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Ecological Vulnerability Assessment of Afram Headwaters Forest Reserve in Ghana

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Disclaimer

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Dedication

I dedicate this work to God and the Ahenema Kokoben Seventh Day Adventist Church for the spiritual nourishment given me.

To my beloved parents, Mr. John Aidoo and Mad. Akosua Nyarko Abronoma for their responsibility towards my education.

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List of Abbreviations and Acronyms

AHP - Analytic Hierarchy Model

GIS - Geographic Information System

OVI - Oil Vulnerability Index

ESI - Environmental Sensitivity Index

VME - Vulnerability of Marine Ecosystems

OSPAR - Oil Spill Prevention, Administration and Response

ReVA - Regional Vulnerability Assessment

EPA - Environmental Protection Agency

UI/VI - Utility Index and Vulnerability Index

VL - Vulnerability of Landscapes

EVA - Ecological Vulnerability Analysis

IPCC - Intergovernmental Panel on Climate Change

ICIMOD - International Centre for Integrated Mountain Development

GSS - Ghana Statistical service

AHFR - Afram Headwaters Forest Reserve

MTS - Modified Taungya System

SDGs - Sustainable Development Goals

UNFCCC - United Nations Framework Convention on Climate Change

FLEG - Forest Law Enforcement and Governance

FC - Forestry Commission

EVI - Environmental Vulnerability Index

NDVI - Normalised Difference Vegetation Index

CFMP - Community Forest Management Project

NTFPs - Non-forest timber products

WTP - Willingness to Pay

UNEP - United Nations Education Program

IDW - Inverse Distance Weighting

Abstract

A vulnerable forest ecosystem impacts both the ecological function and human wellbeing. Forest-fringed communities derive livelihood benefits from the forest through the provision of ecosystem services. In principle, the sustainable management of a forest is about the restoration of forest standing and the development of alternative livelihoods for the forest dwellers. This calls for a better understanding of the factors that influence the vulnerability of the forest. The aim of this piece of research is to identify, map ecosystem services and determine the environmental vulnerability index of the forest. The implication for human security raises a sense of urgency.

The study employed Focus Group Discussion to identify, map and valued ecosystem services. A multi-criteria decision-making tool, the Analytic Hierarchy Process (AHP) offered the integration of several factors under three criteria, environmental, physical and anthropogenic.

The results were treated with GIS tools to generate a vulnerability map for the area. Wild fires (44%), land use options (19%) and population density (17%) are the factors that influence ecosystem vulnerability. Respondents have observed a drastic reduction in the supply of ecosystem services by the forest. The Environmental Vulnerability Index (EVI) of the forest is 2.46 which is interpreted by the natural breaks classification as moderately vulnerable. The contribution of wild fire to the `vulnerability of the forest is 44%. The combined influence of anthropogenic factors is 80%. The vulnerability map demonstrated low to high vulnerability according to the extent of cover change. As policy makers move to restore the forest, wildfire management must be in the spotlight.

CHAPTER 1. INTRODUCTION

1.0 Background

Ghana's total land area is about 23.85 million hectares (ha). Forests are confined to two vegetation zones, each with different forest types: the high forest zone (HFZ) (34%) and (66%) for the savannah zone (Marfo, 2010). The importance of forest in the well-being of the people are expressed through the benefits drawn from it, spanning from provisioning, through regulating to cultural services. The maintenance of forest ecosystems is crucial to the course of global biodiversity protection and provision of essential ecosystem services. Research and experience have proven that "forest ecosystems play crucial roles in reducing the vulnerability of communities to disasters, both in terms of reducing their physical exposure to natural hazards and providing them with the livelihood resources to withstand and recover from crises" (Hammill et al., 2016).

As Ghana moves to implement Sustainable Development Goals (SDGs) agenda – particularly Goal 15 (protect, restore and promote sustainable use of terrestrial ecosystem) – forest and forestry will be one of the key areas for consideration due to the influence of the resource on both local and global climate. Its contribution to economic development (Goal 8) and general well-being (Goal 3) of people and forest-fringed communities, and other complex linkages with both rural and urban communities are equally issues of greater concern globally. The attainment of the targets in this Goal will affect the successful achievement of other related Goals – Clean water and Sanitation (Goal 6), Climate action (Goal 13), Life below water (Goal 14), etc – by the 2030 deadline. The roles forest plays in poverty reduction and integrated water resources management is priceless. For instance, a news item on 3News on September 26, 2017 stated that "the Ghana Water Company Ltd. is considering a shutdown of its operations at the Barekese and Owabi dams in the Ashanti region if pollution of the water bodies serving the plants is not halted". This disclosure stems from the degradation of the forests where the two water stations are situated.

The vulnerability of forest ecosystems is traditionally discussed in terms of the numbers and/or quantity of tree and animal species or the richness of the biodiversity but the quality and availability of goods and benefits enjoyed from the forest are equally important to be considered. Even though the goods and services provided by the forest ecosystem are crucial to human livelihoods and well-being, the control and regulation of the exploitation and usage of the resource, to a far extent influence its vulnerability. The combined effects of the hazard and vulnerability of the ecosystem informs of the degree to which the ecosystem function and services are at risk. The benefits and/or goods and services derived directly from forests include goods such as timber, food, fuelwood, fodder, ornamental and medicinal resources, and recreation prospects. The indirect benefits are services related to carbon sequestration, soil and water regulation and habitat for pollinating species and wildlife.

Plant and animal biodiversity are the pivot of human well-being and survival, largely in the production of food, but also as sources of raw materials and medicines. Interestingly, over the past 50 years, according to the Millennium Ecosystem Assessment (MA, 2005), humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history, largely to meet rapidly growing populations and demands for food, fresh water, timber, fibre, and fuel. Most ecosystems are facing challenges from factors such as a rapid change in the global climate, loss of biological diversity, habitat degradation and loss, desertification, and environmental pollution (ICIMOD, 2012).

There are many factors which influence the vulnerability of the forest ecosystem to hazards or stressors of diverse nature, diminishing the production of goods and services by the forest. Interestingly, the purpose of forests goes beyond the literal and traditional definition. "Forestry is not just about trees, but about how trees can serve people", commented Westoby (1989). To effectively manage this ecosystem to potentially provide all the ecosystem services, it is highly important to adopt a strategy that has the ability to evaluate the numerous factors affecting the resource. The consideration of several factors leads to the engagement of experts in order to determine which factor(s) or criteria (and at what levels or weights) influence(s) the risk analysis of the forest ecosystem. This is a multi-criteria decision-making approach which is based on Analytic Hierarchy Process (AHP) that assigns weights to the different factors to identify which of them have/has more or less influence on the vulnerability of the forest and which part(s) of the forest is/are more vulnerable to the stressor.

The current study aims to analyse the vulnerability status of the Afram Headwaters Forest Reserve using AHP in a Geographic Information System (GIS) environment whilst observing the ethics that define the form of forest ecosystem's vulnerability evaluation – complex, multi-dimensional, wide-ranging and situation-specific.

1.1 Problem Statement and Justification

The Offinso forest district is a prominent area noted for agricultural activities and supply of about 70-80% to both Brong Ahafo and Ashanti Regions of Ghana (FAO/IAEA, 2009). It is equally noted for its six (6) major forest reserves. With a total surface of 189.90 sq. km (GSS, 2010), the Afram Headwaters Forest Reserve is a major socio-economic resource for the people in the district. Here comes the essence of understanding the vulnerability status of the forest ecosystem to inform policy and decision-makers on its protection, management and maintenance, including the ecosystem services thereof.

Baatuuwie & Leeuwen, (2011) reported of the ongoing restoration and plantation programmes in the reserve by the government and private developers – monoculture of exotic tree species such as *Cedrela odorata* (Cedrela) and *Tectona grandis* (Teak) and mixed stands of local tree species. However, the sustainability of livelihood activities of the inhabitants in the area and the overall human security outlook seem threatened due to climate change, land degradation, recurrent ground fires and overexploitation of the Afram Headwaters Forest Reserve (Dwomoh, 2009), clearing for farming and logging for timber (Dowsett-Lemaire and Dowsett, 2011) and increased risk of pesticide usage on crop farms (Fianko et al., 2011). These factors are widely discussed in literature but none of them, including their contributions to the vulnerability of the forest is quantified. Though ecosystem vulnerability is an underdeveloped concept (Ippolito et al., 2010), perhaps due to the difficulty in assessing and measuring the intangible features, the few resources and tools at hand are able to inform of the changes in the environment. For quite a long time, most researchers have carried out vulnerability and risk assessments qualitatively, neglecting the quantitative aspect which is also crucial in economic decision-making. To unravel the uncertainties surrounding the ecosystem vulnerability and risk assessments, quantitative approaches are needed. Adger (2006, p.274) confirms that "all research traditions reviewed in literature struggle to find suitable metrics for vulnerability but it is extremely important, nonetheless, to provide consistent frameworks for measuring vulnerability of ecosystems to natural and human stressors that provide complementary quantitative and qualitative insights into outcomes and perceptions of vulnerability". This development can widen the discussion of vulnerability and risk assessments.

As climate change and other human activities become pressing issues, it is important to monitor all the stressors to which the forest ecosystem is exposed to, its susceptibility and the level of resilience with the same accuracy, frequency and urgency as other important environmental variables: this forms the basis of ecological risk and vulnerability assessment.

The outcome of this work is expected to fill the knowledge gap in ecological vulnerability and risk assessments and for that matter, the sustainable forest management; it further provides managers, government and/or stakeholders with scientific information on the consequences of major stressors on the ecosystem components. It seeks to uncover processes and tools that can be used in the development of conservation objectives and sustainable management measures. The vulnerability assessment allows and even encourages the determination of the most important relationships between expected natural and anthropogenic stressors and the exposure and susceptibility characteristics of the affected ecological systems.

1.2 Objectives

1.2.1 Main Objective

The overall objective is to assess the ecological vulnerability of Afram Headwaters Forest Reserve in Offinso Forest District.

Specifically, this study aims to:

- Identify and map the ecosystem services based on people's perspectives over the past 27 years (1990 – 2017);
- Determine the Ecological Vulnerability Index (EVI) of the forest ecosystem for integration into forest ecosystem management using GIS and Analytical Hierarchy Process;
- Establish the link between forest ecosystem health and human security and recommend strategies for improving the forest reserve management.

1.2.3 Research Questions

Objective 1

a) What services does the forest ecosystem provide and how are they mapped?

b) How are they valuated or how can they be valuated?

Objective 2

a) What is the EVI of the studied forest?

b) What factors drive the vulnerability of the ecosystem?

c) What is the implication of the determined EVI for the sustainable management of the Afram Headwaters Forest Reserve?

