement. One example is the soil stressors from the insertion of the chamber into the soil and release of CO_2 from the compacted soil pores (Bain, et al., 2005). This effect can be overcome by leaving the chambers in place for some time before measurement takes place (Bain, et al., 2005). Also, closure of the chamber for the accumulation of gas produces alterations in soil temperature and moisture in the chamber, which consequently will cause changes in the CO_2 efflux (Rochette et al., 1991; Hutchinson and Livingston, 1993; Welles et al., 2001). This can be more pronounced in the closed static chamber method since the closure time can be up to the order of an hour. The effect is very small when the dynamic chamber method is used because of the quick sampling. However, deep insertion of the chamber into the soil can result in low estimates, particularly in forest environments (Anderson et al., 1983) because the chamber severs and isolates surface roots and prevents horizontal root growth into the chamber, thus altering CO_2 production in the soil (Sandor, 2010). Again, the quick measurement with a dynamic closed chamber minimises the artefacts caused by altering the CO_2 concentration gradient within the soil profile and between the soil atmosphere interface and the chamber headspace (Davidson et al., 2006) and by the lateral escape of the gas.

Errors associated with the radial diffusion of gas when the closed static chamber method is used, can be minimised with simple precautions, such as minimizing duration of the measurement, increasing the chamber height and radius and inserting the chamber walls down to the depth of gas production (Conen & Smith, 1998). Also, the closed static chamber method is currently the most common method for the measurement of other trace gases such as nitrous oxide (N_2O) and methane (CH_4) and has other advantages such as low cost of construction and easy installation and removal (Gaumont-Guay, Black, Griffis, & Barr, 2006) And its application under a wide range of conditions (Smith et al., 1995) make it a popular method. The use of closed static chambers can also inhibit pressure fluctuations associated with the turbulence in air movement over the soil surface (Gaumont-Guay, Black, Griffis, & Barr, 2006), but this problem does not occur with the use of dynamic closed chamber systems. Gaumont-Guay, Black, Griffis, and Barr (2006) proposed that a properly vented closed chamber prevents perturbation in mean air pressure. However, Conen and Smith (1998), after testing vented and non-vented chambers in field experiments, recommended the use of non-vented chambers for the measurement of trace gases. The closed static chamber method has sometimes been criticised for underestimating the soil CO_2 efflux at low flux rates and severely underestimating it at high flux rates, compared to the closed dynamic chamber method which has been shown to be more accurate for a wide range of flux rates (Janssens et al., 2001; Jensen, 1996). However, Rochette et al. (1991) found little differences in fluxes measured by either the closed dynamic or the static chamber method. Until one method is proven to best minimize artifacts when measuring soil CO_2 efflux, and is efficiently deployable, investigators will have to choose among a variety of available methods.

Relationship between Soil Respiration and Soil Temperature

Soil respiration is usually associated with soil temperature (Longdoz, Yernaux, & Aubinet, 2000). Carlyle & Than (1988) have indicated that the rate of soil respiration is principally dependent upon soil moisture and temperature conditions. Palmroth et al., (2005) also reported that the loss of temperature control and a reduction in the temperature sensitivity of soil respiration occur more especially during drought conditions. Further, Griffis, et al (2004) stated that soil temperature is the main variable accounting for seasonal variations of soil respiration, bole and ecosystem respiration but drought leads to a strong reduction in soil respiration. Thus, soil temperature is an important factor relating to the temporal variation in CO_2 efflux from soils and also describe as having an exponential effect on the soil (Lloyd & Taylor, 1994). Curiel-Yuste et al. (2003) have also indicated that at the seasonal time scale and when water is not limiting, soil respiration is strongly correlated with changes in soil temperature.

Guntiñas, Gil-Sotres, Leirós, & Trasar-Cepeda (2013) indicate that numerous studies have found a positive relationship between soil respiration and temperature. Also, soil respiration is sturdily influenced by soil temperature and most studies have shown that soil respiration and temperature display a significant exponential relationship (Guntiñas, Gil-Sotres, Leirós, & Trasar-Cepeda, 2013). For example, in a study on soil respiration and organic carbon by Fan, Yang and Han (2015) a significant and positive correlation was found between soil respiration rates and organic carbon, total nitrogen, and available phosphorous content in a forest system. Each of the sites which they investigated showed a significant exponential relationship between soil respiration and soil temperature measured at 5 cm depth and that explained 84 - 98% of the variation observed.

Relationship between Soil Respiration and Soil Moisture

The relationship between soil moisture and soil respiration has been proven to be dependent on the nature of soil and other environmental factors (Vincent, Shahriari, Lucot, Badot, & Epron, 2006). Some of the factors contributing to the variability include the biodiversity and water conditions in soils which have unique relationship with soil microbial activity (Paul et al., 2004). Factors such as soil texture, bulk density and the total pore space have also been revealed to influence this relationship (Thomsen, Schjonning, Jensen, Kristensen, & Christensen, 1999). According to Davidson & Janssens (2006), moisture limitation can subdue microbial activity, which could reduce the temperature sensitivity of heterotrophic respiration. Thus, soil moisture is an essential environmental factor affecting soil CO_2 efflux, although at varied sites the influence of moisture on the efflux may varies.

Soil carbon models have utilized soil moisture-respiration functions which theoretically represent an average response of microbial respiration to soil moisture content (Rodrigo, Recous, Neel, & Mary, 1997). It however, implies that soil moisture does not account for any possible variation in this relationship without microbial respiration. Furthermore, moisture function is usually developed and validated using soils from particular sites and as a result, may not be suitable for all soil types. Due to this limitation, very few studies have indicated that the variability in soil carbon budget predictions can be associated with the usage different moisture-respiration functions (Falloon, Jones, Ades, & Paul, 2011). The divergence however in simulations which is connected to the choice of moisture function selection is associated with nearly 4% of global carbon stocks (Fallon et al., 2011). Despite these observations, the actual uncertainty may be larger than reported since all the comparison function are based on average responses.

It has also been established undoubtedly that, the prominence of water content as a factor influencing soil respiration cannot be over looked as far as soil moisture and soil respiration are concerned. However, in field studies, the influence of additional factor i.e. temperature is usually more noticeable than the water effect, particularly in temperate and boreal regions. Davidson et al. (1998) postulated that the effects of water content and temperature were confounded in the soils of forest site (using New England temperature), where the winters are cool and wet and summers are warm with dry periods. Rates of soil respiration may increase between summer and winter not only because the soils become warm, but also because water content reduces from saturated conditions in the winter to near optimal water content in the early summer.

Relationship between Climate, Soil Respiration, Soil Temperature and Soil Moisture

Since the industrial revolution, there have been increases in the level of atmospheric concentration of carbon dioxide (CO_2) and other greenhouse gases (GHGs) leading to current climate change conditions. The changing climate simultaneously alters the soil moisture and temperature regimes which are vital determinant of soil respiration (Davidson et al., 2006). The changes are further related to higher atmospheric CO_2 concentration together with an upsurge in global temperatures (Costa & Foley, 1998) which are more likely to affect the carbon storage and net primary productivity of terrestrial ecosystems (Davidson et al., 2006). Although initially not accepted, it has generally been accepted that climate change is occurring, and the activities of humans are significantly a contributory factor (IPCC WG1, 2007). Climate change is revealed by changes in precipitation, temperature, and the length of the seasons (Smith et al., 2008) which in a long run affects forests through the physiological reaction of trees to climate variability. Changes in climate is also known to alter the trends in productivity and mortality as well as subsequent changes in forest succession.

Temperature is a major driver in the rate at which soil carbon is mineralized by microbes into carbon dioxide in forest systems (Cook & Orchard, 2008). According to Liu et al. (2009), temperature may be considered a key determinant of soil microbial activity in many tropical ecosystems. Although tropical forests are among the warmest of the terrestrial ecosystems, it is predicted to be among the first to display adverse temperature responses to the changing climate (Saxe, Cannell, Johnsen, Ryan, & Vourlitis, 2001). As forests form a third of global terrestrial net primary production (NPP), changes in the forest could strongly affect atmospheric CO_2 levels (Kirschbaum M. , 2000) and corresponding soil conditions.

Ecosystem responses to climate change is normally non-additive or nonlinear (Gill et al., 2002). Identifying these nonlinearities could decrease the uncertainties associated with climate change decision-making (Zhou, Weng & Luo, 2008) as far as forest management systems are concerned. Friedlingstein et al. (2003) examining the results from diverse models indicated that climatic warming will fast-track the discharge of carbon dioxide from soils, resulting in additional warming. However, the huge pool of carbon in the soil being susceptible to climatic warming together with the potential loss may intensify warming of the environment (Cox, Betts, Jones, Spall & Totterdell, 2000). Microclimates influenced by vegetation covers and the topography in mountainous and forest areas can affect soil respiration rate by limiting microsite factors such as soil temperature and soil water content (Roxy, Sumithranand, & Renuka, 2014). In desert ecosystems, however, global climate change is predicted to be linked with a rise in temperature and precipitation variability which may hypothetically aggravate aridity (Pendergrass, Knutti, Lehner, Deser, & Sanderson, 2017).

The sensitivity of soil respiration to temperature in the soil, is usually described by the Q_{10} model, a model factor by which soil respiration increases for every 10^0C increment in temperature (Lloyd & Taylor, 1994). According to Fan, Yang and Han (2015) the model shows that, soil temperature and moisture are better parameters for predicting the temporal variation of soil respiration rate. Wang, Zhu, Gao, Wang, & Zheng (2008) also in investigating the responses of soil respiration to soil temperature and soil moisture in China, observed that soil CO_2 efflux increases was strongly related to the two variables.

Land Use and Land Cover (LULC) Dynamics

The detected biophysical cover of the earth's surface, dubbed land-cover, is made of patterns that ensue as a result of series of natural and anthropogenic processes. On the other hand, land-use refers to human activity on the land, influenced by land-tenure factors, economic, political, cultural and historical (Rozenstein & Karnieli, 2011). Changes in LULC is an important driving force of changes in the Earth system and climate. Besides, its impact on GHG emissions, subtler changes in land and forest management and land use practices have significant influence on carbon sequestration (Schulp, Nabuurs, & Verburg, 2008) and land surface properties. Changes in land surface as a result of land use is directly related to changes in vegetation (Chapin, Mcguire, Randerson, & etal, 2000) which have vital impacts on the level of biodiversity, soil and water quality (Dunn, 2004). Anthropogenic actions are changing the terrestrial environment at exceptional magnitudes, rates, and spatial scales.

LULC stemming from human land uses epitomizes a major source of global environmental change.

Remote sensing which comprises information assembled through satellites and aerial photography is the commonest source of data on land cover. Radar actively emitted radiation or solar radiation is reflected from the surface of the earth from vegetation, soil, water and building to instruments that measure the intensity of different frequencies. Each type of surface reflects different frequencies. From these measurements, it is likely to make insinuations about the earth surface. There are numerous indices for emphasising vegetation-bearing areas on a remote sensing scene. The most common and widely used index is the NDVI (Gao, 1996). This is commonly applied to the global environmental and climatic change research and used to assess the relationship between the changes in vegetation growth rate and spectral variability (Bhandari, Kumar, & Singh, 2012).

Vegetation Measurement Using Normalized Difference Vegetation Index (NDVI)

NDVI is calculated as a ratio difference between measured canopy reflectance in the red and near infrared bands respectively (Hu, Ban, Zhang, Liu, & Zhuang, 2008). In other words, it is it calculated as the difference between the visible and near-infrared light reflected by vegetation. Thus, the NDVI is calculated with a normalised ratio ranging from -1 through 1, where increasing positive values signify increasing green vegetation and negative values signifies non-vegetated surface or bare ground features such as water, sand dunes, ice, snow, or clouds (Yacouba, Guangdao, & Xingping, 2010)

Most researchers have recorded the usage of NDVI for vegetation monitoring (Yang, Zhu, Zhao, Liu, & Tong, 2010), assessing the crop cover (El-Shikha, Waller, Hunsaker, Clarke, & Barnes, 2007), drought monitoring among others (Kwak, Lee, Kim, & Kim, 2013). Empirically, Meera, Parthiban and Nagaraj (2015) conducted a study in the Vellore District of India using NDVI. Assessing the vegetation change using remote sensing and GIS, Meera, Parthiban and Nagaraj (2015) found barren lands and forest or shrub lands cover types in the study area to decreased by 6% and 23% from 2001 to 2006 respectively, whereas built-up, water areas and agricultural land increased by about 4, 7and 19 % respectively.

In another study, Bhandari, Kumar, and Singh (2012) examined the method for analysing satellite image based on NDVI, employing the multi-spectral remote sensing data technique, on signature on vegetation index, land cover classification, among others. Their result showed that the percentage of vegetation, in the given study area of Jabalpur region was 32.1304% at NDVI threshold of 0.3, and that of water bodies were found to be about 7%. The simulation result of the study further revealed that the NDVI was highly useful in detecting the surface features while the vegetation analysis indicated that the NDVI was helpful and useful in situations of unfortunate natural disasters. Yacouba, Guangdao and Xingping (2010) assessed land use cover changes using NDVI in the counties of Puer and Simao and the Yunnan Province of China. They observed that barren land cover types and the forest or shrub land had decreased by about 23 % and 6% from 1990 to 1999 respectively. The decrease shows that the earlier year saw more degradation than the later years hence there is a decrease in degradation in the later years in China than in the earlier years.

Intensity Analysis

There is a close association between land cover and land use (Anteneh, Stellmacher, Zeleke, Mekuria, & Gebremariam, 2018). As indicated by Verburg (2009), the attributes of land covers are Earth's land surface and immediate subsurface, such as soil, topography, biota, built-up areas, and water. Conversions, therefore, implies the replacement of a cover type by another and are measured by a transition from a land-cover category to another (Anteneh et al., 2018). On the otherhand, land use involves humans exploit land cover and is made up of the method in which the biophysical characteristics of the land are treated and the main reasons for the manipulation (Lambin & Geist, 2008).

Land change that is noticed at any spatiotemporal scale comprises complex synergy with changes that are witnessed at other analytical scales (Anteneh et al., 2018). Anthropogenic effects and natural processes cause land changes that can have important biophysical, ecological, socioeconomic, and political consequences (Wu, Ye, Qi, & Zhang, 2013).

Intensity analysis is "a quantitatively summarized and cross-tabulated square transition matrix that is used to analyze maps of land categories from several points in time for a site" (Anteneh, et al., 2018, pp. 3). One matrix sums up the changes in each time interval and comprises the intensity of land transition procedures and likely explanations at three levels of detail: interval, category, and transition. This matrix aids in the comparison of the intensity of changes or observed rates with the uniform intensity of changes or a uniform rate that is likely to exist if the intensity of the changes were uniformly distributed across the whole spatial and temporal extent (Anteneh, et al., 2018, pp. 3).

Aldwaik and Pontius (2012) suggest that intensity analysis need to take into consideration all time steps (the interval, category and transition levels) together for a complete land-change analysis and assess various forms of land-change transitions makes intensity analysis a more influential and powerful method. Accordingly, "*interval level examines how the size and rate of change varies across time. For any particular time interval, the category level examines how the size and intensity of gross losses and gross gains in each category vary across categories. For any particular category, the transition level examines how the size and intensity of the category's transitions vary across the other categories that are available for that transition*" (John, et al., 2013, pp. 158).

Water Quality

Aquatic Ecosystems

Aquatic ecosystems have some free-standing water which covers some portions of land surface either by fast moving (rivers and streams) or relatively still water i.e. lakes and ponds (Chapman & Reiss, 1992). They occur in marine habitats, brackish estuaries, rivers, streams, lakes and ponds (Chapman & Reiss, 1992). Several aquatic ecosystem types exist including wetlands, floodland ecosystems etc. In all, the quality of the water component of aquatic ecosystems determines the kind of organisms that may inhabit those particular systems. The quality, however, refers to both the physical and chemical characteristics including temperature, acidity, turbidity, heavy metal composition, total dissolved solids, dissolved oxygen, organic matter and a host of other properties.

With respect to human uses of aquatic systems, again the quality characteristics of the system inform the choice of usage. For example, many rural people close to rivers depend on the water from the rivers for domestic use including cooking, drinking and washing etc. Some people also fish in some of these water bodies for their protein needs. In recent times however, most aquatic systems have been polluted and degraded as a result of anthropogenic interferences through farming, mining and fishing etc. Also, water systems in forest ecosystems which contain mineral resources such as gold are being used for washing the minerals during gold processing.

Physico-Chemical Assessment of Surface Water Quality

Water is copious on the surface of the earth, despite this, potable water is very often not available to all human (Chapman, 1996) and other living organism. History shows that water resource is an important yardstick for health and socioeconomic status of individuals and communities in spite of this, pollution of waters usually affects the quality of water resources (Chapman, 1996). The assessment of water quality (valuation of the physical, chemical and biological nature of water in relation to the natural quality, human effects and intended uses) (Fernández, Ramírez, & Solano, 2004) are critical for water resource management. The gesture provides vital information on the concentration of diverse solutes at a given time and place making available, the basis for judging the appropriateness of water for its designated uses and to improve existing conditions (Ali, Salam, Ahmed, Khan, & Khokhar, 2004).

In many instances including the ARFR, the extent and nature of water pollution is as a result of numerous physical, chemical and biological parameter changes. Increases in anthropogenic activities as a result of increase logging, mining and farming activities have largely contributed to the rising decline in water quality in forest areas. The deteriorating nature of the Birim River for example which traverse the study area is affected by anthropogenic influences leading to the destruction of ecosystem (Ayivor, Gordon, & Ntiamoa-Baidu, 2013).

Assessments of water quality in lakes and rivers reveal changes with geography and seasons (Ayivor, Gordon & Ntiamoa-Baidu, 2013). The striking global industrialization with its associated anthropogenic stressors, rapid development of cheap sources of energy, expansion of chemical industries and agricultural mechanization with current agricultural practices have been identified as major causes of pollution and stress on ecosystems (Quilbe, et al., 2004). Although there is no simple and single measurement for water quality, substantial number of procedures and tools have been developed to examine water quality depending on the uses of the resource in question (Kolawole, Ajayi, Olayemi & Okoh, 2011). The procedures include the analysis of diverse parameters such as pH, conductivity, turbidity, total dissolved solids (TDS), total suspended solids (TSS), total organic carbon (TOC), and heavy metals etc. Also, the quality of water is regarded as a network of variables such as oxygen concentration, pH, temperature, and changes in the physical and chemical variables (Kolawole et al., 2011).

Physico-Chemical Properties of Water

pH

The pH of water refers to measurement of the acidity of the water or its concentration of the free hydrogen ions (Gupta, Nafees, Jain, & Kalpana, 2011). Usually natural water has a pH value ranging from 4 to 9 due to the carbonates and bicarbonate of alkaline and alkali earth metals. The measurement of water acidity vary from place to place and for different sources. For example, Gupta, Nafees, Jain and Kalpana (2011) upon analyses of the pH of River Chambal in Kota City Area of Rajasthan State in India observed that for sampled water in the pre-monsoon season, variation from 7.50 to 8.25 which was in the permissible limit of pH value of drinking water. In the Densu River in Ghana, Karikari and Ansa-Asare (2006) identified anthropogenic influence through agriculture to caused pollution although the water sample was almost neutral in pH with recorded ranges from 7.20 to 7.48.

Earlier study by Ansa-Asare and Asante (2000) on the water quality of Birim River in the South-East Ghana between in the 1990s showed slightly acidic conditions of pH ranging from 6.2 to 6.9. In somewhere Ethiopia, Gebreyohannes, Gebrekidan, Hadera and Estifanos (2015) upon the assessment of the Elala River found in Mekelle, Tigray, observed pH values of minimum 7.47 ± 0.03 and maximum 7.91 ± 0.19 which are within permissible limit set by the WHO and FAO for drinking and irrigation purposes (WHO, 2008).

Turbidity

Turbidity is the evaluation of the fine suspended matter and its capability to obstruct light fleeting through water (Caux, Moore & MacDonald, 1997). Turbidity is caused by colloidal matter and suspended matter such as silts, clay, finely divided organic and inorganic matter, soluble coloured organic compounds and plankton and other microscopic organisms (Mandal, 2014) Water turbidity, reflects transparency of the water as it is an essential criterion for assessing the quality of water. Turbidity is measured in Nephelometric

Turbidity Unit (NTU) and according to Shelton (2000) a longer dry season between rainfalls lead to a greater turbidity in water.

Again, assessment of physio-chemical quality of water by Gupta, Nafees, Jain and Kalpana (2011) on River Chambal revealed turbidity ranges from 3.9 to 8.2 NTU. They attributed the turbidity to the colloidal and extremely fine dispersion and the suspended matters such as clay in the river. In Ghana, research has shown that the water in the Densu basin whose source is from the Atewa forest is slightly hard and moderately soft (91.2 – 111 mg/l $CaCO_3$) with high turbidity as a result of poor farming practices (Karikari & Ansa-Asare, 2006). Ansa-Asare abd Asante (2000) in another study found that the turbidity of water from the Birim River contain pollutants from both diamond and gold extraction as a result of the activities of small scale miners who have degraded the forest land littering it with trenches and water-filled excavation and marshy areas.

Total Dissolved Solids (TDS)

Total dissolved solids (TDS) refers to the measure of the total ions in solution. TDS and electrical conductivity (EC) are reasonably comparable in a diluted solution whilst the TDS of a water sample is based on the measured EC value which is calculated with the equation: TDS (mg/l) = 0.5 x EC (µS/cm). TDS is made up of bicarbonates, carbonates, chlorides, sulphates, phosphates, calcium, nitrates, magnesium, sodium, iron, potassium and manganese (Boman, Wilson, & Ontermaa, 2002). Gebreyohannes et al. (2015) upon investigation of water quality of Elala River observed that the total dissolved solid (700.22 to 1328.22 mg/L) was within quality parameters standard of FAO although above the prescribed limit of WHO guidelines. In a similar study by Varunprasath and

Daniel (2010) who conducted comparative studies for three freshwater rivers (Cauvery, Bhavani and Noyyal) in Tamil Nadu, India, it was seen that the value for the total solids for the freshwater rivers ranges from a minimum of 1030 to 1130 mg/L to a maximum of 1630 to 1800 mg/L.

Electrical Conductivity (EC)

The California Water Quality Resources Board (CWQRB) (2009) defines conductivity as a measure of the capability of water to pass an electrical current. EC therefore estimates the amount of total dissolved salts/solids (TDS) or the total amount of dissolved ions in the water. The presence of inorganic dissolved solids such as nitrate, chloride, sulphate, and phosphate anions or magnesium, sodium, calcium, iron, and aluminum cations affects the conductivity of water (Boman, Wilson, & Ontermaa, 2002). Organic compounds have a low conductivity when in water since they do not conduct electrical current very well. The conductivity of water is measured in microsiemens per centimetre (µS/cm).

Over the years, studies have shown that the conductivity of water resource depend on anthropogenic activities surrounding the resource since such activities usually introduce both organic and inorganic materials into the resource. Such materials determine the level of conduction of currents (Gebreyohannes et al., 2015; Karikari & Ansa-Asare, 2006). Also, the position and topography of the area in which the water resource is found may have effect on amount of components leading to it conductivity. For instance, the Densu River indicated variations in electrical conductivity values of 237 and 402 µS/cm for downstream and upstream of the same water source. Further, Ashalaja which is in the downstream had the highest conductivity value of 402 µS/cm whilst the conductivity of the Densu River was lowest at the source of its catchments. The EC indicator shows that less amount of water will be available to plants at higher EC although the soil might appear wet. The reason being that plants only transpire water as the usable plant water in the soil as soil solution may reduce intensely with a rise in EC (Gebreyohannes et al., 2015).

A combined effect of most physio-chemical parameters is generally observed in most studies. For instance, Joshi, Kumar and Agrawal (2009) upon the assessment of water quality index of River Ganga in Haridwar District of India, observed connectivity of physico-chemical parameters including temperature, velocity, dissolved oxygen, pH, carbonate, bicarbonate, total alkalinity, turbidity, hardness, calcium, magnesium, sodium, nitrate, potassium, phosphate, sulphate, electrical conductivity, chloride, total dissolved solids and total suspended solids. In most cases, water quality Index value point to the fact that water samples of some sampling locations are quite unfit for drinking purpose due to the high value of dissolved solids and sodium. Further, Khalik, Abdullah, Amerudin and Padli (2013) examination of the seasonal variation of the physico-chemical in the Bertam River in Cameron Highlands found connectivity between more than two physico-chemical parameters. They observed that Bertam River was slightly better in dry season than in wet season, a difference indicating that the meteorological change such as rainfalls have significant negative impacts on water quality. Finally, examinations by Sa'eed & Mahmoud (2014) of the physio-chemical parameters along the Jakara River showed connectivity between the physico-chemical properties as the parameters were largely within the maximum contaminant levels set by WHO (2008).

Heavy Metals in Aquatic Ecosystems

Effects of heavy metals in environmental pollution is a global epidemic which is associated with human functions through intensive agriculture, mining, power transmission, sludge dumping, smelting, electroplating, energy and fuel production and melting operations (Malik, Shinwari, & Waheed, 2012). The term heavy metal is defined as" any metallic element that has a relatively high density and is toxic or poisonous even at low concentration" (Lenntech, 2004). Heavy metals are normally a collective terminology, which is applicable to a group of metals and metalloids with atomic density greater than 4 g/cm3, or 5 times or greater the density of water (Hawkes, 1997). Examples of heavy metals usually found in aquatic environments include iron, lead, zinc, cadmium, among other.

Metallic iron often occurs in a free-state and is widely distributed in nature. The metal is next to aluminium is ranked in abundance when compared to the total elements in the earth's crust (Antonovics, Bradshaw, & Turner, 1971). The most important ore of iron is hermatite whilst other vital ores include goethite, magnetite, bog iron (limonite) and siderite (Ralph, 1998).

Lead is almost certainly not a key problem in drinking water, however, earlier studies have reported that leaded gasonline and lead from mining or smelting and pesticide usage is the key anthropogenic sources of lead (Pb) in the environment (Balba, Shibiny & El-Khatib, 1991).

The concentration of zinc in natural surface of water is usually below 10μg/l and in groundwater 10-40μg/l. The vital corrosive waters are those of low pH as Zinc conveys an uninvited severe taste to water. The WHO (2008) indicated that 5% of a population cannot differentiate between zinc-free water and water containing zinc at a level of 4 mg/l as zinc sulphate.

Cadmium (Cd) is a soft, ductile, silver-white metal that belongs to group IIb in the Periodic Table. Although Cadmium has a relatively high vapour pressure, it has relatively low melting (320.9 °C) and boiling (765 °C) points. Cadmium (Cd) exists in water as hydrated ion and may enter aquatic systems through weathering, erosion of soils and bedrock, atmospheric deposition and direct discharge from industrial operation. There is limited amount of cadmium in most rocks, coal and petroleum but most cadmium are found in combination with zinc (WHO, 2008). Cadmium is usually introduced to the environment from mining smelting and industrial operations as well as from reprocessing cadmium scrap, electroplating and incineration of cadmium containing plastics.

Some Effect of Heavy Metals on Riparian Zones in Forest Vegetation

Legacy effects of earlier vegetation can affect water quality for many decades and regulate the potential level and effectiveness of water quality improvement once the vegetation is restored (Dosskey et al., 2010). Riparian zones usually referred to as floodplain are located immediately adjacent streams, lakes, shorelines, or other surface waters and through which overland and subsurface flow paths link waterways with runoff from uplands. The boundaries of riparian zone extend outward from the stream or river channel and travel into the canopy of streamside vegetation (Sedell, Steedman, Regier, & Gregory, 1991).

Riparian zones mostly occupy a smaller fraction of the landscape, though they normally play a disproportionately significant role in regulating water and chemical exchange between surrounding lands and stream systems

(Burt & Pinay, 2005). The boundary of the riparian area and the connecting uplands is steady and not continuously well-defined. Nevertheless, riparian areas vary from the uplands because of high levels of soil moisture, frequent flooding, and the unique assemblage of plant and animal communities found there. Water in the riparian zones may converge from many directions into the riparian zones. Through the interaction of their soils, biotic and hydrology, riparian forests maintain many key physical, biological, and ecological functions, and significant social benefits.

Riparian zones are unique and dynamic aspect of the forest zone since it's among the most disturbed aspect of forests. Major natural and anthropogenic stressors recoded in riparian areas are associated with management activities such as timber harvesting, natural perturbation such as fire, action of water, recreational use, and the creation of physical structures like dams and roads (Hall, 1988). Anthropogenic stressors in riparian zones increases the surface runoff in riparian systems, alter the flow of water through aquatic systems and remove protective riparian vegetation (Poff, Koestner, Neary, & Merritt, 2012) .Timber harvesting increases soil erosion and changes the soil microclimates by increasing soil temperatures (Hall, 1987).

Riparian zones retain high levels of soil moisture as a result of both the presence of water in the lake or stream and the movement of groundwater into the rooting zone of riparian vegetation (Bilby, 1988). Riparian zones are important sinks for heavy metals from river water by the process of adsorption (Du Laing, Rinklebe, Vandecasteele, Meers, & Tack, 2009)Thus, pollution of the water body in the riparian zones with heavy metal such as copper (Cu), zinc (Zn) and cadmium (Cd) has a serious effect on the vegetation. Apart from the nutrient chemicals which are absorbed by plant roots in the riparian vegetation, non-nutrient chemical or heavy metals such as cadmium, zinc and lead are also taken up in smaller quantities and sequestered in plant tissues (Roca & Vallejo, 1995). Most heavy metals are toxic to plants, nonetheless sub lethal concentrations in plant tissues are common where they are present in soil in trace amounts. Since heavy metals are non-degradable, their accumulation in the soil remains for a long time (Zhuang, Zou & Li, 2009) and this affect and poses risk to the absorbing plant. However, different plant varieties vary considerably in terms of their tolerance to the heavy metal taken by the plant (Evlard et al., 2014).

Heavy metal pollution has been empirically found to have different reduction rates in root and shoot growth parameters of most plant (Kuzovkina, Knee & Quigley, 2004). Demirezen and Aksoy (2004) also advanced the argument that the relationships among heavy metal concentrations in water, soils and plants are usually different based on plant species together with habitat types. Whilst Mitsch (1995)indicated that the capacity of riparian zone to absorb heavy metals largely depends on the combined effects of water, soils and plants through a combination of physical, chemical and biological processes. Canario et al. (2010) have indicated that the function of vegetation in wetlands also indicated that the plant-covered plays an essential role in the reduction of heavy metals pollution by storing these metals in various parts such as roots and shoots. Zhang et al. (2017) upon evaluation of the distribution and accumulation of Cd, Cr, Cu, Ni, Pb and Zn in Scirpus tripueter Linn and Cyperus malaccensis Lam., in water and soils sampled from reclaimed tidal riparian wetlands and the natural riparian wetlands in the Pearl River Estuary, observed that the concentrations of heavy metals in soils exceeded the eco-toxic threshold recommended by the US EPA.

Bacteriological Quality of Water

The underlying assumption is that an improvement in the physico-chemical water quality is usually followed by the restoration of the biological integrity of water. However, according to Borrego and Figueras (1997) almost all-natural waters are home to coliform bacteria. The populations of the coliform bacteria are curtailed by analyzing the waters for the presence of particular pathogens of concern for treatment. It is usually impractical to examine all potential pathogen present in water since there are hundreds of different microorganisms linked with waterborne diseases (Borrego & Figueras, 1997). Although water quality is widely measured using bacterial indicators, universally there is no agreement on which indicator organism(s) to measure nor the singular standard bacterial indicator(s) to look out for. Different standard and indicator levels are used in different water quality programs, but the common bacterial indicators are Total coliform (TC), Faecal coliform (FC), and Escherichia Coli (EC). Despite this, indicator organisms such as total coliform and faecal coliform bacteria have the highest application used in determining microbial quality of the drinking water.

Total Coliform Counts

By definition, Total coliform bacteria are “aerobic or facultative anaerobic, gram negative, non-spore forming, rod shaped bacteria, which ferments lactose and produce gas at 35°C” (APHA, 1995). The manifestation of total coliform in water samples is an indication of the presence of bacteria such as *Klebsiella sp,* the causal agents for dysentery, typhoid fever and cholera diseases (APHA, 1995). Total coliform bacteria are mostly found in the environment (soil or vegetation) and are typically harmless. Total Coliform do not essentially indicate fresh water contamination by faecal waste, though its presence or absence in treated water is normally used as a determinant of a properly working water disinfection.

Faecal coliform

Faecal coliform bacteria also known as thermo-tolerant coliforms or presumptive *E. coli* is gram negative bacteria. Thermo-tolerant coliforms are a subdivision of the total coliform set. The coliform species well thought-out as parts of this broader subdivision are merely those that are able to ferment lactose at a temperature of 44.5°C. The term thermo-tolerant is often used interchangeably with “faecal”, erroneously combining original classifications and temperature. Maier and Kress (2000) have indicated that faecal coliform are a more precise indicator of the presence of faeces and an indication of the presence of disease carrying organisms found in the same environment as the faecal coliforms bacteria.

The origin of the organism is from the gut of warm-blooded animal species and human beings. Faecal coliform bacteria are microscopic organisms whose measurement is expressed as the number of organisms per 100 mℓ sample of water (FC/100mℓ). In addition, faecal coliform in a drinking water sample usually indicates fresh faecal contamination, implying a greater risk compare to other pathogens present. Faecal coliforms are the main cause of use impairment in streams. Assaf and Saadeh (2008) indicated that faecal pollution escalate in the dry months especially in the summer while Sinclair et al. (2009)

reported that during low flows of water bodies as assessment of the outlet discharge shows that the faecal coliform counts exceed the national standards.

Escherichia coli

Escherichia coli, popularly known as *E. coli* is an indicator of faecal pollution of water samples and a gram-negative bacterium found in the intestines of warm blooded animals and humans. It is the only species subgroup of faecal coliforms, with many stains but a smaller portion cause disease. In spite of this, the presence of any strain of *E. coli* is probable an indication of faecal contamination of the water source. Although *E. coli* is as an indicator for the presence of harmful microbes, unlike faecal coliforms it may essentially provide a threat in and of itself since it is mostly harmless.