<u>Objective 3</u>

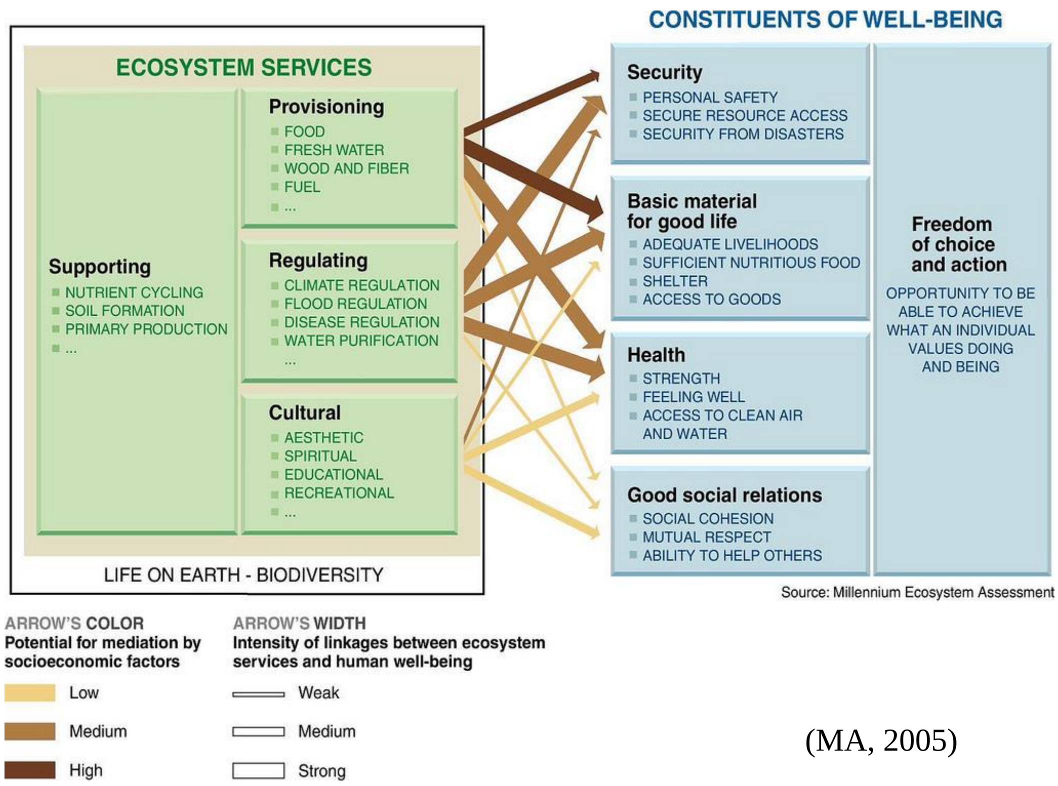
a) What are the human security implications of the EVI of the Afram Headwaters Forest Reserve?

1.2.4 Hypotheses

a. The factor that influences forest ecosystem vulnerability is related to climate change but the contribution of human activities is worth discussing.
b. The vulnerability of the forest ecosystem affects the provision of ecosystem services.

1.3 Study Concept

The human well-being framework – security, basic material for good life, human health, good social relations and personal freedom and will power – are sustained and maintained by ecosystem processes and functions. Figure 1 depicts the connectivity between ecosystem services and human well-being.



(MA, 2005)

Figure 1: Ecosystem Services and Human well-being

The study is conceptualised around the interaction between stressors and underlying vulnerabilities which characterise the risk a system is likely to suffer and the interventions necessary to minimise the severity. In figure 2, the capacity of the interventions to either increase or decrease vulnerability of the forest ecosystem will depend on how they are implemented and managed. A sustainable approach (++) will potentially decrease vulnerability resulting in people, communities and ecosystem's improved resilience to stressors. On the contrary (--), it risks being degraded to an extent that potentially will affect human wellbeing.

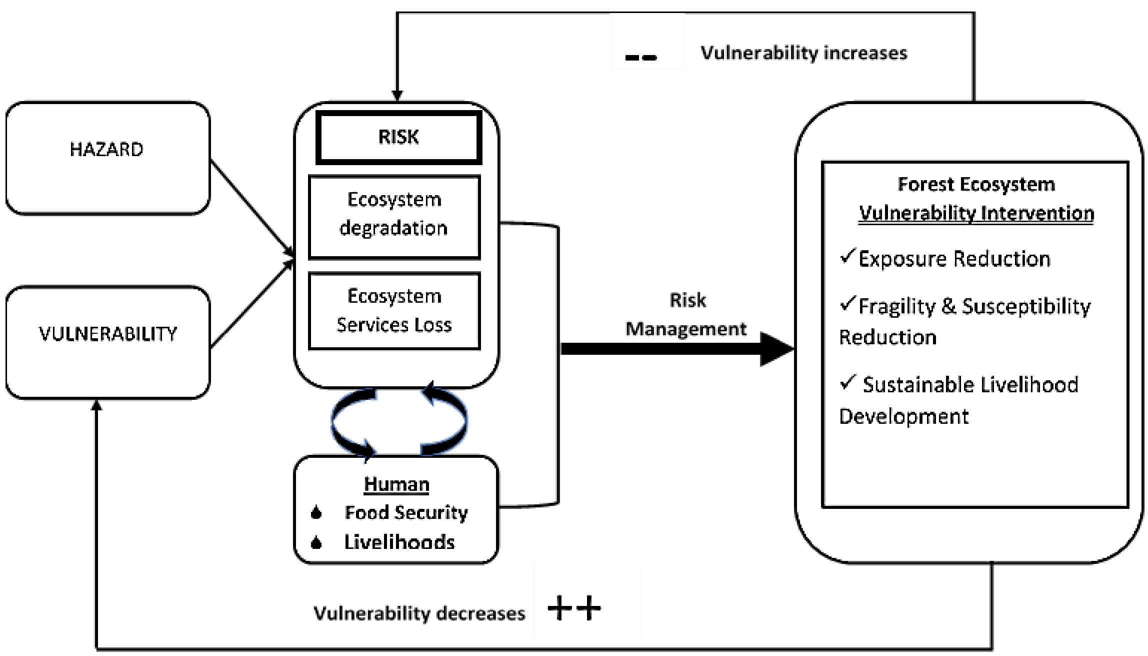


Figure 2: Conceptual Framework of the Study

1.4 Organisation of Chapters

The research work was organised into five (5) chapters. Chapter One (I) covered introduction, problem statement, objectives and questions the research sought to answer. Chapter Two (II) reviewed related literature by other researchers, explained the concept of vulnerability and its application in forest ecosystem management. Chapter Three (III) featured the study area, methods and methodology for the research work. It encompasses all data used for the study and techniques for collecting and analysing them. Results, discussion and inferences constituted Chapter Four (IV). The final chapter is committed to conclusion, limitations, policy recommendations and references. Appendix and other necessary pieces of information follow suit.

CHAPTER II. LITERATURE REVIEW

2.0 Introduction

This section reviews existing literature relevant to ecosystem, ecosystem services provision and valuation, forest and ecological vulnerability assessment. It also captures briefly, internationally-accepted frameworks for assessing ecosystem services and discusses their association with the human security concept. The reduction in the provision of ecosystem services by the forest are highlighted in view of their vulnerability to stressors. A review of quantitative assessment of vulnerability is discussed. These are organised into sub-headings.

2.1 Definition of Forest

Forests, both natural and planted are among the most important suppliers of ecosystem services to people and communities near or far away from the resource. Forest has been defined and described differently according to the background of researchers and scholars from the diverse fields of studies – Ecology, Environmental Science, Forestry, Agriculture. However, the Food and Agricultural Organisation's (FAO) definition is widely accepted. It defines forest as "Land with tree crown cover (or equivalent stocking level) of more than 10 percent and area of more than 0.5 hectares (ha)" (FAO, 2010). For Ghana, forest is "a piece of land with a minimum area of 0.1 hectares, with a minimum tree crown cover of 15% or with existing tree species having the potential of attaining more than 15% crown cover, with trees which have the potential or have reached a minimum height of 2.0 meters at maturity in-situ"(Agyemang-Bonsu, 2007).

Generally, forests are made of trees. Technically, the limitation of the definition to only trees, the attainment of a certain height and the extent of cover excludes the equally important biological diversity that also plays important roles in people's livelihood. The definition does not highlight the complex interaction among the components of the forest ecosystem and with other external communities.

The ten largest plantation countries account for 71 per cent, and the 20 largest countries account for 84 per cent of the world's total plantation area. Productive plantations represented 79 per cent and protective plantations 19 per cent of the total area of plantations, respectively (Bauhus et al., 2010). Globally, there is growing recognition of the importance of forests not only in the lives of humanity but also in other aspects of the Earth's environment, notably the atmosphere composition and the sequestration of greenhouse gases. In Ghana, though recognition is given to the traditional authorities as "land-owners" and royalties and other benefits go to them, they are not mandated to manage forest and forest resources.

2.1.1 Forest Ecosystem Structure and Ecosystem Services

The forest ecosystem is broadly composed of biotic and abiotic components. These components are basically made of invertebrates, microbes, birds and mammals, etc., along with physical environmental variables such as climate, soils and topography (Ollinger, 2002). In perspective, researchers use forest ecosystem to compensate for the complex interactions within a forest. Forest ecosystem, here in, according to Wikipedia is "a natural woodland unit consisting of all plants, animals and micro-organisms (biotic components) in that area functioning together with all of the non-living physical (abiotic) factors of the environment". The natural interaction existing between the components results in the supply of ecosystem services and goods. Like wetland ecosystems which filter water, produce nutrients and serve as habitats to some key plant and animal species; rangelands providing forage for livestock and wildlife, which serve as food for human consumption, generate income and are used for recreation; and agro-ecosystems providing food and income for humans, forest ecosystems ensuring soil formation, air and water purification, carbon sequestration, and home to diverse plant and animal species, climate modification, food, water, fruits, etc. The Millennium Ecosystem Assessment (MA) report referred to ecosystem as the plants, animals (including humans) and micro-organisms that live in biological communities and which interact with each other (MA, 2005). The interaction extends to the physical and chemical environment and with adjacent ecosystems. This complex interaction and self-rejuvenating systems lead to the provision of ecosystem services i.e. the benefits obtained from ecosystems. An interruption, whether from natural or anthropogenic sources transforms into many environmental problems. This interruption causes severe alteration of the biophysical environment whose effects are cascading in nature among other components of the ecosystem. The composition of a forest ecosystem is to an extent a function of an area's climatic condition. In tropical regions, it is the seasonality of rainfall that determines the type of forest that occurs in a particular area, emphasised Ollinger, (2002).

Many frameworks have attempted to classify ecosystem services in different ways for easy quantification and valuation. A group of authors argued that "once the functions of an ecosystem are known, the nature and magnitude of value to human society can be analysed and assessed through the goods and services provided by the functional aspects of the ecosystem" thus the classification can be based on ecological functions (Groot et al., 2002) . These authors grouped the ecosystem functions into four main categories:

1. Regulation functions: this group of functions relates to the capacity of natural and semi-natural ecosystems to regulate essential ecological processes and life support systems through bio-geochemical cycles and other biospheric processes. In addition to maintaining ecosystem (and biosphere) health, these regulation functions provide many services, which have direct and indirect benefits to humans (such as clean air, water and soil, and biological control services).
2. Habitat functions: natural ecosystems provide refuge and reproduction-habitat to wild plants and animals and thereby contribute to the (in situ) conservation of biological and genetic diversity and evolutionary processes.
3. Production functions: Photosynthesis and nutrient uptake by autotrophs converts energy, carbon dioxide, water and nutrients into a wide variety of carbohydrate structures which are then used by secondary producers to create an even larger variety of living biomass. This broad diversity in carbohydrate structures provides many ecosystem goods for human consumption, ranging from food and raw materials to energy resources and genetic material.
4. Information functions: because most of human evolution took place within the context of undomesticated habitat, natural ecosystems provide an essential 'reference function' and contribute to the maintenance of human health by providing opportunities for reflection, spiritual enrichment, cognitive development, re-creation and aesthetic experience.

In another school of thought, the Millennium Ecosystem Assessment classified the ecosystem services into four categories which together sustain the existence and survival of human life and well-being on planet earth (MA, 2005):

1. Provisioning services: This encompasses harvestable goods such as wood fuel, food, mushrooms, fruits, water, timber, fibre and bush meat;
2. Supporting services: These are soil formation, photosynthesis, and nutrient cycling;
3. Regulating services: These are services that result in climate modification, flood regulation, disease control, wastes recycling, and purification of water and air; and

4. Cultural Services: These deal with services that provide recreational, educational, aesthetic, and spiritual benefits.

The MA investigated the contribution of ecosystem services on human well-being and the consequences upon changes in the ecosystem through a scientific evaluation of ecosystem services. This has been reiterated that croplands, forests, grasslands, rivers, wetlands, lakes, and oceans (ecosystems) provide the food we eat, the water we drink, and a wide array of other products, cultural benefits, and spiritual values (MA, 2005).

2.1.2 Forest Management

The rapid degradation and deforestation largely trigger the management of Ghana's forest resources. The Forestry Commission Act 571 mandates the Forestry Commission to ensure the regulation of utilization of forest and wildlife resources, the conservation and management of those resources and the coordination of policies related to them (Parliament of Ghana, 1999). The Act clearly states that, the commission shall undertake the development of the forest plantations for the restoration of degraded forests areas, the expansion of the country's forest cover and the increase in the production of industrial timber. The Commission, through the collective efforts of four divisions – Forest Services, Forest Commission Training Center, Timber Export Development, Wildlife – performs its functions and duties.

Since its inception, the Commission has embarked on remarkable forest policies and management strategies to conserve and protect the resource to enable future generations use it to meet their own needs. Key among these are the involvement in the negotiations of the United Nations Framework Convention on Climate Change (UNFCCC), the adoption of the national Forest Law Enforcement and Governance (FLEG), and the Natural Resources Environmental and Governance (NREG) programmes. As a matter of need, the Climate Change Unit of the Forestry Commission doubles as the Reducing Emission from Deforestation and Forest Degradation (REDD+) secretariat of the National REDD+ Technical Working Group. The REDD+ agenda fosters the effort by Ghana to improve conservation, sustainable management of forests, and enhancement of forest carbon stocks. With these steps taken towards the course of sustainable management of Ghana's forest cover, the other side of the equation begging for critical but qualified attention is proper implementation, monitoring and evaluation and the enforcement of laws.

The management of forests has become crucial to the national development agenda of the country and potentially for the achievement of the targets for the Sustainable Development Goals (SDGs), especially Goal 15 – protect, restore and promote the sustainable use of terrestrial ecosystems. The achievement of these targets will need massive mobilisation of human and financial resources at all levels (IIED, 2015). It presupposes that, in going the sustainability way, a multidisciplinary approach will be of immense need. Effectively, forest dwellers, gender and the youth whose future is of great interest must be fully integrated into sector policies and projects. Among other things, the Government of Ghana in 1994 resurrected and modified the traditional Taungya System (T.S.) of the 18th century. The approach is a means of replenishing the fast decreasing forest stock of the country to meet future market demands for wood, alongside the rehabilitation and restoration of degraded forest areas, explained (Kalame et al., 2011). Perspective-wise, this system offers very good grounds for fostering the regeneration of degraded forests and providing a sort of livelihood benefits to farmers. The Taungya System was a win-win situation where indigenous people from forest communities get allocation for planting crops for themselves and growing woody species at the same time for the Forestry Commission.

However, the system, in 2000, was replaced with the Modified Taungya System (MTS) which gave participating farmers, the Forestry Commission, traditional councils and Heads of Stool Lands some percentages of the proceeds at tree maturity and harvest. But under this era of consumerism and non-compliance of binding agreements, whether this management option can be sustained in the long term remains an open question.

2.2 Climate Change

According to ICIMOD, (2014), with as high as 66.7% of households in the Offinso Municipality engaged in agriculture, almost seven out every ten households (73.6%) are agricultural households in the rural localities. Of the 76,895 population, the rural population represented by 71.8% which gives a fair idea of the possible interaction with and/or dependency on the forest reserve for material resources. ICIMOD, (2012) cautions that despite the inherent resilience of ecosystems, they are now approaching the point where they may not be able to meet the human demand for adequate food, clean water, energy, medicines, and a healthy environment. But climate change will exacerbate the increase in vulnerability of the forest. Climate change presents severe and additional obstacles to ending poverty (Care International, 2009) but its impact on forest management, the adaptation and livelihood of forest-fringed communities could be traumatic.

The Intergovernmental Panel on Climate Change (IPCC) explains climate change as a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer (Barker, 2007). The impacts of climate change are related to rising temperatures and heat waves, increasingly distorted rainfall pattern, and more frequent and severe floods, cyclones and droughts. These are transformed into disasters when the underlying vulnerabilities of communities and people are high.

Climate change has a toll on the forest growth and development and the management of forest and forest resources. The IPCC, with more evidence from a wider range of species, states that the changing climatic conditions heavily affect terrestrial biological systems, including severe transpiration, animal-species migration.

2.3 The Concept of Vulnerability Assessment

Many researchers have studied vulnerability in different contexts and from different schools of thought. The concept "vulnerability" shares similarities with another concept commonly used in studies of impact of stressors: "resilience". Whereas "vulnerability" traces its roots in social sciences, and is now widely used in ecological studies, the concept "resilience" originates from ecological research, and its use in social sciences now is on the ascendancy (De Lange et al., 2010). It may be a highly contested term as for, Fussel and Klein, (2006), the long history of vulnerability assessments discussed in other spheres, such as food security, livelihoods, disasters and risk management in general is a common knowledge. A number of traditions and disciplines, from economics and anthropology to psychology and engineering, use the term vulnerability. Though the dynamic, location-specific and multi-dimensional characteristics of vulnerability make the study of socio-ecological systems complex; human geography and human ecology have, in particular, applied vulnerability to environmental change (Adger, 2006). Consequently, their meaning often relies on the context in which they are discussed. In reference to systems, Timmerman (1981, p.21) asserts that "vulnerability is the degree to which a system acts adversely to the occurrence of a hazardous event" and the capacity of the system to absorb and recover from the hazardous event.

The vulnerability of natural systems to rapid changes in climate patterns is regarded as one of the most challenging issues in recent years (Zereini and Hötzl, 2008) but disturbances from human activities are also enormous and need considerable attention. For an ecosystem, purposefully, the Afram Headwaters Forest Reserve, to deviate from natural (reference) conditions to something undesirable is a function of the intensity of stressors and of ecosystem vulnerability (Ippolito et al., 2010). Human activities have an increasing impact on virtually all the processes that govern ecosystem properties and function (Vitousek 1994 cited Kulhavý et al., 2014). Clearly, the adaptive capacity or resilience of the ecosystem, to a much extent, depends on the inherent characteristics of the ecosystem. Contextually, these characteristics are related to the structure, communities and biodiversity state of the forest and they offset the challenges of interactive controls such as water availability, disturbance regime, and biotic diversity. In the context of ecosystem, Gaaloul (2008), cited in Zereini and Hötzl (2008), posited that there is a growing recognition of the significance of the quantitative assessment due to the difficulty in separating both the qualitative and quantitative components of vulnerability. Assessing ecological vulnerability at different hierarchical levels – population, community, ecosystem, landscape – has been commented by (De Lange et al. 2010). It has been cautioned that though characteristics of a community are not merely the sum of the characteristics of individual populations, structure and function of the community are also regulated by emergent properties that are not easily described and predicted from lower hierarchical levels, therefore ecosystem vulnerability considers the response at the community level (Ippolito et al., 2010).

Ecosystem vulnerability refers to "the potential of an ecosystem to modulate its response to stressors over time and space, where that potential is determined by characteristics of an ecosystem that include many levels of organization, such as a soil, a bioregion, a tissue, a species, an organism, a stream reach. It is an estimate of the inability of an ecosystem to tolerate stressors over time and space" (Williams and Kapustka, 2000, p.1056). Forest Ecosystem Vulnerability, here in, describes the likelihood of decline in ecosystem services provision and the benefits humans derive from them expressed as 1: exposure to stressors and disturbances that rapture ecosystem function; 2: sensitivity, which dictates the system's response to forcing from exposures and the magnitude of potential impacts, and 3: adaptive capacity, which is the social and environmental capacity of the system to shift or alter its conditions to reduce its vulnerability or to establish resilience. The concept of vulnerability has been a powerful analytical tool for describing states of susceptibility to harm, powerlessness, and marginality of both physical and social systems, and for guiding normative analysis of actions to reduce risk and improve human well-being (Adger, 2006). In all formulations, the key parameters of vulnerability are the stressor to which a system is exposed, its sensitivity, and its adaptive capacity (White et al., 2001).

2.4 Ecosystem Vulnerability and Human Security

In the assessment of ecological vulnerability, De Lange et al. (2010) state that, apart from structural and functional relationships between the organisms and the abiotic environment, the temporal and spatial scales connected to it need to be considered. The former approach defines the complex nature of ecosystem vulnerability. The predominant considerations in many parts of the world for environmental management decisions and ecosystem protection include understanding and establishing land and resource use priorities, establishing time frames for management, using comparative valuation of ecosystems and comparative risk assessment, and clarifying where decision authority resides – local, regional, national (Williams and Kapustka, 2000).

The application of vulnerability assessment to ecosystems is underdeveloped because of the fragility of the ecosystem components. By convention, laboratory test for an ecosystem's exposure to, for instance, pesticides will demand for laboratory test to merely determine how vulnerable the resource is to the hazard. However, as Ippolito et al. (2010) argue, such an approach may be hampered by lack of information for site-specific representative species, as well as for interactions related to structure and functioning of the ecosystem.

Apart from its capacity to mitigate hazardous events or disaster to safeguard human-beings, the forest ecosystem provides them with livelihood resources to withstand and recover from crises. It presupposes that a vulnerable forest ecosystem exacerbates the plights of people whose dependence and association are inseparable. It is therefore important to understand that changes in natural environment and human activities are occurring faster than people, ecosystems and institutions can successfully respond (Brien and Leichenko, 2008). The REDD DESK states that, "aside from the devastating effects tropical forest loss has on biodiversity and forest-dependent communities, a major consequence of deforestation and forest degradation is the release of heat-trapping carbon dioxide (CO_2) into the atmosphere" (redddesk.org). In climate change discussions, vulnerability assessment has often centred on social vulnerability and differential exposure, sensitivity, and adaptive capacities; unfortunately, there has been relatively little attention to the implications of differential outcomes and changing vulnerabilities in natural systems for human security. Vulnerability studies of ecosystems have become an integral part of sustainable development agenda and health of ecosystems.

Human Security implications for a vulnerable ecosystem will be discussed on the basis of the provisions by the Millennium Ecosystem Assessment which draws a strong relationship between ecosystem benefits and human well-being. The framework shows the strength of linkages between categories of ecosystem services and components of human well-being that are commonly encountered, and includes indications of the extent to which it is possible for socioeconomic factors to mediate the linkage (MA, 2005).