A study by McLellan and Salmore (2003) on the bacterial water quality of a swimming beach area on Lake Michigan showed that *E. coli* concentrations were lower on offshore regions than on shoreline regions during wet well as dry seasons. They observed that the water samples exceeded the 235 cfu/100mL *E. coli* in 66% of the shoreline samples (n=675) and 5% of the offshore samples (n=209). They however concluded that the source of contamination originated from the localized and shoreline impacts of storm water and bird faeces contributing to high bacterial densities.

CHAPTER THREE

MATERIALS AND METHODS

Introduction

This chapter describes the area in which the study was undertaken as well as the methods and materials used in the collection of data and analysis. The location and history of the ARFR were considered as part of the study area likewise the type of vegetation, soil, topography and drainage. The methods section addressed the sampling design, vegetation assessment, enumeration of plant diversity, tree biomass and carbon stock measurement, determination of soil characteristics, assessment of human-induced stress on vegetation quality, intensity of induced anthropogenic activities on vegetation, water sampling and analysis, and data analysis employed.

Study Area

Location and History

The ARFR is one of the important ecosystems in West Africa. It is an ecologically unique site in Ghana which accommodates diverse fauna and flora resources of Okyema the Akyem Abuakwa Traditional Area. ARFR is located within 5°58' to 6°20' N and 0°31' to 0°41' W and occurs within the Moist Semi-Deciduous Forest Zone in the Eastern Region of Ghana. The area covers 258.3 km^2 and is made up of two forest blocks namely Atewa Range and Atewa Range Extension with the Atewa Range occupying majority of 237 km^2. According to Mayaux et al. (2004), the Atewa Range represents approximately 33.5% of the closed forest in the Eastern Region.

The ARFR which was established as a National Forest Reserve in 1925 has since been designated as a Globally Significant Biodiversity Area (GSBA).

It has also been designated as an Important Bird Area IBA (Abu-Juam et al., 2003). Over the years, the area has experienced changes following encroachment and initiatives from the Government of Ghana although attempts to maintain the biodiversity or ecological value have been made. The area has been classified severally based on prevailing importance at specific times. For example, the area was classified as a Special Biological Protection Area in 1994, a Hill Sanctuary in 1995 and one of Ghana's 30 Globally Significant Biodiversity Areas (GSBAs) in 1999 (Abu-Juam et al., 2003). The designation of the area as a GSBA is equivalent to IUCN's Category IV which is set aside for protection and conservation through management intervention (IUCN, 1994). Further, the ARFR was listed as an (IBA) by Bird Life International based on its avian diversity, one of 36 such areas in Ghana (Ntiamoa-Baidu, Owusu, Daramani, & Nuoh, 2001).

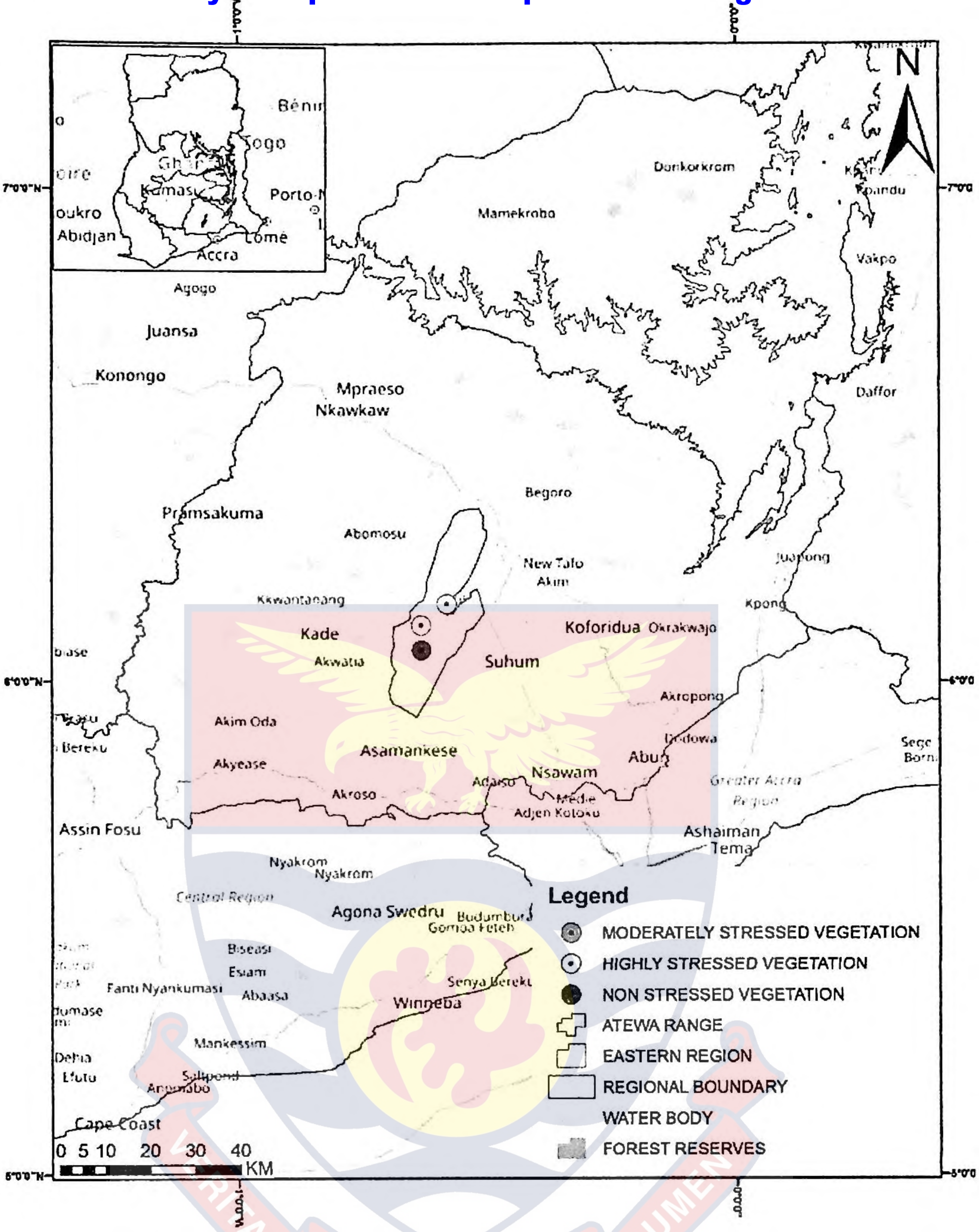

Figure 2: Map of study area showing the various stress levels in the ARFR
Source: Geographic Information Systems Laboratory, University of Ghana

Climate and Vegetation

ARFR is part of the Moist Semi-deciduous Forest type and occurs on an isolated hill ranging from 500 to 750 m above sea level and within Upland Evergreen Forests (Hall & Swaine, 1981). The forest is characterized by high temperatures and a double maxima rainfall regime. The area has mean monthly temperatures of between 24 and 29 °C and mean annual rainfall of between 1,200 and 1,600 mm (Conservation International, 2013). Usually, the first rainfall peak occurs in May-July whereas the second occurs in September-November, with mild Harmattan season occurring from November to March (Hall & Swaine, 1981).

ARFR vegetation is an Upland Evergreen Forest and regarded as botanically important in terms of plant species richness and floral diversity (Hall & Swaine, 1981; Abu-juam et al., 2003). The area houses six hundred and fifty-six (656) species of vascular plants, comprising 323 tree species, 83 shrub species, 155 liane and climber species, 68 herbaceous species, 22 epiphytes and 5 grasses (Larsen, 2006) . It further forms the home for many endemic and rare species including black star plant species (Hawthorne D, 1998; Larsen, 2006) as well as seasonal marshy grasslands, swamps and thickets species (Hall & Swaine, 1981). Commonly amongst woody epiphytes species in the area are *Anthocleista microphylla*, *Epistemma assianum*, *Medinilla mannii*, *Cyathea manniana* (Treefern), *Rubus pinnatus* var. *afrotropicus* and *Hymenocoleus multinervis*, a group of plants rarely seen in most tropical West African forests. The area is also home to shade loving plants including *Alsodeiopsis staudtii*, *Buforrestia obovata*, *Cola boxiana*, *Dicranolepis persei*, *Diospyros chevalieri*, *Drypetes pellegrini*, *Mapania baldwinii*, *M. coriandrum*, *Nephthytis afzelii*, *Pauridiantha sylvicola*, *Combretum multinervium*, *Neolemonniera* *clitandrifolia*, *Newtonia duparquetiana*, *Strephonema pseudocola* and *Strychnos icaja* (Bakarr et al., 2001).

Soil, topography and drainage

ARFR is underlain by Birimi rocks with derived soils mostly red clays, aggregated by humus to form light-textured soil, basic lithosols and ochrosols (Hall & Swaine 1981). The area is characterized by a series of plateaus running roughly from north to south with remnants of a tertiary peneplain. The area is known to harbour mineralogical wealth including both gold and bauxite deposits (Forestry Commission of Ghana, 2007).

The study area forms part of an elongated mountainous range, varying between 200 m and 750 m above sea level and with many steep slopes dissected by numerous streams (Adombire, Adjewodah, & Abrahams, 2013). Streams to the east and south of the study area form the headwaters of the River Ayensu while those to the west form the headwaters of Rivers Supon and Amaw, which drain into the Birim River (Adombire, Adjewodah, & Abrahams, 2013). The headwaters of three river systems, Ayensu, Densu and Birim, are the most important sources of domestic, agricultural and industrial water for local communities around Atewa.

Methods

Sample design

Following a reconnaissance survey of the study area (ARFR) using LANSAT imagery, the study area was classified into a Non-Stressed Vegetation (NSV), Moderately Stressed Vegetation (MSV) and Highly Stressed Vegetation

(HSV). This classification is based on extent of human induced activities such as logging, mining and farming. The NSV area was constituted by

primary vegetation with no anthropogenic induced activities, MSV comprised vegetation areas that had experienced selective logging and mild farming activities, whereas the HSV comprise areas that have undergone high intensity of anthropogenic activities such as mining, logging and farming over the past years as well as the fringes of the reserve.

Vegetation Assessment

A total of fifteen 50 x 50 m vegetation plots comprising five 50 x 50 m NSV plots, five 50 x 50 m MSV plots and five 50 x 50 m HSV plots were established and assessed. During assessment, each 50 x 50 m at the stress levels were further sub-divided into four 25 x 25 m subplots for easy assessment. The 25 x 25 m plot sizes were chosen following standards used by Hawthorne & Abu-Juam (1995), Van Gemerden, Shu, Olff (2003) and Asase et al. (2014) in similar vegetation studies. In all, 20 sub-plots were observed for each stress level and assessed for plant diversity, carbon stocks and soil characteristics.

Enumeration of plant diversity

Enumeration of plant diversity was undertaken at the 25 x 25 m sub-plot level and summed to form enumeration at the main 50 x 50 m plot level. Demarcations of the main plots and the sub-plots were accomplished using a compass, tape measure and Global Position System (GPS) Garmin E-trex with accuracy level of 3 meters. Within each of the 25 x 25 m sub-plots, trees with diameter at breast height (dbh) 10 cm and over were individually spot identified and their dbh measured at 1.3 m above ground level. For trees with larger buttress, dbh was measured at 1.3 m from top of the buttress (Figure 3). The dbh of trees were measured using a diameter tape and recorded in a standard field data sheet. Additional information on tree tagging, dbh measurement and special situation procedure guide were given to field assistant (Appendix B). Plant species were identified as far as possible on site using plant part (e.g, leaves, flowers, and fruits), bark characteristics and significant exudates (Hawthorne & Jongkind, 2006; Hawthorne & Gyakari, 2006). In few instances where plants could not be identified on the field, plant parts were collected and compared with voucher specimens at the Herbarium unit of the school of Biological Sciences, University of Cape Coast and the Ghana Herbarium at the Botany Department, University of Ghana. Various manuals and flora notably Poorter et al. (2004) and Hawthorne and Jongkind (2006) were also consulted. The nomenclature followed is that of Hawthorne & Jongkind (2006). Following the field measurements, the data collected were entered into standard data sheet in Microsoft Excel for analysis.

Figure 3: Demarcation of 1.3m above a buttressed plant for the measurement of dbh.

Measurements of Tree Biomass and Carbon Stocks

Above ground biomass of trees was determined using the allometric model of Henry et al. (2010). The allometry estimates tree biomass as Y= 0.30 x $dbh^{2.31}$, where Y is tree biomass and dbh the diameter at breast height. The model which was specifically developed for tropical African forest has been used in similar studies by Asase et al. (2014). The dbh measurements which were taken during the enumeration of plant diversity in the 25 x 25 m sub-plots were used in the estimation of the biomass. Plant root biomass was calculated indirectly from the above ground biomass estimated according to methods of Cairns et al. (1997) these researchers estimated root biomass to be approximately a quarter of the above-ground biomass. Following the estimated biomass obtained, tree carbon was calculated as half the Albrecht & Kandji (2003) and Glenday (2006) postulate that the amount of tree carbon is half the biomass calculated from the method of Cairns et al. (1997).

Determination of soil characteristics

To determine the physical, chemical and biological properties of soils in the study area, soil samples were taken from the four corners and center of the sub-plots at depths of 0 – 15 and 15 – 30 cm using a soil auger. The soil samples were air-dried to obtain constant weight. Various soil parameters including soil carbon stocks, soil respiration, soil particle size, pH etc., were determined by using various standard methods.

Determination of Soil Carbon Stock

To determine soil organic carbon, soil samples were collected from two randomly selected spots in each of the 25 × 25 m vegetation types based on stress intensity. Soil samples were collected at two different depths, namely 0–15 and 15–30 cm, since soil carbon stocks vary with depth (Williams et al., 2008). Previous works have sampled soil carbon stocks in the tropics at similar depths (Williams et al., 2008). Percentage soil organic carbon was determined using the Walkley–Black method (Walkley & Black, 1934) as modified by Anderson and Ingram (1989) and corrected for the un-oxidized organic carbon as described by Nelson and Sommers (1996).

Determination of Soil Respiration

Soil respiration was measured monthly over a twelve-month period using a modification of the NaOH absorption method by Kirita (1971). The method involved the use of a 22 cm high cylinder of diameter 15 cm as CO_2 isolation chamber (Figure 2).

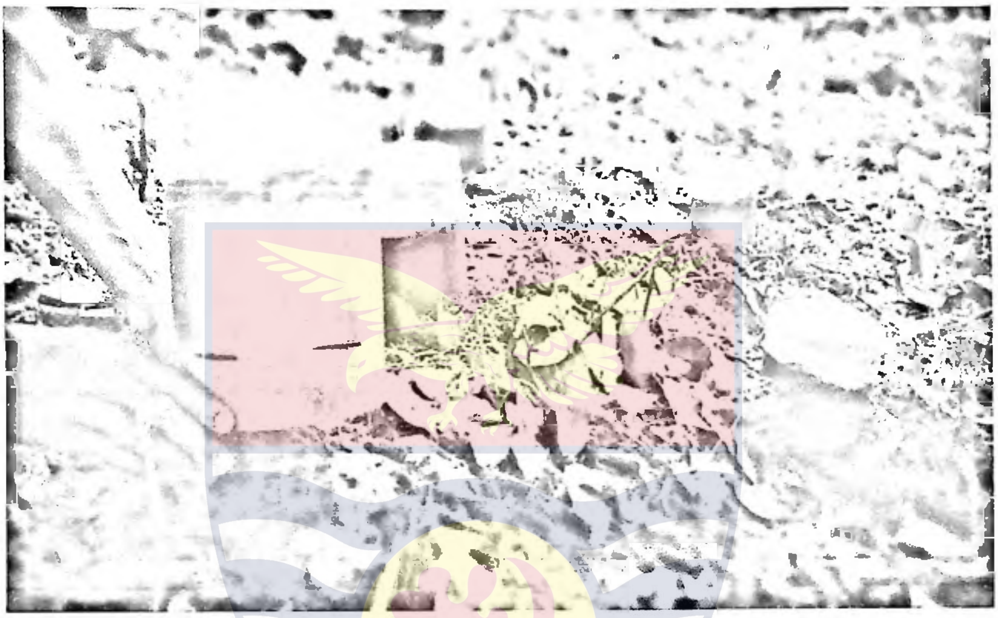

Figure 4: Setting the apparatus for the measurement of soil respiration

Ten cylinders were randomly trusted into the soil at a depth 5 cm observing minimal soil disturbance. A beaker containing 10 ml of 3 M NaOH was placed under the cylinder and shielded from direct sunlight by covering it with aluminum foil. Soil respiration rates were measured for 24 hours after which the beakers were retrieved and refrigerated at 0-3 °C prior to transporting to the laboratory. The alkali solutions were analyzed for CO_2 evolved from the soil. The volume of CO_2 evolved was determined by back titration in which excess NaOH in solution was back titrated against 1.0 M HCl using phenolphthalein indicator after precipitating the carbonate/bicarbonate formed with 1.0 M $BaCl_2$. Resultant chemical equations are the following:

$$CO_2 + 2NaOH \rightarrow HCO_3^- + OH^- + 2Na^+$$

$$2Ba^{2+} + 2HCO_3^- \rightarrow 2BaCO_3 + 2H^+$$

$$Na^+ + HCl + OH^- \rightarrow NaCl + H_2O$$

The HCl neutralized the remaining OH^-, and the amount of CO_2 trapped in the NaOH was calculated using the equation:

$CO_2\ (\text{mmol}) = 0.5 \times (\text{ml HCl}_{\text{blank}} - \text{ml HCl}_{\text{sample}}) \times M_{HCl}$

Where, M_{HCl} is the molarity of the HCl used in the titration.

Determination of Physical and Chemical Properties of the Soil

Following soil sampling using bucket auger at 0-15 cm and 15- 30 cm depths in which the four corners and the center of the plots were sampled, the samples were bulked to obtain one sample from each plot. The soil samples were thoroughly mixed, air-dried and sieved using 2 mm sieve. They were further examined for particle size, bulk density, moisture content, pH, organic carbon, available P, total N and cation exchange capacity (CEC).

Analysis of Soil Particle size

Soil particle size distribution was determined by the modified Bouyoucos hydrometer method described by Day (1965). Soil samples from the 0 – 15 and 15 – 30 cm depth were analysed for clay, sand and silt content. During the process, 40 g of the 2 mm sieved soil was weighed into a beaker and 60 ml of 6% H_2O_2 was added to oxidize the organic matter. The content was transferred into a dispersion cup and mixed with 100 ml of 5% Sodium hexametaphosphate solution. The suspension was shaken and transferred into a settling cylinder and filled to the 1000 ml mark with distilled water. The suspension was agitated vigorously with a plunger and the time noted immediately shaking was stopped. The temperature of the suspension was recorded after equilibration. A hydrometer (ASTM 15 2H) was then placed into the suspension and the first and second readings noted after 5 min and 5 hrs, respectively. Suspension was then poured directly onto a 0.5 mm sieve and the particles retained on the sieve washed thoroughly with water and dried in the oven at 105 °C for 24 hrs. The dried samples were weighed to represent sand fraction. The particle size distribution was then determined using the following formulae:

$$\text{Silt}\ (\%) + \text{Clay}(\%) = \frac{\text{5 minutes hydrometer reading}}{\text{weight of soil}} \times 100$$

$$\text{Clay}\ (\%) = \frac{\text{5 hours hydrometer reading}}{\text{weight of soil}} \times 100$$

$$\text{Silt}(\%) = \%(\text{Silt} + \text{Clay}) - \%(\text{Clay})$$

$$\text{Sand}\ (\%) = \frac{\text{Over dry mass (g)of particles on the 0.5 mm sieve}}{\text{weight of soil}} \times 100$$

The soil textural classes were determined using the texture triangle (Soil Survey Division Staff, 1993).

Determination of bulk density

Soil bulk density was determined for each sample collected by using core method. Three replicates of cylindrical soil cores were taken from depths of 0 – 15 cm and 15 – 30 cm, weighed and oven dried at 105°C to obtain constant weight or mass (M_s). Volume (V_s) of soil was obtained by multiplying the cross-sectional area and height of cylinder. Bulk density (ρb) was however calculated using the formula:

$$\rho b = \frac{M_s}{V_s}$$

Where ρb is the bulk density; M_s is the mass of soil and V_s is the volume of soil.

Determination of soil pH

Twenty grams of the sieved soil sample were weighed into 50 ml beaker. Twenty ml distilled water was added to obtain a 1:1 (W/V) ratio. The soil suspension was stirred for 30 minutes and allowed to stand for an hour to enhance settling of suspended particles. Glass electrode pH meter (pH 212 model) standardized with two aqueous solutions of pH 4 and 7, respectively was then dipped into the suspension to measure the pH.

Total nitrogen determination

Total nitrogen was determined using the micro-Kjedahl method by Guebel, Nudel, and Giulietti, (1991). Two grams of air-dried sieved soil sample was transferred into a 250 ml Kjeldahl flask. This was followed by the addition of digestion accelerator, selenium catalyst and 5 ml of concentrated Sulphuric acid (H_2SO_4). The mixture was allowed to digest to obtain a clear digest which was allowed to cool and transferred into a 50 ml volumetric flask and made up to the volume using distilled water. Five millitres aliquot of digest was pipetted into distillation flask and 5 ml of 40% sodium hydroxide (NaOH) added with

100 ml distilled water. Sample was further distilled and collected in 5 ml of 2% boric acid to which 2 drops of methylene blue indicator were added. The distillate was titrated against using the method of Bremner (1955) in° which the distillate was titrated against 0.01 N HCl. The colour change was from green to red at the end point.

The amount of nitrogen, N in percentage was calculated using the formula:

$$N\ (\%) = \frac{\text{Molarity of HCl} \times \text{titre volume} \times 0.014 \times \text{vol. of extractant}}{\text{Weight of soil sample} \times \text{volume of aliquot}} \times 100$$

Determination of Available Phosphorus (P)

Available P of the soil sampled was determined using the standard method of Watanabe and Olsen (1965). Ten grams (10 g) of the sieved soil samples were weighed into extraction bottles. A volume of 100 ml of sodium bicarbonate (pH 8.5) was added, capped and shaken for 30 min on a mechanical shaker. The extracts were filtered using Whatman's No. 125 filter paper to obtain clear solution. 10 ml aliquot of the extract was transferred into a test tube. Drops of 1 ml of 1.5 M H_2SO_4 were added to decolourise the solution by settling the organic matter in it. The solution was kept in a refrigerator and allowed to cool for few a minute. Extracts in the test tubes were centrifuged, and gently decanted for colour development and phosphorus analysis.

Concentration of P in extracts was then determined using the method of Murphy and Riley (1962). An aliquot of 1mL of the sample solution was pipetted into a 50 ml volumetric flask and a drop each of P-nitrophenol and ammonium hydroxide were added. Further, 8 ml of solution containing concentrated sulphuric acid, ammonium molybdate, potassium antimony tartrate, and ascorbic acid were added. The content was topped up to the 50 ml mark with distilled water. Concentration of phosphorus was then determined using a Philips' UV spectrophotometer (UV-1800 UV-VIS) at a wavelength of 712 nm. Available phosphorus content of the soil was calculated using the formula;

$$P\ (\text{mg kg} - 1) = \frac{\text{Spectrometer reading} \times \text{total volume of extract}}{\text{Volume of aliquot} \times \text{weight of soil sample}}$$

Available potassium (K)

Ten grams of soil were taken in a 150 mL Erlenmere flask and 25 mL neutral 1 N ammonium acetate (pH 7.0) was poured in to it. The contents were shaken on a reciprocating shaker (180 rpm) for 10 min and immediately filtered and K in the extract was determined using flame photometer.

Determination of Cation Exchange Capacity (CEC)

Ten grams (10g) of sieved soil sample were weighed into extraction bottle and 100 ml of 1 M ammonium acetate solution added. The bottle with its contents were shaken for 30 minutes using a mechanical shaker. The content was filtered through a Whatman No. 42 filter paper and the sample leached four times with 25 ml of methanol to wash out excess ammonium. Twenty-five millilitres of 1 M acidified potassium chloride were further used to leach the soil four times. A 5 ml aliquot of the leachate was distilled in a Markham distillation apparatus and 5 ml of 40% NaOH solution added to distil. The distillate was collected into 5 ml of 2% boric acid to which three drops of methyl red and methylene blue indicators were added. The distillate was back titrated against 0.01 M HCl to purplish end point. The cation exchange capacity in soil was calculated from the number of moles of HCl consumed in the back titration.

Assessment of Human-induced Stress on the Vegetation Quality

Following anthropogenic activities in the reserve area, the quality of the vegetation over the years have been affected. Normalized Differential Vegetation Index (NDVI) and Remote Sensing techniques were used for the assessment of vegetation quality for the past decades. The NDVI techniques was adopted to map effect of human induced stress on the vegetation for the period between 1986 and 2016 using LandSat satellite data. Time series satellite data from Landsat MSS satellite image, together with vegetation parameters were analyzed to establish the effects of land uses including farming, logging and mining etc on vegetation quality. Geometric correction, image enhancement, restoration, and classification were remote sensing methods and techniques.

Unsupervised Classification

The false colour image was used for unsupervised classification (Cluster) which was used for ground truthing. The cluster was produced using Idrisi Image Processing Module and Sub-Module Cluster using a broad generalization level set, to maximum number of six (unsupervised classes). Unsupervised classification was carried out in order to generate possible cluster to give the researcher an idea of changes and their relative types in the study area.

Supervised Classification

The study area was extracted, and stratified approach adopted to generate landuse/land cover map from digital classification of LandSat 7 ETM acquired in 2016, LandSat 7 ETM data acquired in 2006, landsat 4TM of 1991 and LandSat 5TM acquired in 1985. The first step was to perform linear contrast stretch of the bands respectively to enhance the quality of features. The ETM+ bands with 30 m pixel size were combined in order to select the most suitable band combination. The enhanced false colour composite of bands depicting the vegetation was chosen for supervised classification using maximum likelihood (MXL) mode with necessary ground truth information. Information gathering during the site visits pertaining to landuse/landcover. This analysis offers the changing trends in landuse/landcover patterns of the study area. In total, four landuse/landcover classes were adopted for the study; rainforest, farmland, logged land, settlement/bareland.

Normalize Differential Vegetation Index (NDVI)

The NDVI of the study area was calculated from the visible and near-infrared light reflected by vegetation. Healthy vegetation absorbs most of the incoming visible light, and reflects a large portion (about 25%) of the near infrared (NIR) light, but a low portion in the red band (RED). Unhealthy or sparse vegetation reflects more visible light and less NIR light. NDVI data provide an opportunity to assess quantitatively and qualitatively the vegetation cover status in the past and the present, to determine trends, and to predict the ecosystem processes (Herrmanna, Anyambab, & Ukerc, 2005). Result from average greenness can be applied for inter-annual assessment of vegetation cover status over the study area and give the opportunity to compare and predict for each year in terms of vegetation growth, stress and productivity.

Intensity of Induced Anthropogenic Activities on Vegetation

Data and Pre-Processing

Post-classification comparison approach was used to evaluate variations in land-cover maps obtained from satellite images acquired on different dates (Lu, Moran, & Mausel, 2002; Yuan, Sawaya, Loeffelholz, & Bauer, 2005).The process included data processing, image classification, accuracy assessment, and change detection were achieved as was done by Huang et al. (2012). Satellite imagery (Landsat Thematic Mapper (TM)) from 1986, 1998, 2007 and 2016 with 25 m resolution were utilized in the creation of land-cover classifications for the four years (Table 1).

Table 1: Landsat satellite imagery data

Data Source	Acquisition Date	Path/Row by data
Landsat 5TM	22 – Dec – 1986	193/56
Landsat 4TM	10 – Jan – 1991	193/56
Landsat 7ETM	05 – Dec – 2006	193/56
Landsat 7ETM	31 – Jan – 2016	193/56

Source: Explorer United States Geological Survey (www.usgs.gov)

The 2007 image was registered to topographic maps with the use of distinctive characteristics including road intersections and stream confluences that are clearly visible as used by Huang et al. (2012). The image was further georeferenced to the study area map after which the image was used as reference to rectification of images obtained for the years 1986, 1998, 2007 and 2016. The categorization of land was generated with the combination of both unsupervised classification as well as spatial reclassification following manual on-screen digitizing (Yang & Liu, 2005). Further classification using ancillary data, including finer resolution satellite imagery data from Google Earth and GIS data of the study area was used. The data obtained (Landsat TM data) were separated into 40 categories which were combined to obtain four land-uses which include Rainforest, Logged lands, Farmlands and Settlements/ Bare lands. This was relevant to aid the examination of the relationship existing between patterns and processes contributing to land change from a broad perspective and also to remove errors existing among the categories (Pontius, Shasas, & McEachern, 2004).

Transition Matrix for Time Interval

Quantitative analysis was computed for the transition matrices with respect to the percent of the study area for 1986 - 1998, 1998 - 2007, and 2007 - 2016. The matrices were used to obtain both the stocks and flows of the land categories. Conventional matrix including the types of flows i.e. gross losses and gross gains were used as the basis for analysis.

Land Change Summary for Each Time Interval

As percentage change in the landscape does not directly indicate the annual area change due to the fact that differences were observed in the time interval, the rate of change was calculated in square kilometres per year between each interval. Total change at category level was calculated as the sum of the categories gross gain and gross loss. Also, the total change for a category was the sum of net change and swap change (Huang et al., 2012). The net change for example was calculated as the absolute value of the difference between the gross gain in a category and the gross loss in the same category. Swap change on the contrary was calculated by subtracting the net change from the total change. According to Huang et al. (2012), the swap change for a specific category may be seen as a type of change in which the gross gain in a category at a specific location on the landscape occurs simultaneously with the gross loss category at a different place on that landscape.

Levels of Intensity Analysis

The study analysed intensity of anthropogenic impacts at the interval, category, and transition levels as suggested by Huang et al (2012). At the interval level, the study examined the area (size) and the rate of change over time intervals or durations. At specific time intervals, the study through the categories assessed the relationship between the size and intensity of gross losses and gross gains according to the various categories. Further, with specific category, the transition level was used to assess how the area or size and intensity of transitions vary with regards to other categories that are present for that transition. The interval intensity analysis further examined the variations in the annual overall change area over the time intervals. This analysis was further used to estimate the annual area change for each time interval and by comparing the uniform rate of change that existed assuming all the changes were equally or uniformly distributed over the study time. The equations below were used to calculate the various parameters for assessing the changes and intensity during the study. Equation 1 for instance was used to define the uniform annual rate of overall change, whereas Equation 2 was used to define specific interval annual rate of overall change. Equations 3 and 4 were used to define the intensity of a particular category's annual gross gain as percent of the size of the category at the end of the time interval and intensity of a particular category's annual gross loss as a percent of the size of the category at the beginning of the time interval (Huang et al., 2012).

Equation 1:

$$U = 100\%\ x\ \frac{\text{Change area during all intervals/Area of study region}}{\text{Duration of all intervals}}$$

Equation 2:

$$St = 100\%\ x\ \frac{Change\ area\ during\ interval\ [Yt, Y1]/Area\ of\ study\ region}{Duration\ of\ interval\ [Yt, Y1]}$$

Equation 3:

$$G = 100\%\ x\ \frac{Gross\ gain\ area\ of\ categoryj\ during\ [Yt, Y1]/Duration\ of\ [Yt, Y1]}{Area\ of\ categoryj\ at\ time\ interval\ [\ Y1]}$$

Equation 4:

$$L = 100\%\ x\ \frac{Gross\ loss\ area\ of\ categoryi\ during\ [Yt, Y1]/Duration\ of\ [Yt, Y1]}{Area\ of\ categoryi\ at\ time\ interval\ [\ Yt]}$$

Where U is the value of uniform line for time intensity analysis at [Y_1, Y_T]; St the annual intensity of change for the interval [Y_1, Y_T]; G the annual intensity of gross gain of category j for time interval [Y_t, Y_1]; L the annual intensity of gross loss of category i for time interval [Y_t, Y_1]; i is the index for a category at an initial time; j the index for a category at a subsequent time, t the index for a time point which ranges from 1 to T - 1; Yt is the year at time point.

Water Sampling

Four sampling areas were considered for water sampling. Water samples were collected from the Birim River at the following sites: non-stressed water (NSW), moderately stressed water (MSW), highly stressed water (HSW) and upstream of non-stressed water which served as the control. The Birim River was chosen for this study because it is the only water body among the other water bodies (Densu River and Ayensu River) which passes through the sampling site. Water samples were taken at monthly interval over a period of twelve months. The locations were selected based on the intensity of anthropogenic induced stress such as logging, farming and illegal mining. Water samples for physicochemical analyses were collected at a depth of about 20–30 cm, a total of five samples were collected at each location using water sampling bottles. The samples were collected against the direction of flow as suggested by Lapham et al. (1997). The samples were transported in an ice box to the laboratory for further analysis.

Laboratory Analysis of Water Samples

Physical properties of the water which include conductivity, pH, turbidity, temperature and total dissolved solids (TDS) were measured *in situ* in the field. The pH measurement of each sampled water was determined using the PHYME cobros 3 basic unit USB pH meter. The probe was dipped into 200 ml of the water sample. Conductivity was measured using Jenwey 4010 conductivity meter in 200 ml water sample. Turbidity was determined with the aid of a Hanna instrument LP 2000 turbidity meter. The temperature and TDS were measured using mercury in glass thermometer and Jenwey 4010 conductivity meter, respectively.

Determination of Heavy Metals in Water Samples

Water samples from the field were analysed for the presence of heavy metal including Cd, Cu, Fe, Pb and Zn as well as a metalloid As. The heavy metal analyses began with acidification with concentrated Nitric acid to a pH of 2. Acidified samples were kept in refrigerator to prevent metal precipitation

(APHA, 1995). This was followed with calibration which involved single or multiple dilutions of stock metal solutions. Reagent blanks and three calibration standards in graduated amounts in appropriated range of the linear part of the curve were prepared with same acid concentration as in samples. A Unicam 929 Atomic Absorption Spectrophotometer was used to analyse the concentrations of all the heavy metals listed above except mercury which was determined using an Automatic Mercury Analyser (model HG 5000).

Bacteriological Analysis of Water Samples

Samples for bacteriological analyses were collected into sterilized plain glass bottles and stored at 4°C in icebox to prevent alteration of parameters by light and to further ensure that microorganisms remained viable through transportation process to the laboratory for further analysis.