2.5 Ecosystem Services Valuation

The analysis and valuation of the numerous benefits provided by forest ecosystems have received growing recognition over the years. Apart from the tangibles which are harvested and used or sold, the capacity of the forest ecosystem to modify the climate and regulate temperature and humidity is enormous. The growing interest about the subject matter was triggered by an increasing awareness that the benefits provided by natural and semi-natural ecosystems were often underestimated in decision making (Hein et al., 2006). Many people may not understand the underlying biophysical functions and interactions happening in an ecosystem; the why, how and what happens in there but the beneficial outcomes, that is the goods and services produced thereof must be highly appreciated. The appreciation becomes more important when these outcomes diminish in quantity and quality over time. The MA (2005, p. 39), laments that, “approximately 60% (15 out of 24) of the ecosystem services examined are being degraded or used unsustainably”. Interestingly, the quantification and costing of the loss and degradation of these ecosystem services are difficult to measure. Similarly, putting values on the services and/or goods provided by the ecosystem is also challenging. Wilson and Howarth (2002, p. 441) recount that “the conventional application of ecosystem services valuation relies heavily on methodologies like the contingent valuation method whereby individual citizens are asked to express their values of ecosystem goods and services in social isolation”. In this valuation method, the individual (valuator) takes his/her level of income into consideration. Various methodologies have been developed and numerous researchers have worked on valuating ecosystem services. The purpose of economic valuation is to make the disparate services provided by ecosystems comparable to each other, using a common metric. All these attempts, as put forward by the MA are to create possibility and ease in quantifying the importance of ecosystems or natural environment to human well-being in order to make better decisions regarding the sustainable use and management of ecosystem services. In addition, ecosystem services valuation informs of decision-making and policy formulation and these are extremely relevant to forest management.

2.6 Methods Used in Ecological Vulnerability Assessment

The methods and approaches used in ecological vulnerability assessment are situation and ecosystem-specific. Methods for forest ecosystem vulnerability assessment may not be suitable for the same objective for the marine or aquatic ecosystems.

A combination of social and ecological indicators has been used to assess vulnerability of ecosystems and management interventions in biodiversity hotspots in Morogoro region, Tanzania (Ojoyi et al., 2015). Focusing on the vulnerability status of natural forests in Morogoro based on satellite imagery and socio-economic indicators, the forces that drive ecosystem vulnerability, and feasible management interventions for future natural ecosystem protection were studied. Vulnerability studies have also been applied to the management of oil spill in the marine and freshwater ecosystems. A methodology was developed to determine an integrated index which represents the ‘‘global’’ oil spill vulnerability of a coast and recounted that the assessment of the oil spill vulnerability of coastal environments is a fundamental issue when planning an oil spill response as it is one of the key components of the risk determination (Castanedo et al., 2009) . In the evaluation of the potential response of features of a river ecosystem to multiple stressors, Ippolito et al. (2010) developed numeric “Vulnerability index”. They opined that each ecosystem consists of a community of species living in a specific biotope and hence the evaluation of its vulnerability assessment should comprise both community and habitat aspects. There exist a strong and complex interaction among the community and habitat levels and vulnerability assessment of the on dwells on the nature, circumstances and performance of the other.

In another work, GIS and Analytic Hierarchy Model (AHP) were used to develop a relatively reasonable regional evaluation system that quantitatively calculated a regional ecological vulnerability index, and to analyse changes in the ecological environmental vulnerability (Hou et al., 2016).

Diverse tools have been developed to assess ecological vulnerability: these include Oil Vulnerability Index (OVI) - for the description of vulnerability of seabird species to oil spills (King and Sanger, 1979); Environmental Sensitivity Index (ESI) developed in the USA to map the vulnerability of shores to oil spills (Tortell, 1992); Halpern et al. (2007) used Vulnerability of Marine Ecosystems (VME) to solicit for expert opinions that describe which threats affect marine ecosystems; Robinson et al. (2009) used Oil Spill Prevention, Administration and Response (OSPAR) to assess the status of communities and habitats in OSPAR region; Regional Vulnerability Assessment (ReVA) developed by the Environmental Protection Agency (EPA) in the USA as an early warning system to identify those ecosystems most vulnerable to being lost or permanently harmed in the next 5 to 25 years and to determine which stressors are likely to cause the greatest risk (Boughton et al., 1999); Utility Index and Vulnerability Index (UI/VI) developed by Golden and Rattner (2003) as a tool to rank terrestrial vertebrate species; Penghua et al., (2007) compared seven types of land use for vulnerability to desertification and soil erosion using Vulnerability of Landscapes (VL); Ecological Vulnerability Analysis (EVA) used by De Lange et al. (2009) gathered nineteen (19) ecological traits for 144 wildlife species (aquatic and terrestrial, vertebrate and invertebrate).

Certainly, ReVA by U.S. EPA could be appropriate and flexible tool for this current study but the regional scale requirement poses a setback. Again, most of these methods have been used for quantitative analysis; however, the variables used in the model are not always easily acquired and employed (Hou et al., 2016). The combined Analytic Hierarchy Process (AHP) and GIS tool to evaluate ecological vulnerability in Yan'an, China (Hou et al., 2016).

The AHP is a systematic approach developed in the 1970s to make decisions based on experience, intuition and exploration of a well-defined methodology derived from sound mathematical principles. It was developed as a reaction to the finding that there is a lack of common, easily understood and easy-to-implement methodology to enable the taking of complex decisions (Saaty, 1990). The method then becomes a useful tool for measuring the parameters and components of ecosystems in both quantitative and qualitative expressions. The main advantage of using GIS for vulnerability analyses is not only based on its ability to generate a visualization of vulnerable zones, but it also creates potential to further analyse these events and estimate probable damage due to hazards. Compared to traditional mapping, GIS offers definite comparisons across spatial units, categorised stressor themes; merging of qualitative with quantitative assessment and spatial database, through which rational and/or numerical operations can be performed dynamically.

CHAPTER III. MATERIALS AND METHODS

3.0 Introduction

This chapter presents detailed methods and techniques which were used for the study. The forest ecosystem services in Afram Headwaters Forest Reserve (AHFR) were mapped and categorized according to The Millennium Ecosystem Assessment framework (MA, 2005) and their importance value subsequently estimated. The study design and tools for data collection and analysis, including the evaluation of Environmental Vulnerability Index (EVI) are also highlighted in this chapter. The chapter also discussed the research ethics deployed in the course of field activities and possible limitations encountered. Method for ecosystem valuation according to the local people's perspective in five (5) fringe communities is also captured under this chapter.

3.1 The Study Area

The Afram Headwaters Forest Reserve, was selected for the following reasons:

- typical tropical forest situated in an agricultural zone with significant community-forest interaction and dependence;
- availability of spatial and secondary data; and
- forest accessibility and economic relevance (many people draw their livelihoods from the forest).

Afram Headwaters Forest Reserve (Latitude: 7° 13' (7.2167°) north; Longitude: 1° 41' (1.6833°) west with elevation: 334 meters (1,096 feet)) is located in Offinso Forest District in the Offinso Municipality (1°60'W and 1°45'E and 7° 20 N and 6°50'S), Ashanti Region of Ghana. It covers an area of 189.90 sq. km.

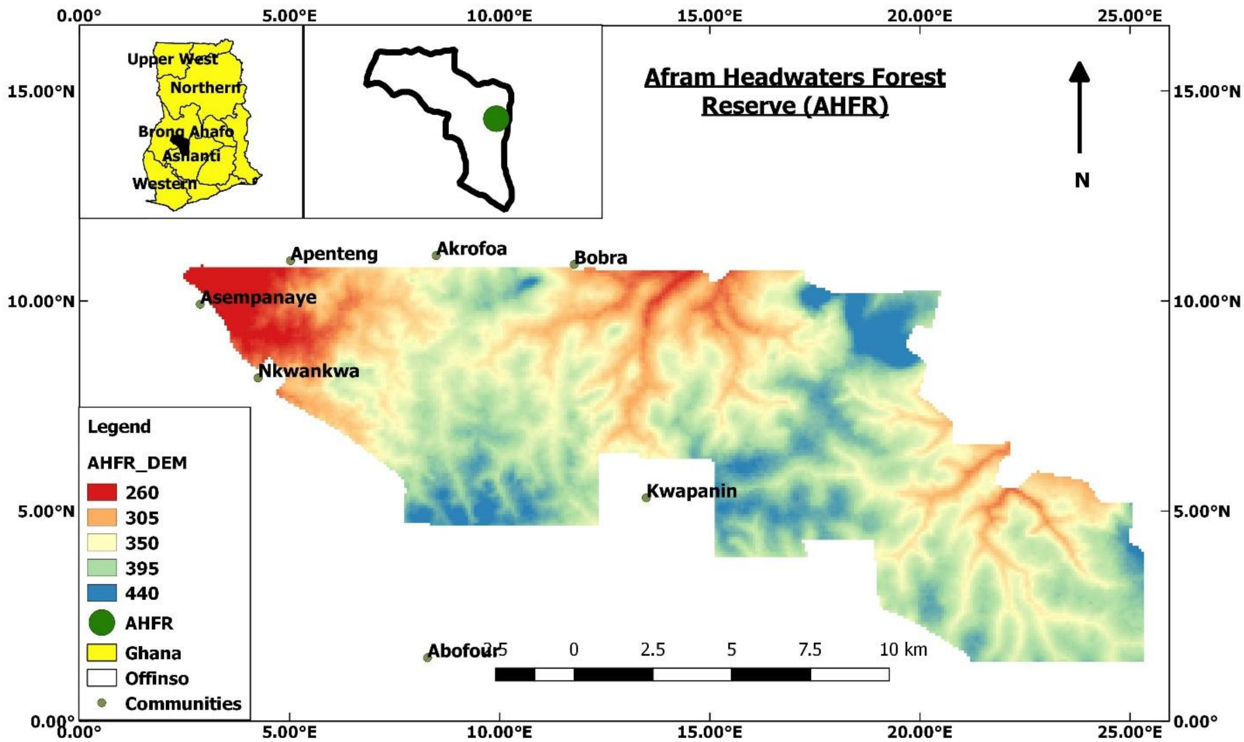


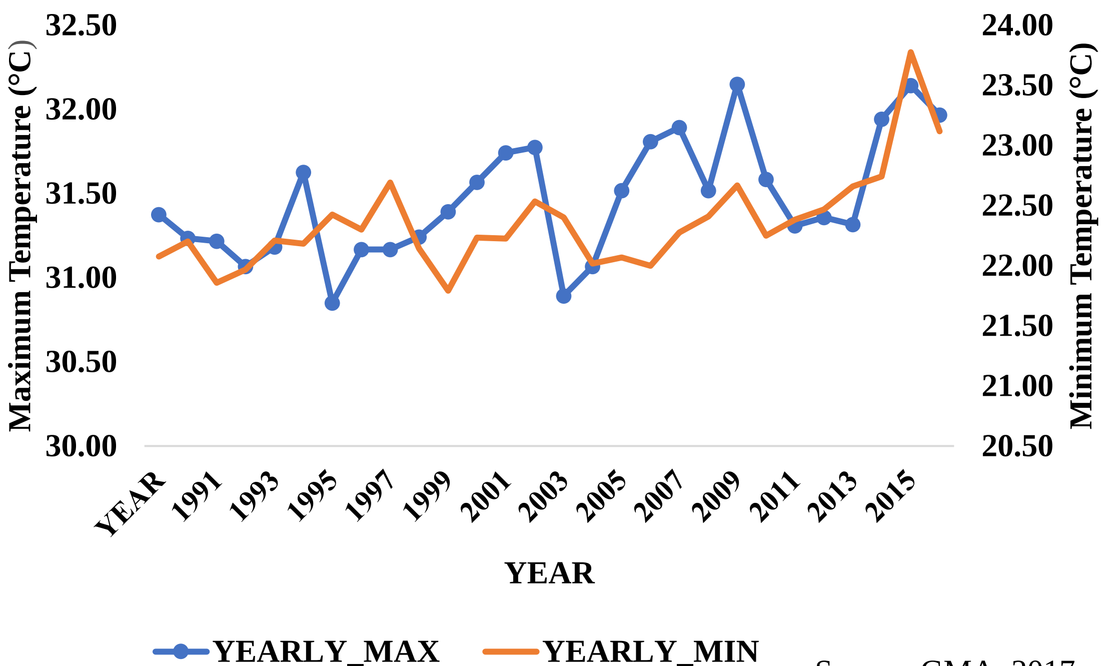
Figure 3: Map of Study Area

3.1.2 Vegetation

The Offinso Municipality lies in the Moist Semi-Deciduous Forest Zone, which is interspersed with a thick vegetative cover (Ministry of Local Government & Rural Development, 2013). In some parts of the Municipality there are vast Guinea Savannah vegetation, which are used as farms. The Municipality has six (6) forest reserves namely, the Afram Headwaters Forest Reserve (189.90 sq. km), Asufu East Forest (11.4 sq. km), Asufu West Forest (13.7 sq. km), Giamaian Forest (17.09 sq. km), Kwamisa Forest (82.83 sq. km) and the Opro River Forest Reserve (103.60 sq km) (GSS, 2014a). Forest plantations, mainly of Teak (*Tectona grandis*) established through the Modified Taungya System remain the largest vegetation cover at present. Other tree species found in the forest are wawa (*Triplochiton scleroxylon*), cedar (*Cedrus libani*), odum (*Milicia excelsa*), ofram (*Terminalia superba*), emire (*Terminalia ivorensis*) among others.

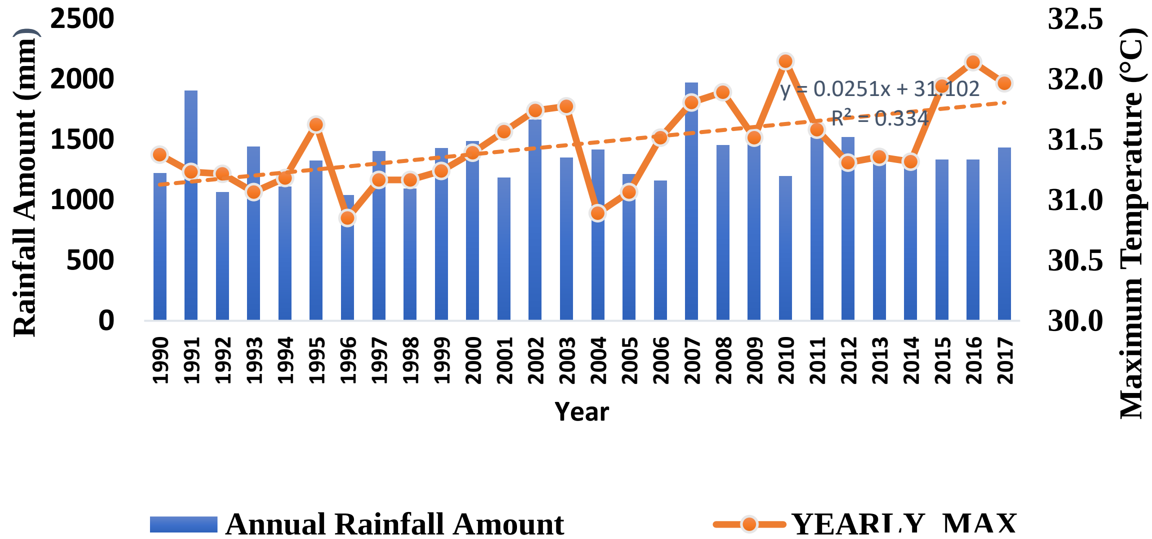
3.1.2 Climate

The area lies in the Semi-Equatorial Climatic Zone, which experiences a bi-modal rainfall pattern. The major rainfall season begins in April and ends in June, whilst the minor period spans from September to October. The mean annual rainfall ranges from 1,250 – 1,500 mm (Dwomoh, 2009). Shortly afterwards, the dry Harmattan season, commences usually from November to March. Relative humidity is generally high, ranging between 75-80% in the rainy season and 70-72% in the Harmattan season (GSS, 2014b). In March and April, the area records a maximum temperature of 30°C and averagely, 27°C. The comparison of annual rainfall distribution and mean temperature values, revealed that rainfall amount was fairly stable from 1992 to 2001 with low temperature. From Figures 5, there was relative sharp increase in temperature from 2005 to 2010 with a small increase in rainfall amounts over the same period. The years that recorded highest rainfall amounts were 1991, 2002, 2007 whilst 2010, 2015 to 2017 witnessed higher temperatures with higher rainfall amounts. In 1996 and 2004, temperatures were relatively low.



Source: GMA, 2017

Figure 4: Temperature Profile of Study Area (1990 – 2017)



Source: GMA,

Figure 5: Rainfall Distribution of Study Area (1990 – 2017)

3.1.3 Topography and Drainage

The highest point in terms of relief is 277.8 m above sea level. There are a number of streams and rivers that traverse the area although some of them dry up during the dry season (GSS, 2014b). It is drained by four main rivers, Offin, Anyinasu, Ode and the Pro Rivers. Voltain, Birimian and the Granite rock are the types of rocks found in the area and they are the basis for soil formation.

3.1.4 Soil Characteristics

Many parent rocks contribute to soil formation and type in the Municipality. The types of soils found there include the Kumasi-Offinso-Adjuemso soil type, which has a deep profile, well-drained and permeable, supporting the farming activities and tree plantation, the Dedesi-Sutawa and Ampimso Association developed from the Voltaian sandstone which are red, well-drained and suitable for the cultivation of crops such as tomatoes, cassava, maize and yam (GSS, 2014a)

3.1.5 Demography

According to the Ghana Statistical Service (GSS), the population of Offinso Municipality as at 2010 Population and Housing Census stood at 76,895, representing 1.6 percent of the total population of Ashanti Region. The population density for the Municipality in 1970, 1984 and 2000 and 2010 were estimated at 45, 64, 110 and 144 persons respectively. The 2000 and 2010 population densities are higher than the national figure of 79.3 in 2000.

3.1.6 Socio-economic Situation

Cultural practices which are of the Asante tradition play an important role in shaping the life of people, including their beliefs, attitudes and behaviour. About 96.0 percent of the economically active population are employed while 4.0 percent are unemployed. Of the employed population, about 50.1 percent are engaged as skilled agricultural, forestry and fishery workers, 20.3 percent in service and sales, 12.0 percent in craft and related trade, and 7.5 percent are engaged as managers, professionals, and technicians (GSS, 2014b).

3.2. Study Method and Design

Focus Group Discussion (FGD), Analytic Hierarchy Process (AHP), expert judgement and spatial analysis were methods used for data collection in the study. The adoption of FGD aided the mapping of ecosystem services and subsequent valuation of the services. Based on the level of importance attached to an ecosystem service, respondents scored on a 1-10 scale after constructive deliberation. The AHP helped in identifying the stressor that most influences vulnerability of the forest ecosystem. The vulnerability and stressors were thus quantified. Map layers for the various factors were developed and over-laid using ArcGIS. Figure 6 details the methods and tools for achieving each objective.

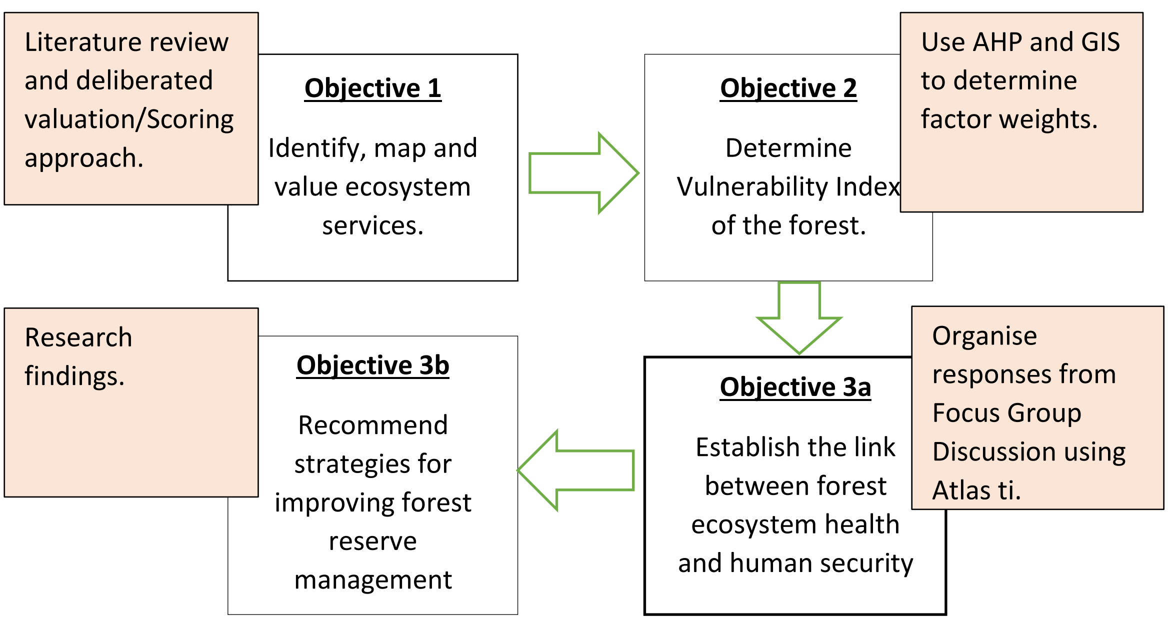


Figure 6: Research Design

3.3. Data Collection

Five types of data were used for this study. They included primary and secondary data. Field work was conducted from September to November, 2017 in Afram Headwaters Forest Reserve and selected fringe communities in the Offinso Forest District. The (Table 1) below provides the details of the different data types.

Table 1: Data used and sources

Data Type	Data	Details	Source
Primary Data	Field work	Ground-truth points, Training samples, Questionnaire for focus group discussion.	Communities and Forest Reserve officials, forest
Secondary Data	Maps	Roads, Rivers, Forest Reserve Boundary, District Boundary	DIVA GIS and Forestry Commission of Ghana.
	Sociocultural Data	Population data	Ghana Statistical Service
	Meteorological Data	Rainfall and Temperature data (1990 to 2017)	Ghana Meteorological Agency
	Satellite Data	Landsat Resources TM (Landsat-7): 2000, 2010 and 2017.	United States Geological Survey

3.3.1 Softwares

The ERDAS Imagine 2014 software was used to pre-process, classify, perform accuracy assessment and change detection for the forest. Other softwares, QGIS and ENVI 5.3 were used for gap filling and atmospheric correction. The transcribed qualitative data from the focus group discussion was analysed and organised using Atlas.ti. Using a multicriteria approach, Arc GIS was the software used to generate the Forest Ecosystem Risk Map. An Analytic Hierarchy Process Spreadsheet was used to evaluate the expert judgements, based on (Saaty, 1980).

3.3.2 Meteorological data

Historical daily rainfall and temperature (maximum and minimum) data for the area covering a period of 27 years (1990 to 2017) were collected from Ghana Meteorological Agency (GMA). Data cleaning exercise was done by Microsoft Excel.

3.4 Satellite Image Processing

3.4.1 Radiometric Correction

Radiometric correction, here in, refers to the reduction of atmospheric noise and haze that come with downloaded satellite images. This corrects data loss and enable mosaicking. QGIS, ENVI 5 and ERDAS Imagine were used to correct these defects. The amount of haze on a particular image has effect on the Digital Number (DN) values and the contrast, and each band is affected differently. The blue range band is impacted most and less in infrared range.

3.4.1.1 Image Geometric Correction

Remotely sensed images normally contain geometric distortions that can significantly affect the quality and usability of processed base map products. Geometric corrections are done in order to compensate for these distortions so that the geometric representation of the imagery will be as close as possible to the real world (Bishaw, 2012).