Determination of Total Coliform Counts

One hundred milliliters (100 ml) portion of the water sample was filtered through 47 mm membrane filters of 0.45µm pore size. Membrane filter was incubated on M-Endo agar (Wagtech Int.) and alternatively on Mac Conkey Agar at 37°C for 24 hours. Total coliform was detected as dark-red colonies with a metallic (golden) sheen on the M-Endo agar; and all bacteria colonies with yellow ring around them on the Mac Conkey Agar. The total number of colonies appearing was counted for each plate.

Determination of Faecal Coliform

Again, 100 ml portion of the water sample was filtered through 47 mm membrane filters of 0.45µm pore size. The membrane filter was incubated on M-FC agar at 44°C for 24 hours. Faecal coliform was detected as blue colonies on the M-FC agar. The total numbers of colonies appearing were counted for each plate.

Data Analysis

Analysis of vegetation data

Species diversity was evaluated using both Shannon-Wiener index (*H'*) and Simpson diversity index (*D*).

Shannon-Wiener index (*H'*)

The index was computed using the equation:

$$H' = \sum_{i=1}^{s} pi \, In \, pi \, ,$$

where *s* is the total number of species and *p* is the relative abundance of the *i* species

Simpson diversity index (*D*)

Simpson diversity index was computed using the equation:

$$D' = \frac{\sum_{i=1}^{s} ni(ni-1)}{\mathrm{N(N-1)}} \, ,$$

where *n* is the number of each species , N the total number of individual of all species.

To understand the population characteristics of the trees in the study area, the following parameters were calculated using standard formulae below:

1. Basal Area of trees

The basal area of trees was calculated using the formula:

$$Basal\ area = \frac{\pi d^2}{4}$$

where d is the diameter of the tree.

2. Density

$$Density = \frac{Number\ of\ individual\ species}{Area\ Sampled}$$

3. Frequency

$$Frequency = \frac{Number\ of\ plots\ in\ which\ species\ occur}{Total\ Number\ of\ plots\ Sampled}$$

4. Dominance

$$Dominance = \frac{Basal\ area\ of\ species}{Area\ Sampled}$$

5. Relative Frequency

$$Relative\ Frequency = \frac{Frequency\ for\ species}{Total\ Frequency\ of\ all\ species} \times 100$$

6. Relative Dominance

$$Relative\ Dominance = \frac{Dominance\ of\ Species}{Total\ Dominance\ of\ all\ Species} \times 100$$

With regards to the plant family, relative frequency (based on the enumeration of individuals) and basal area (based on the dbh measured) Mori et al., (1983) calculation approach were used. Further, Family Importance Value (FIV) was calculated as follows;

$$FIV = Relative\ Family\ Richness + Relative\ Density + Relative\ Dominance$$

Importance Value Index (IVI) of trees at species level was calculated as the sum of the relative density, the relative frequency and the relative dominance, thus;

$$IVI = Relative\ Density + Relative\ Frequency + Relative\ Dominance$$

Normalize Differential Vegetation Index (NDVI) was generated using the following formula:

$$\text{NDVI} = (\text{NIR} - \text{RED}) / (\text{NIR} + \text{RED})$$

Calculation of NDVI for a given pixel always results in a number that ranges from minus one (-1) to plus one (+1): Bare soils give a value close to zero and very dense green vegetation have values close to +1 (0.8-0.9).

Analysis of Land use Change

The analysis of the land use change was calculated using the formula below:

$$\text{Percentage LULC change} = \frac{\text{Area final year} - \text{Area initial year}}{\text{Area initial year}} \times 100$$

Analysis of soil data

Statistically significant differences among vegetation classes i.e Non-Stressed, Moderately Stressed and Highly Stressed were analyzed using analysis of variance (ANOVA). Pearson product momentum correlation analysis was used to determine the relationship between tree diversity, soil characteristics and carbon stocks within the vegetation. Multivariate analysis specifically Principal Component Analysis (PCA) was used to determine contributions of soil characteristics in explaining tree properties. Statistical analysis was performed using R software 2.6.0 and GenStats.

Analysis of water data

Descriptive statistics involving means, standard deviation as well as charts and graphs were used to express observations. In some cases, mean values were compared with world acceptable limits or standards and variations determined. Significant differences were tested at 95% confidence level.

The soil analysis was performed using the Analysis of Variance (ANOVA).

CHAPTER FOUR

RESULTS

Introduction

This chapter presents the results of the study. It focusses on the diversity of plants and physico-chemical properties of the soils underlying the vegetation and that of the Birim River in relation to anthropogenic stress in the study area. The areas covered include classification of tree species into various plant families, the ecological guilds and the conservational importance in terms of star rating according to Hawthorn et al. (1995). Others are tree density, frequency and dominance and importance value and diversity of tree species. Furthermore, carbon storage and soil characteristics was assessed first at the general vegetation level and at individual anthropogenic-induced stress level are presented. The chapter also presents findings on the influence of anthropogenic stresses on the quality of vegetation observed in the study area from the year 1986 to the year 2016 as well as findings on anthropogenic impacts on the quality of water resources. It finally concludes by presenting findings on the relationships between various vegetation characteristics, soil characteristics and the quality of water resources in the study area.

Vegetation Characteristics at the Study Sites

In all, a total of 1,768 individual trees were encountered during the study. One hundred and seventy-seven tree species were identified while 19 species representing 1.07% of the total number of species sampled were unidentified. The species identified were classified into 47 plant families with Apocynaceae (19.17%), Meliaceae (18.83%) and Fabaceae (18.10%) constituting the most dominant families. Of the 1,768 individual trees assessed, there were 117.9±22.1 individual trees, 36.4±12.6 species and 15.2±4.6 families per 50 × 50 m plot. At the vegetation stress level, a total of 526 trees was categorized into the Highly Stress Vegetation (HSV) while 603 trees and 639 trees were categorized into the Moderately Stressed Vegetation (MSV) and Non Stressed Vegetation (NSV), respectively.

Ecological Guild Classification of Species

The ecological guilds of the trees assessed showed variations in the proportions of Non Pioneer Light Demanders (NPLD), Pioneer, Shade-Bearers, and Swamp and Savanna/Non Forest plants (Figure 5). Shade-Bearers constituted the highest proportion followed by the Non-pioneer Light Demanders, Pioneers, Savanna/Non-forest and then the Swamp species.

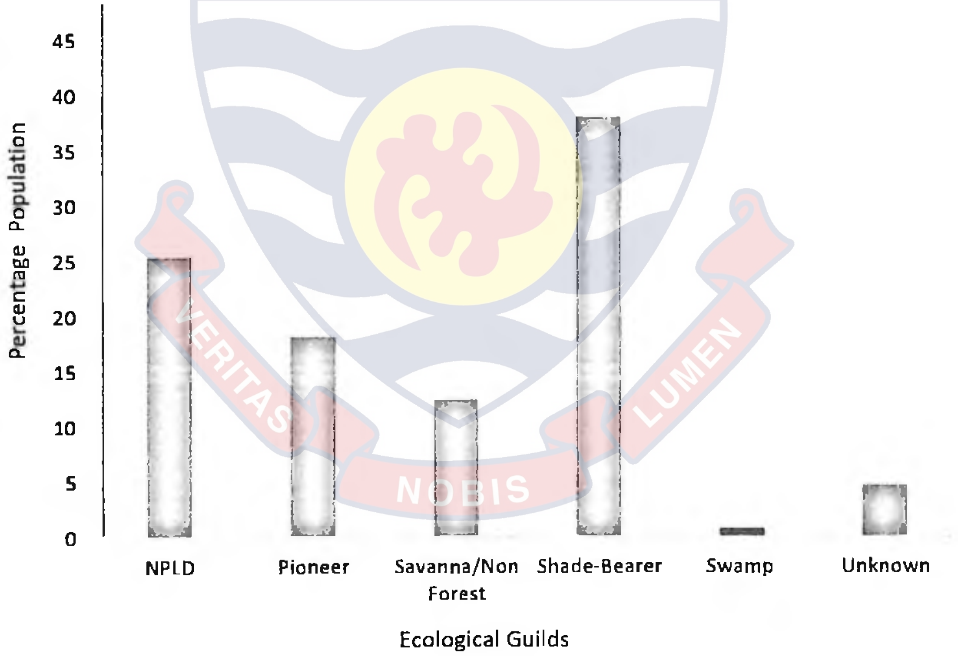

Figure 5: Percentage distribution of ecological guilds tree species encounted in the study area.

Star Rating of Species

Conservation wise, the identified tree species were star-rated into categories including Green, Blue, Black, Gold, Pink, Red or Scarlet star based on Hawthorne's (1995) protocol for rating forest tree species of Ghana for the purpose of conservation, (Table 2).

Table 2: Summary of Star categorization of forest trees species for conservation priority

Star	No. Degree squares in Africa	Comment
Black	1.6 ± 0.5	Urgent attention to conservation of population needed. Rare internationally, and at least uncommon in Ghana. Ghana must take particular care of these species
Gold	7.8 ± 3.8	Fairly rare internationally and/or locally. Ghana has some inescapable responsibility for maintaining these species
Blue	24.5 ± 12.6	Widespread internationally but rare in Ghana, or vice-versa. It may be in Ghana's interests to pay attention to protecting some of these species
Scarlet	(inc. in Red)	Common, but under serious pressure from heavy exploitation. Exploitation needs to be curtailed if usage is to be sustainable. Protection on all scales are vital
Red	39.6 ±16	Common, but under pressure from exploitation. Need careful control and some tree by tree and area protection
Pink	(inc. in Red)	Common and moderately exploited. Also non-abundant species of high potential value
Green	69.2 ±49.8	No particular conservation concern
Others	>100	Non forest species, or excluded from analysis for other reason

Source: Hawthorn (1995)

In all, the Green Star species formed the majority (54%)—they belong to the group with no particular conservation concern. This was followed by Pink Star (17%), Blue Star (9%), Red Star (2%), Scarlet Star (1%), Black Star (1%) and Gold Star (1%) respectively, (Figure 6). Approximately 17% of the species encountered during the study could not be rated due to their non-inclusion in the protocol used.

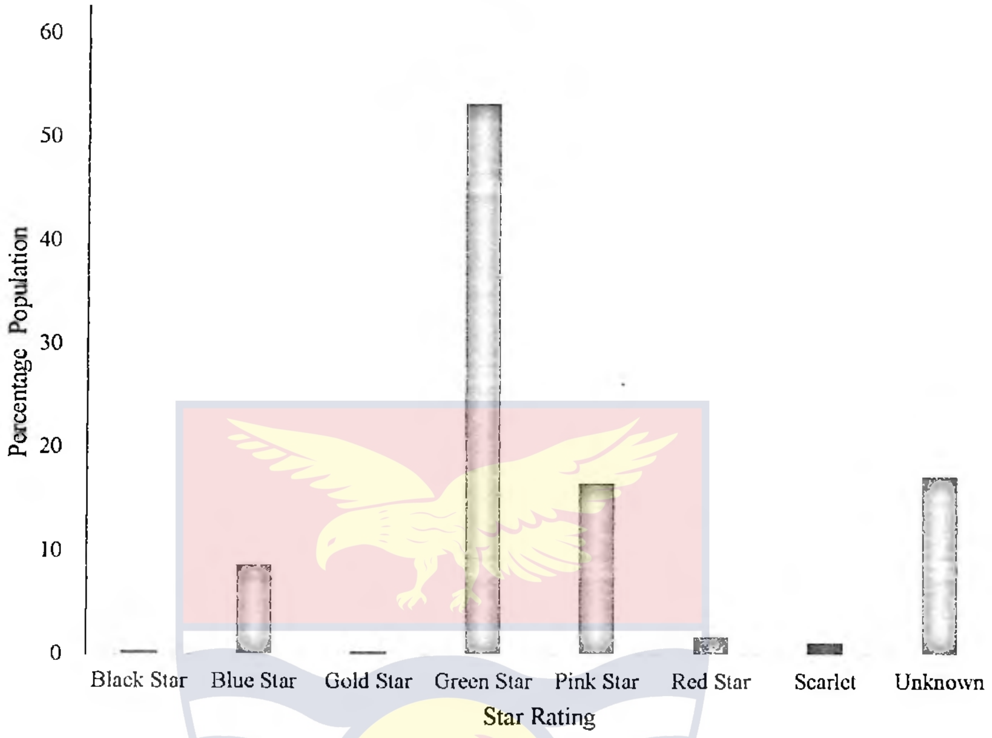

Figure 6: Star rating of identified species in the study area.

Diameter at Breast Height Distribution (DBH) of Species

In terms of the classification and distribution of the measured diameter at breast height, majority of the encountered species may be classified as sapling poles (Higman, Mayers, Bass, Judd, & Nussbaum, 2005) (Appendix C), followed by small trees, medium trees, large trees and giant trees (Table 3). A positively skewed distribution of the diameter at breast height was however observed in the study (Figure 7).

Table 3: Classification of encountered trees based on DBH

Tree classification	Population
Sapling poles	1318
Small trees	268
Medium trees	102
Large trees	62
Giant trees	18

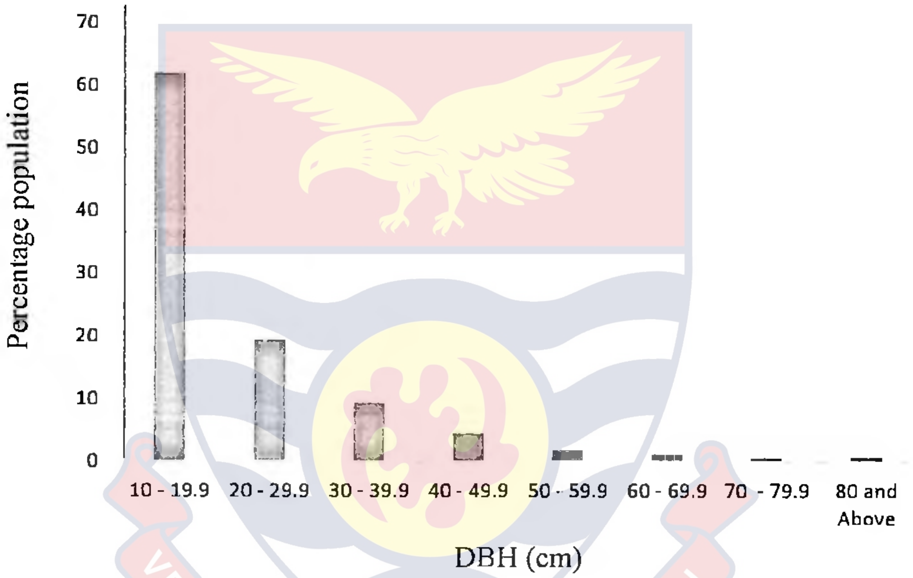

Figure 7: Distribution of diameter at breast height of encountered species

Plant Species Diversity and Plant Families in the Study Area

The diversity of plant species in the study area was generally high with several plant families. Shannon-Weiner and Simpson diversity indices were 4.21 and 0.97, respectively. The most species-rich families include Apocynaceae, Meliaceae and Fabaceae each of which contributed more than 18% of the total number of species identified. Other abundant families include the Malvaceae, Euphorbiaceae, Moraceae and Phyllanthaea (Table 4). The most important family according to the Family Importance Value (FIV) was Fabaceae while Verbenaceae and Erythroxylaceae had the lowest FIV values. Other important families included Meliaceae, Apocynaceae, Malvaceae, Phyllanthaceae, Moraceae, Euphorbiaceae and Sapotaceae in decreasing order (Table 4).

At the species level, the first ten most important tree species based on density, frequency and dominance include *Cedrela odorata*, *Funtumia africana*, *Tabernaemontana africana, Hymenostegia afzelii*, *Protomegabaria stapfiana*, *Chidlowia sanguinea, Alstonia boonei, Piptadeniastrum africanum, Ficus sur* and *Musanga cecropioides*. Table 5 however gives the rest of the encountered species together with the ten less important species including *Copaifera salikounda, Diospyros monbuttensis, Erythroxylum mannii, Khaya anthotheca, Pachystela brevipes, Picralima nitida, Sterculia oblonga, Tectona grandis, Trichilia martineaui* and *Vernonia amygdalina*

Table 4: Familial attributes of trees species in the study area

Family	Family Richness	Rel. Family Richness	Family Density	Rel. Family Density	Family Dominance	Rel. Family Dominance	FIV
Achariaceae	8	0.45	8.89	0.45	0.68	0.68	1.58
Anacardiaceae	11	0.62	12.22	0.62	0.42	0.42	1.67
Annonaceae	34	1.92	37.78	1.92	4.46	4.46	8.31
Apocynaceae	339	19.17	376.67	19.17	9.75	9.75	48.10
Araliaceae	3	0.17	3.33	0.17	0.12	0.12	0.45
Arecaceae	4	0.23	4.44	0.23	0.43	0.43	0.88
Asteraceae	5	0.28	5.56	0.28	0.10	0.10	0.67
Bignoniaceae	4	0.23	4.44	0.23	0.11	0.12	0.57
Boraginaceae	5	0.28	5.56	0.28	0.41	0.41	0.98
Brassicaceae	3	0.17	3.33	0.17	0.22	0.22	0.56
Burseraceae	9	0.51	10.00	0.51	0.27	0.28	1.29
Cannabaceae	31	1.75	34.44	1.75	1.97	1.97	5.48
Chrysobalanaceae	4	0.23	4.44	0.23	0.43	0.43	0.88
Clusiaceae	7	0.40	7.78	0.40	0.40	0.40	1.19
Combretaceae	10	0.57	11.11	0.57	1.13	1.13	2.26
Dichapetalaceae	1	0.06	1.11	0.06	0.04	0.04	0.16
Ebenaceae	8	0.45	8.89	0.45	0.16	0.16	1.06
Erythroxylaceae	1	0.06	1.11	0.06	0.01	0.01	0.12
Euphorbiaceae	86	4.86	95.56	4.86	2.51	2.51	12.24
Fabaceae	320	18.10	355.56	18.10	21.98	21.99	58.19
Gentianaceae	4	0.23	4.44	0.23	0.89	0.89	1.34
Humiriaceae	3	0.17	3.33	0.17	0.15	0.16	0.49
Irvingiaceae	1	0.06	1.11	0.06	0.24	0.24	0.35

Table 4 Continued

Family	Family Richness	Rel. Family Richness	Family Density	Rel. Family Density	Family Dominance	Rel. Family Dominance	FIV
Lauraceae	2	0.11	2.22	0.11	0.24	0.24	0.46
Lecythidaceae	13	0.74	14.44	0.74	0.52	0.52	1.99
Malvaceae	88	4.98	97.78	4.98	7.35	7.35	17.30
Medusandraceae	3	0.17	3.33	0.17	0.08	0.08	0.42
Melastomataceae	3	0.17	3.33	0.17	0.15	0.15	0.49
Meliaceae	333	18.83	370.00	18.83	16.11	16.12	53.79
Moraceae	75	4.24	83.33	4.24	4.31	4.31	12.79
Myristicaceae	9	0.51	10.00	0.51	0.67	0.67	1.69
Olacaceae	18	1.02	20.00	1.02	2.34	2.34	4.37
Pandaceae	2	0.11	2.22	0.11	0.03	0.03	0.26
Phyllanthaceae	75	4.24	83.33	4.24	4.40	4.40	12.89
Rhamnaceae	1	0.06	1.11	0.06	0.16	0.16	0.28
Rhizophoraceae	1	0.06	1.11	0.06	0.80	0.80	0.92
Rubiaceae	49	2.77	54.44	2.77	2.47	2.47	8.01
Rutaceae	14	0.79	15.56	0.79	0.37	0.37	1.95
Salicaceae	1	0.06	1.11	0.06	0.11	0.11	0.22
Sapindaceae	12	0.68	13.33	0.68	1.46	1.46	2.82
Sapotaceae	48	2.71	53.33	2.71	5.31	5.31	10.74
Simaroubaceae	10	0.57	11.11	0.57	0.36	0.36	1.49
Ulmaceae	3	0.17	3.33	0.17	0.53	0.53	0.87
Urticaceae	27	1.53	30.00	1.53	2.08	2.08	5.14
Verbenaceae	1	0.06	1.11	0.06	0.01	0.01	0.12
Violaceae	22	1.24	24.44	1.24	0.26	0.26	2.75
Unknown	57	3.22	63.33	3.22	2.94	2.94	9.39

Table 5: Species composition and structural attributes of tree species in the ARFR

Species	Family	Guild	Star Rating	Density	Rel. Density	Freq.	Rel. Freq.	Dominance	Rel. Dominance	IVI
Afzelia Africana	Fabaceae	NPLD	Red Star	2.22	0.11	0.13	0.11	0.09	0.09	0.32
Afzelia bella	Fabaceae	NPLD	Pink Star	1.11	0.06	0.07	0.06	0.05	0.05	0.16
Albizia adianthifolia	Fabaceae	NPLD	Green Star	8.89	0.45	0.53	0.45	1.00	1.00	1.90
Albizia zygia	Fabaceae	NPLD	Green Star	26.67	1.35	1.60	1.35	1.40	1.40	4.10
Allanblackia floribunda	Clusiaceae	Shade-bearer	Green Star	1.11	0.06	0.07	0.06	0.02	0.02	0.13
Allanblackia parviflora	Clusiaceae	Pioneer	Green Star	1.11	0.06	0.07	0.06	0.03	0.03	0.15
Alstonia boonei	Apocynaceae	Pioneer	Green Star	42.22	2.13	2.53	2.13	2.09	2.09	6.36
Amphimas pterocarpoides	Fabaceae	NPLD	Green Star	3.33	0.17	0.20	0.17	0.53	0.53	0.87
Annickia polycarpa	Annonaceae	-	-	3.33	0.17	0.20	0.17	0.11	0.11	0.45
Anopyxis klaineana	Rhizophoraceae	NPLD	Red Star	1.11	0.06	0.07	0.06	0.80	0.80	0.92
Anthocleista djalonensis	Gentianaceae	Pioneer	Green Star	1.11	0.06	0.07	0.06	0.03	0.03	0.14
Anthocleista nobilis	Gentianaceae	Pioneer	Green Star	3.33	0.17	0.20	0.17	0.86	0.86	1.20
Anthonotha fragrans	Fabaceae	NPLD	Green Star	7.78	0.39	0.47	0.39	0.70	0.70	1.48

Table 5 Continued

Species	Family	Guild	Star Rating	Density	Rel. Density	Freq.	Rel. Freq.	Dominance	Rel. Dominance	IVI
Anthonotha macrophylla	Fabaceae	Shade-bearer	Blue Star	5.56	0.28	0.33	0.28	0.10	0.10	0.66
Antiaris toxicaria	Moraceae	NPLD	Pink Star	7.78	0.39	0.47	0.39	0.52	0.52	1.30
Antidesma laciniatum	-	Shade-bearer	Green Star	2.22	0.11	0.13	0.11	0.03	0.03	0.25
Antrocaryon micraster	Anacardiaceae	NPLD	Red Star	5.56	0.28	0.33	0.28	0.20	0.20	0.76
Aprotumia indet	-	-	-	2.22	0.11	0.13	0.11	0.02	0.02	0.25
Aubrevillea kerstingii	Fabaceae	NPLD	Blue Star	1.11	0.06	0.07	0.06	0.02	0.02	0.13
Aulacocalyx jasminiflora	Rubiaceae	Shade-bearer	Green Star	5.56	0.28	0.33	0.28	0.11	0.11	0.68
Baphia nitida	Fabaceae	Shade-bearer	Green Star	3.33	0.17	0.20	0.17	0.05	0.05	0.39
Baphia pubescens	Fabaceae	Pioneer	Green Star	3.33	0.17	0.20	0.17	0.06	0.06	0.40
Beilschmiedia mannii	Fabaceae	Shade-bearer	Green Star	6.67	0.34	0.40	0.34	0.34	0.34	1.02
Berlinia indet	Fabaceae	NPLD	Green Star	3.33	0.17	0.20	0.17	0.18	0.18	0.52
Berlinia tomentella	Fabaceae	Shade-bearer	Green Star	8.89	0.45	0.53	0.45	0.81	0.81	1.71
Blighia sapida	Sapindaceae	NPLD	Green Star	6.67	0.34	0.40	0.34	0.60	0.60	1.27
Blighia welwitschii	Sapindaceae	NPLD	Green Star	5.56	0.28	0.33	0.28	0.71	0.71	1.28
Bombax buonopozense	Malvaceae	Pioneer	Green Star	2.22	0.11	0.13	0.11	0.06	0.06	0.29

Table 5 Continued

Species	Family	Guild	Star Rating	Density	Rel. Density	Freq.	Rel. Freq.	Dominance	Rel. Dominance	IVI
Bridelia atroviridis	Phyllanthaceae	Pioneer	Green Star	2.22	0.11	0.13	0.11	0.04	0.04	0.26
Buchholzia coriacea	Brassicaceae	Shade-bearer	Green Star	3.33	0.17	0.20	0.17	0.22	0.22	0.56
Bussea occidentalis	Fabaceae	NPLD	Green Star	18.89	0.95	1.13	0.95	1.01	1.01	2.92
Calpocalyx brevibracteatus	Fabaceae	Shade-bearer	Green Star	18.89	0.95	1.13	0.95	0.60	0.60	2.51
Calpocalyx monadelpha	Fabaceae	Shade-bearer	Green Star	1.11	0.06	0.07	0.06	0.02	0.02	0.13
Canarium schweinfurthii	Burseraceae	NPLD	Pink Star	1.11	0.06	0.07	0.06	0.03	0.03	0.14
Carapa procera	Meliaceae	Shade-bearer	Green Star	23.33	1.18	1.40	1.18	0.64	0.64	3.00
Cecropia peltata	Urticaceae	Pioneer	Green Star	1.11	0.06	0.07	0.06	0.02	0.02	0.13
Cedrela odorata	Meliaceae	Savanna/non forest		245.56	12.41	14.73	12.41	11.39	11.40	36.22
Ceiba pentandra	Malvaceae	Pioneer	Green Star	3.33	0.17	0.20	0.17	1.81	1.81	2.15
Celtis adolfi-friderici	Cannabaceae	Pioneer	Green Star	5.56	0.28	0.33	0.28	0.33	0.33	0.89
Celtis mildbraedii	Cannabaceae	Shade-bearer	Green Star	10.00	0.51	0.60	0.51	0.56	0.56	1.57
Celtis philippensis	Cannabaceae	-	-	8.89	0.45	0.53	0.45	0.48	0.48	1.37
Celtis zenkeri	Cannabaceae	NPLD	Green Star	5.56	0.28	0.33	0.28	0.37	0.37	0.93
Chidlowia sanguinea	Fabaceae	Shade-bearer	Blue Star	58.89	2.98	3.53	2.98	3.86	3.86	9.82

Table 5 Continued

Species	Family	Guild	Star Rating	Density	Rel. Density	Freq.	Rel. Freq.	Dominance	Rel. Dominance	IVI
Chrysophyllum albidum	Sapotaceae	Shade-bearer	Pink Star	5.56	0.28	0.33	0.28	0.25	0.25	0.81
Chrysophyllum giganteum	Sapotaceae	Shade-bearer	Pink Star	3.33	0.17	0.20	0.17	0.09	0.09	0.42
Chrysophyllum perpulchrum	Sapotaceae	NPLD	Green Star	2.22	0.11	0.13	0.11	0.05	0.05	0.27
Chrysophyllum pruniforme	Sapotaceae	Shade-bearer	Green Star	1.11	0.06	0.07	0.06	0.03	0.03	0.14
Chrysophyllum subnudum	Sapotaceae	Shade-bearer	Green Star	20.00	1.01	1.20	1.01	2.21	2.21	4.24
Cleidion gabonicum	Euphorbiaceae	Shade-bearer	Green Star	22.22	1.12	1.33	1.12	0.29	0.29	2.53
Cleistopholis patens	Annonaceae	Pioneer	Green Star	3.33	0.17	0.20	0.17	1.24	1.24	1.57
Cola edulis	Malvaceae	-	-	1.11	0.06	0.07	0.06	0.20	0.20	0.31
Cola gigantean	Malvaceae	NPLD	Green Star	10.00	0.51	0.60	0.51	0.42	0.42	1.43
Cola heterophylla	Malvaceae	-	-	7.78	0.39	0.47	0.39	0.10	0.10	0.89
Cola indet	Malvaceae	-	-	2.22	0.11	0.13	0.11	0.03	0.03	0.25
Cola lateritia	Malvaceae	Shade-bearer	Green Star	3.33	0.17	0.20	0.17	0.11	0.11	0.44
Cola millenii	Malvaceae	NPLD	Green Star	1.11	0.06	0.07	0.06	0.01	0.01	0.13
Cola nitida	Malvaceae	Shade-bearer	Pink Star	21.11	1.07	1.27	1.07	2.20	2.20	4.33
Cola verticillata	Malvaceae	Shade-bearer	Pink Star	4.44	0.22	0.27	0.22	0.08	0.08	0.53

Table 5 Continued

Species	Family	Guild	Star Rating	Density	Rel. Density	Freq.	Rel. Freq.	Dominance	Rel. Dominance	IVI
Copaifera salikounda	Fabaceae	Shade-bearer	Red Star	1.11	0.06	0.07	0.06	0.01	0.01	0.12
Cordia indet	Boraginaceae	Pioneer	Green Star	2.22	0.11	0.13	0.11	0.21	0.21	0.44
Cordia millenii	Boraginaceae	Pioneer	Green Star	2.22	0.11	0.13	0.11	0.16	0.16	0.39
Cordia senegalensis	Boraginaceae	Pioneer	Blue Star	1.11	0.06	0.07	0.06	0.04	0.04	0.15
Corynanthe pachyceras	Rubiaceae	NPLD	Green Star	17.78	0.90	1.07	0.90	0.78	0.78	2.58
Cussonia bancoensis	Araliaceae	Pioneer	Gold Star	3.33	0.17	0.20	0.17	0.12	0.12	0.45
Dacryodes klaineana	Burseraceae	Shade-bearer	Green Star	8.89	0.45	0.53	0.45	0.24	0.24	1.14
Dialium aubrevillei	Fabaceae	Shade-bearer	Green Star	5.56	0.28	0.33	0.28	0.28	0.28	0.84
Dichapetalum madagascariense	Dichapetalaceae	Shade-bearer	Green Star	1.11	0.06	0.07	0.06	0.04	0.04	0.16
Diospyros canaliculata	Ebenaceae	Shade-bearer	Green Star	3.33	0.17	0.20	0.17	0.03	0.03	0.36
Diospyros kamerunensis	Ebenaceae	Shade-bearer	Green Star	1.11	0.06	0.07	0.06	0.02	0.02	0.14
Diospyros monbuttensis	Ebenaceae	Shade-bearer	Green Star	1.11	0.06	0.07	0.06	0.01	0.01	0.12
Diospyros sanza-minika	Ebenaceae	Shade-bearer	Green Star	3.33	0.17	0.20	0.17	0.09	0.09	0.43
Discoglypremna caloneura	Euphorbiaceae	Pioneer	Green Star	17.78	0.90	1.07	0.90	0.59	0.59	2.39
Distemonanthus benthamianus	Fabaceae	NPLD	Pink Star	1.11	0.06	0.07	0.06	0.02	0.02	0.13

Table 5 Continued

Species	Family	Guild	Star Rating	Density	Rel. Density	Freq.	Rel. Freq.	Dominance	Rel. Dominance	IVI
Guarea thompsonii	Meliaceae	Shade-bearer	Pink Star	3.33	0.17	0.20	0.17	0.05	0.05	0.38
Hannoa klaineana	Simaroubaceae	Pioneer	Green Star	11.11	0.56	0.67	0.56	0.36	0.36	1.48
Hexalobus crispiflorus	Annonaceae	Shade-bearer	Green Star	7.78	0.39	0.47	0.39	2.35	2.35	3.14
Holoptelea grandis	Ulmaceae	Pioneer	Green Star	3.33	0.17	0.20	0.17	0.53	0.53	0.87
Hunteria eburnean	Apocynaceae	Shade-bearer	Green Star	2.22	0.11	0.13	0.11	0.08	0.08	0.30
Hunteria umbellata	Apocynaceae	Shade-bearer	Green Star	3.33	0.17	0.20	0.17	0.09	0.09	0.43
Hymenostegia afzelii	Fabaceae	Shade-bearer	Green Star	92.22	4.66	5.53	4.66	2.63	2.64	11.96
Isolona campanulata	Annonaceae	Shade-bearer	Green Star	2.22	0.11	0.13	0.11	0.07	0.07	0.30
Khaya anthotheca	Meliaceae	NPLD	Scarlet Star	1.11	0.06	0.07	0.06	0.01	0.01	0.12
Kigelia Africana	Bignoniaceae	NPLD	Green Star	1.11	0.06	0.07	0.06	0.02	0.02	0.13
Klainedoxa gabonensis	Irvingiaceae	NPLD	Green Star	1.11	0.06	0.07	0.06	0.24	0.24	0.35
Lannea welwitschii	Anacardiaceae	Pioneer	Green Star	3.33	0.17	0.20	0.17	0.16	0.16	0.49
Lophira alata	Sapotaceae	Pioneer	Red Star	5.56	0.28	0.33	0.28	1.80	1.81	2.37
Lovoa trichilioides	Meliaceae	NPLD	Red Star	2.22	0.11	0.13	0.11	0.06	0.06	0.28
Macaranga barteri	Euphorbiaceae	Pioneer	Green Star	27.78	1.40	1.67	1.40	0.87	0.87	3.67

Table 5 Continued

Species	Family	Guild	Star Rating	Density	Rel. Density	Freq.	Rel. Freq.	Dominance	Rel. Dominance	IVI
Macaranga heterophylla	Euphorbiaceae	Pioneer	Green Star	8.89	0.45	0.53	0.45	0.32	0.32	1.22
Macaranga heudelotii	Phyllanthaceae	Pioneer	Green Star	1.11	0.06	0.07	0.06	0.02	0.02	0.13
Macaranga hurifolia	Euphorbiaceae	Pioneer	Green Star	1.11	0.06	0.07	0.06	0.02	0.02	0.13
Maesobotrya barteri	Euphorbiaceae	Shade-bearer	Green Star	7.78	0.39	0.47	0.39	0.12	0.12	0.91
Maesopsis eminii	Rhamnaceae	Pioneer	Green Star	1.11	0.06	0.07	0.06	0.16	0.16	0.28
Maranthes chrysophylla	Chrysobalanaceae	Shade-bearer	Blue Star	2.22	0.11	0.13	0.11	0.39	0.39	0.62
Margaritaria discoidea	Phyllanthaceae	Pioneer	Green Star	14.44	0.73	0.87	0.73	1.07	1.07	2.53
Memecylon afzelii	Melastomataceae	Shade-bearer	Green Star	3.33	0.17	0.20	0.17	0.05	0.05	0.39
Memecylon indet	Melastomataceae	-	-	2.22	0.11	0.13	0.11	0.11	0.11	0.33
Microdesmis keayana	Pandaceae	Shade-bearer	Green Star	1.11	0.06	0.07	0.06	0.02	0.02	0.13
Milicia excels	Moraceae	Pioneer	Scarlet Star	10.00	0.51	0.60	0.51	0.12	0.12	1.13
Millettia rhodantha	Fabaceae	Shade-bearer	Green Star	1.11	0.06	0.07	0.06	0.08	0.08	0.19
Monodora myristica	Annonaceae	Shade-bearer	Green Star	8.89	0.45	0.53	0.45	0.33	0.33	1.23
Morinda lucida	Rubiaceae	Pioneer	Green Star	4.44	0.22	0.27	0.22	0.09	0.09	0.53
Musanga cecropioides	Urticaceae	Pioneer	Green Star	26.67	1.35	1.60	1.35	2.01	2.01	4.71

Table 5 Continued

Species	Family	Guild	Star Rating	Density	Rel. Density	Freq.	Rel. Freq.	Dominance	Rel. Dominance	IVI
Myrianthus libericus	Urticaceae	Shade-bearer	Green Star	2.22	0.11	0.13	0.11	0.06	0.06	0.28
Napoleonaea vogelii	Lecythidaceae	Shade-bearer	Green Star	6.67	0.34	0.40	0.34	0.10	0.10	0.77
Nauclea diderrichii	Rubiaceae	Pioneer	Scarlet Star	1.11	0.06	0.07	0.06	0.19	0.19	0.30
Nesogordonia papaverifera	Malvaceae	Shade-bearer	Pink Star	11.11	0.56	0.67	0.56	0.61	0.61	1.73
Newbouldia laevis	Bignoniaceae	Pioneer	Green Star	1.11	0.06	0.07	0.06	0.02	0.02	0.14
Octoknema borealis	Olacaceae	Shade-bearer	Green Star	1.11	0.06	0.07	0.06	0.21	0.21	0.32
Omphalocarpum ahia	Sapotaceae	Swamp	Blue Star	6.67	0.34	0.40	0.34	0.27	0.27	0.94
Omphalocarpum elatum	Meliaceae	Shade-bearer	Green Star	1.11	0.06	0.07	0.06	0.02	0.02	0.13
Ongokea gore	Olacaceae	NPLD	Green Star	1.11	0.06	0.07	0.06	0.44	0.44	0.55
Ophiobotrys zenkeri	Salicaceae	NPLD	Blue Star	1.11	0.06	0.07	0.06	0.11	0.11	0.22
Pachystela brevipes	Sapotaceae	Swamp	Green Star	1.11	0.06	0.07	0.06	0.01	0.01	0.12
Panda oleosa	Pandaceae	Shade-bearer	Green Star	1.11	0.06	0.07	0.06	0.01	0.01	0.13
Parinari excels	Chrysobalanaceae	NPLD	Green Star	2.22	0.11	0.13	0.11	0.03	0.03	0.26
Parkia bicolor	Fabaceae	NPLD	Green Star	17.78	0.90	1.07	0.90	2.06	2.06	3.86
Pentaclethra macrophylla	Fabaceae	NPLD	Green Star	10.00	0.51	0.60	0.51	1.90	1.90	2.91

Table 5 Continued

Species	Family	Guild	Star Rating	Density	Rel. Density	Freq.	Rel. Freq.	Dominance	Rel. Dominance	IVI
Pentadesma butyracea	Clusiaceae	Shade-bearer	Blue Star	3.33	0.17	0.20	0.17	0.30	0.30	0.64
Persea Americana	Lauraceae	-	-	2.22	0.11	0.13	0.11	0.24	0.24	0.46
Petersianthus cecropioides	Lecythidaceae	Pioneer	Green Star	2.22	0.11	0.13	0.11	0.27	0.27	0.49
Petersianthus macrocarpus	Lecythidaceae	Pioneer	Green Star	2.22	0.11	0.13	0.11	0.03	0.03	0.25
Picralima nitida	Apocynaceae	Shade-bearer	Blue Star	1.11	0.06	0.07	0.06	0.01	0.01	0.12
Piptadeniastrum africanum	Fabaceae	NPLD	Pink Star	25.56	1.29	1.53	1.29	3.50	3.51	6.09
Placodiscus boya	Sapindaceae	Shade-bearer	Gold Star	1.11	0.06	0.07	0.06	0.15	0.15	0.26
Protomegabaria stapfiana	Phyllanthaceae	Shade-bearer	Blue Star	65.56	3.31	3.93	3.31	3.27	3.27	9.90
Pseudospondias microcarp	Anacardiaceae	Swamp	Green Star	3.33	0.17	0.20	0.17	0.07	0.07	0.40
Psydrax arnoldiana	Rubiaceae	Pioneer	Blue Star	5.56	0.28	0.33	0.28	0.82	0.82	1.39
Psydrax parviflora	Rubiaceae	Pioneer	Green Star	1.11	0.06	0.07	0.06	0.04	0.04	0.15
Pterygota macrocarpa	Malvaceae	NPLD	Red Star	4.44	0.22	0.27	0.22	0.21	0.21	0.66
Pycnanthus angolensis	Myristicaceae	NPLD	Pink Star	10.00	0.51	0.60	0.51	0.67	0.67	1.68
Rauvolfia vomitoria	Apocynaceae	Pioneer	Green Star	34.44	1.74	2.07	1.74	0.65	0.65	4.13
Ricinodendron heudelotii	Euphorbiaceae	Pioneer	Green Star	4.44	0.22	0.27	0.22	0.13	0.13	0.58

Table 5 Continued

Species	Family	Guild	Star Rating	Density	Rel. Density	Freq.	Rel. Freq.	Dominance	Rel. Dominance	IVI
Rinorea oblongifolia	Violaceae	Shade-bearer	Green Star	23.33	1.18	1.40	1.18	0.26	0.26	2.62
Rothmannia hispida	Malvaceae	Shade-bearer	Green Star	2.22	0.11	0.13	0.11	0.02	0.02	0.25
Sacoglottis gabonensis	Humiriaceae	Swamp	Blue Star	3.33	0.17	0.20	0.17	0.15	0.16	0.49
Scottellia klaineana	Achariaceae	Shade-bearer	Pink Star	8.89	0.45	0.53	0.45	0.68	0.68	1.58
Scytopetalum tieghemii	Lecythidaceae	Shade-bearer	Blue Star	3.33	0.17	0.20	0.17	0.12	0.12	0.46
Soyauxia grandifolia	Medusandraceae	Shade-bearer	Blue Star	3.33	0.17	0.20	0.17	0.02	0.02	0.35
Soyauxia velutina	Medusandraceae	Shade-bearer	Green Star	2.22	0.11	0.13	0.11	0.06	0.06	0.29
Spathodea campanulata	Bignoniaceae	Pioneer	Green Star	2.22	0.11	0.13	0.11	0.07	0.07	0.30
Sterculia oblonga	Malvaceae	NPLD	Green Star	1.11	0.06	0.07	0.06	0.01	0.01	0.12
Sterculia rhinopetala	Malvaceae	NPLD	Pink Star	1.11	0.06	0.07	0.06	0.09	0.09	0.21
Sterculia tragacantha	Malvaceae	Pioneer	Green Star	15.56	0.79	0.93	0.79	0.75	0.75	2.32
Strephonema pseudocola	Combretaceae	Shade-bearer	Blue Star	3.33	0.17	0.20	0.17	0.76	0.76	1.10
Strombosia glaucescens	Olacaceae	Shade-bearer	Green Star	4.44	0.22	0.27	0.22	0.76	0.76	1.21
Strombosia pustulata	Olacaceae	Shade-bearer	Green Star	13.33	0.67	0.80	0.67	0.93	0.93	2.28
Symphonia globulifera	Clusiaceae	Swamp	Green Star	1.11	0.06	0.07	0.06	0.03	0.03	0.14

Table 5 Continued

Species	Family	Guild	Star Rating	Density	Rel. Density	Freq.	Rel. Freq.	Dominance	Rel. Dominance	IVI
Synsepalum afzelii	Sapotaceae	Shade-bearer	Black Star	5.56	0.28	0.33	0.28	0.48	0.48	1.04
Tabernaemontana African	Apocynaceae	Shade-bearer	Green Star	107.78	5.45	6.47	5.45	2.26	2.27	13.16
Tectona grandis	Verbenaceae	-	-	1.11	0.06	0.07	0.06	0.01	0.01	0.12
Terminalia ivorensis	Combretaceae	Pioneer	Scarlet Star	4.44	0.22	0.27	0.22	0.23	0.23	0.68
Terminalia superba	Combretaceae	Pioneer	Pink Star	3.33	0.17	0.20	0.17	0.14	0.14	0.48
Tetrorchidium didymoster.	Euphorbiaceae	Pioneer	Green Star	6.67	0.34	0.40	0.34	0.17	0.17	0.84
Tieghemella heckelii	Sapotaceae	NPLD	Scarlet Star	1.11	0.06	0.07	0.06	0.07	0.07	0.18
Treculia Africana	Moraceae	NPLD	Green Star	1.11	0.06	0.07	0.06	0.37	0.37	0.49
Trema orientalis	Cannabaceae	Pioneer	Green Star	4.44	0.22	0.27	0.22	0.24	0.24	0.69
Tricalysia discolor	Rubiaceae	Shade-bearer	Green Star	22.22	1.12	1.33	1.12	0.41	0.41	2.66
Tricalysia pallens	Rubiaceae	Shade-bearer	Green Star	1.11	0.06	0.07	0.06	0.02	0.02	0.13
Trichilia fragrans	Meliaceae	NPLD	-	1.11	0.06	0.07	0.06	0.02	0.02	0.13
Trichilia heudelotii	Meliaceae	NPLD	Green Star	3.33	0.17	0.20	0.17	0.12	0.12	0.45

Table 5 Continued

Species	Family	Guild	Star Rating	Density	Rel. Density	Freq.	Rel. Freq.	Dominance	Rel. Dominance	IVI
Trichilia martineaui	Meliaceae	NPLD	Gold Star	1.11	0.06	0.07	0.06	0.01	0.01	0.12
Trichilia monadelpha	Meliaceae	NPLD	Green Star	26.67	1.35	1.60	1.35	0.73	0.73	3.43
Trichilia prieureana	Meliaceae	NPLD	Green Star	14.44	0.73	0.87	0.73	0.56	0.56	2.02
Trichilia tessmannii	Meliaceae	NPLD	Green Star	7.78	0.39	0.47	0.39	0.32	0.32	1.10
Trilepisium madagascariense	Moraceae	NPLD	Green Star	22.22	1.12	1.33	1.12	1.48	1.48	3.72
Triplochiton scleroxylon	Malvaceae	Pioneer	Scarlet Star	5.56	0.28	0.33	0.28	0.63	0.63	1.19
Turraeanthus africanus	Meliaceae	Shade-bearer	Pink Star	22.22	1.12	1.33	1.12	1.59	1.59	3.84
Vernonia amygdalina	Asteraceae	Pioneer/Savanna		1.11	0.06	0.07	0.06	0.01	0.01	0.12
Vernonia conferta	Asteraceae	Pioneer	Green Star	4.44	0.22	0.27	0.22	0.09	0.09	0.54
Vismia guineensis	Clusiaceae	-		1.11	0.06	0.07	0.06	0.02	0.02	0.13
Xylia evansii	Fabaceae	NPLD	Blue Star	5.56	0.28	0.33	0.28	0.34	0.34	0.91
Xylopia aethiopica	Annonaceae	Pioneer	Blue Star	2.22	0.11	0.13	0.11	0.07	0.07	0.29
Xylopia quintasii	Annonaceae	Shade-bearer	Green Star	2.22	0.11	0.13	0.11	0.03	0.03	0.25

Table 5 Continued

Species	Family	Guild	Star Rating	Density	Rel. Density	Freq.	Rel. Freq.	Dominance	Rel. Dominance	IVI
Xylopia sp	Annonaceae			2.22	0.11	0.13	0.11	0.00	0.00	0.22
Xylopia staudtii	Annonaceae	Shade-bearer	Green Star	3.33	0.17	0.20	0.17	0.09	0.09	0.43
Xylopia villosa	Annonaceae	Shade-bearer	Green Star	2.22	0.11	0.13	0.11	0.14	0.14	0.37
Zanthoxylum gilletii	Rutaceae	Pioneer	Green Star	5.56	0.28	0.33	0.28	0.10	0.10	0.66
Zanthoxylum leprieurii	Rutaceae	Pioneer	Green Star	10.00	0.51	0.60	0.51	0.27	0.27	1.28
Unknown 1	-	-	-	54.44	2.75	3.27	2.75	2.05	2.05	7.55
Unknown 2	-	-	-	4.44	0.22	0.27	0.22	0.84	0.84	1.29

Impacts of Stress Levels on Plant Diversity

Of the 1768 individual woody plants identified in the study, 639 was identified in the NSV. This was made up of 65 species belonging to 25 families with 12 species being unidentified. In the MSV, 603 individual trees made up of 53 species belonging to 19 families were assessed with 7 unknowns. The HSV had 526 individual trees identified into 51 species belonging to 20 families and 4 unknowns. In all, 14 species were shared by NSV and MSV, 3 by NSV and HSV and 10 by MSV and HSV. All three vegetation types had 12 species in common.

On the average, the NSV recorded the highest tree population followed by the MSV and then the HSV. Species wise, the MSV was observed to contain the most number of species followed by NSV and HSV whereas the NSV recorded the highest plant family followed by the MSV and HSV. Further, there was statistically no significant difference observed in the mean number of individual trees, mean species, mean basal area, Shannon diversity index and Simpson diversity index—for each of these variables, $p>0.05$ (Table 6).

Table 6: Effect of stress on stand structure and diversity of woody plant species (mean ± S.D)

Parameters	Stress type			
	HSV	MSV	NSV	p-value
Mean individuals per plot	105.2 ± 28.8	120.6 ± 20.1	127.8 ± 24.5	0.367
Mean basal area (m^2 per	6.6 ± 1.7	8.3 ± 1.2	7.7 ± 1.9	0.52
Mean number of species	29.8 ± 14.5	41.6 ± 7.6	37.8 ± 14.0	0.05
Mean plant families	14.2 ± 6.3	15.2 ± 3.2	16.2 ± 4.7	0.6
Shannon-Weiner index	2.5 ± 1.1	3.2 ± 0.2	2.9 ± 0.7	0.378
Simpson index	0.78 ± 0.2	0.9 ± 0.1	0.9 ± 0.1	0.429

Impacts of Stress Levels on Conservation Importance of Plant Species

In general, stress through the various anthropogenic activities had varying impacts on the conservation rating of plant species. Green Star, the most dominant category formed 46%, 67% and 49% per hectare in the HSV, MSV and NSV respectively. Table 7 and Figure 8 show the population and percentage distributions of the various conservational importance of species at the three stressed vegetation levels.

Table 7: Rating of species according to stress level

Star Rating	HSV (%)	MSV (%)	NSV (%)
Black Star	0.00	0.00	0.95
Blue Star	2.19	7.14	18.63
Gold Star	0.16	0.17	0.57
Green Star	45.23	66.78	48.86
Pink Star	12.36	21.43	16.73
Red Star	2.19	1.00	2.09
Scarlet	1.72	1.33	0.38
Others	36.31	2.16	11.79

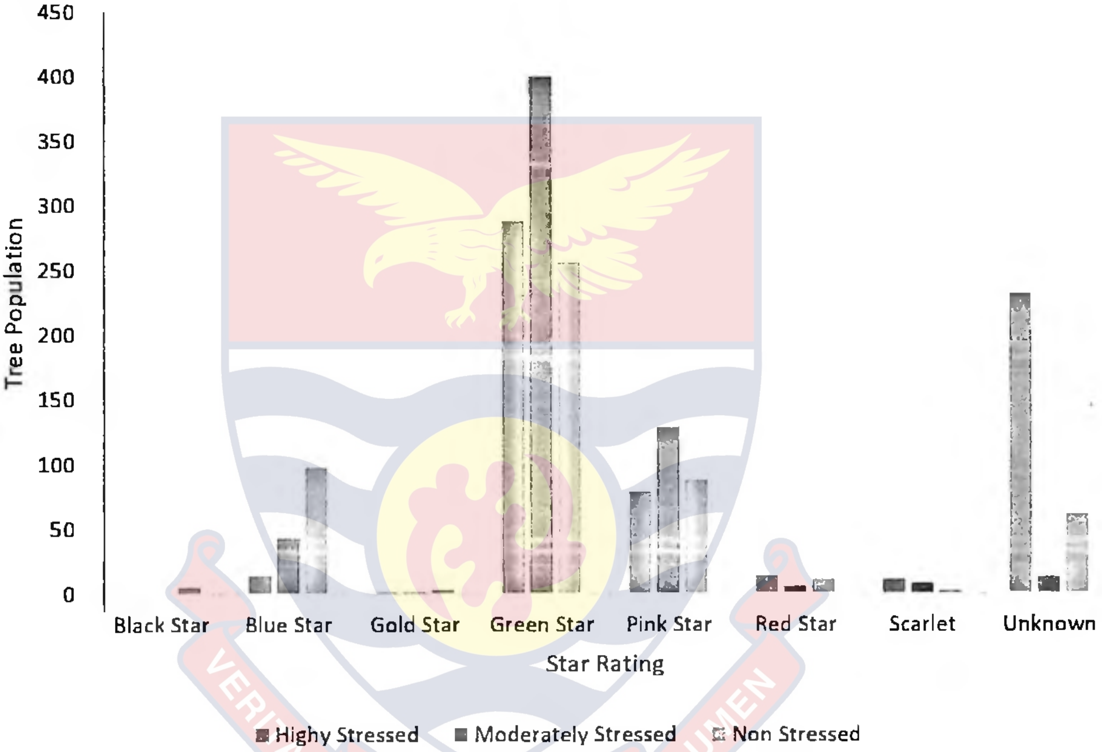

Figure 8: Conservational rating of encountered tree species in the study area

Impacts of Stress Levels on Ecological Guild Composition

There was significant difference in the ecological guilds in the stressed vegetation ($p<0.05$) (Figure 9) with Shade-bearer forming the majority in both the MSV (50%) and the NSV (52%). However, in the HSV, pioneer species formed the greatest proportion of the woody plant species encountered (Table 8).

Table 8: Percentage population of ecological guilds of plant species encountered in the study area

Ecological guild	HSV (%)	MSV (%)	NSV (%)
NPLD	21.75	31.06	23.57
Pioneer	25.51	15.95	12.17
Savanna/Non Forest	32.71	0.33	1.90
Shade-Bearer	15.81	50.33	51.71
Swamp	0.94	0.66	0.76
Unknown	3.29	1.66	9.89

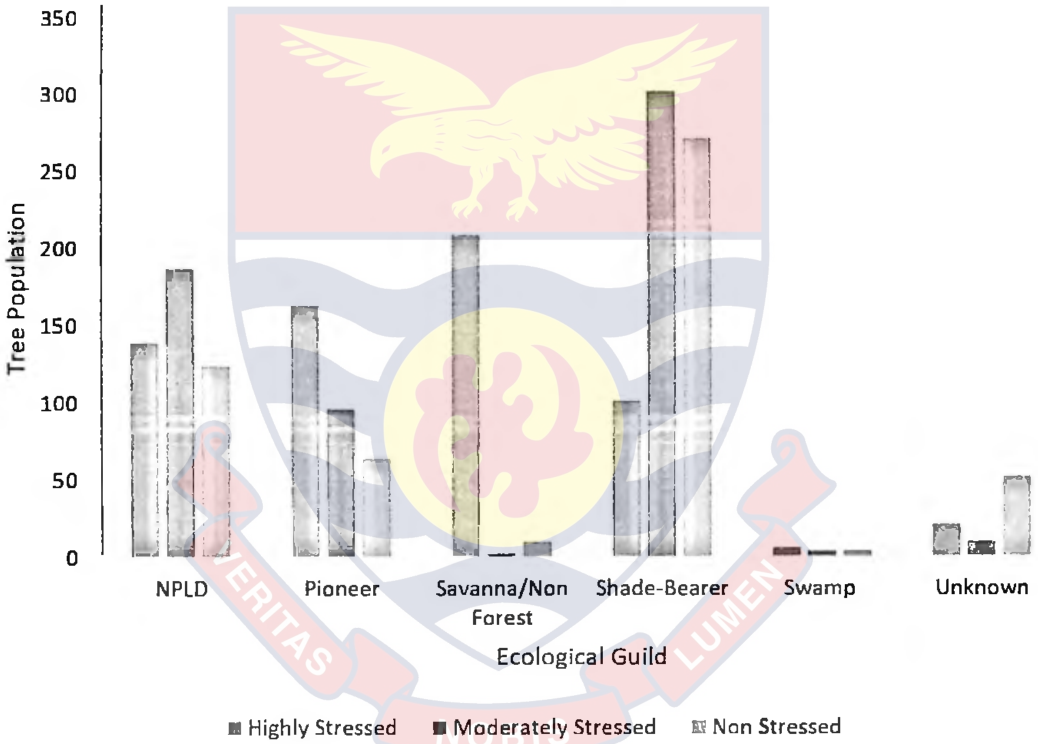

Figure 9: Ecological guilds of tree population in the study area

Impacts of Stress Levels on Diameter at Breast Height (DBH)

Regarding DBH of the species per the levels of stresses, the categorical distribution of the woody plants did not vary significantly (p = 0.319) with respect to stress levels (Figure 10), although all the three stressed areas had majority of the identified woody plant species having DBH between 10 and 20 cm. The HSV however recorded more woody plants in this category compared to the MSV and the NSV as shown in Figure 10. Again, majority of the population of woody trees encountered may be classified as sampling pole with positive skewness in all three stress levels.

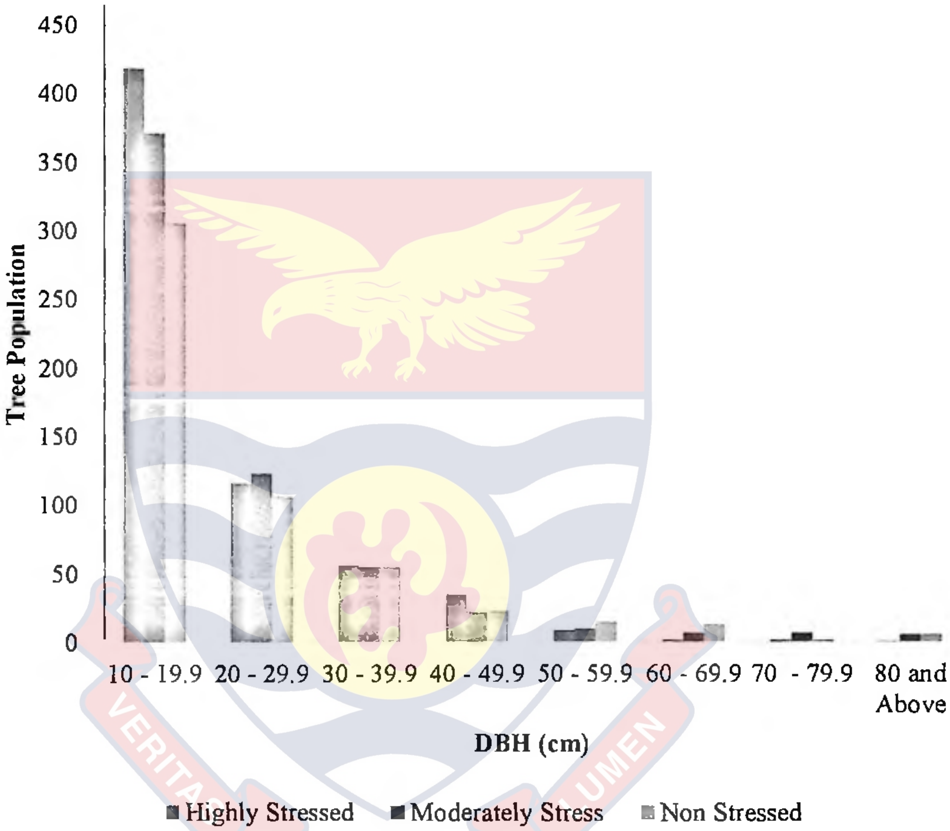

Figure 10: Distribution of diameter at breast height of tree population at the three stress levels

Estimation of Above- and Below-ground Carbon Stocks

Impacts of Stress levels on Carbon Stocks

A total of 2,648.72 Mg C ha^{-1} was estimated as the above ground and below ground biomass of the woody plants during the study with a mean of 176.58 ± 64.51

Mg C ha^{-1}. Of the total estimated carbon, 2,136.06 Mg C ha^{-1} constituted the above-ground carbon with 512.5 Mg C ha^{-1} accounting for the below-ground carbon recorded. A mean of 142.40 ± 32.91 Mg C ha^{-1} was obtained as the above-ground carbon whereas 34.18 ± 7.90 Mg C ha^{-1} was the average below-ground carbon obtained. Although there was no significant variation ($F_{2, 12} = 1.0$ $p = 0.396$) in the total amount of carbon sequestrated at the various stress levels, the MSV contributed the highest amount of carbon followed by the NSV and HSV (Table 9)

Table 9: Woody plant density (WPD), biomass (Mg) and carbon stocks (Mg C ha^{-1} ± s.e.) per plot in the three stressed levels in the study area

Parameter	HSV	MSV	NSV	P-value
WPD	105.20 ± 28.78	120.60 ± 20.08	127.80 ± 24.47	0.367
Biomass	289.44 ± 57.66	401.96 ± 72.35	368.08 ± 62.66	0.396
AGC	116.71 ± 46.50	162.08 ± 58.35	148.42 ± 50.53	0.396
BGC	28.01 ± 11.16	38.90 ± 14.00	35.62 ± 12.13	0.396

Thus, in the above ground biomass category, the HSV accounted for 27.32 % of the total carbon measured as against 37.94 % from the MSV and 34.74% from the NSV. The same percentages were recorded for the various stress levels in terms of the below-ground carbon measured.

Pieces of evidence of anthropogenic interferences in ARFR are shown in Figure 11, 12 and 13.

Figure 11: Observed activity of artisanal mining within the ARFR

Figure 12: Observed group of illegal miners undertaking their activities within the ARFR

Figure 13: Observed logged tree species undergoing splitting during the study

Carbon Stocks According to Ecological Guilds in the Study Area

Tree-stored carbon stock per plot ranged from 144.72 ± 57 for HSV through 200.98 ± 72.35 for MSV to184.05 ± 62.66 Mg C ha $^{-1}$ for NSV. Although there was no significant difference (p = 0.347) in the total mean tree-stored carbon stocks contributed by the different ecological guilds, the highest amount of tree-stored carbon (33.53 ± 3.6 Mg C ha $^{-1}$) was recorded for the Shade-bearer followed by NPLD (23.59 ± 6.31 Mg C ha $^{-1}$) and Pioneer (21.01 ± 4.32 Mg C ha $^{-1}$) species. The least amount of tree-stored carbon was however contributed by Savanna/ Non forest (1.56 ± 0.62 Mg C ha $^{-1}$) and Swamp (0.37 ± 0.31 Mg C ha $^{-1}$).

Table 10, displays the measured carbon stocks according to the ecological guilds in the three land-use types. The largest contribution of tree-stored carbon stocks by pioneer species was recorded in the HSV which formed about 24.75 % of the total mean tree-stored carbon. In the MSV and the NSV, the largest contribution to above ground carbon stocks was recorded for the Shade-Bearers species with 42.15 % and 40.96 % contributions respectively.

Table 10: Carbon stocks (Mg C ha^{-1}) according to ecological guilds and stress level

Carbon Pool	Ecological Guild	Stress Levels			
		HSV	MSV	NSV	Total
Above-Ground Carbon	NPLD	14.04	23.59	23.51	61.14
	Pioneer	14.6	21.01	14.75	50.36
	Savanna/Non forest	21.34	0.23	1.56	23.13
	Shade-Bearer	6.84	33.53	30.74	71.11
	Swamp	0.37	0.31	0.32	1
	Unknown	1.83	0.88	4.18	6.89
Below-Ground Carbon	NPLD	3.37	5.66	5.64	14.67
	Pioneer	3.5	5.04	3.54	12.08
	Savanna/Non forest	5.12	0.06	0.38	5.56
	Shade-Bearer	1.64	8.05	7.38	17.07
	Swamp	0.09	0.08	0.08	0.25
	Unknown	0.44	0.21	1	1.65
Total Carbon	NPLD	17.41	29.25	29.15	75.81
	Pioneer	18.1	26.05	18.29	62.44
	Savanna/Non forest	26.46	0.29	1.94	28.69
	Shade-Bearer	8.48	41.58	38.12	88.18
	Swamp	0.45	0.39	0.39	1.23
	Unknown	2.26	1.09	5.18	3.35

Specifically from the HSV, the Savanna/Non forest species were identified as the major contributor to the total carbon sequestrated (Figure 14).

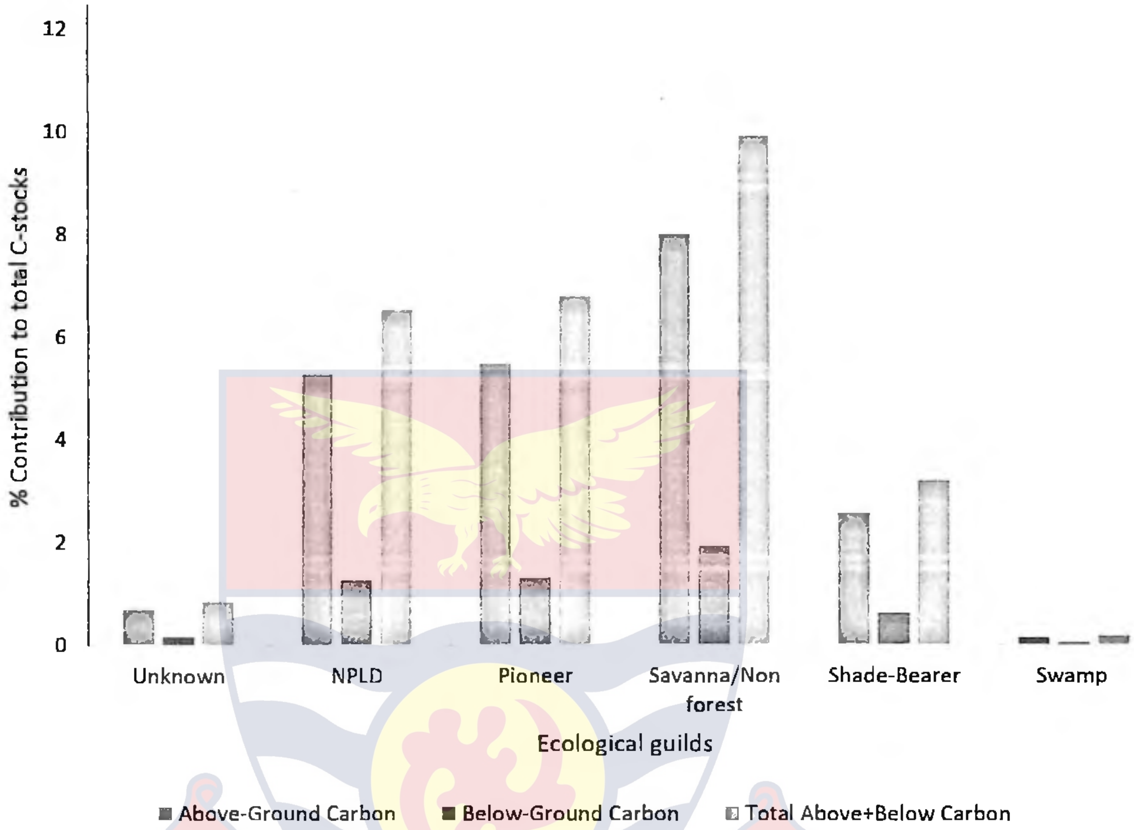

Figure 14: Percentage contribution of ecological guild to total carbon in the HSV

However, in the MSV and NSV areas, the Shade-bearers, the Non-Pioneer Light Demanders and the Pioneer species sequestrated the most carbon (Figures 14 and 15).