3.4.1.2 Ground Truth Points

Using a preliminary unsupervised land cover map, the forest was stratified into specified classes – Natural Forest, Plantation Forest, and Bare lands. At each sample point, cover type was noted and Global Positioning System (GPS) used to capture the coordinates of the point. Training and test samples were generated for supervised classification and accuracy assessment of the classification respectively.

3.4.1.3 Image Classification

An unsupervised classification (five classes – Natural forest, Plantation forest, Settlement, Farmlands and Bare lands) was performed to identify the various land cover types in the forest. The result aided in choosing appropriate use-defined classes for the actual supervised classification. Classifying the area, into Natural forest, Plantation forest and Bare land, spectral signatures were created. Several samples were selected from the image by drawing a polygon around training sites of interest. Using the set of signatures created, a supervise classification was done by ERDAS 2014. The Maximum Likelihood option was chosen in all classification processes. Finally, the training samples were used to run accuracy tests.

3.4.1.4 Creation of thematic maps

Thematic maps of elevation, slope, precipitation, temperature, land use, population density and wildfire were prepared using ArcGIS. The elevation and slope maps were developed from the digital elevation model of the study area. A classified land use map was used. The precipitation, temperature, population density and wildfire data were interpolated by the Inverse Distance Weighting method. All maps were resampled and reclassified as low (1), moderate (2) and high (3).

3.5 Ecosystem Services Mapping and Vulnerability Evaluation

3.5.1 Focus Group Discussion

A combined participatory GIS and Focus Group Discussion (FGD) was employed to solicit from inhabitants from selected communities how the ecosystem and ecosystem services pertinent to Afram Headwaters Forest Reserve have changed over the years. The significance of the interaction between the individual communities and the forest formed the basis for the selection. With such description, the Forest Rangers of the Offinso Forest District assisted in selecting the communities – Kuapanin, Asuboi, Abofour, Akrofoa and Asempanaye.

The groups considered for the FGD included hunters, farmers, charcoal producers, herbalists and wood loggers with each group represented by a male and a female. These actors have significant interaction with the forest reserve. Gender balance was ensured during the recruitment and discussion. With ten (10) males and females each, two focus group discussions were conducted in selected community. The main aims of the exercise included the identification and assessment of the forest ecosystem services, their contribution to human wellbeing and sustainable management.

3.5.1.1 The Forced Decision Matrix

The forced decision matrix (FDM) aided focus group members to rate one service over the other and thus revealed which ecosystem services are supplied or not by the forest. Respondents were asked to choose one service over the other at each level based on the importance of the service. Comparisons were strictly done with zero (0), denoting “not of important” and one (1), denoting “important”.

3.5.1.2 Ecosystem Services Mapping and Valuation

Using simple and open-ended questions, information on the previous and current state of the forest ecosystem, on-going development activities in the district in view of forest management, perceptions regarding vegetation cover changes from 1990 to 2017, ecosystem services and goods enjoyed from the forest were recorded. Each group valued the forest ecosystem by scoring the services on a scale of 1-10. On the scoring scale 1 to 10, when two products or goods for instance A and B scored 5 and 10 respectively, the scorers meant that the B is of high importance than A. With this approach, (Kenter et al., 2016) shared that deliberated values may give a true idea of a subject under discussion than non-deliberated individual values, whilst giving a positive reflection of participants’ obscured values.

Apart from this, some opinion leaders – chiefs and/or community elders, heads of the Modified Taungya System – were interviewed. The Microsoft Excel was used to analyse the quantitative data whilst Atlas.ti was used for qualitative analysis. The data was validated by confirming responses given by the participants after the data analysis. A four-step modified procedure of Hein et al., (2006) was used for the ecosystem services mapping and valuation as follows (figure 7):

- Generating basic map (land cover map);
- Identifying the services provided by the ecosystem;
- Identifying the criteria and indicator that can be used as the basis of the valuation and mapping;
- Comparing the assessment of the valuation on the services based on local people’s perspective.

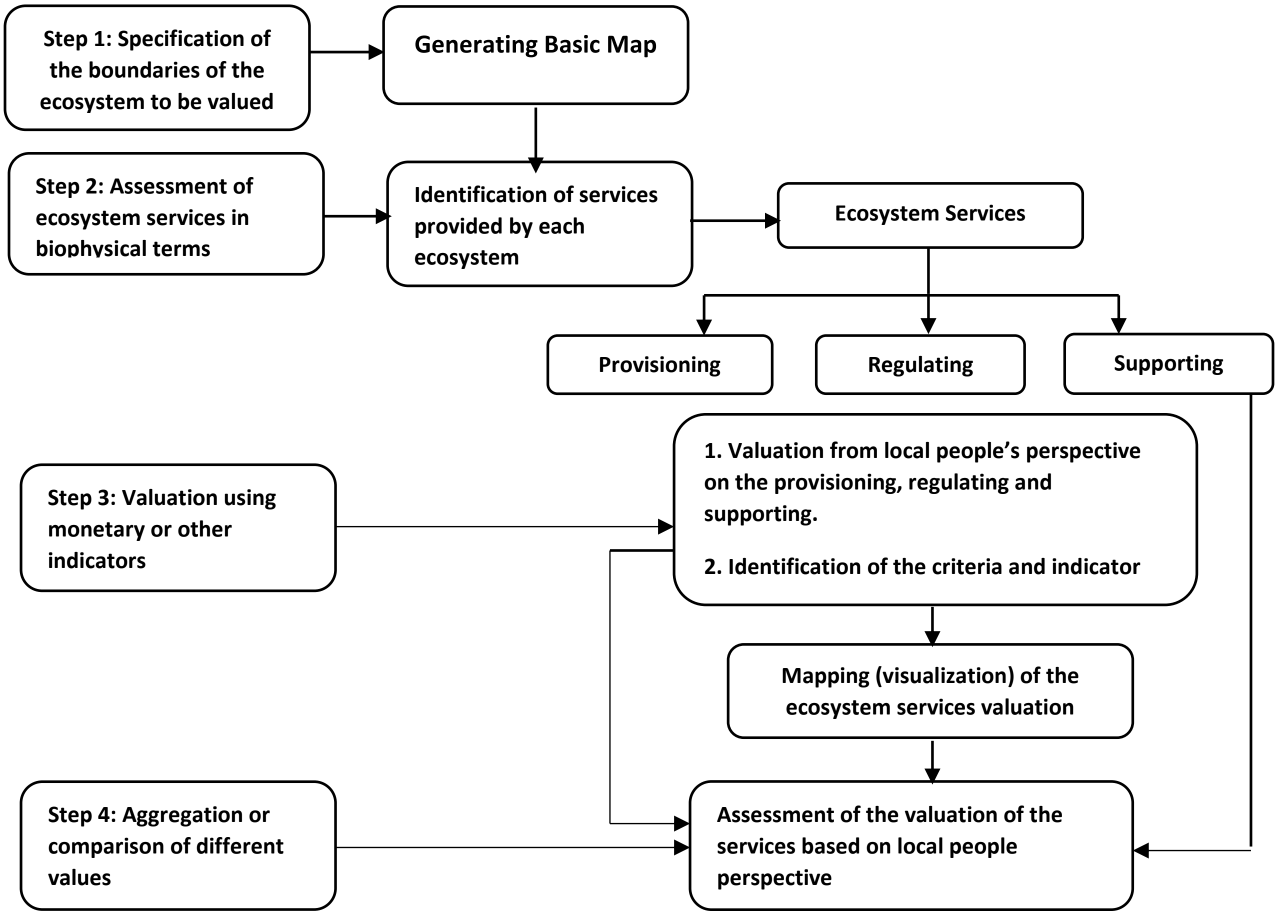


Figure 7: The ecosystem valuation framework (adapted from Hein et al., 2006. p 211)

The ecosystem valuation framework according to (Hein, et al., 2006) helped to identify the services provided by the forest ecosystem. In this study, they were identified upon posing questions such as, "What are the services you enjoy or benefit from the forest ecosystem" and "Which goods would you like be most concerned about losing"? It should be noted that, ecosystems are dynamic in function, temporal and spatial terms (Berkes et al., 2003) and hence provide goods and services in diverse quantity and quality at every different location. With guidance from the Millennium Ecosystem Assessment framework (MA, 2005), the ecosystem services provided by the forest and as given by respondents were grouped into four (4) – provisioning, regulating, supporting and cultural – were prioritized by respondents in each community on gender basis using the forced decision matrix (FDM).

3.5.1.3 Ecological Vulnerability Evaluation

In this research work, Geographic Information System (GIS) was seen as a vital tool, especially when graphics or maps are used to discuss ecological vulnerability changes of a forest ecosystem. It provided flexible ways of integrating multiple layers of the factors. Spatial data were processed and calculations made using the specified ratings and weights obtained from the AHP. The approach overcomes the existing difficulties in combining numerous spatial-related parameters involved in environmental vulnerability, and thereby provide a useful and effective tool (Hou et al., 2016). The final ecological vulnerability map in three classes (high, moderate and low vulnerability) was generated. Figure 8 shows the step-by-step guidance to organising expert interviews, judgements and evaluating the pairwise comparison matrix using the Analytical Hierarch Process. Six (6) steps, as shown in the chart were followed.

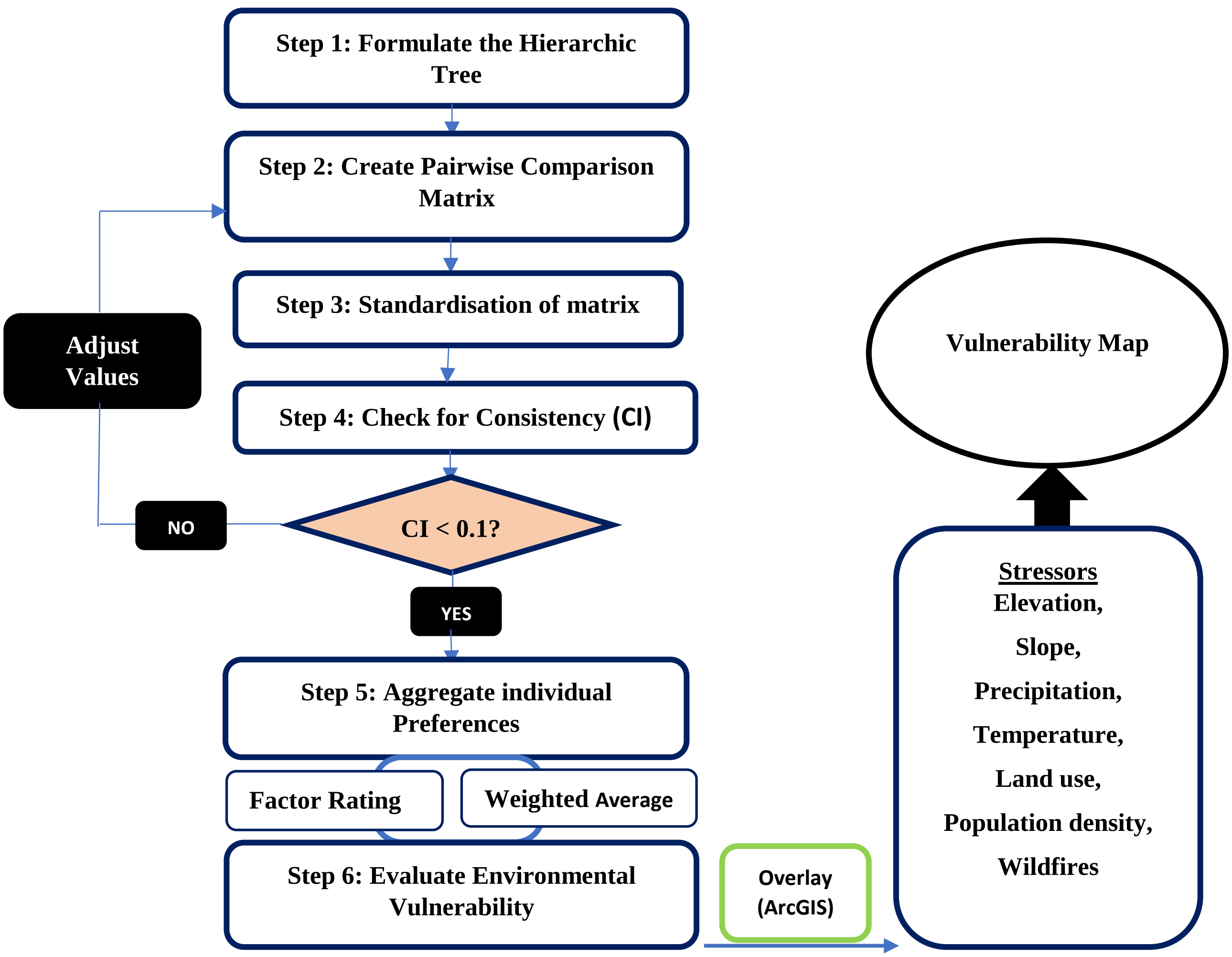


Figure 8: Flow chart to conduct AHP study (adapted from Talib et al., 2011. p 1337)

Step 1: The problem is broken down into a hierarchy of goal, criteria and alternatives as expressed in figure 9.