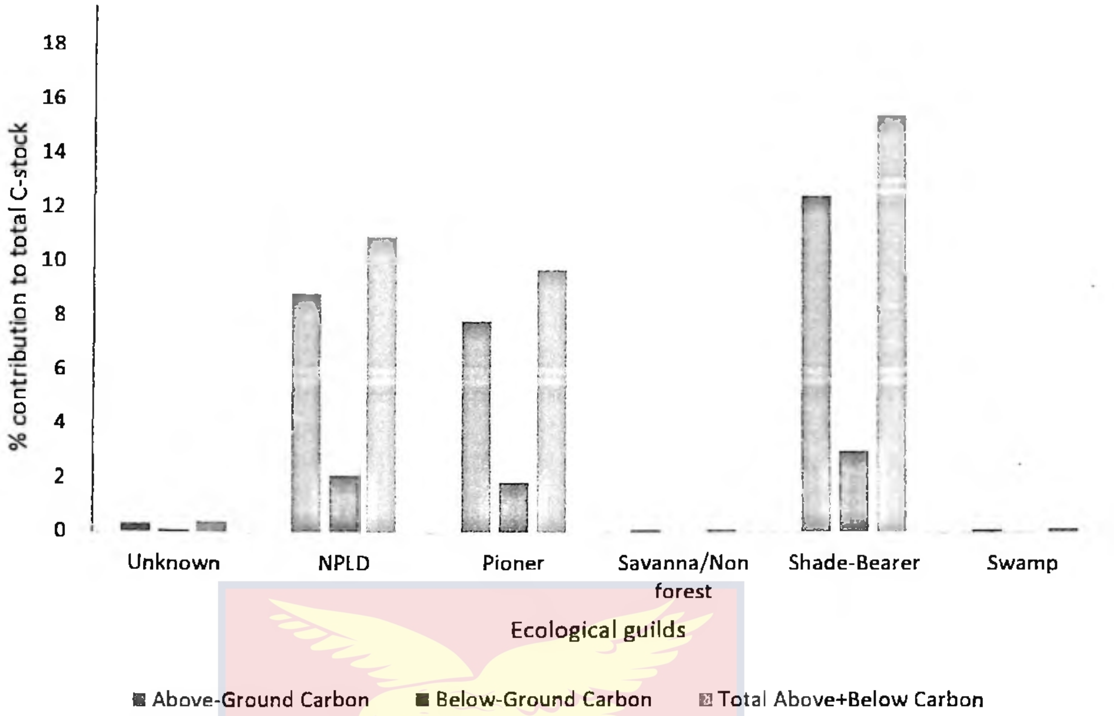

Figure 15: Percentage contribution of ecological guild to total carbon in the MSV

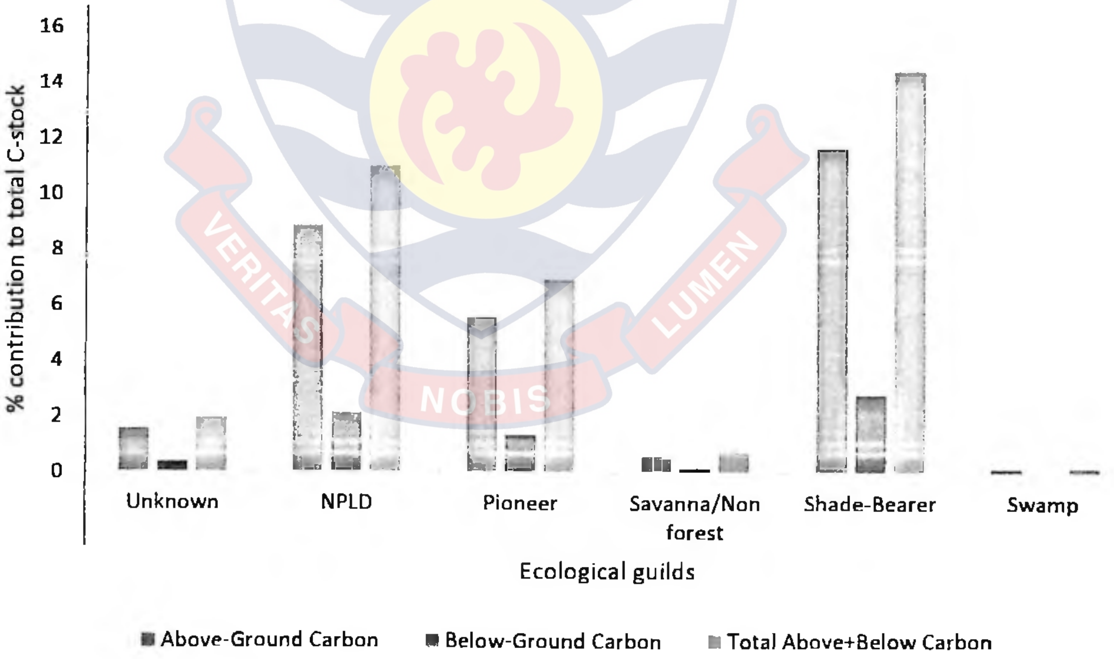

Figure 16: Percentage contributions of ecological guild to total carbon in the NSV

Soil Characteristics on the Study Area

The soils observed in the study areas were generally acidic in nature with mean pH for the top soil (0 - 15 cm) and subsoil (15 – 30 cm) ranging from 5.12 to 5.81. However, soils in the HSV were found to have the highest acidity followed by the MSV and the NSV in the first top soil whereas in the subsoil, the MSV recorded the highest followed by the HSV and the NSV. Textural analysis of the soils revealed majority of the sampled areas to be largely Loamy-Clay. All soil parameters measured varied significantly ($p < 0.05$) across the three stress levels (Table 11).

The HSV in most cases recorded the least soil quality based on the various tests conducted except in the case of soil bulk density in which it recorded the highest followed by the MSV and the NSV for the 0 – 15 cm soil depth (Table 11). Although there was statistically no significant differences in the percentage dry matter at three stress levels, the highest percentage dry matter was observed in the MSV followed by the NSV and the least in the HSV in the top soil. In the subsoil however, the quantity of dry matter decreased from the NSV through MSV to the HSV.

Table 11: Physicochemical properties of soils of the study sites

Parameter	Depth	HSV	MSV	NSV	p-value
P^H (1:2)	0 – 15	5.33 ± 0.04	5.81 ± 0.08	5.57 ± 0.02	<0.001
	15 – 30	5.38 ± 0.03	5.15 ± 0.04	5.59 ± 0.01	<0.001
Bulk density (g cm^{-3})	0 – 15	1.02 ± 0.04	0.95 ± 0.01	0.81 ± 0.01	<0.001
	15 – 30	1.01 ± 0.02	1.06 ± 0.01	0.97 ± 0.01	<0.001
Moisture (%)	0 – 15	9.65 ± 4.29	15.03 ± 1.88	19.86 ± 2.57	<0.001
	15 – 30	6.81 ± 3.76	14.06 ± 1.90	20.64 ± 1.31	<0.001
CEC ($cmolkg^{-1}$)	0 – 15	2.46 ± 0.17	6.12 ± 0.18	8.09 ± 0.80	<0.001
	15 – 30	1.84 ± 0.09	5.87 ± 0.60	9.04 ± 0.14	<0.001
Organic C (mg/kg)	0 – 15	1.16 ± 0.09	1.80 ± 0.03	2.62 ± 0.04	<0.001
	15 - 30	0.22 ± 0.04	0.32 ± 0.03	0.52 ± 0.02	<0.001
Organic Matter (%)	0 – 15	1.93 ± 0.07	3.19 ± 0.02	4.56 ± 0.03	<0.001
	15 - 30	0.41 ± 0.05	0.5 ± 0.04	0.91 ± 0.03	<0.001
Nitrogen (mg/kg)	0 – 15	0.01 ± 0.05	0.02 ± 0.00	0.15 ± 0.01	<0.001
	15 - 30	0.02 ± 0.01	0.01 ± 0.00	0.12 ± 0.01	<0.001
Phosphorus (mg/kg)	0 – 15	0.15 ± 0.02	0.16 ± 0.01	0.24 ± 0.01	<0.001
	15 - 30	0.17 ± 0.01	0.15 ± 0.01	0.19 ± 0.01	<0.001
Potassium (mg/kg)	0 – 15	0.07 ± 0.01	0.09 ± 0.01	0.08 ± 0.01	<0.001
	15 - 30	0.01 ± 0.01	0.1 ± 0.01	0.07 ± 0.01	<0.001
Clay (%)	0 - 15	21.8 ± 2.49	29.41 ± 3.51	24.2 ± 1.48	<0.001
	15 - 30	34.8 ± 3.36	25.21 ± 1.30	45.6 ± 6.61	<0.001
Sand (%)	0 - 15	35.2 ± 2.59	45.4 ± 5.55	30.2 ± 3.11	<0.001
	15 - 30	35.8 ± 1.30	39,0 ± 2.0	20.8 ± 5.40	<0.001
Silt (%)	0 - 15	43.0 ± 1.52	25.2 ± 2.28	45.6 ± 2.24	<0.001
	15 - 30	27.8 ± 3.51	36.2 ± 1.79	33.6 ± 4.49	<0.001
Soil texture	0 - 15	Loam	Sandy Clay Loam	Loam	
	15 - 30	Clay Loam	Loam	Clay	

Monthly Variations in Soil Moisture Content (2015 – 2016) at the Study Sites

Soil moisture recordings in the study are showed a normal distribution from January to December with slight differences with respect to stress levels (Figure 17). However, there was a general increase in moisture was observed between January and May followed by a stability between May and August after wish a decline was observed till December (Figure 17). The variations in Figure 17 are significantly different across the stress levels as indicated by the F-value of 85.148 from the anova analysis (p-value of 0.000069). Comparatively, the amount of soil moisture observed during the study was lowest in the HSV followed by the MSV and the NSV (Figure 17).

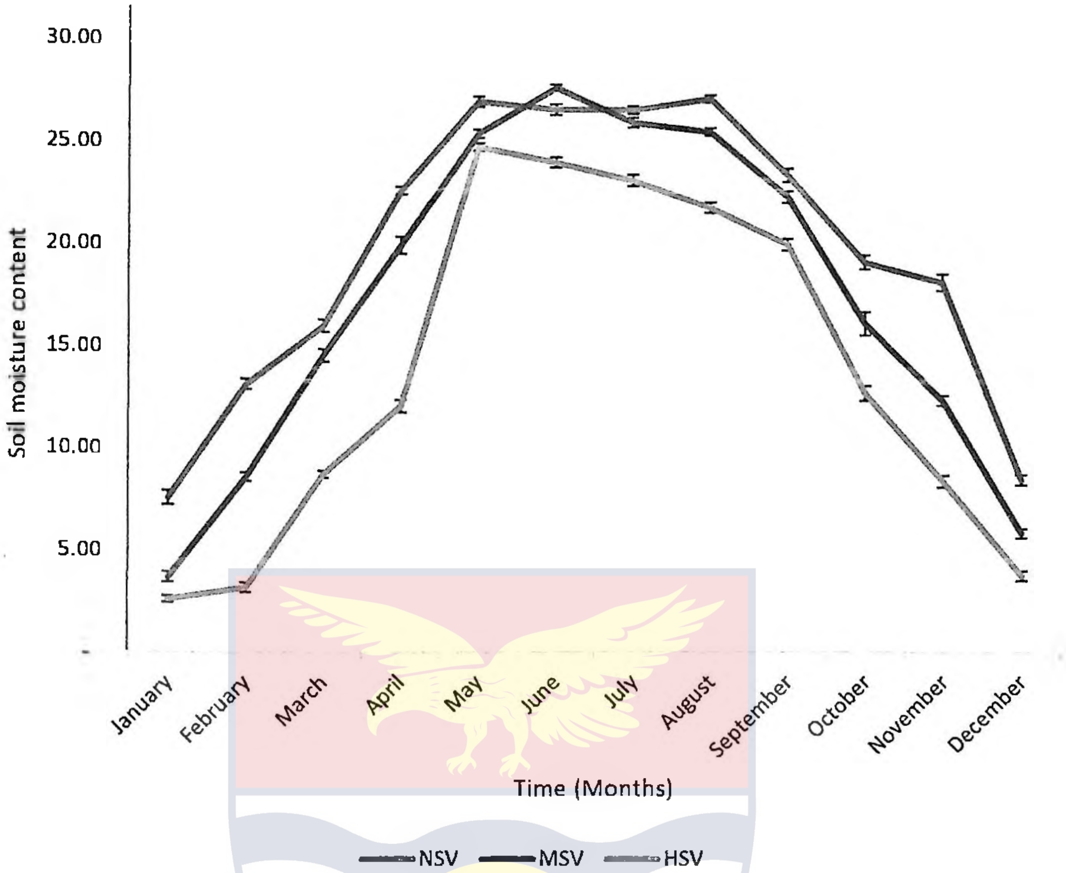

Figure 17: Monthly variations in soil moisture content at the various stress level

Monthly variations in Soil Temperature (2015 – 2016) at the Study Sites

An increase in temperature was observed between November 2015 and April 2016 Afterwards, a decline in temperature was observed between April and October (Figure 18). The variations in soil temperature in Figure 18 are significantly different across the stress levels as indicated by the F-value of 207.3972 from the anova analysis (p-value of 0.00001606). Lowest soil temperature was recorded in the NSV compared to the MSV and HSV (Figure 18).

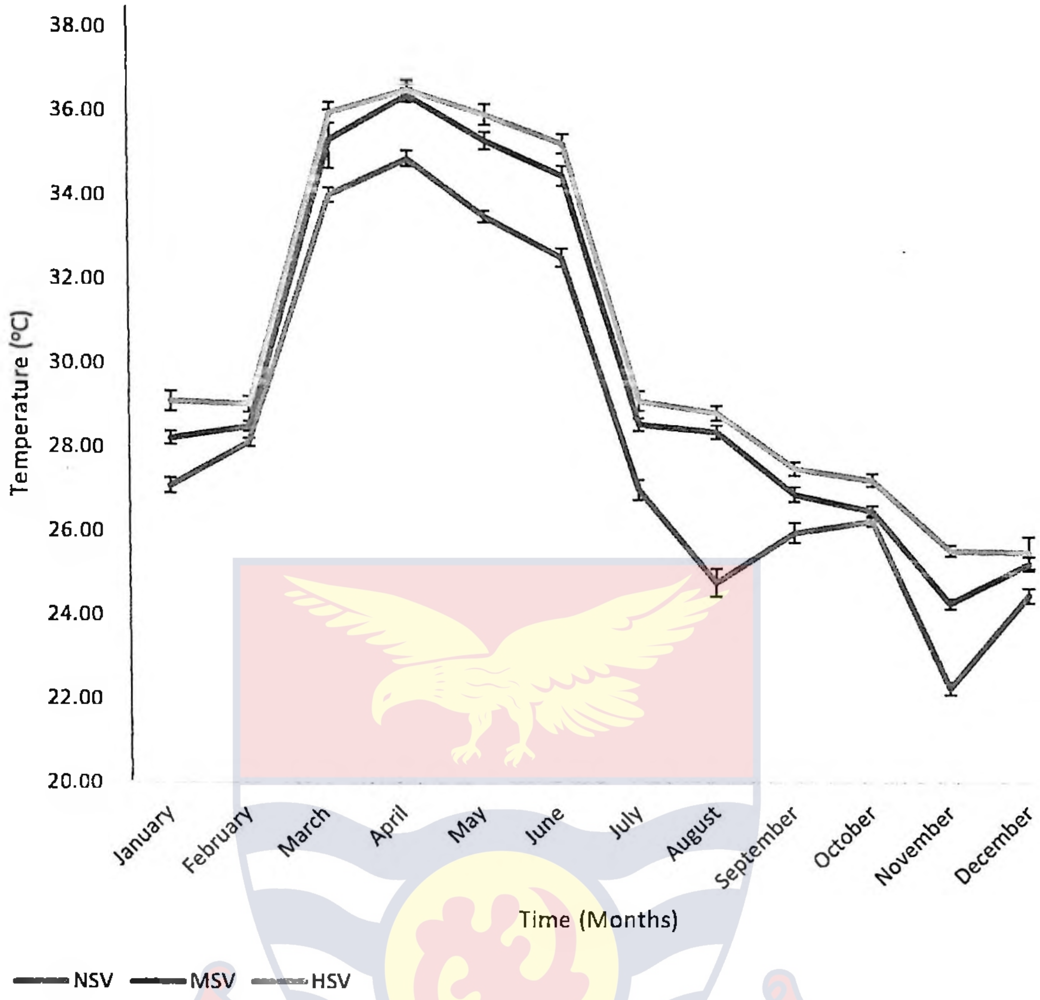

Figure 18: Annual soil temperature distribution in the various stressed vegetation

Monthly Variations in Soil Respiration (2015 to 2016) in the Study Sites

Soil respiration measurement during the study showed an uneven trend with a generally higher respiration in the NSV compared with the HSV and MSV. Relatively, the highest recordings were observed in the month of March, April, September and November (Figure 19). There were statistically significant differences (p = 2.68 x 10^{-6}) observed between the three stress levels

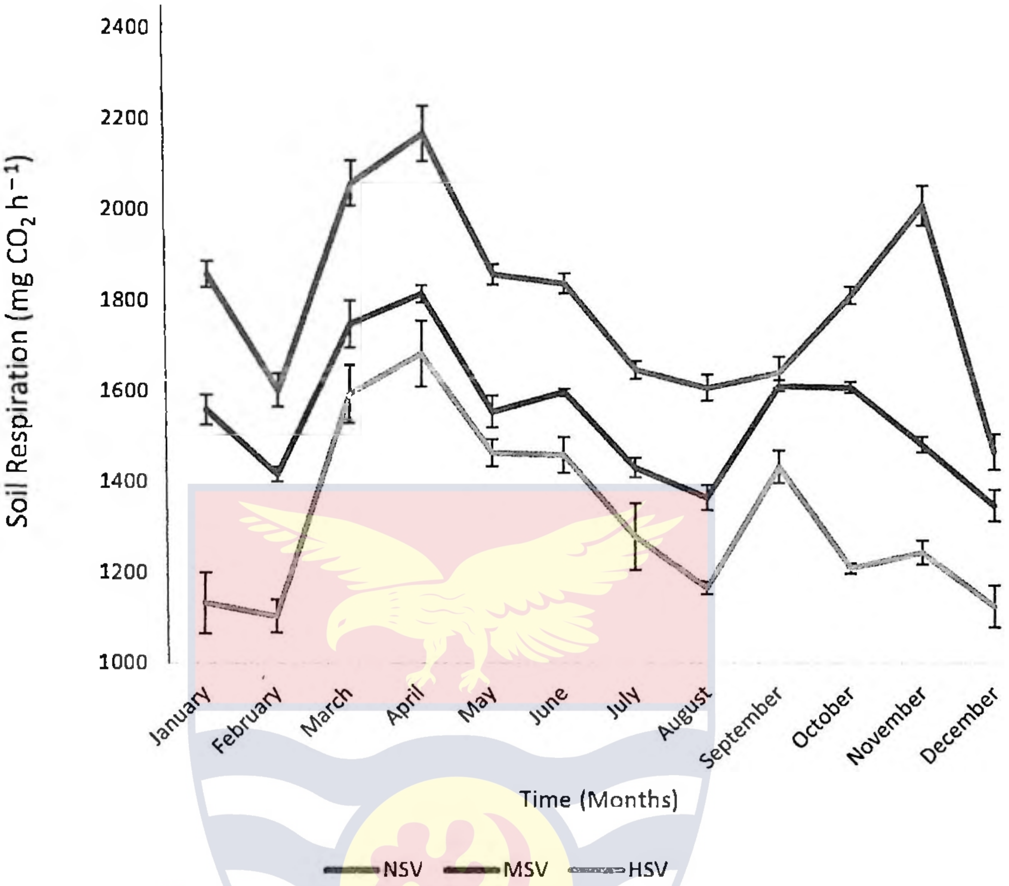

Figure 19: Monthly variations in soil respiration in the various stressed vegetation

Relationships between Vegetation and Soil Characteristics

The relationships observed between vegetation variables and soil characteristics were examined through multivariate analysis (Figure 20). Observed parameters including tree diversity, species richness and dominance, and each soil characteristic are represented by arrows. It was observed that tree diversity, species richness and species dominance showed relatively strong relationship with the soil parameters. However, tree diversity together with species dominance accounted for 84.1% of the relationship observed with indications in the first three ordination axes. The first axis accounted for most of the total Pearson product momentum (44.4 %) examined, followed by the second axis (27.1 %) and the third axis (13.6 %). The percentage nitrogen of the soil and soil carbon indicated strong positive loading for ordination axis one while the second ordination axis showed strong Pearson product momentum with the soil bulk density. In total, the percentage nitrogen of the soil accounted for the largest magnitude of variation in tree diversity, species richness and dominance of the tree species sampled whereas the potassium and phosphorus of the soil were observed to have had weak impacts.

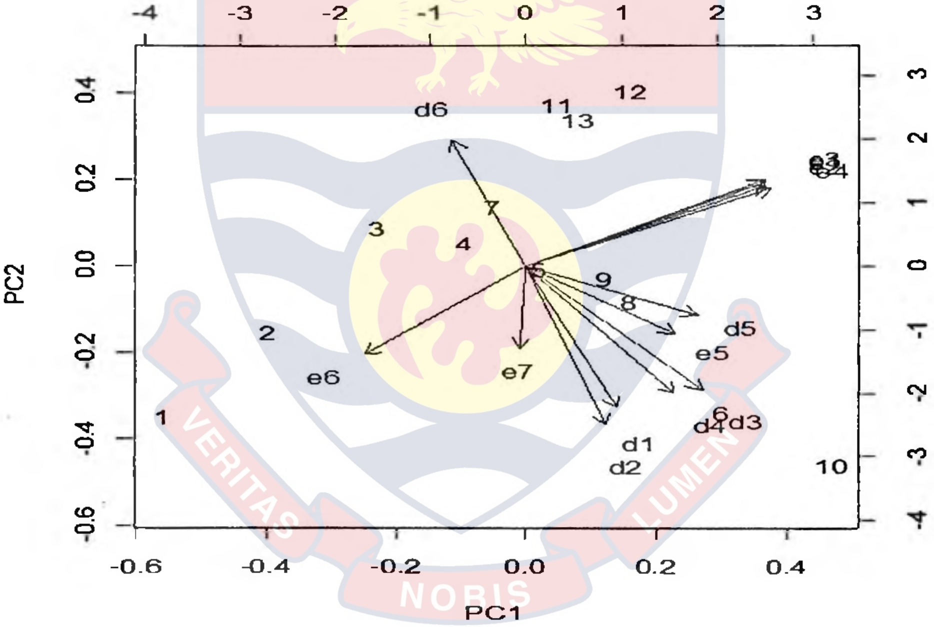

Figure 20: Biplot of trees and soil characteristics: d1= soil potassium; d2= soil phosphorus; d3 = nitrogen; d4= soil carbon; d5= soil pH; d6= soil bulk density; e1= Shannon-Wiener index for trees; e2 = Shannon-wiener index trees; e3 =Simpson index for trees; e4 = Simpson index for trees; e5 = dominance of trees; e6 = dominance of trees; e7= Species richness of trees

Ta1ble 12 further gives the Pearson product momentum analysis of the various vegetation characteristics and the soil characteristics. Apart from tree dominance which showed significant correlation with sequestrated carbon, there was no significant correlation between the vegetation characteristics and the soil parameters assessed (Table 12)

Table 12: Pearson product momentum analyses between carbon stocks, tree diversity and soil characteristics

Carbon stocks pools	Variables	Correlation coefficients, p-value
Total carbon stocks	Species richness of tree	-0.023, p = 0.93
	Density of trees	-0.026, p = 0.93
	Dominance of trees	0.94, p = 4.7e-06
	Shannon-wiener index for trees	0.22, p = 0.32
	Simpson index for trees	0.25, p = 0.43
	Soil potassium content	0.38, p = 0.43
	Soil phosphorus content	0.31, p = 0.35
	soil nitrogen content	0.59, p = 0.053
	soil carbon	0.44, p = 0.18
	Soil bulk density	- 0.57, p = 0.071
	Soil pH	0.55, p = 0.059
Total above-ground carbon stocks	Species richness of tree	-0.033, p = 0.96
	Density of trees	-0.041, p = 0.87
	Dominance of trees	0.91, p = 3.9 e-07
	Shannon-wiener index for trees	0.28, p = 0. 48
	Simpson index for trees	0.22, p = 0.43

Table 12 Continued

Carbon stocks pools	Variables	Correlation coefficients, p-value
Total above-ground carbon stocks	Soil potassium content	0.33, p = 0.25
	Soil phosphorus content	0.3, p = 0.37
	% soil nitrogen content	0.51, p = 0.065
	% soil carbon	0.43, p = 0.21
	Soil bulk density	-0.55, p = 0.064
	Soil pH	0.56, p = 0.055
Total soil organic carbon (SOC)	Species richness of tree	0.25, p = 0.47
	Density of trees	0.34, p = 0.32
	Dominance of trees	- 0.23, p = 0.56
	Shannon-wiener index for trees	0.5, p = 0.40
	Simpson index for trees	0.36 , p = 0.33
	Simpson index for trees	0.32, p = 0.38
	Soil potassium content	0.45 , p =0.27
	Soil bulk density	0.15, p = 0.76
	Soil pH	-0.14, p =0.63

Evaluation of the Intensity of Human-induced Stress on Vegetation Quality between 1986 and 2016

Anthropogenic Induced Stress Influences on Land Use Change and Vegetation Quality

The study identified and classified four land uses in the study area between 1986 and 2016. These included, rainforest, logged lands, farmlands and settlement areas in three time intervals (i.e., 1986 – 1998, 1998 – 2007 and 2007 – 2016). In assessing the impacts of anthropogenic interference on the vegetation and its quality in the ARFR, the NDVI used indicated a decreasing trend in general vegetation cover (rainforest) and logged lands as against relatively increasing coverage of farmlands and settlements (Figure 21).

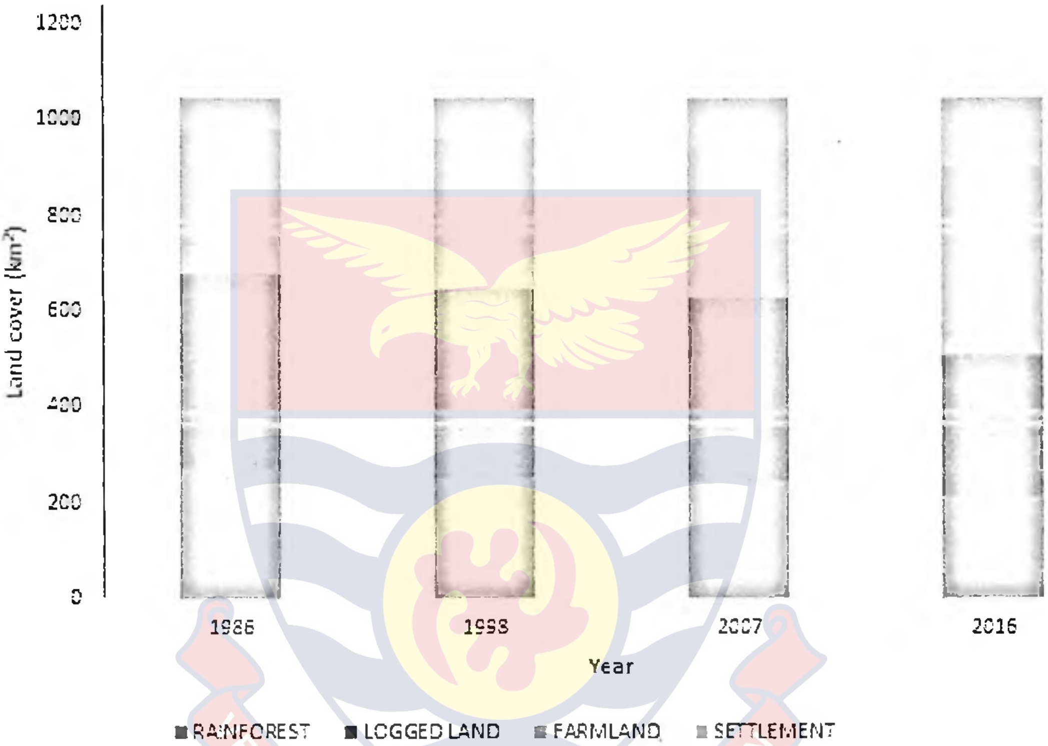

Figure 21: Changes in land uses through anthropogenic activities in the study area over a 30-year period.

In terms of the land masses or cover during the periods, the rainforest was observed to have decreased by 20 km^2 in a space of 12 years (1986 - 1998) followed by further decline of approximately 10 km^2 by 2007. The highest impact in terms of the rainforest depletion was observed between 2007 and 2016 where about 31.54 km^2 of the forest was converted to other land use forms. Altogether, a total of 61.72

km^2 of the rainforest was depleted within 30 years at a rate of approximately 2 km^2 every year. The logged lands recorded decreasing trend of conversion with a total of 108.57 km^2, at a rate of 3.62 km^2 per annum. Farmland increased by about 14.3 km^2 between 1986 and 2007. It further saw an astronomical increase in coverage from 320.39 km^2 to 399.28 km^2 at a rate of 78.89km^2 per annum for the next 9 years. Progressively, the settlement area observed an increase from 62.75 km^2 in the year 1986 to 139.85 km^2 in the year 2016 with a total of 77.1 km^2 conversion of rainforest to settlement at a rate of 2.57 km^2 per annum. Table 13 however, gives the various coverage of land uses between 1986 and 2016.

Table 13: Land use cover between 1986 and 2016 in the study area

	Area cover (km^2)			
Land use	**1986**	**1998**	**2007**	**2016**
Rainforest	271.5619	251.5619	241.3818	209.8377
Logged land	405.9469	395.9469	384.4252	297.3789
Farmland	306.0908	316.0908	320.3943	399.2778
Settlement	62.74759	82.74759	100.1459	139.8528

Transformation of Rainforest to other land uses

With respect to the change in the vegetation of the study from rainforest to other land uses, Figures 22, 23 and 24 below show the classified imageries of the anthropogenic induced impact in the ARFR area between 1986 and 2016.

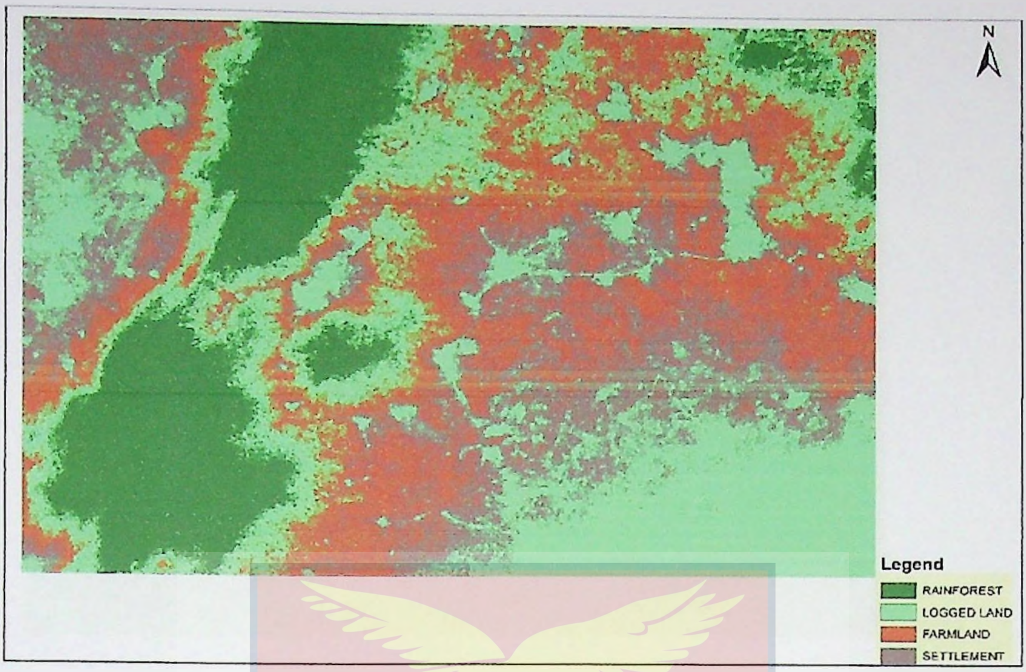

Figure 22: Imagery of study area in the year 1998

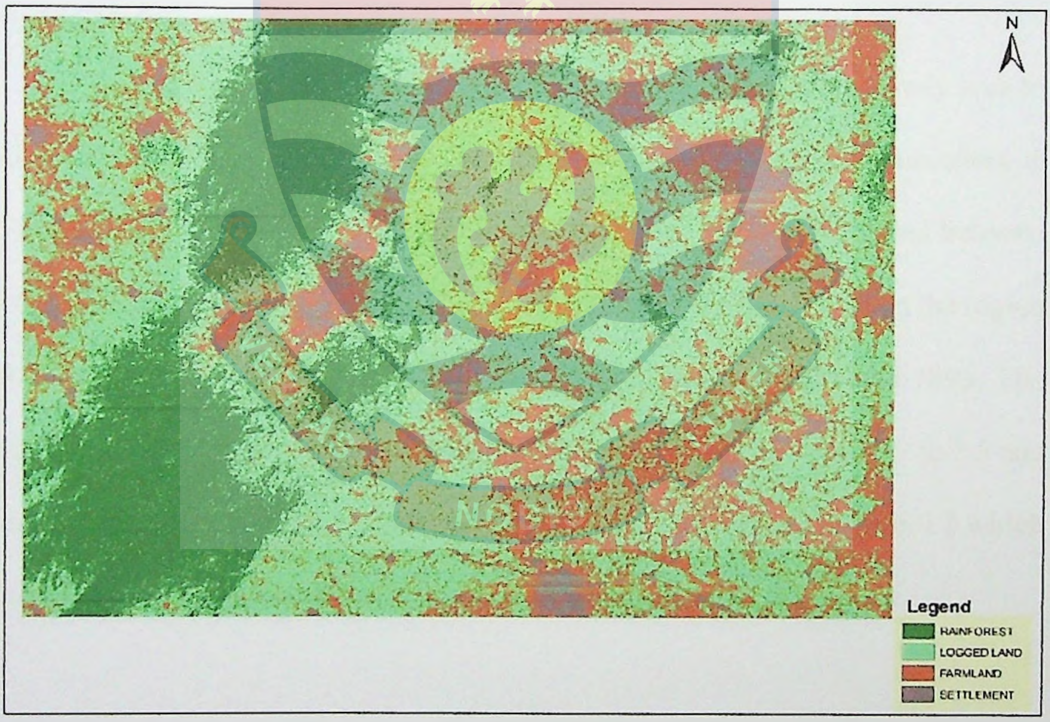

Figure 23: Imagery of study area in the year 2007

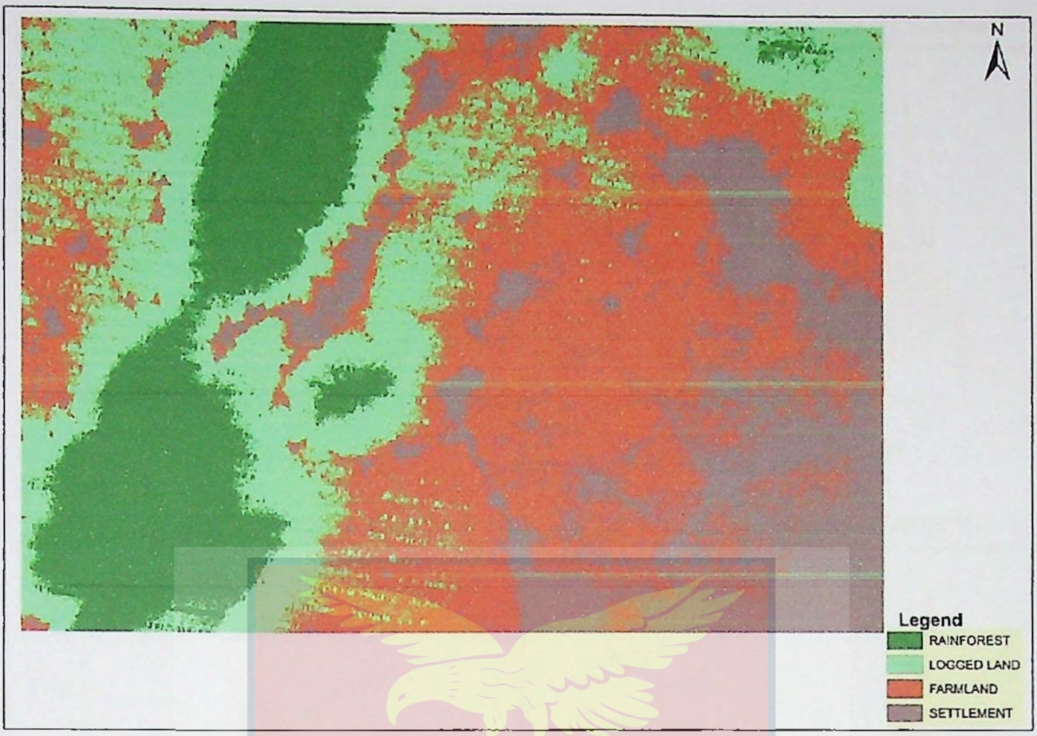

Figure 24: Imagery of study area in the year 2016

To further buttress the transformation of the rainforest in the study area to other land use systems, the use of the NDVI showed a gradual transformation in (Figure 25). The observed bands in Figure 25 showed high concentrated between 0.6 - 0.7 in the year 1986. In 1999, the concentration of the bands were in the region of 0.2 to 0.4 indicating a very drastic change from between 1986 and 1998. The bands in 2007 showed slight decreases form the observed 0.2 - 0.4 to 0.2 to 3.5 and finally in the year 2016, the bands were observed in the region of 0.1 to 0.2 which showed very substantial decrease in the vegetation cover.