Step 2: Collection of data through expert judgement or decision-makers according to the hierarchic structure. A square matrix is developed out from the pairwise comparison generated using the standard comparison scale (Table 3). The sums of columns are determined.

Multiple pairwise comparisons based on a standardized comparison scale of nine levels (1-9) in AHP is shown by Table 3 for two elements *i* and *j*: The judgement made by experts was based on the definition and descriptions in this table.

Table 2: Standard Comparison Scale

Intensity of Importance	Definition	Description
1	Equal importance of *i* and *j*.	Two factors contribute equally to the objective.
3	Weak importance of *i* over *j*.	Experience and judgement slightly favour one over the other
5	Strong importance of *i* over *j*.	Experience and judgement strongly favour one over the other.
7	Demonstrated importance of *i* over *j*	Experience and judgement very strongly favour one over the other.
9	Absolute importance of *i* over *j*	The evidence of favouring one over the other is of the highest possible validity.
2, 4, 6, 8	Intermediate values	When compromise is needed
Reciprocals of above	If an element *i* has one of the above numbers assigned to it when compared with element *j*, then *j* has the reciprocal value when compared with *i*.	--

Source: (Saaty, 1980)

Step 3: Standardise the matrix by dividing each element by the sum of its column. The eigenvector of the comparison matrix is calculated to determine the relative weights of the factors or criteria using the equation:

$$[\boldsymbol{B}] = \frac{[\boldsymbol{A}]}{\boldsymbol{n}} \qquad \textbf{(1)}$$

where *n* is the number of factors under consideration and [A], row averages of the standardised matrix.

Step 4a: The consistency of the matrix of order *n* is evaluated. Comparisons made by this method are subjective and the AHP tolerates inconsistency through the amount of redundancy in the approach. The consistency matrix of the judgement is done by multiplying each element (column) of the comparison matrix by the corresponding eigenvector [B]. Sum each row of the consistency matrix [C].

b) Determine the maximum eigen value (λmax) using the rational priority [D]:

$$[\boldsymbol{D}] = \frac{[\boldsymbol{C}]}{[\boldsymbol{B}]} \qquad \textbf{(3)}$$

and

$$\boldsymbol{\lambda}\text{max} = \frac{\boldsymbol{\Sigma}[\boldsymbol{D}]}{\boldsymbol{n}} \qquad \textbf{(4)}$$

The consistency index, CI, was calculated as,

$$\text{C I} = \frac{(\boldsymbol{\lambda_{max}} - \boldsymbol{n})}{(\boldsymbol{n} - \boldsymbol{1})} \qquad \textbf{(5)}$$

where $\boldsymbol{\lambda_{max}}$ is the maximum eigenvalue of the judgement matrix and $\boldsymbol{n}$ is the number of factors. The consistency ratio (CR), is used to indicate the probability that the matrix judgments were randomly generated (Saaty, 1977).

$$\boldsymbol{CR} = \frac{\boldsymbol{CI}}{\boldsymbol{RI}} \qquad \textbf{(6)}$$

where RI is the average of the resulting consistency index depending on the order of the matrix given by Saaty, (1977). If value of CR is < 0.1, then it shows the uniformity of judgment matrix, otherwise adjustment is required for judgment matrix.

Table 3: Random index matrix of the same dimension

Number of criteria (n)	2	3	4	5	6	7	8	9	10	11
RI	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51

Source: (Saaty, 1980)

Step 5: The rating of each alternative is multiplied by the weights of the factor. The AHP produces weight values for each alternative based on the judged importance of one factor over another with respect to a common criterion (Saaty, 1990). The contribution of each factor, here in referred to as the weight was determined with the AHP model.

3.5.1.4 Environmental Vulnerability Index

The weighted linear combinations method was used to build the evaluation model to calculate the EVI. The factors evaluated were combined by applying the weight of each factor, followed by a summation of the results to yield a vulnerability index (Hou et al., 2016). From this, the ecological vulnerability index can be calculated using this formula:

$$\boldsymbol{EVI = \sum_{i=1}^{7} w_i f_i} \qquad \textbf{(7)}$$

…where EVI is the environmental vulnerability index, $\boldsymbol{w_i}$ the weight of factor $\boldsymbol{i}$**,** $\boldsymbol{f_i}$ the rating of factor *i* and 7 is the number of factors. The higher the EVI value, the more vulnerable the ecological environment is to the stressors and the human security outlook of the people may be compromised. The results of the EVI will foster the development and planning of solutions to the factor(s) that influence the vulnerability of the forest ecosystem.

3.5.1.5 Generation of Vulnerability Map

Using ARCGIS 10 software, all data in the vector format is were interpolated, using the Inverse Distance Weighting (IDW) method to generate respective raster files. The natural breaks classification method was used to reclassify the raster data into three grades: low, moderate, and high. The final vulnerability mas was generated by using Raster calculator to overlay the different raster files and inputting their respective weight. Li et al., (2006) cautions that, the result computed from EVI model is a continuous value, which needs classification into several levels because vulnerability differs from one environment to the other. Subsequently, the EVI was classified into three ranks to reflect the different vulnerability levels of the forest.

Generally, a combination of social and ecological indicators was applied to assess vulnerability of ecosystems in the Afram Headwaters Forest Reserve at Offinso: (1) satellite imagery used to assess the vulnerability, stressor and risk status of Afram Headwaters Forest Reserve; (2) the factors or forces that drive ecosystem vulnerability; and (3) sustainable management interventions for future natural ecosystem conservation.

3.5.1.6 Criteria Selection

Major variables were considered for the vulnerability assessment. The evaluation criteria system for stressor or exposure component of risk involves: including Elevation (E), Slope (S), Temperature (T), Precipitation (Pr) and Land use (L), Population density (Pd), and Wildfires (W). According to Li et al., (2006), these factors form an important determinant of vulnerability evaluation. The structure of Analytic Hierarchy Process (AHP) for multi-criteria decision-making, modified from (Hou et al., 2016) is shown by Figure 6. The goal is to choose among the competing factors (sub-criteria), the factor that influences the vulnerability of the forest and the risk there of, on the basis of a ranking score when judged individually by experts. Figure 9 shows the hierarchy tree.

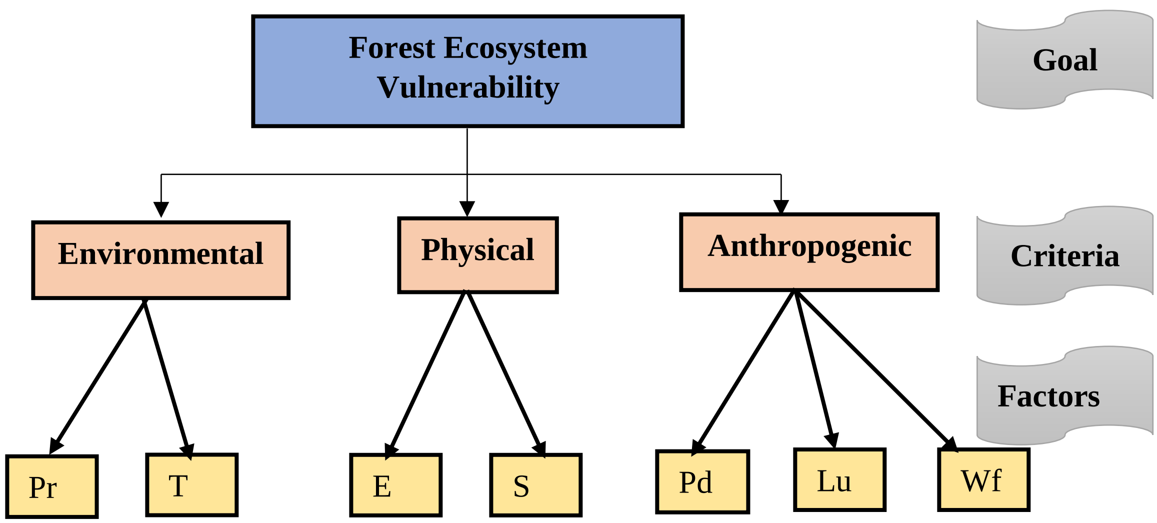


Figure 9: An integrated evaluation criterion for the study area

The description of the factors considered in the AHP structure is contained in Table 4.

Table 4: Definition of factors

S/No	Factor	Description
1	Elevation	Elevation (altitude), the height above sea level, is an important factor because species distribution across elevation gradient relied upon the assumption that increasing is analogous to decreasing soil moisture (Steele, 2007).
2	Slope	The microclimatic conditions on slopes vary dramatically, affecting the biology of organisms at all levels. It controls the duration of overland flow, infiltration and subsurface flow (Ouma & Tateishi, 2014).
3	Rainfall	Low and unevenly distributed annual precipitation is a major factor limiting successful afforestation. Both principal factor analysis and the

		correlation between FGS and precipitation suggested positive effect of precipitation on forest growth (Yang et al., 2006)
4	Temperature	An increase of temperature under climate change might increase evapotranspiration and reduce soil moisture, further limiting plant growth (Yang et al., 2006)
5	Land use	Woody vegetation clearance affects not only moisture availability in the soil but also chemical content of the soil water and soil temperature (Özkan & Gökbulak, 2017).
6	Population Density	There is an indication that some 85 percent of existing Protected Areas have human populations living either inside or immediately adjacent to the reserve (World Bank, 2004).
7	Bushfires	For instance, in the transit ion zone of Ghana, annual bush fires cause havoc to forest resources resulting in large tracts of reserves being burnt to the ground (Asare-Kissiedu, 2014).

3.5.1.7 Selection of Experts

The interview was conducted with five (5) experts from Forestry Commission of Ghana, Offinso Forest District who are familiar with the forest and have knowledge about issues of its exposure to stressors. The background of experts covered the fields of Natural Resource Management, Forestry and Geographic Information System (GIS).

CHAPTER IV. RESULTS AND DISCUSSION

4.1 Ecosystem Services Identification and Valuation

4.1.1 Characteristic of Respondents

A group of ten (10) people each for males and females from each of the selected communities were interviewed in a focus group discussion. The detailed description and the composition of the respondents from communities are listed in Table 5.