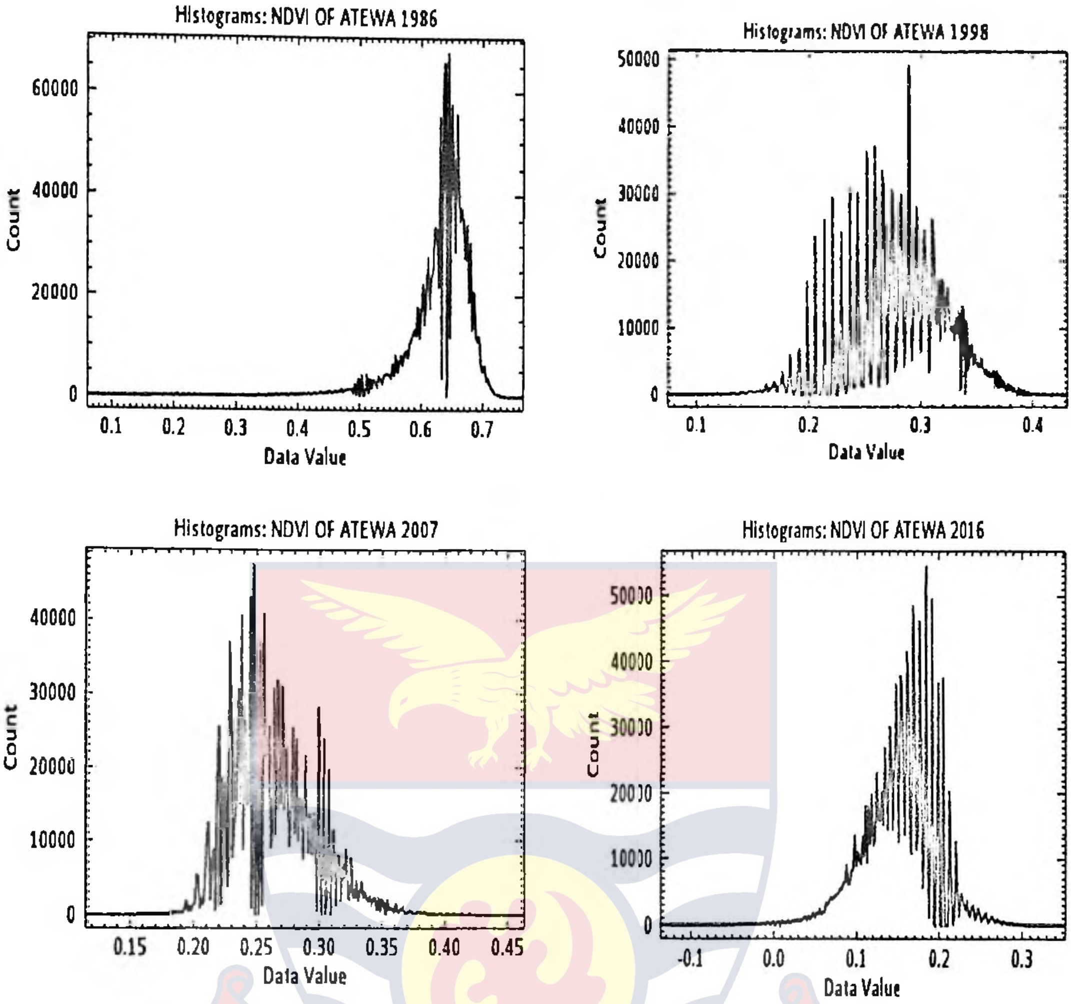

Figure 25: NDVI vegetation analysis of study area between 1986 and 2016

Gross Patterns of Land Change in the ARFR

In all, the logged lands formed the majority of land-cover type in the study area and accounted for 38.80, 37.84, 36.74 and 28.42% of the total land area in the four time points; 1986, 1998, 2007 and 2016 respectively. This was followed by farmlands with 29.25, 30.21, 30.62 and 38.16% respectively in the years 1986, 1998, 2007 and 2016. Rainforest was third and accounted for 25.95, 24.04, 23.07 and 20.65% coverage for the respective years 1986, 1998, 2007 and 2016. Figure

26 shows the comparative imageries of the land use categories observed for the study area between 1986 and 2016.

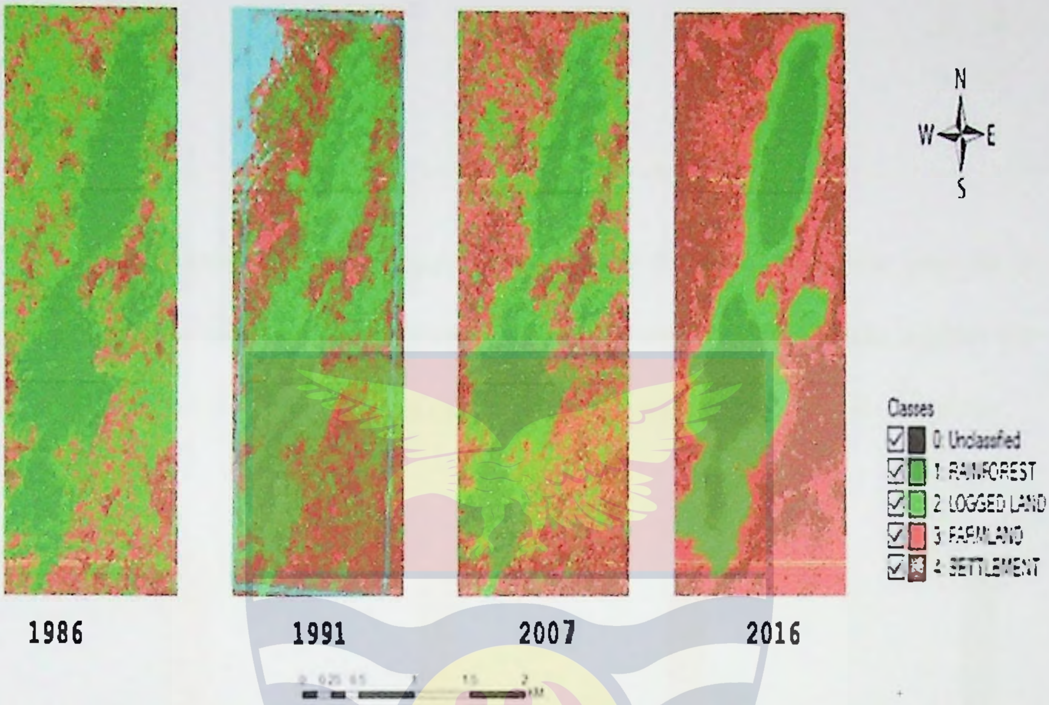

Figure 26 : Comparative land use categorization between 1986 and 2016

With respect to the change magnitudes over the assessed duration, Table 14 shows the various changes observed in the land uses for the study area between 1986 and 2016. Farming and Settlement showed net gains in the first, second and third time intervals as shown in the analysis of the study area. On the contrary, rainforest and logged lands declined in the same time intervals (Table 14).

Table 14: Magnitude of land area converted over specific time intervals

Land use / Time intervals	Land mass (km^2) 1986 - 1998	1998 - 2007	2007 – 2016
Rainforest	25.95	24.04	23.07
Logged land	38.80	37.84	36.74
Farmland	29.25	30.21	30.62
Settlement	6.00	7.91	9.57

Overall patterns and comparisons resulting from the land-use analysis is shown in Figure 27 where the horizontal axis indicates the time points against the vertical axis which shows the area of total land use according to the time points.

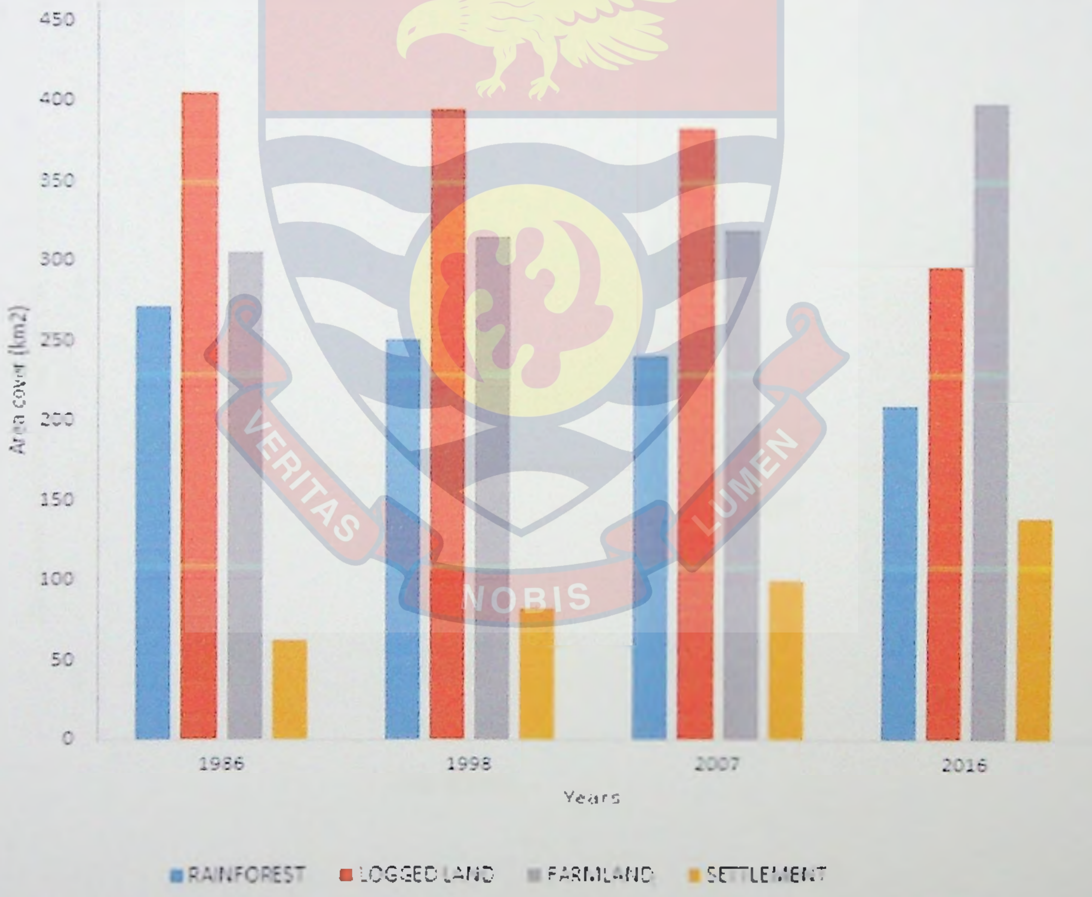

Figure 27: Land use cover over thirty years

Intensity of land Use Transformation in the ARFR

In assessing the intensity of the transformation resulting from the land use change, Figure 28 further showed an overall fast rate of change or growth during the period of assessment between 2007 and 2016. A uniform change of about 1% was observed across all the three time intervals with respect to all the land uses combined. The red solid horizontal line shows the uniform annual change (based on Equation (1) form the previous chapter). The change was relatively slow for the first and second period (1986 -1998 and 1998 -2007) but relatively fast for the last intervals (2007 – 2016).

Figure 28: Intensity of land use transformation between 1986 and 2016 in the study area

Land Use Transformation from 1986 to 1998

When the land use transformation was assessed for the above time period, the analysis showed that the rainforest and settlements were actively transforming to other land use types, whereas Logged lands and Farmlands were relatively dormant (Figure 29).

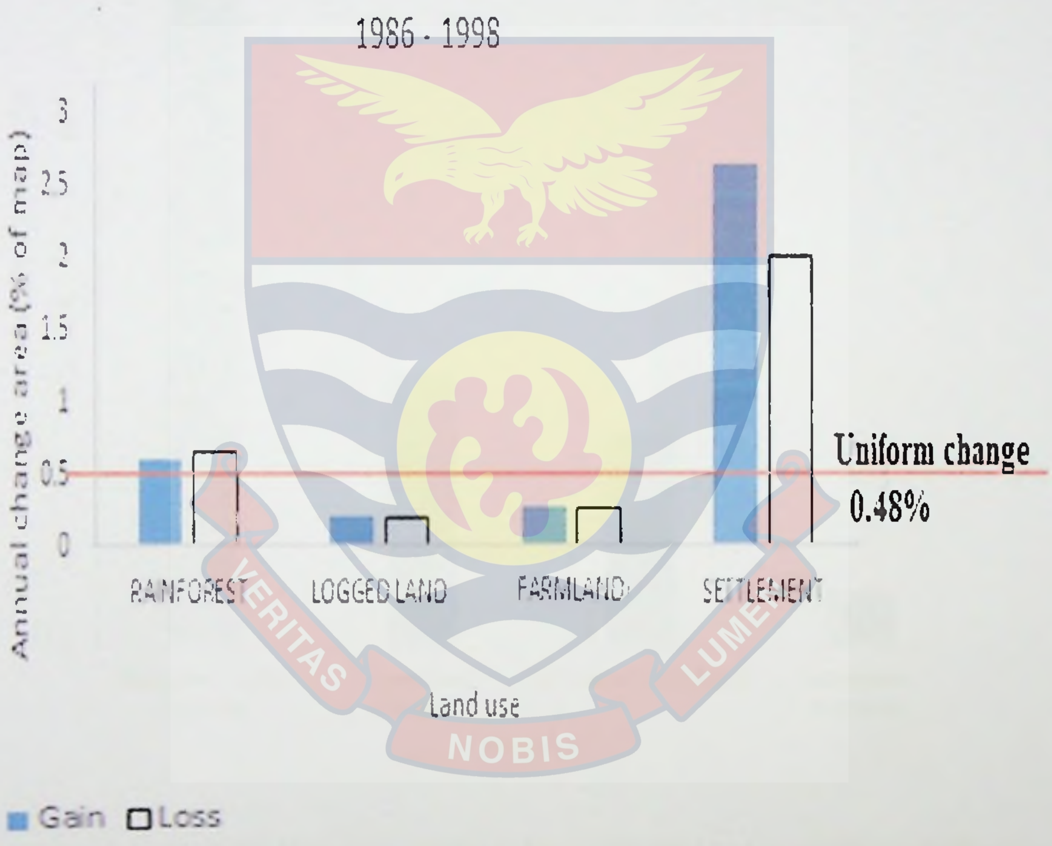

Figure 29: Land use transformation in the time interval 1986 - 1998

Further, the results from the intensity analysis indicated high percentage transition from one category of land use to the other. There was an active transition of 3.15%, 2.52% and 0.66% from logged forest, farmlands and settlement respectively to rainforest (Figure 30) However, the transition from rainforest to logged land, farmland and settlement was equal to the uniform line at 0.48% rate per annum.

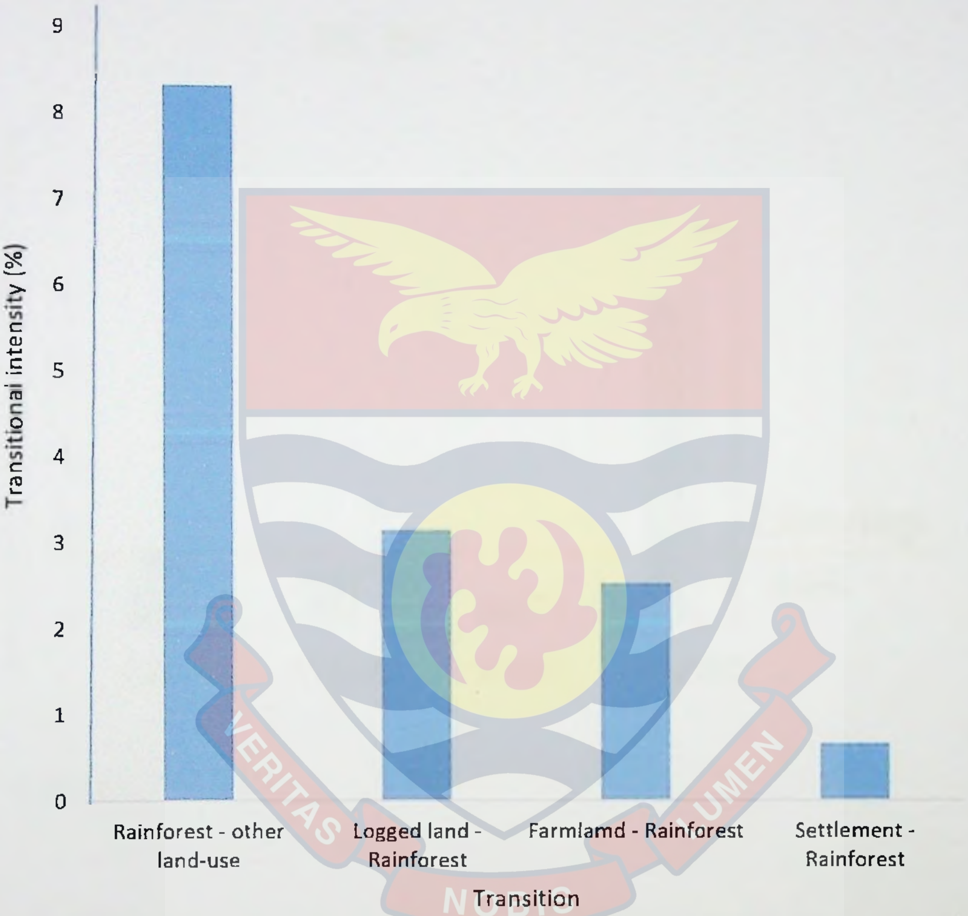

Figure 30: Percentage transition intensity from one land use to another (1986 – 1998)

Transformation between 1998 and 2007

Between 1998 and 2007, only settlement and slightly the rainforest land uses experienced active change whereas the logged land and farmlands was dormant (Figure 31).

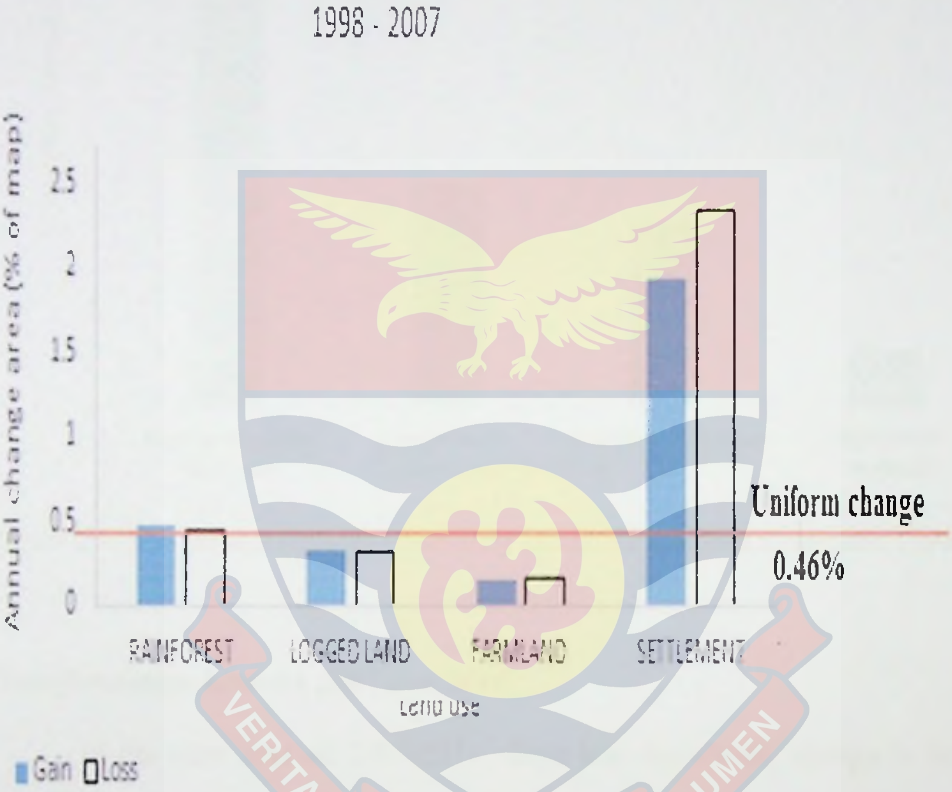

Figure 31: Land use transformation in the time interval 1998 - 2007

Between 1998 -2007, 4.08, 3.40 and 1.06% were observed for the transition from logged lands, farmlands and settlement respectively to rainforest as shown in Figure 32. The transition from rainforest however to logged land, farmland and settlement was equal to the uniform line at 0.46% rate per annum (Figure 31).

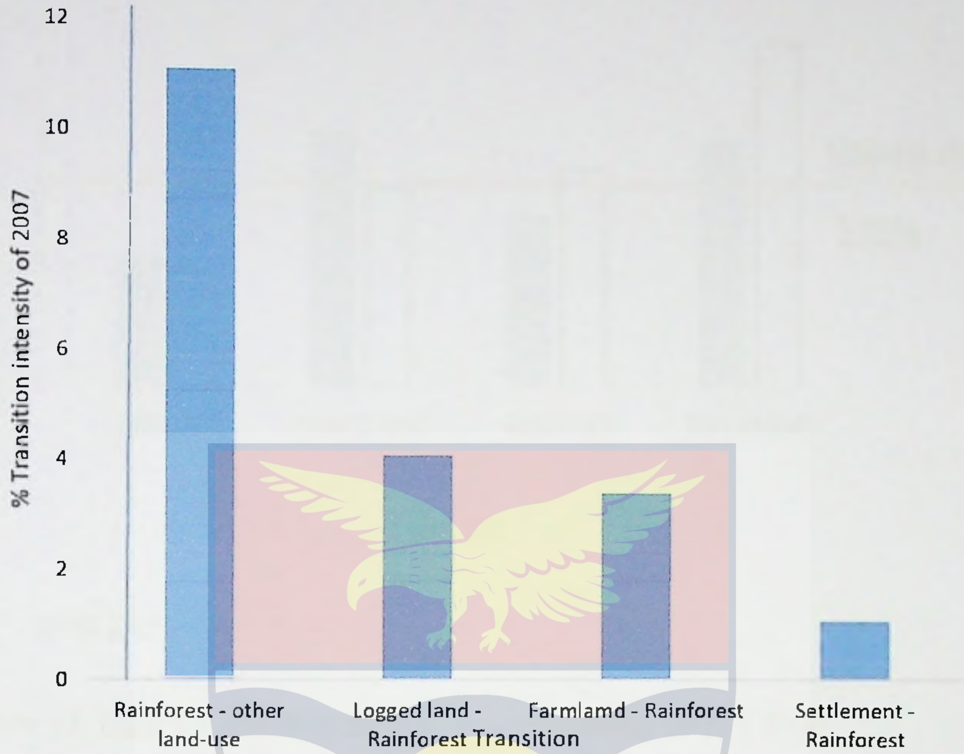

Figure 32: Percentage transition intensity from one land use to another (1998 - 2007)

Transformation between 2007 and 2016

In the time interval 2007-2016, there was significant change in land use experienced across Logged lands, Farmlands and the Settlement areas. There was however, a subtle change in the area of rainforest as the bars of both gain and loss were below the uniform change line (Figure 33). The time interval further saw unit losses in both rainforest and logged land as against the gains in those same categories. The farmland and settlements on the contrary recoded greater losses than gains in the same time interval (2007 – 2016).

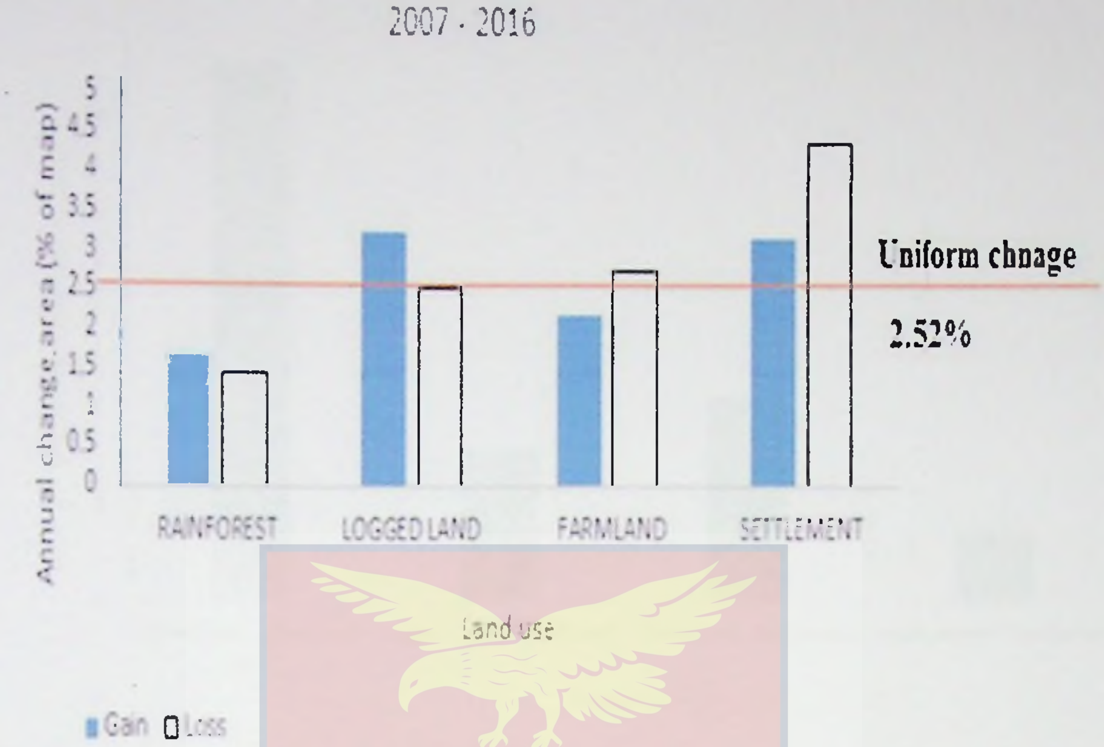

Figure 33: Land use transformation in the time interval 2007 - 2016

Within the same time period, the study area recorded an active transition of 3.16, 4.24 and 1.49% from logged lands, farmlands and settlement respectively to rainforest as shown in Figure 33. On the contrary, the transition from rainforest however to logged land, farmland and settlement was equal to the uniform line or change at 2.52% rate per annum (figure 33).

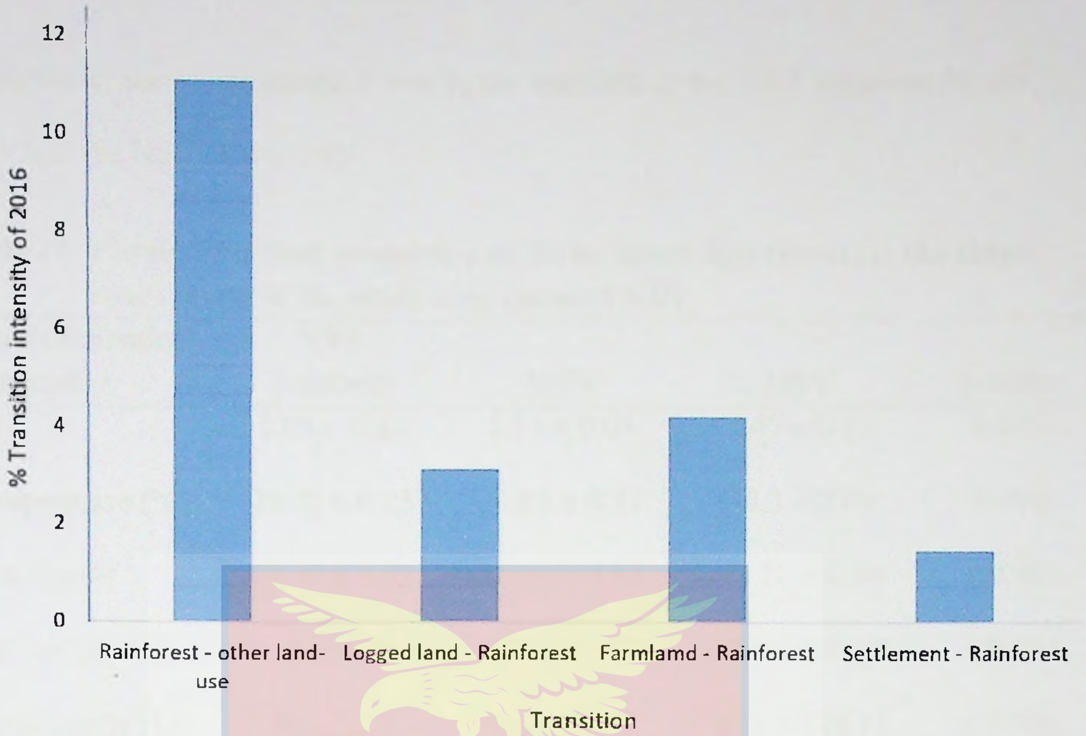

Figure 34: Percentage transition intensity from one land use to another (2007 - 2016)

Determination of the Physicochemical, Biological and Heavy metals Impacts of Anthropogenic Activities on Water Resource Quality in the Study Area

Physical and Chemical Characteristics

Apart from pH and Temperature which did not show significant variations with anthropogenic induced stress levels, all other physicochemical properties of the water samples analysed showed significant variations among the NSV, MSV and the HSV (Table 15). The water samples were generally neutral with very little or minimal basic occurrence.

In total, water samples from the HSV zones recorded the highest pH values indicating the most basic followed by the MSV and the NSV. Regarding temperature, the water sampled was again warmest at the HSV followed by the MSV and the NSV (Table 15).

Table 15: Physicochemical properties of Birim River that traverses the three stress levels in the study area (mean ± S.D)

Physicochemical parameter	NSV (control)	MSV	HSV	p-value
pH	7.03 ± 0.22	7.13 ± 0.07	7.45 ± 0.87	0.605
Temperature (°C)	29.77 ± 0.25	29.83 ± 0.57	30.3 ± 0.69	0.463
TDS (mg/l)	27.33 ± 1.53	36.00 ± 2.65	41.67 ± 0.58	< 0.001
TSS (mg/l)	16 ± 4.73	153 ± 22.54	576 ± 120.02	< 0.001
Turbidity (NTU)	14 ± 2.58	161 ± 1.73	635 ± 108.13	< 0.001
EC (µS/cm)	58.7 ± 2.08	78 ± 7.00	92.3 ± 2.08	< 0.001
NO_3 (mg/l)	0.5 ± 0.1	0.87 ± 0.25	2.23 ± 0.64	0.004
PO_4 (mg/l)	0.16 ± 0.04	0.363 ± 0.11	0.823 ±0.14	< 0.001

Heavy Metal Concentration of the Birim River in the Study Area

Upon assessing the heavy metals concentrations in the Birim River that traverses the study area, there were significant variations observed between the sampling points in the three stress levels except in the case of zinc. Apart from cadmium in which the highest observed concentration was made in the Non Stressed Vegetation, arsenic (As), iron (Fe), mercury (Hg), and lead (Pd) recorded highest concentrations in the HSV followed by the MSV and then the NSV (Table 16).

Table 16: Heavy metal concentration in Birim River from the ARFR

Heavy metals	NSV (mg/l) (control)	MSV (mg/l)	HSV (mg/l)	WHO Limit	p-value
As	0.007 ± 0.002	0.021 ± 0.003*	0.042 ± 0.002*	0.01	< 0.001
Cd	0.002 ± 0.001	0.001 ± 0.001	0.003 ± 0.001*	0.003	0.011
Fe	0.03 ± 0.01	2.6 ± 0.19	3.78 ± 0.6		< 0.001
Hg	0.003* ± 0.001	0.121 ± 0.002*	0.356 ± 0.048*	0.001	< 0.001
Pb	-	-	0.012 ± 0.004*		< 0.001
Zn	0.008 ± 0.004	0.014 ± 0.003	0.037 ± 0.027	3	0.138

*Values exceeding the WHO/ EPA limits

Generally, the NSV recorded concentrations of heavy metals below the WHO and EPA standard limits (WHO, 2011). However, in the MSV, arsenic and mercury were observed to be higher than the WHO and EPA standard limits of 0.01 mg/l and 0.001 mg/l, respectively. Apart from iron and zinc which were within the WHO and EPA limits, all the other heavy metal concentrations were above the limits in the HSV (Table 16)

Bacteriological characteristics of water samples

The study in assessing the water resource for bacteria pathogens recorded no presence of *Escherichia coli* (E. coli) nor Feacal *E. coli* in the river samples taken at various points. Meanwhile, the Total Coliform recorded was highest at the NSV as compared to the HSV and MSV (Table 17).

Table 17: Bacteriological properties of river samples

Stress levels	**Total Coliform**	***E. coli***	**Feacal *E. coli***
Moderately Stress	2.0*10 (CFU/100UL)	0	0
Non –Stress	3.0 (CFU/100UL)	0	0
Highly Stress	2.0 (CFU/100UL)	0	0

CHAPTER FIVE

DISCUSSION

Introduction

The study sought to assess the impacts of anthropogenic activities defined by stressor indicators on the vegetation, soil and water resources in the Atewa Range Forest Reserve (ARFR) in the Eastern Region of Ghana. The study was guided by five objectives, which include: determination of the vegetation characteristics; estimation of the above and below ground carbon stock; assessment of human-induced stress impacts on the vegetation and estimation of the effects of anthropogenic impacts on soil characteristics in relation to vegetation characteristics. The rest are evaluation of the intensity of human-induced stress on vegetation quality between 1986 and 2016, and determination of the physicochemical, biological and heavy metals impacts of anthropogenic activities on water resource quality. It was hypothesized that, induced anthropogenic stressors have no effects on the vegetation characteristics, carbon sequestration, and soil and water quality in the ARFR.

Determination of the Vegetation Characteristics in the Study Area

The vegetation characteristics presented include general vegetation characteristics, ecological guilds and conservation star rating of species, diameter at breast height distribution (dbh) of species, plant species diversity and plant families, impacts of stress on stand structure, influence of stress level on conservation status and ecological guild of plant species.

General Vegetation Characteristics

The high number of trees (1768 individuals) enumerated in the study area covering 3.75 ha (i.e., 471.47 trees ha^{-1}) is worth noting as most forests in tropical regions are being rapidly converted to other land-use forms (Zhang et al., 2012; Rembold et al., 2017) for socio-economic benefits. Studies on tropical rain forests in Ghana (Abu-Juam et al., 2003) and other parts of the world (Berenguer et al., 2014; Rembold, et al., 2017) have reported varied tree species densities. Though this current study observed lower estimated species density, Naidu and Kumar (2016) observed a high species density of an average of 919.5 trees ha^{-1} in the Eastern Ghats of Andhra, India. The differences in species densities identified in Eastern Ghats of Andhra was explained by the stringent management policies (Naidu & Kumar, 2016) applied such as the constant monitoring, protection and management in order to direct successional processes towards maintaining species and habitat diversity. The ARFR can be said to be under massive pressure from forest conversion to other forms resulting in, land-use habitat destruction, hence the lower species densities reported in this study.

At the species and family levels, higher values were recorded, compared to 73 species belonging to 28 plants families reported by Pappoe et al. (2010) for a tropical moist semi-deciduous forest, the Kakum National Park of Ghana. Comparing these two studies, the Atewa range tropical forest may be considered as high species density forest. The difference between the species richness and diversity of this study and that reported by Pappoe et al. (2010) could probably be as a result of the extensiveness of the survey carried out which might affect the number of species identified. While Pappoe et al. (2010) used a plot size of 15 m x 15 m for a total number of 100 plots covering 22500 m^2 of the forest stands, the present study used a plot size of 50 m x 50 m for a total number of 15 plots covering 37500 m^2 of the forest stands. The current study also confirms the findings of Abu-Juam et al. (2003) who reported 323 tree species in the ARFR. The dominant families identified were Apocynaceae, followed by Meliaceae, Fabaceae and Malvaceae in the ARFR which may be linked to the environmental conditions such as rainfall, temperature and humidity. The temperature ranges between 24 and 29 ^{0}C in tropical evergreen forest with a greater daily than monthly range while the rainfall tends to be highest near the equator, where the sun's evaporative power causes high evapotranspiration, and rising air cools and then sheds its moisture. Evergreen forests are replaced by deciduous forests as precipitation becomes seasonal.

This finding contradicts those of Erhenhi and Obadoni (2016) and Pappoe et al (2010). Erhenhi and Obadoni (2016) in their study of the Urhonigbe Forest Reserve in the Edo State of Nigeria reported the Fabaceae as the most dominant family, followed by Apocynaceae and Meliaceae. Pappoe et al (2010) reported Meliaceae, Sterculiaceae, Mimosaceae, Moraceae and Annonaceae as the dominant families in the Kakum National Park of Ghana. This is an indication that the domination of plant species, and by extension, plant families in different forest ecosystems is a stochastic event.

Ecological Guilds and Star Rating of Species

The ecological guilds of the trees in the study area include Non-pioneer Light Demanders (NPLD), Pioneer, Shade-Bearers, Swamp and Savanna/ Non-Forest plants. Hawthorne (1995) in an earlier study identified similar guilds in the high forests in Ghana in general and Atewa in particular. The highest proportion of Shade-Bearers observed in this study was similar to the findings of Hawthorne and Abu-Juam (1995) for protected forests in Ghana. The dominance of shade Bearer in the current study area may be attributed to the area having contiguous crowns of trees forming closed canopies that are broken only where gaps are created by tree falls.

The high proportions of Pioneer and Savanna/Non-forest species observed in the study area may be accounted for by anthropogenic influences in the ecosystem over the years (Swaine & Agyeman, 2008). The considerable proportion of Pioneers may be attributed to possible openings in the forest canopies as a result of natural phenomena like lighting, flooding and death as a result of ageing, disease and deliberate actions of humans like general clearing of the vegetation for socio-economic benefits. Other similar studies have shown that the increase in pioneer species is the most common trend linked to areas affected by anthropogenic stressors (Arets, 2005; Swaine & Agyeman, 2008). The opening of previously closed canopy allows enough light together with right temperature and moisture regimes to trigger endogenous factors of the provenances of the light-loving pioneer species to germinate or sprout, grow and establish themselves. However, the

Savanna/Non-forest species may have been introduced by vagrant birds, mammals and humans.

The present study found a high number of Non-Pioneer Light Demanders (NPLD). The NPLD species are not pioneers but require some amount of light for their establishment. Hawthorne (1995) argued that in forests where there are a high number of NPLD, the vegetation had experienced some form of openings which facilitated the survival, establishment and development of such category of plant species.

The representation of species of the Swamp guild affirms the existence of swampy and marshy areas in tropical forest ecosystems. The dominant guild were the shade-bearers while the swamp contributed the least to the ecological guild of the ARFR. As pointed out, River Birim takes its source from ARFR and meanders its way through it creating preferred habitat for water specialist species. This supports the claim of Wong (2003) and Hawthorne & Jongkind (2006) that the distribution of low-lying swampy land is an essential source of local variation and ecological differences in forest composition.

Based on Hawthorne's (1995) protocol, various proportions of Black, Gold, Blue, Scarlet, Red, Pink and Green Star in decreasing order of conservational importance were recorded in the ARFR. Nothwithstanding this, every species is important in maintaining the integrity of the community and so every individual species deserves to be given the necessary attention in the conservation and preservation of species. This is because a seemingly unimportant species today, may become very valuable in future given the spate of scientific research and discoveries. According to Hawthorne (1995), forest trees classified as Green Stars which currently are tree species with no conservational importance may in future become Black Star, Gold Star or Blue Star.

Additionally, the Green Star species which form the majority of tree species in the study area, contribute to the total species diversity of the ecosystem. The large proportions of the Pink, Blue, Red, and Scarlet require that the area be accorded a high degree of protection. The Black and Gold Star species show that the ARFR is of high conservation importance both locally and internationally hence the need for protection and exclusion of degradative activities like mining and logging which pose high risk to the existence of the entire spectrum of biological diversity associated with it.

Plant Species Diversity and Plant Families

Globally, plant diversity varies from vegetation to vegetation based on several factors including physiographic, topographic and edaphic conditions as well as land-use and management systems among others (Rembold, Mangopo, Tjitrosoedirdjo, & Kreft, 2017; Katovai, Edwards, & Laurance, 2015). In the study area, the overall plant diversity determined using Shannon-Weiner (4.21) and Simpson (0.97) diversity indices was relatively high. Comparatively, the value of the Shannon-Wiener index for this study was higher than the results of Katovai et al. (2015) for the tropical rainforest in Papua New Guinea, but similar to those reported by Naidu and Kumar (2016) for the Eastern Ghats of Andhra Pradesh in India, which ranges from 3.76 to 3.96. This confirms that the ARFR biologically is diverse. The extent of species dominance in the current study is relatively higher than those reported by Kumar et al. (2010) and Naidu & Kumar (2016). The differences observed between the current study and the others studies may be attributed to factors such as varying environmental influences (Clark & Clark, 2000; Zhang et al., 2012; Chazdon, 2003). These varying environmental conditions include differences in soil moisture and temperature, soil fertility and topographical features as well as the intensity of anthropogenic disturbances and herbivory.

The most species rich families include Apocynaceae, Meliaceae, Fabaceae Malvaceae, Euphorbiaceae, Maraceae and Phyllanthaceae each of which contributed more than 18% of the total number of species identified. However, the most important family according to the Family Importance Value (FIV) obtained was Fabaceae, followed by Meliaceae and Apocynaceae while the Verbenaceae and Erythroxylaceae had the lowest FIV values. Kacholi (2014), in a similar study in the Kilengwe Forest in the Morogoro Region of Tanzania, reported the dominance of the Fabaceae, followed by Sterculiaceae and Moraceae in terms of FIV. The diversity of the FIV recorded can be attributed to the high species richness. Apart from Meliaceae, which was common to this study and those of Laidlaw et al (2007), Kessler, et al., (2005), and Kacholi (2014), all other families were different in terms of FIV for the different forests. For instance, Laidlaw, et al. (2007) reported Meliaceae, Euphorbiaceae, Lauraceae, Myrtaceae and Apocynaceae as the most important families according to FIV for the Australian tropical rainforest while Kessler (2003) identified Meliaceae, Moracease, Lauraceae, Euphorbiaceae, and Urticaceae as the most important families in the tropical forest of Lore Lindu National in Central Sulawesi, Indonesia. Nath et al. (2005) in their analysis of vegetation and tree population structure of tropical wet evergreen forests in and around the Namdapha National Park, northeast India identified Hamamelidaceae Hippocastanaceae, Meliaceae, Apocynaceae, and Lauraceae to be the most important value families.

At the species level, the most abundant trees with highest relative density included *Cedrela odorata*, *Funtumia africana*, *Tabernaemontana africana,* and *Hymenostegia afzelii*. Their importance could be explained by their adaptability and survival potential in the face of competition as well as their mode of dispersal. According to Ewel and Mazzarino (2008), a tree species like *Cedrela odorata* is largely able to thrive in the diffuse light of the understory during its young stage of development and this ability allows it to survive in most tropical forests. The species is also known to withstand termites and rotting naturally in forest ecosystems, a condition which affect the existence other forest species. The narrow crown, little branching and straight trunk of *Funtumia africana,* enable it to penetrate the canopy in its quest to obtain enough light for photosynthesis. Unlike *Cedrela odorata*, *Tabernaemontana africana* and *Hymenostegia afzelii, Funtumia africana* relies on its attractive flowers and tasty barks to attract pollinators and dispersal agents. These adaptations may have contributed to the success of these species in dominating the study area. Other studies have reported different IVI. Laidlaw et al. (2007) found the most important species in the Australian tropical rainforest to be *Cleistanthus myrianthus* (Euphorbiaceae), *Alstonia scholaris* (Apocynaceae), *Normanbya normanbyi* (Arecaceae), *Myristica insipida* (Myristicaceae) and *Acmena graveolens* (Myrtaceae). The difference between the

IVI of this study and Laidlaw et al. (2007) could be attributed to the different temperature and soil quality.

Impacts of Stress on Plant Diversity

Changes in land-use and the intensification of such changes in regions of tropical rainforest may be linked to the decline in species diversity and other vegetation related characteristics (Rembold et al., 2017). In most instances, anthropogenic conversions of forest cover to other land-use have varied impacts on the vegetation in terms of the density of species, species richness and species evenness in an area. In the ARFR, for example, this study revealed a higher population of plants in the NSV followed by the MSV and the HSV. This observation points to some kind of relationship between species population and the magnitude or severity of disturbance and lends credence to the intermediate disturbance hypothesis which suggests species diversity declines due to low and high levels of disturbance but at intermediate level, species diversity increases in a similar vein. The finding of this study is consistent with studies by Pukkala and Gadow (2012) and Katovai et al. (2015), who have indicated that previous levels of disturbance have roles to play in vegetation characteristics of many forest ecosystems.

In this study, the MSV had the highest species richness which is in accordance with the intermediate disturbance hypothesis (Schwilk, Keeley, & Bond, 1997). Addo-Fordjour, Obeng, Anning and Addo (2009) reported a similar result for their studies on the Tinte Bepo Forest Reserve of Ghana. For instance, Addo-Fordjour et al. (2009) showed that the species richness was highest in the undisturbed followed by the disturbed-invaded and disturbed forest.

Diameter at Breast Height Distribution (DBH) of Species

The study of tree size diameter distribution in forests is important for understanding the structure, function and dynamics for management of such ecosystems. An important finding of the study was that majority of the trees were below 30 cm DBH reflecting the magnitude of disturbances or exploitations of resources of the area both past and present. Similar to the finding of this study, Rembold et al. (2017) also found that most land-use changes, especially, those emanating from logging and agriculture have significant influence on the distribution and size categories of tree species. This finding is consistent with (Van Gemerden, Olff, and Parren (2003) whose study on the biodiversity hotspot in the Guinean tropical rainforest of West Africa portrayed clustering of the trees in the sapling and pole categories which signifies a high potential for regeneration of the exploited vegetation.

Furthermore, Zhang et al. (2013) stated that depending on the duration of fallow, intensity of disturbance, site characteristics and the type of species, the regeneration rate of the vegetation may delay after the disturbance. According to Addo-Fordjour et al. (2009) the dominance of a species in one forest and not the other is an indication that different species probably respond differently to disturbance. The climax stage is mostly characterized by trees with larger than 50 cm DBH with very little proportions of those below 50 cm DBH.

Impacts of Stress on Stand Structure

The skewness of the distribution of saplings and poles in the study area is dependent on the magnitude of anthropogenic disturbances of the vegetation. The population of saplings and poles is greatest in the MSV and HSV. Similar observation was made by Addo-Fordjour et al. (2009) and Naidu and Kumar (2016) for tropical rainforest in Atewa, Ghana and Pradesh, India respectively. Although, the average tree population per hectare for each of the stress categories was higher than what was observed in most vegetation studies in the southern sections of the forest belt in Ghana (Asase et al. 2014; Hawthorne, 1993), the density of saplings and poles species in this study is similar to the findings of Katovai et al. (2015) for the tropical forests in Papua New Guinea, where the mean densities ranged between 41.3 and 62.3 ha^{-1}.

The NSV and MSV recorded higher tree densities than the HSV. The high proportion of trees belonging to the 10 – 30 cm DBH category in both the HSV and MSV holds much promise for regeneration of the stands provided the degradative activities cease.

The mean basal area of the trees (27.4 m^{2}ha^{-1}) was within the basal area expected of many tropical forests. For instance, Nath et al. (2005) and Naidu and Kumar (2016) reported 33.76 m^{2}ha^{-1} and 25.8 m^{2}ha^{-1} in the wet evergreen forest of Namdapha National Park in northeast India and in a tropical forest in Eastern Ghats of Andhra Pradesh, India. The high basal area observed in the MSV compared to the HSV may be linked to the magnitude of disturbances experienced, and soil moisture content, all other factors being equal. The MSV is mostly located in riverine areas where soil moisture is certainly not limiting thereby facilitating the growth and development of the tree species.

Influence of Stress Level on Conservation Status and Ecological Guild of Plant Species

The preponderance of green star species across all stress categories may be attributed to the low economic value of trees in this category. The presence of black star in the NSV may be credited to the vegetation not being stressed through logging, and mining activities. The black star plant species are globally very rare and are highly threatened (Larsen, 2006; Abu-Juam et al., 2003).

Most red and scarlet tree species are highly exploited; it is surprising that they could be found in the HSV. The fact that such categories of species are not uncommon may account for their abundance. Consistent with this study, Afriyie (2010) noted low representation of the 'common but under exploited stars' (i.e. Scarlet, and Red) in the forest zone of Tano Offin and attributed it to encroachment activities.

The predominance of the shade-bearers in the MSV and NSV is indicative of the compact nature of the canopy structure of these vegetation types. On the other hand, the prominence of pioneer species in the HSV compared to the other categories may be due to the intensity of light prevailing in such areas. According to Pappoe et al. (2010), shade-bearers are usually found in the understory; yet, their considerable presence among pioneer species may have arisen because the guild might contain some cryptic pioneers which tolerate light later in life. The high proportion of savanna or non-forest species in the HSV compared to the NSV and

MSV is indicative of the eventual transformation of the affected areas of the forest to possible savanna vegetation if the spate of deforestation and degradation is unchecked.

Estimation of Above- and Below-Ground Carbon Stock

Anthropogenic Influences on Carbon Sequestration and Stock in the Vegetation

Tropical deforestation through land-use changes accounts for approximately 25% of carbon emissions from anthropogenic sources (IPPC, 2001; Thomas et al., 2004). In tropical forest environments, carbon sequestration is mostly associated with plant biomass and soils (Blanco-Canqui & Lal, 2004; Kaiser, Eusterhues, Rumpel, Guggenberger & Kogel-Knabner, 2002; Lal, 2003; Lamlom & Savidge, 2003) with pieces of evidence linking higher carbon stocks to higher plant species diversity and density (Catovsky, Kobe, & Bazzaz, 2002; Kirby & Potvin, 2007). Nonetheless, the amount of carbon sequestration in a forest may be affected by varied anthropogenic activities like logging, mining and farming. The findings of the study indicated that in the ARFR, the relatively high amount of sequestrated carbon was observed at the MSV followed by the NSV and the HSV. This finding is similar to observations made by Asase et al. (2012) in the Bia Conservation Area in the Western Region of Ghana and Katovai et al. (2015) for the tropical rainforest in Papua New Guinea.

The results for both the above- and below-ground biomass components of the tree species show that the MSV contributed most to the sequestrated carbon, followed by the NSV and the HSV. The finding of the current study is consistent with the findings of Asase et al (2012) and Katovai et al (2015) who indicated that lower carbon is an indication of the negative impact of anthropogenic activities. It contradicts the finding of Berenguer et al. (2014) who reported that regardless of disturbances, the patterns of carbon stocks were similar for both the primary and secondary forests in the Amazon.

The slightly lower carbon stock in the Atewa forest compared to the cited studies might be due to the different land-uses and the magnitude of disturbances observed. The ARFR has in recent times witnessed massive encroachments from the activities of illegal gold mining, logging, farming and settlement. The Bia Conservation Area has attracted national and international interest towards the protection of biological species (IUCN, 2007). As suggested by Smith and Stitt (2007) increasingly anthropogenic activities are becoming common in most tropical forests as these forest resources are largely connected with the lives of the ever increasing population. Nevertheless, over dependence on the forest ecosystem for socio-economic and cultural relief is putting too much stress on it. Thus, growing human population is contributing to agricultural expansion and intensification, and logging. These are major causes of deforestation, degradation, biodiversity loss and significant carbon emission during the past decades in forest ecosystem (Van Gemerden, et al., 2003; Norris, et al., 2010).

Contribution of Ecological Guilds to Tree-Stored Carbon Stocks in the Study Area

The carbon stock per plot was made-up of the contributions from Shade-Bearers, Pioneer Non-Pioneer Light Demanders, Savanna/Non-forest and swamp.

The shade-bearers recorded the highest carbon stock, followed by the Non Pioneer Light Demanders and the other ecological guilds. This differs from the observation of Yeboah (2011) for the Oda-kotoamso and the Bobiri forest reserve of Ghana. Yeboah (2011) found that tree carbon content did not differ for the guilds classification, that is the pioneer, non-pioneer light demanders, and shade bearers.

The large proportions of Savanna or Non-forest species recorded in the HSV can be attributed to the anthropogenic activities in that area which has led to the transformation of the vegetation from the expected rainforest to the savanna vegetation, as has been observed above. As expected, the largest contribution of tree stored carbon stocks by Pioneer species was recorded in the HSV while the MSV and the NSV recorded the largest contribution of tree stored carbon stocks from the Shade-Bearers.

Characteristics of Soils of the Study Sites

The nature of soil affects plant growth as well as distribution in various parts of tropical forests (Martins et al., 2015). Soil quality in the study area is comparable to those of other tropical forest vegetation (Asase et al., 2014). The soil at the Atewa Forest was not very poor in nutrients but high in acidity which confirms the assertion by Asase et al. (2014) that soils in moist forests in the tropics are usually high in acidity as a result of leaching. Comparatively, the soil in the HSV was highest in acidity followed by the MSV and then the NSV in the top soils. As soil depth increased, the MSV recorded the highest acidity followed by the HSV and then the NSV. Other studies have reported that the acidity of forest soil varies with different types of land-use (Asase et al., 2012; Zhang et al., 2012; Rembold et al., 2017), forest types, elevations and the intensity of human disturbance (Rembold et al., 2017). The use of agrochemicals for pest and disease control, fertilizer applications and other sources of chemical usage in agriculture related land-use is known to contribute to increase in soil acidity in most forest areas (Altieri, 2004; Scherr & McNeely, 2008). The finding of this study is supported by Álvarez-Yépiz et al. (2008), Gutman, et al. (2004), and Reiners et al. (1994).

Soil structure and SOM are two of the most dynamic properties that are extremely sensitive to plant and soil management; and changes in land-use significantly influence the characteristics of the soil, hence affecting plant establishment (Álvarez-Yépiz et al., 2008; Moran et al., 2000; Reiners et al., 1994). The observed soils in the study areas were largely loamy and loamy- clay but also differed at the three stress levels with respect to the amount of organic carbon and nitrogen. The soil recorded in this present study is similar to the loamy soil recorded by Cuni-Sanchez et al. (2017) in a tropical montane forest in Indonesia despite the soil types being significantly different.

The highest bulk density recorded in the HSV is a common feature of soils that have experienced high level of anthropogenic disturbances (Alongi & de Carvalho, The effect of small-scale logging on stand characteristics and soil biogeochemistry in mangrove forests of Timor Leste, 2008). As maintained by Alongi and de Carvalho (2008) and Hendrison (1990) a significant indicator of vegetation soils that are disturbed is the increase in bulk density due to compaction. Logging and mining activities for instance affect soil bulk density and reduces the nutrient contents of the soil due to the introduction of machineries whose weight and movement on the soil lead to compaction and compression of the soil (Adekunle & Olagoke, 2010; Alongi & de Carvalho, The effect of small-scale logging on stand characteristics and soil biogeochemistry in mangrove forests of Timor Leste, 2008).

The present study reports that the soil bulk densities of the Atewa Forest decreased with depth. Similar observation was made for the deciduous forest and evergreen tropical forests in Cambodia, Southeast Asia (Toriyama et al., 2013). The probable reason could be the direct impacts top soils receive from the weight of the heavy equipment used in logging and mining operations. Aside the soil, bulk density impacts through anthropogenic activities, there are often increases in runoffs due to the compaction effects which on most occasions lead to the washing away of organic materials and nutrients from the top soil. In the study area however, various observations were made of heavy vehicle tracks that had been eroded following heavy rainfall. According to Asase et al. (2014) and Paudel et al. (2015), many tropical forests experience high rate of litter fall and decomposition ensuring tight cycling of nutrients between the plants and the soil. However, the amount of organic matter usually from litter fall may be influenced by environmental conditions, the type of plant species as well as the intensity of anthropogenic disturbance in the forests.

An activity like logging for instance increases the amount of plant materials in the form of debris and undesired branches which add to the organic matter content of the forest soil. The variability in the three stressed sites in the Atewa Forest may be explained by the various intensities of anthropogenic activities which according to Zhang et al. (2012) affects soil characteristics and fertility. The high level of organic matter in the NSV and MSV compared to that of HSV may however be attributable to the intensity variations in anthropogenic activities experienced in the vegetation. For instance, the removal of soil and vegetation cover through mining and logging activities in the HSV affected the amount of organic matter remaining to cover the soil. The logging and mining activities led to the removal of the vegetation cover and top soils, thereby exposing the soil to high temperatures and high soil moisture evaporation which are inimical to microbial activities towards decomposition of forest litter and other dead organisms (Jangid et al., 2011). These in totality affect the percentage organic matter, organic carbon and available soil nutrients for forest tree growth and development. Although the observed soil organic carbon at NSV was similar to that recorded by Toriyama et al (2013) study in a deciduous forest, the levels were less for HSV and MSV. In fact the entire levels of soil organic carbon in this study was much less than observed in the evergreen forest in Cambodia (Toriyama, et al., 2013).

The removal of vegetation covers through logging, mining and farming have contributed to increase evaporation of soil moisture. This affected the soil moisture content especially in the HSV as most trees were lost to mining and logging. The soil acidity variation observed across the stress levels is linked to the intensity of anthropogenic activities which directly influenced organic decomposition and the distribution of organic matter. According to Asase et al. (2014), the distribution of organic matter directly influences the pH and CEC of the soil in forest vegetation. The distribution of organic matter may be said to have influence the soil texture of various segments of the study area. For example, higher composition of organic matter is usually expected to increase the loamy constitution of the soil making the soil more fertile for plant growth.

Regarding percentage nitrogen, phosphorus and potassium, the significant variation observed in the study in favour of the NSV and MSV was expected. These observations were expected as soil nutrient replenishment and availability for plant use are linked to litter and other organic materials (Paudel et al., 2015). The rate of organic matter decomposition is influenced by the level of anthropogenic disturbances in the forest ecosystems (Zhang et al., 2012).

Effects of Anthropogenic Impacts on Soil Characteristics in Relation to Vegetation Characteristics

Soil Moisture, Soil Temperature and Soil Respiration at the Study sites

The effects of forest vegetation cover on soil moisture and soil water differ for different forest types (Özkan & Gökbulak, 2017). Generally, the amount of soil moisture observed during the study was lowest in the HSV followed by the MSV and then the NSV. As observed by Singh, Malik, and Sharmaa (2016) in their study of the rainforest of Garhwal Himalaya in India, the most disturbed portion of the forest had the least soil moisture due to human-induced activities. Thus, anthropogenic disturbance adversely affects soil moisture content. The removal of vegetation cover exposes the soil to high rates of evaporation. The longer the exposed soil surface to the sun energy, the higher the rate of evaporation resulting in reduction in the soil moisture content. In the HSV, the extensive activities of logging and mining caused a higher loss of vegetation cover compared to the MSV and the NSV which might have direct influence on the amount of soil water lost to evaporation (Sotta, et al., 2004). Contrary to expectation soil temperature increased alongside moisture content between January and March but as expected decreases in temperature w observed between April and September. This period constitute the rainy season leading to increase in soil moisture content. In most cases, the presence of vegetation covers provides barrier against the direct impact of solar radiations which contributes to increases in soil temperatures.

As expected, the NSV in the ARFR entirely had the lowest soil temperature compared to the MSV and HSV. This was because the NSV has higher extent of forest canopy closure than the MSV and HSV. The MSV and the HSV have portions or their entire canopies removed giving rise to higher exposure of their soils to the direct effect of solar radiation. The gaps created in the canopy through the deliberate actions (e.g. farming, logging and mining) of humans may have contributed to the higher soil temperatures recorded in the MSV and the HSV. The current observation is consistent with the observation of Zhang et al. (2012) and Rembold et al. (2017).

Soil moisture and temperature per se are meaningless unless they are linked up with ecosystem functions such as organic matter decomposition and soil respiration. The observed higher soil respiration rates in the NSV compared to the HSV and MSV was expected. A higher soil moisture is associated with better decomposition and higher rate of organic materials through microbial activities (Vincent et al., 2006) which directly determines the rate of soil respiration. The relatively high fluctuating trend observed in the soil respiration rates during the months of March, April, September and November in the study area may be attributed to the annual fluctuation in the temperature and rainfall during those months. According to Zhou et al. (2011), soil respiration usually increases nonlinearly with increase in soil temperature (Davidson & Janssens, 2006). Katayama et al., (2009) also found that there was no relationship between soil respiration, soil temperature and soil moisture. This phenomenon was observed in the present study.

Relationships between Soil and Vegetation Attributes

The importance of the soil in the growth and distribution of plants cannot be overemphasized in tropical forests (Drewitt, et al., 2002; Sollins, 1998; Martínez-Sánchez, 2005; Martins, Marques, dos Santos, & Marques, 2015) Apart from the anchorage soils provide, they also supply essential nutrients that are necessary for the growth and establishment of plant species in the forest ecosystem. The direct effect of soil on vegetation as observed in this study is influenced by a set of soil-vegetation variables (e.g., tree diversity, species richness and dominance, and soil variables such as bulk density, moisture content, and pH). The tree size and density are responsible for the continuous support of vegetation regeneration and are responsible for protecting the soil from erosion (Martin et al. 2015). It also helps in maintaining the soil moisture, and conserving the soil fertility via biomass accumulation and consequent decay in the in the ARFR. Phosphorus, nitrogen, and carbon are important nutrients for the growth and regrowth distribution of plant species luxuriant characteristics (Sollins, 1998). The findings of this present study corroborates that of Eni et al. (2012) who investigated the soil-vegetation interrelationships in a South-Southern forest in Nigeria.

The observed relationship between the sequestrated carbon and tree dominance is an indication that tree dominance is vital to tree carbon sequestration when compared to parameters, such as species richness, tree density, potassium, phosphorus, nitrogen, soil carbon, bulk density and soil respiration in the Atewa Forest. This also implies that an increase in tree dominance would lead to an increase in carbon sequestration in the Atewa forest (Eni, Iwara, & Offiong, 2012) as the dominance is directly linked to the diameter of the trees. Further, increases in tree diameters directly imply that increase in the amount of carbon sequestrated through photosynthesis results in increment in stem sizes. In many forest ecosystems according to Gleixner, Kramer, Hahn, & Sachse (2005), diameter growth of tree species is impacted by the availability, quantum and quality of water resources. The water forms part of root exudates as well as the enhancement of carbon compositions in soil profiles as they are directly linked to organic matter decomposition making available nutrients for growth and hence carbon sequestration. Bunker et al. (2005) also established that tropical forest sequestration of carbon and other ecological functions of forest vegetation are dependent on several factors apart from soil conditions.

Evaluation of the Intensity of Human-induced Stress on Vegetation Quality between 1986 and 2016

Anthropogenic Induced Stress on the Vegetation Quality

Forest vegetation worldwide is continuously under pressure from anthropogenic activities to address the needs of mankind which eventually affect the quality of the resource namely vegetation, soil and water quality. In assessing the impacts of anthropogenic interference on the vegetation and its quality in the ARFR, the NDVI identified decreases in the vegetation cover over the past decades. The decline in vegetation cover observed in this study may be explained by the increase in logged areas, farmlands and settlement areas. The ARFR was observed to have tremendously decreased by 61.54 km^2 over the past three decades (1986-2016), and the total land mass for logging had in the same period increased due to the demands for timber products for export, infrastructural development and housing. Farmlands together with mined areas represent bare lands during the remote sensing analysis. Bare areas in forest come about because of competition among the three major economic sectors (agriculture, mining, and logging) in Ghana (Hens & Boon, 1999). Ichii, Kawabata, and Yamaguchi (2002) found that an increase in the NDVI in the equatorial regions are largely attributed to deforestation and fertilisation. Basommi & Guan (2015) have suggested that the increased conversion of forest to farm lands and bare lands between 1986 and 2007 may be attributed to the high rate of illegal mining recorded mostly in the reserved forests of Ghana. Many of the protected areas of Ghana have failed to fulfil the objective of conserving biodiversity for which they were established (Movement, World Rainforest, 2002). Polyakov and Zhang (2008) have also indicated that growth in human population is associated with the eventual expansion of land area for housing which affect vegetation closest to forest reserves.

The high rate of land-use change from forest to settlement may be attributed to the growing population coupled with the growing demand for shelter. The World Rainforest Movement (2002) estimates that between 1977 and 1997, Ghana lost 5.6 million ha of forest cover as a result of increase in human population. The study further showed a gradual transformation of the vegetation in the study area to bare lands. Guida-Johnson and Zuleta (2013) found that land-use changes are major hazard to both forest conversation and biodiversity and are major sources of degradation.

Gross Patterns and Land-use Transformation in the ARFR

The trend or pattern of land-use depends on several factors including the population's demands for food, shelter and social values (Basommi et al. 2015). The four different years (1986, 1998, 2007 and 2016) indicate that all logged areas dominated the land-cover types within these periods. The periods before the 2000s recorded more logging than the period after. The study area is rich in timber species of high economic value, and this accounts for increased logging of the timber species for the construction of housing units, roads and bridges and furniture among others. Zak et al (2008) attributed the loss in forest ecosystems of central Argentina to logging, followed by agricultural expansion while Guida-Johnson & Zuleta (2013) indicated that cropland expansion was the main factor responsible for the depletion of the forest in the Espinal ecoregion of Argentina.

The geo-spatial images show that the unlogged and the logged areas in ARFR have decreased whilst the farmland and settlements have increased within the past three decades. The forest cover decreased at a rate of 2 km^2 per annum with a reduction of 20 km^2 between 1986 and 1998, 10 km^2 between 1998 and 2007, and 31.54 km^2 between 2007 and 2016. This fits into the confirmation made by Antwi et al. (2014) who reported that the deforestation rate in Ghana stood at 65,000 km^2 annually. The high deforestation rate in Ghana is as a result of the increasing population size and opportunities associated with resource use. The active transition from rainforest to logged lands, farmlands and settlement is consistent with the findings of Sala et al. (2000). Alo and Pontius (2008) pointed to the fact that the transition from the rainforest to the other land-use forms could be considered systematic because it increased with population growth. The increased land change is largely associated with agriculture intensification, infrastructure expansion and gold extraction (Guida-Johnson & Zuleta, 2013). This has largely resulted in deforestation, degradation and the loss of biological diversity in rainforest areas (Van Gemerden et al., 2003; Norris et al., 2010).

Impacts of Anthropogenic Activities on Water Quality of the Birim River

Physical and Chemical Characteristics

There are many factors that can affect pH in water bodies, both anthropogenic and natural. Most anthropogenic changes occur due to fluctuation with precipitation (especially acid rain) and fertiliser or mining discharges. The pH range of the water resource in the study was higher than what was reported (i.e., 6.2 – 6.9) by Ansa-Asare and Asante (2000) for the Birim river.

Higher temperatures were recorded in this study, compared to what was reported about two decades ago by Ansa-Asare and Asante (2000) and Karikari and Ansa-Asare (2005). At the micro level, the HSV recorded the highest temperature followed by the MSV and the NSV. The probable reason for this finding could be the exposure of the water body to heat radiation from the sun. The removal of the forest canopy in the HSV resulted in higher temperatures compared to the MSV and NSV because forests together with their canopies provide protection for water bodies from the direct solar radiation reaching to water surface to warm it up (Paul & Meyer, 2001).

The Turbidity and TSS in the Birim River have increased exponentially over the past two decades, when compared to that of Ansa-Asare and Asante (2000) and Karikari and Ansa-Asare (2005). These observed changes may be explained by increased anthropogenic activities which have direct impact on the soil. The movement of soil particles and the washing of gold in the Birim River (Bampoe, 2015) as well as soil erosion and runoff from the catchment areas could be responsible for the high turbidity in the water body. This finding is consistent with those of Karikari and Ansa-Asare (2006) who found increased turbidity in the Densu Rivers as a result of the soil carried in surface runoff, fine particulate organic matter inputs, and in-stream production and morphology.

Levels of Heavy Metal

The concentration of heavy metals at various locations in the Birim River at the study sites depend on the time and the intensity of the anthropogenic activities. Apart from zinc which did not vary, all the other heavy metals (arsenic, cadmium, iron, mercury and lead) varied in the different study site. The high concentration of metals found in the HSV zones as compared to both the MSV and NSV zones suggests that anthropogenic activities in the area were probably the main sources of the high concentration of the heavy metals (Dai et al., 2004).

Generally, the NSV recorded lower concentration of heavy metals than the standard values set by the World Health Organisation (WHO, 2011) and the Ghana EPA. Arsenic and mercury were observed to be higher at the MSV than the standard values of WHO and Ghana EPA. The levels of cadmium, lead, iron and zinc reported in this current study were higher than those reported by Ansa-Asare and Asante (2000) and Ansa-Asare and Gordon (2007). The sources of these heavy metals are largely attributed to anthropogenic stressors such as agriculture and the use of agrochemicals to control pests and disease during crop production (2012). Similar Ansa-Asare and Gordon (2007), this present study report that the heavy metals often leach into the Birim river and are carried in the surface water bodies by rain water. In some cases, the use of fossil fuels in machinery and other lubricants containing heavy metal constituents around the water bodies in ARFR may serve as sources for the introduction of heavy metals. Additionally, the significant concentration of iron observed may be attributed to the ferruginous nature of sediments in the river, low acidity and soft nature of the river water (Ansa-

Asare & Asante, The water Quality of Birim River in South-East Ghana, 2000). The high level of mercury beyond WHO and EPA limits may be linked to the amalgamation process in small scale mining.

Bacteriological Characteristics

River pathogen contamination, which is often assessed by enumerating pathogen indicators such as *Escherichia coli* and Fecal coliform in river bodies, is a major water quality concern in the developing countries. High concentrations of *Escherichia coli* and Faecal coliform suggested greater water pollution in some rivers of developing countries. This study did not record the pathogenic *Escherichia coli* (*E.coli*) nor the Faecal coliform in the water samples taken at the various sampling sites. This finding contradicts the argument by WHO (2011) that *Escherichia coli* is known to be present in many river bodies in most developing and Sub-Saharan African countries. The probable reasons for these findings could be the non-infection of people engaged in activities of farming, mining and logging in the study area; and the washing away of pathogens before the sampling times of this study. This is because the Birim River is continuously flowing from one point to another.

The total coliform recorded for the microbial water quality of the study site was unacceptable according to the World Health Organisation (1993) standard. The poor microbiological quality might be due to contamination caused by livestock and human activities. This is an indication of the presence of bacteria that cause dysentery, typhoid fever and cholera.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Introduction

This study was undertaken to assess the condition of biological systems to confirm that the vegetation, soil and water quality is adequate and also define the existing ecological problem whilst taking into account the existing condition of the plant species in ARFR. The vegetation data was obtained from 50 m × 50 m plots in each of the three stress levels (NSV, MSV, and HSV) of the ARFR. Soil samples from each identified area were collected and analysed for the physical, chemical and biological properties. The water samples were obtained from the Birim River for analysis. The findings emanating from the analysed data and the conclusions drawn from the findings as well as the recommendations for policy and further research are presented in the sections below.

Summary

The ARFR provides important ecosystem services. The study addressed the following specific objectives; (i) determination of vegetation characteristics in the study area, (ii) estimation of the above and below ground carbon stock and assessment of human-induced stress impacts on the vegetation (iii) estimation of the effects of anthropogenic impacts on soil characteristics and the corresponding relationship with vegetation characteristics in the study area, (iv) evaluation of the intensity of human induced stress on the vegetation quality through land use changes between 1986 and 2016, and (v) determination of the physicochemical, biological and heavy metal impacts of anthropogenic activities on water resource quality in the study area.

The study identified a total of 1,768 individual trees ≥ 10 cm dbh. The taxa were constituted by 177 species which belonged to 47 plants families of which Apocynaceae, Meliaceae and Fabaceae formed dominant. An average of 117.9±22.1 trees, 36.4±12.6 species and 15.2±4.6 families per the 50 x 50m plots was estimated. At the vegetation stress levels, the HSV dominated in terms of total tree population whereas the MSV dominated regarding the number of species and the number of plant families. The ecological guilds identified were Non-Pioneer Light Demanders (NPLD), Pioneer, Shade-Bearers, Swamp and Savanna / Non-Forest. The Shade-Bearers were predominant while Swamp and Savanna categories were least dominant. This was an indication of vegetation transformation and the opening of the forest canopy due to anthropogenic influences. In terms of conservation star rating status, Green Star, Pink Star, Blue Star, Red Star, Scarlet Star, Black Star and Gold Star were identified in descending order of proportions. The occurrence of Black Star and Gold Star species indicated the significance of the area in terms of conservation on both local and international fronts in the wake of degrading species diversity. The distribution of the trees into dbh classes revealed that most of the encountered species were below 20 cm followed by those between 20 cm and 29.9 cm, 30 cm and 39.9 cm. This distribution showed a stage of regeneration of the vegetation especially that of the HSV area.

The Shannon-Weiner and Simpson diversity indices calculated for the study area indicated variability with respect to land use and stress level, although there were high species diversity observed. At the scale of plant families, Apocynaceae, Meliaceae, Fabaceae, Malvaceae, Euphorbiaceae, Maraceae and Phyllanthaea contributed mainly to the species population found in the study area. However, Fabaceae was the most important family whereas Verbanaceae and Erythroxylaceae were the least. Plant species such as *Cedrela odorata*, *Funtumia africana*, *Tabernaemontana africana,* and *Hymenostegia afzelii* were observed as the most important species according to the calculation of Important Value Index for each species.

At the anthropogenic induced stress levels, 639 trees comprising of 65 species belonging to 25 families were distinguished for the Non-Stressed Vegetation (NSV); 603 individual trees consisting of 53 species which belonged to 19 families for the MSV; and 526 individual trees distinguished to 51 species belonging to 20 families for the HSV. A total of 14, 3 and 10 species were shared by NSV and MSV, NSV and HSV, and MSV and HSV respectively. On the average, 128±24.5, 121±20.1 and 105±28.8 were enumerated for the NSV, MSV and HSV respectively. In totality, MSV (42±7.6) contained the highest mean species richness followed by NSV (37.8±14.0) and HSV (30±14.5). The MSV (16±4.7) recorded highest followed by the NSV (15±3.2) and HSV (14±6.3) plant families. Despite, these observations, there were significant differences observed in the mean number of individual trees ($F_{2,12}=1.09$, $p > 0.367$) and species ($F_{2,12}= 0.6$, $p > 0.05$) at the three stress levels in the ARFR. Mean basal area was also found not to have varied significantly ($F_{2,12}=0.68$, $p > 0.52$) amongst the stress levels but recorded the highest in the MSV (33.08 cm$^{2)}$ followed by the NSV (30.67 cm) and then the HSV (26.20 cm^2). There were no statistical significant differences observed further in term of tree species diversity (Shannon diversity: $F_{2,12}$=1.5, p > 0.53; and Simpson diversity: $F_{2,1}$ = 2.6 p > 0.38) providing average environment anytime there is disturbance. Green Star species formed majority of species encountered in all tree stress levels followed by Pink Star species with Black and Gold Stars forming the least. The study areas were however observed to vary significantly with respect to the composition of the various ecological guilds although Shade-bearer dominated in both MSV and the NSV while Pioneer species formed the greatest proportion in the HSV.

The carbon stock was higher in the above-ground than the below-ground component. The MSV, recorded the highest stock of carbon followed by the NSV and then the HSV. Comparatively, the carbon sequestrated in this study forms approximately 75% the stocks. The stress level contribution to carbon stock was highest at MSV followed by NSV and HSV; although there was no significant difference (p = 0.347). At the guild level, the highest carbon stock was due to Shade-Bearer followed by the Non-Pioneer Light Demanders, Pioneer, and the least were Savana/ Non forest and Swamp in descending order. Pioneer species (24.75%) contributed the most to the carbon stock at the HSV whereas Shade-Bearers accounted for most quantity at MSV and NSV in proportionate manner.

The soils were found to be acidic in both the top and subsoils. The soils at HSV were most acidic followed by the MSV and NSV. The soils were largely Loamy-Clay with slight sandy observations in the MSV. The HSV recorded the least soil quality except in the case of soil bulk density in which it recorded the highest. The percentage organic matter and organic matter variations were linked to the removal of soil and vegetation cover through mining and logging as these affected soil surface temperatures, soil moisture and microbial activities resulting in litter and dead matter decomposition.

Soil moisture content was lowest at HSV but highest at NSV. Lowest soil temperatures were recorded at NSV followed by MSV and HSV. Soil respiration was generally higher at NSV followed by HSV and MSV.

The percentage nitrogen of the soil and soil carbon indicated strong positive loading for ordination axis one while the second ordination axis showed strong correlation with the soil bulk density. Percentage nitrogen further accounted for the largest magnitude of variation in tree diversity, species richness and dominance of the tree species sampled whereas the Potassium and Phosphorus of the soil were observed to have had weak impacts. A significantly strong positive relationships was seen between the total sequestrated carbon and tree dominance ($r = 0.93$, $p < 0.0001$). Species richness, tree density, diversity indices, and soil characteristics did not show significant relationships ($p > 0.05$) with above-ground, below-ground and total carbon stock.

The NDVI showed a decreasing cover of rainforest against increasing logging, farming and settlement areas 1986, 1998, 2007 and 2016. The rainforest decreased at a rate of 2 km^2 per annum. Logged areas formed the majority of land-use type followed by Farmlands / Bare-land.

There was active transition between Rainforest and Settlements whereas Logged lands and Farmlands were relatively dormant. Between time intervals

2007-2016, there was significant change in land use experienced across Logged lands, Farmlands and the Settlement areas with the Farmland and Settlements further recoding greater losses than gains in the same time interval.

Between 1986 and 1998, there was active transition from Logged forest, Farmlands and Settlement respectively to Rainforest meanwhile, the transition from Rainforest to Logged land, Farmland and Settlement followed a uniform line of 0.48% rate every year. Between 1998 and 2007, again active percentage of transition was observed from Logged lands, Farmlands and Settlement respectively to Rainforest whereas the transition from Rainforest to Logged land, Farmland and Settlement was again equal at a uniform change at 0.46% rate per annum. Finally, between 2007 and 2016, the study area recorded an active transition percentage of 1.49% - 4.24% from Logged lands, Farmlands, and Settlement respectively to Rainforest while transition from Rainforest Logged land, Farmland and Settlement followed equal uniform change at 2.52% rate per annum. In all, the transition from Rainforest to the other land use forms may be considered as systematic.

Acidity and the temperature of the Birim River sampled did not show significant variations at the stress levels although they were almost neutral with slightly basic concentrations. That notwithstanding, other physicochemical properties including TDS, TSS, Turbidity and EC etc, showed significant variation between the NSV, MSV, and HSV. Water sampled from the area were almost neutral with very little margin into being basic. The HSV areas recorded highest pH values followed by the MSV zone and then the NSV zone whereas the NSV area recorded the highest temperature followed by the HSV and the MSV. The heavy metals showed significant differences at the three stress levels apart from zinc. Cadmium recorded the highest concentration at NSV. All heavy metals recorded highest concentrations in the HSV followed by MSV. The NSV recorded acceptable concentrations of heavy metals. The same could be said of MSV but for arsenic and mercury. At HSV, apart from iron and zinc which were at acceptable levels, had all other heavy metals concentrations were inconsistent with acceptable limits. The water samples had no *Escherichia coli* (E.coli) and faecal coli, meanwhile, total Coliform was highest at NSV.

Conclusions

The findings of the study indicate that the ARFR is very diverse in terms of plant species. The plant families registered in the area included Apocynaceae, Meliaceae, Fabaceae Malvaceae, Euphorbiaceae, Maraceae and Phyllanthaea which formed the majority whereas species wise, *Cedrela odorata*, *Funtumia africana*, *Tabernaemontana africana,* and *Hymenostegia afzelii* dominated. The area is characterised by a closed–canopy forest and does contain many species of conservation importance. The study area contains a number of individual trees made up of varied species and plant families which are of great ecological importance. The Rainforest has undergone series of transformation due to anthropogenic interference hence the presence of Pioneer and Savanna/Non Forest species. The rivers provide a source of water for the sustenance of biodiversity and the rejuvenation of water cycle within the ecosystem. Plant species of both local and international conservational priorities, especially Red, Gold and Black Star species are largely facing some level of threat and extinction in the ARFR. The study area has experienced some level of disturbance and is witnessing regeneration with moderate sized trees of diameter less than 30 cm.

Anthropogenic activities, such as logging, mining and farming together with variations in environmental conditions (rainfall and temperature) have influenced the species found in the forest. All stress areas have similar plant diversity as the closeness provided avenue for refuge and reintroduction of exploited species. The Atewa forest is an upland evergreen rainforest vegetation due to the close canopies and optimal rainfall and this has resulted in the dominance of shade-bearers in the MSV and NSV. The HSV has undergone high anthropogenic activities resulting in the removal of indigenous species and have provided conditions for the transfer or emergence of alien species to the forest environment. The high level of 'Light-demander' and 'Shade-bearer' further shows there have been series of anthropogenic interferences.

Sequestrated carbon stocks in the ARFR was generally high and varied across the three stress levels. Within the forest, the intensity of anthropogenic activities have negatively impacted the amounts of carbon sequestrated at various levels. The magnitude of anthropogenic impacts at the various ecological guild species have contributed differently to the amount of carbon sequestrated in the area. The abundance of gold and other mineral deposits in the ARFR have attracted mining activities which have adversely affected the plant diversity, amount of carbon sequestration and emission in the area. Logging and farming activities have also altered the total mean carbon in the study area.

Human activities in the ARFR has and is largely affecting the quality of the soil supporting the vegetation growth. The soils are losing their organic matter composition, soil moisture and essential nutrients required for photosynthesis and other important processes leading to tree growth and establishment. The loamy soil in the forest is characterized by nitrogen, potassium and phosphorus and has been significantly influenced by the logging activities at the upper layer. Generally, the NSV had higher respiration compared with the HSV and MSV.

There has been noticeable reduction in the vegetation quality due to the many anthropogenic influences and the increase in human populations. The socio-economic demands, demand for food, and shelter by both indigenes and foreigners have led to the increasing and varied intensities of anthropogenic interferences at the ARFR. From 1986 to 2016, the forest has experienced decrease total rainforest coverage but increase magnitude of logged areas, farming areas and the area of settlements. This has, further led to the significant transformation of the Atewa from rainforest to other land-use forms such as farmlands, logged lands and settlement areas. This transformation is rapid with variations within different time intervals which is severely influenced by the human demands.

The engagement of both citizenry and foreigners in illegal mining and logging has negatively impacted water quality in the ARFR catchment area. Apart from the acidity and temperature of the water resource which was similar for all stressed vegetation, other physicochemical properties varied for all stress level vegetation. The water is generally neutral, the numerous anthropogenic activities have exposed the water bodies to direct sun influence, increase the turbidity and total suspended solids. The activity of gold mining and logging have negatively impacted the water resource in ARFR leading to increasing concentrations of almost all heavy metals beyond acceptable WHO and EPA limits. Within the Atewa forest, anthropogenic activities did not cause variations in the zinc concentrations but did so for arsenic, cadmium, iron, mercury and lead across stressed zone. Finally, there was no contamination of *Escherichia coli* (E.coli) and Faecal E. coli in the water source but the Total Coliform was particularly impacted by anthropogenic activity.

Recommendations

The following recommendations are made in the hope that they will improve vegetation, soil and water quality and reduce the effect of anthropogenic activities in the ARFR.

i. Further research can focus on specific species carbon contribution and establish the most important species that contribute significantly to carbon sequestration in forest regions.

ii. Studies should investigate and enhance our ability to understand the mechanism responsible for the dynamics of soil properties and their importance and functions to sequester carbon.

iii. Further studies should investigate the extensiveness of anthropogenic activities and conduct a robust assessment of the effects of these activities on species composition and structure of the vegetation.

iv. Further studies can determine the effects of heavy metals concentration on riparian vegetation along a free-flowing river in relation with anthropogenic activities.

v. There is a need to implement succession inventory service which requires formalizing and enforcing land rights for forest dwellers, alongside payments for ecosystem services to those living near the ARFR.

vi. The threat to the local and conservational priority plant species in the ARFR calls for attention and protection of Red, Gold and Black Star species. There is, therefore, the need for stringent management approach for the control of human activities in the area.

vii. Strategies for reducing heavy metals contamination resulting from anthropogenic activities should be put in place and regularly monitored by management of the ARFR.

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APPENDICES

CHECKLIST OF SPECIES AT THE STUDY SITES

Species	Family
Afzelia africana Pers.	Fabaceae
Afzelia bella Harms	Fabaceae
Albizia adianthifolia W.Wight	Fabaceae
Albizia zygia J.F.Macbr.	Fabaceae
Allanblackia floribunda Oliv.	Clusiaceae
Allanblackia parviflora A.Chev.	Clusiaceae
Alstonia boonei De Wild.	Apocynaceae
Amphimas pterocarpoides Harms	Fabaceae
Annickia polycarpa (DC.) I.M.Turner	Annonaceae
Anopyxis klaineana Pierre	Rhizophoraceae
Anthocleista djalonensis A.Chev.	Gentianaceae
Anthocleista nobilis G.Don	Gentianaceae
Anthonotha fragrans (Baker f.) Exell & Hillc.	Fabaceae
Anthonotha macrophylla P.Beauv.	Fabaceae
Antiaris toxicaria Lesch.	Moraceae
Antidesma laciniatum Müll.Arg.	Phyllanthaceae
Antrocaryon micraster A.Chev. & Guillaumin	Anacardiaceae
Aubrevillea kerstingii (Harms) Pellegr.	Fabaceae
Aulacocalyx jasminiflora Hook.f.	Rubiaceae
Baphia nitida G.Lodd.	Fabaceae
Baphia pubescens Hook.f.	Fabaceae
Beilschmiedia mannii (Meisn.) Benth. & Hook.f. ex B.D.Jacks.	Fabaceae
Berlinia sp. Sol. ex Hook.f.	Fabaceae
Berlinia tomentella Keay	Fabaceae
Blighia sapida K.D.Koenig	Sapindaceae
Blighia welwitschii (Hiern) Radlk.	Sapindaceae
Bombax buonopozense P.Beauv.	Malvaceae

Species	Family
Bridelia atroviridis Müll.Arg.	Phyllanthaceae
Buchholzia coriacea Engl.	Brassicaceae
Bussea occidentalis Hutch. & Dalziel	Fabaceae
Calpocalyx brevibracteatus Harms	Fabaceae
Calpocalyx monadelpha (Thonn.) J.J.de Wilde	Fabaceae
Canarium schweinfurthii Engl.	Burseraceae
Carapa procera DC. (GCI)	Meliaceae
Cecropia peltata Billb. ex Beurl.	Urticaceae
Cedrela odorata Blanco	Meliaceae
Ceiba pentandra (L.) Gaertn.	Malvaceae
Celtis adolfi-friderici Engl.	Cannabaceae
Celtis mildbraedii Engl.	Cannabaceae
Celtis philippensis Blanco	Cannabaceae
Celtis zenkeri Engl.	Cannabaceae
Chidlowia sanguinea Hoyle	Fabaceae
Chrysophyllum albidum G.Don	Sapotaceae
Chrysophyllum giganteum A.Chev.	Sapotaceae
Chrysophyllum perpulchrum Mildbr. ex Hutch. & Dalziel	Sapotaceae
Chrysophyllum pruniforme Engl.	Sapotaceae
Chrysophyllum subnudum Baker	Sapotaceae
Cleidion gabonicum Baill.	Euphorbiaceae
Cleistopholis patens Engl. & Diels	Annonaceae
Cola edulis	Malvaceae
Cola gigantea A.Chev. & A.Chev.	Malvaceae
Cola heterophylla (P.Beauv.) Schott & Endl.	Malvaceae
Cola sp. (P.Beauv.) Schott & Endl.	Malvaceae
Cola lateritia K.Schum.	Malvaceae
Cola millenii K.Schum.	Malvaceae

Species	Family
Cola nitida A.Chev.	Malvaceae
Cola verticillata Stapf ex A.Chev.	Malvaceae
Copaifera salikounda Heckel	Fabaceae
Cordia sp. L.	Boraginaceae
Cordia millenii Baker	Boraginaceae
Cordia senegalensis Hochst. ex Baker	Boraginaceae
Corynanthe pachyceras K.Schum.	Rubiaceae
Cussonia bancoensis Aubrév. & Pellegr.	Araliaceae
Dacryodes klaineana (Pierre) H.J.Lam	Burseraceae
Dialium aubrevillei Pellegr.	Fabaceae
Dichapetalum madagascariense Poir.	Dichapetalaceae
Diospyros canaliculata De Wild.	Ebenaceae
Diospyros kamerunensis Gürke	Ebenaceae
Diospyros monbuttensis Gürke	Ebenaceae
Diospyros sanza-minika A.Chev.	Ebenaceae
Discoglypremna caloneura Prain	Euphorbiaceae
Distemonanthus benthamianus Baill.	Fabaceae
Guarea thompsonii Sprague & Hutch.	Meliaceae
Hannoa klaineana Pierre & Engl.	Simaroubaceae
Hexalobus crispiflorus A.Rich.	Annonaceae
Holoptelea grandis (Hutch.) Mildbr.	Ulmaceae
Hunteria eburnea Pichon	Apocynaceae
Hunteria umbellata Hallier f.	Apocynaceae
Hymenostegia afzelii Harms	Fabaceae
Isolona campanulata Engl. & Diels	Annonaceae
Khaya anthotheca C.DC.	Meliaceae
Kigelia africana (Lam.) Benth.	Bignoniaceae
Klainedoxa gabonensis Pierre ex Engl.	Irvingiaceae
Lannea welwitschii (Hiern) Engl.	Anacardiaceae
Lophira alata Banks ex C.F.Gaertn.	Sapotaceae
Lovoa trichilioides Harms	Meliaceae
Macaranga barteri Müll.Arg.	Euphorbiaceae
Macaranga heterophylla Müll.Arg.	Euphorbiaceae

Species	Family
Macaranga heudelotii Baill.	Phyllanthaceae
Maesobotrya barteri Hutch.	Euphorbiaceae
Maesopsis eminii Engl.	Rhamnaceae
Maranthes chrysophylla (Oliv.) Prance ex F.White	Chrysobalanaceae
Margaritaria discoidea (Baill.) G.L.Webster	Phyllanthaceae
Memecylon afzelii R.Br. ex Triana	Melastomataceae
Memecylon sp. R.Br. ex Triana	Melastomataceae
Microdesmis keayana J.Léonard	Pandaceae
Milicia excelsa (Welw.) C.C.Berg	Moraceae
Millettia rhodantha Baill.	Fabaceae
Monodora myristica Blanco	Annonaceae
Morinda lucida A.Gray	Rubiaceae
Musanga cecropioides R.Br.apud Tedlie	Urticaceae
Myrianthus libericus Rendle	Urticaceae
Napoleonaea vogelii Hook. & Planch.	Lecythidaceae
Nauclea diderrichii Merr.	Rubiaceae
Nesogordonia papaverifera (A.Chev.) Capuron ex N.Hallé	Malvaceae
Newbouldia laevis (P.Beauv.) Seem.	Bignoniaceae
Octoknema borealis Hutch. & Dalziel	Olacaceae
Omphalocarpum ahia A.Chev.	Sapotaceae
Omphalocarpum elatum Miers	Meliaceae
Ongokea gore Pierre	Olacaceae
Ophiobotrys zenkeri Gilg	Salicaceae
Ophiobotrys zenkeri Gilg	Salicaceae
Pachystela brevipes Engl.	Sapotaceae
Panda oleosa Pierre	Pandaceae
Parinari excelsa Sabine	Chrysobalanaceae
Parkia bicolor A.Chev.	Fabaceae
Pentaclethra macrophylla Benth.	Fabaceae
Pentadesma butyracea Sabine	Clusiaceae
Persea americana Mill.	Lauraceae

Species	Family
Petersianthus cecropioides	Lecythidaceae
Petersianthus macrocarpus (P.Beauv.) Liben	Lecythidaceae
Picralima nitida T.Durand & H.Durand	Apocynaceae
Piptadeniastrum africanum (Hook.f.) Brenan	Fabaceae
Placodiscus boya Aubrév. & Pellegr.	Sapindaceae
Protomegabaria stapfiana Hutch.	Phyllanthaceae
Pseudospondias microcarpa Engl.	Anacardiaceae
Psydrax arnoldiana (De Wild. & T.Durand) Bridson	Rubiaceae
Psydrax parviflora (Afzel.) Bridson	Rubiaceae
Pterygota macrocarpa K.Schum.	Malvaceae
Pycnanthus angolensis (Welw.) Exell	Myristicaceae
Rauvolfia vomitoria Wennberg	Apocynaceae
Ricinodendron heudelotii Pierre ex Pax	Euphorbiaceae
Rinorea oblongifolia C.Marquand	Violaceae
Rothmannia hispida (K.Schum.) Fagerl.	Malvaceae
Sacoglottis gabonensis Urb.	Humiriaceae
Scottellia klaineana Pierre	Achariaceae
Scytopetalum tieghemii Hutch. & Dalziel	Lecythidaceae
Soyauxia grandifolia Gilg & Stapf	Medusandraceae
Soyauxia velutina Hutch. & Dalziel	Medusandraceae
Spathodea campanulata Buch.-Ham. ex DC.	Bignoniaceae
Sterculia oblonga Mast.	Malvaceae
Sterculia rhinopetala K.Schum	Malvaceae
Sterculia tragacantha Lindl.	Malvaceae
Strephonema pseudocola A.Chev.	Combretaceae
Strombosia glaucescens Engl.	Olacaceae
Strombosia pustulata Oliv.	Olacaceae
Symphonia globulifera L.f.	Clusiaceae
Synsepalum afzelii (Engl.) T.D.Penn.	Sapotaceae
Tabernaemontana africana A.DC.	Apocynaceae
Tectona grandis L.f.	Verbenaceae
Terminalia ivorensis A.Chev.	Combretaceae
Terminalia superba Engl. & Diels	Combretaceae
Tetrorchidium didymostemon (Baill.) Pax & K.Hoffm.	Euphorbiaceae
Tieghemella heckelii Pierre ex A.Chev.	Sapotaceae
Treculia africana Decne. ex Trécul	Moraceae

Species	Family
Trema orientalis	Cannabaceae
Tricalysia discolor Brenan	Rubiaceae
Tricalysia pallens Hiern	Rubiaceae
Trichilia fragrans C.DC.	Meliaceae
Trichilia heudelotii Planch. ex Oliv.	Meliaceae
Trichilia martineaui Aubrév. & Pellegr.	Meliaceae
Trichilia monadelpha (Thonn.) J.J.de Wilde	Meliaceae
Trichilia prieureana A.Juss.	Meliaceae
Trichilia tessmannii Harms	Meliaceae
Trilepisium madagascariense DC.	Moraceae
Triplochiton scleroxylon K.Schum.	Malvaceae
Turraeanthus africana Pellegr.	Meliaceae
Vernonia amygdalina Delile	Asteraceae
Vernonia conferta Sch.Bip. ex Baker	Asteraceae
Vismia guineensis Druce	Clusiaceae
Xylia evansii Hutch.	Fabaceae
Xylopia aethiopica A.Rich.	Annonaceae
Xylopia quintasii Pierre ex Engl. & Diels	Annonaceae
Xylopia sp. L.	Annonaceae
Xylopia staudtii Engl. & Diels	Annonaceae
Xylopia villosa Chipp	Annonaceae
Zanthoxylum gilletii (De Wild.) P.G.Waterman	Rutaceae
Zanthoxylum leprieurii Guill. & Perr.	Rutaceae

Protocol for dbh measurement

Tree tagging and dbh measurement procedure	Incharge
Start in SW subplot, then move to NW, NE and finish in SE	ALL
Mark this direction of movement on the plot map, especially if you change it.	Booker
Measure all trees 10 cm dbh and above. Check the dbh, don't guess. Include all palms and lianas (see details for lianas)	DBH man
Measure standing dead trees but don't tag them.	DBH man
Pay careful attention to trees near the boundary. If half the roots are inside the plot then include. For lianas, if the stem is inside the plot at 1.3m vertical above the ground then include.	DBH man
Use a pole with 1.3m marked, pushed firmly into the leaf litter to the mineral soil next to the tree and mark the point of measurement – POM – with chalk.	DBH man
Measure 1.3m as the straight line distance ALONG THE TRUNK, even if it is leaning or bent.	DBH man
If 1.3m is not used in order to avoid deformities or buttress roots then measure from the POM to the ground along the trunk. If the tree is leaning or on a slope, take this measurement on the down slope side, or on the underside of the tree.	DBH man
Measure diameter in mm at the POM ensuring the tape is perpendicular to the stem, avoiding deformities and buttresses. Clean the trunk, remove moss and small climbers.	DBH man
If tree has buttresses or stilt roots making it too hard to measure normally, ensure it is tagged and recorded so it can be returned to later.	DBH man, tagger, booker
Fix tag 30cm above POM. This will usually be 1.6m up the trunk. Use a mark on the handle of the hammer to measure exactly 30 cm	Tagger
In SW subplot fix tag on S side of tree In NW subplot fix tag on W side of tree In NE subplot fix tag on N side of tree In SE subplot fix tag on E side of tree	Tagger
Hammer nail slightly upwards so that tag hangs down at the end of the nail. Make sure tag number is facing outwards and only a single tag is attached.	Tagger

Tree tagging and dbh measurement procedure	Incharge
Hammer nail in just below the bark so you leave the maximum length of nail for tree growth	Tagger
Use iron nails only on hardest trees	Tagger
Paint the POM with yellow oil paint on the same side as the tag	Painter
Ensure straight upper edge to paint along the POM. Paint can run down below the POM if necessary.	Painter
Identify all trees to species level, or genus, or family. Use local name only if no other option available.	Botanist
List all tag numbers in notebook and write identifications next to them to ensure no tags are missed.	Botanist
Trees that can't be identified need to have a botanical specimen collected including fruit or flowers if available. Record tag number on specimen envelope and note that specimen was collected.	Botanist
List all tag numbers in sequence on the sheet to ensure no numbers are missed.	Booker
Check each tag number to ensure dbh and other data are recorded against the correct tag.	Booker
For trees with more than one stem, use a new line for additional stems and write the tag number followed by **b**, **c**, **d** etc depending on number of stems.	Booker
Record the position of the tree in metres east (X) and north (Y) from the SW corner of the subplot (the origin). Use orange flagging tape fixed along the boundary strings to help estimate precise position.	Booker
Record height to POM in cm. Normally this is 130 cm. If it is not 130 cm then give reason in notes column – e.g. buttress or deformity	Booker
Record ***Tree alive codes*** for all trees – see box. Use a separate code for each stem of multiple stemmed trees.	Booker
Record **mortality** for dead trees in notes column: died standing (dead tree still has branches visible) or broken (dead tree is just a snapped trunk)	Booker
Record ***crown position*** for a trees as 1=canopy, 2=subcanopy	Booker
Record the diameter measurement technique used 1= Normal measurement, diameter tape 2= Ladder, with diameter tape 3= Climbing 4= Camera method	Booker
Don't ignore any tree that you can't measure. Ensure that it is recorded.	Booker

Special situations	Procedure
Climbers	Lift climbers off trunk, don't cut them, and pass tape underneath, clearing any debris. If still impossible then hold tape up to the climber and estimate diameter.
Buttresses	If the tree is buttressed at 1.3 m, measure stem 50 cm above the top of the buttress. Record POM height and paint trunk.
Large buttress	Use a ladder first, then try a climber; last resort use the digital photo method – see box. Record POM height and paint trunk.
Deformities	If the tree has a major stem deformity at 1.3 m height, then measure 2 cm below the deformity. Record POM height and paint trunk.
Fluted stem	Trees that are fluted for their entire length should be measured at 1.3 m.
Slopes	Measure POM on downhill side of the tree
Leaning/Fallen	Measure POM along the side of the stem closest to the ground.
Stilt-roots	Measure POM 50 cm above the highest stilt root. Record POM height and paint trunk.
Forked tree	Include all stems greater than 10 cm at 1.3 m individually.
Resprouts	On standing, but broken trees, or fallen individuals, measure the main stem at 1.3 m from the base of the tree. Measure any resprout if it is >1.3m from the base of the tree and >10 cm dbh at 1.3m from where it comes out of the main stem.

Tree Size Categories Based on DBH

Regeneration	< 3 inches	<7.5 cm
Sapling/ ploes	1 - 9 inches	2.5 - 24 cm
Small trees	10 - 14 inches	25 - 37 cm
Medium trees	15 - 19 inches	38 - 49 cm
Large trees	20 - 29 inches	50 - 75 cm
Giant trees	> 29 inches	> 75 cm

Source: http://ecoplexity.org/?q=node/236