Table 5: Description of the focus groups and number of the respondents

S/No.	Group	Number of Respondents	Gender		Description
			M	F	
1	Hunter	11	11	0	Respondents who kill or trap animals in the wild.
2	Wood logger	12	10	2	Respondents who fell down trees for firewood, charcoal or timber, including chainsaw activities.
3	Farmer	40	18	22	Those who own an area of land and its buildings used for growing crops and rearing animals.
4	Charcoal Producers	16	8	8	Respondents specialized in burning wood logs into charcoal.
5	Herbalist	31	12	9	Respondents who fetch and prepare leaves, flowers, roots and tree barks for medicinal purposes.
	TOTAL	**100**	**59**	**41**	

From Table 5, the interview included 59% of males and 41% females. The general knowledge of the characteristics of the respondents depict that, their main occupation is farming (40% farming). The farming sites are either situated in or off the forest reserve. Whereas farms found off reserve are privately owned, those that are within the boundaries of the forest are under the Modified Taungya System (MTS), a kind of agroforestry. The aim binding this program is mainly to restore the forest ecosystem to its best fit. In this system, the farmers intercrop with the seedlings of tree species supplied by the Forestry Commission until the trees developed extensive canopies.

The Table reveals that Hunters, Wood loggers and Charcoal producers, had the lowest representations in the Focus Group Discussions in all the selected communities. For wood loggers and charcoal producers, the reason could be due to the illegality tag with unauthorized logging of trees for lumber or charcoal making. This forms the basis for the unwillingness for people to reveal their identity as wood loggers and charcoal producers. Marfo (2010), reported that, chainsaw milling has been banned in Ghana since 1998 and presently, the Forestry Commission has rolled out policies and activities to combat illegal logging. The enforcement of the law comes with fine or jail term placed on culprits. Figure 10 shows the graphical representation of respondents' distribution.

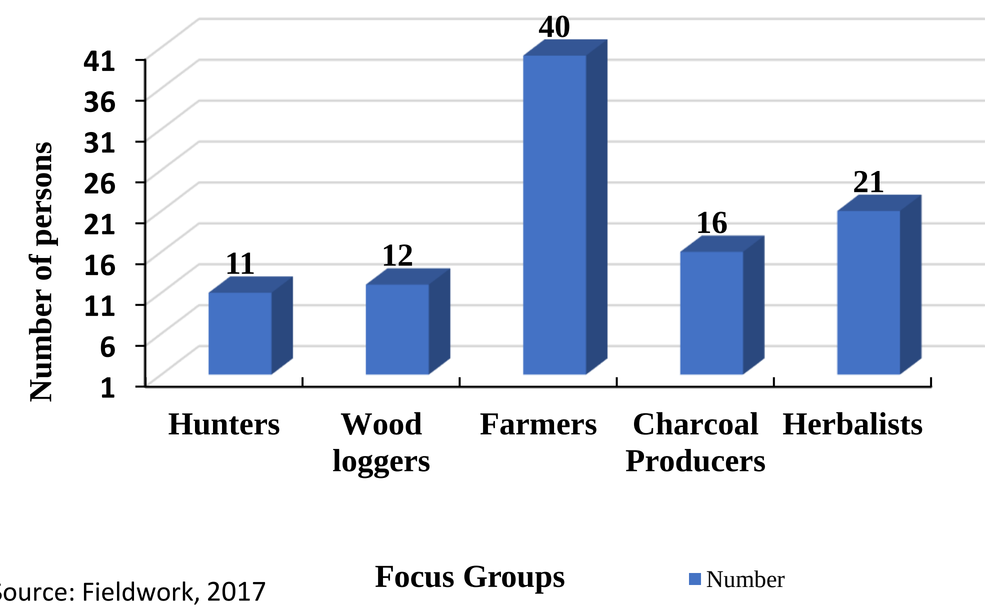


Figure 10: Representation of Focus Groups

Another group worth discussing is the Hunters, which had only 11% representation with no female. In Ghana, hunters are chiefly specialized to working in the night. Their activities span from shooting at a range to setting traditional traps in the wild to catch animals for sale or domestic use. Other people do not use any of the mentioned methods but resort to setting the forest reserve ablaze, when rodents are smoked out of their dug holes. Regardless of which method is considered, society places limitation on women as hunters.

4.1.2 Identification of Ecosystem Services

Both male and female groups gave priority to Provisioning, Regulating and Supporting over Cultural services. It showed that, cultural services are less relevant to the forest dwellers or such services are not available in the area. There are no or under-developed monuments or sites that have the potential of attracting tourists, however, much studies have been conducted in the reserve but the benefits to the community could be untraceable. Global Forum, (2004) argues that an ecosystem service is regarded a service only when its goods and services are directly or indirectly felt by people. Furthermore, it can be speculated that, the extent of degradation and deforestation could be good reasons for this feature. The pieces of information are detailed in Table 6.

Table 6: Forced Decision Matrix

		Forced Decision Matrix													
	E S	**Males**							**Females**						
		P	R	S	C	Score (S)	Rating (S/N)			P	R	S	C	Score (S)	Rating (S/N)
1	Provisioning (P)		0	0	1	1	0.17		P		1	1	0	2	0.33
2	Regulating (R)	1		0	1	2	0.33		R	1		0	1	1	0.17
3	Supporting (S)	1	1		1	3	0.50		S	1	1		1	3	0.50
4	Cultural (C)	0	0	0		0	0.00		C	0	0	0		0	0.00
	(N)					6								6	

N: Total number of Comparison

From the decision matrix, both groups maintained the importance of supporting services at 50% whilst provision and regulating services changed across gender perspectives. Whereas males assigned 17 and 33% to provisioning and regulating services, the reverse was done by the females.

4.1.3 Ecosystem Services Pertaining to Afram Headwaters Forest Reserve (AHFR)

Using the land cover map as the forest boundary, respondent groups were guided to identify the major ecosystem services supplied by the AHFR, together with their usage and examples. These details are summarized in the Table 7.

Table 7: Ecosystem Services in AHFR

	SERVICES	**USES/EXPLANATION**	**EXAMPLES**
	PROVISIONING		
1	Bush Meat	Household consumption; sell to generate income.	Antelopes, Grass cutters, Rats, Tortoise etc.
2	Grass	Making hay and silage for livestock; Roof buildings.	Elephant grass
3	Food	Household consumption; sell to generate income; Medicinal purposes.	Plantain, Yam, Cocoyam, Honey, Mushroom.

4	Fruits	Household consumption; sell to generate income.	Oranges, Pawpaw,
5	Lumber	Roofing; building cages for animals, furniture; construction works; Sell to generate income	Wawa (*Triplochiton scleroxylon*), Cedar, Odum (*Milicia excelsa*), Ofram (*Terminalia superba*), Emire, Teak.
6	Medicinal Herbs	Cure diseases and sicknesses; sell to generate income.	(Nyame dua": for treating stomach upset,
7	Wood Fuel	Cooking food and baking bread; sell to generate income.	Teak (*Tectona grandis*), York (*Broussonetia papyrifera*), Acacia.
	REGULATING		
1	Water Purification	Quality Water	
2	Climate Modification	Carbon storage in trees	
3	Air Regulation	Removal of contaminants from air	
4	Disease Regulation	High dense forest maintains atmospheric moisture which controls the breeding and survival of mosquitoes	
	SUPPORTING		
1	Nutrient recycling	Agricultural productivity inside the reserve far outweighs that of off reserve	
2	Soil Formation	Humid soil that supports plant growth	

4.1.4 Ecosystem Services Valuation

Generally, nutrient recycling, soil formation, food, medicinal plants and climate modification were of greater importance to the people – 8.9, 8.5, 8.7, 7.4 and 7.5 respectively.

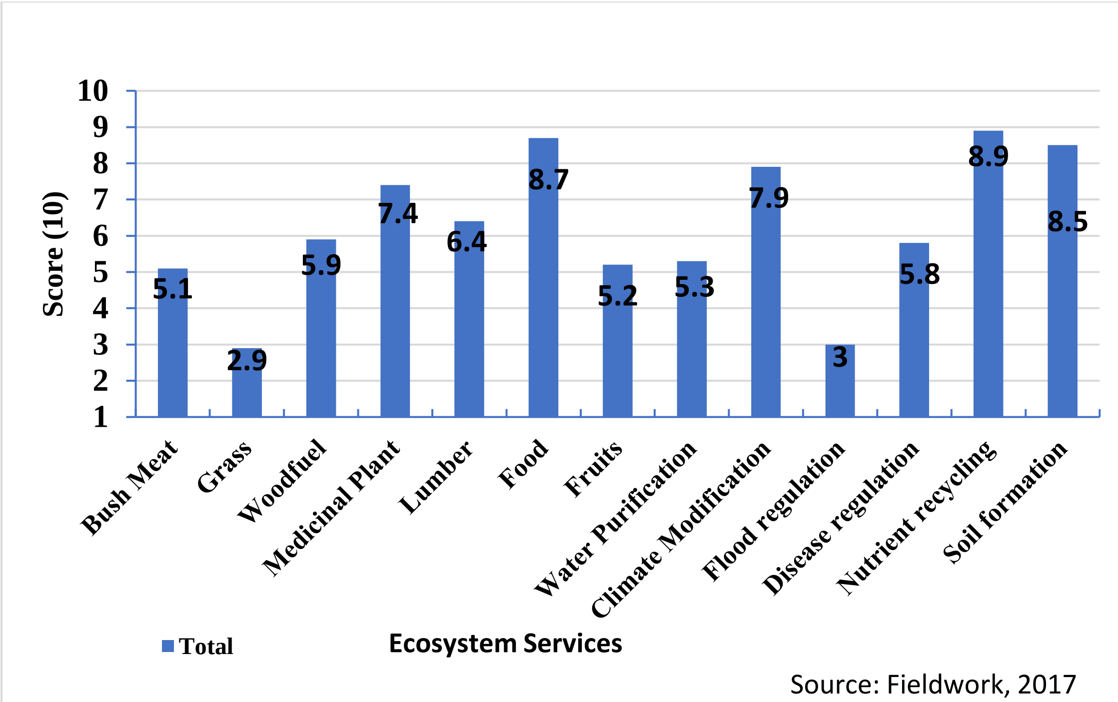
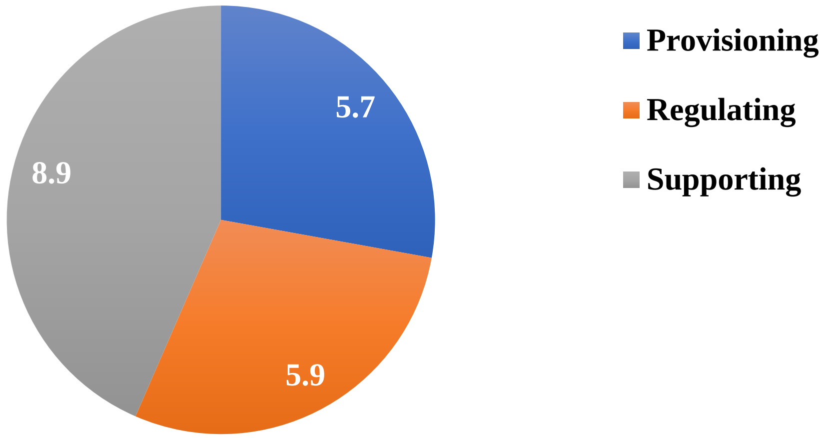


Figure 11: Percentage score for each ecosystem service or goods

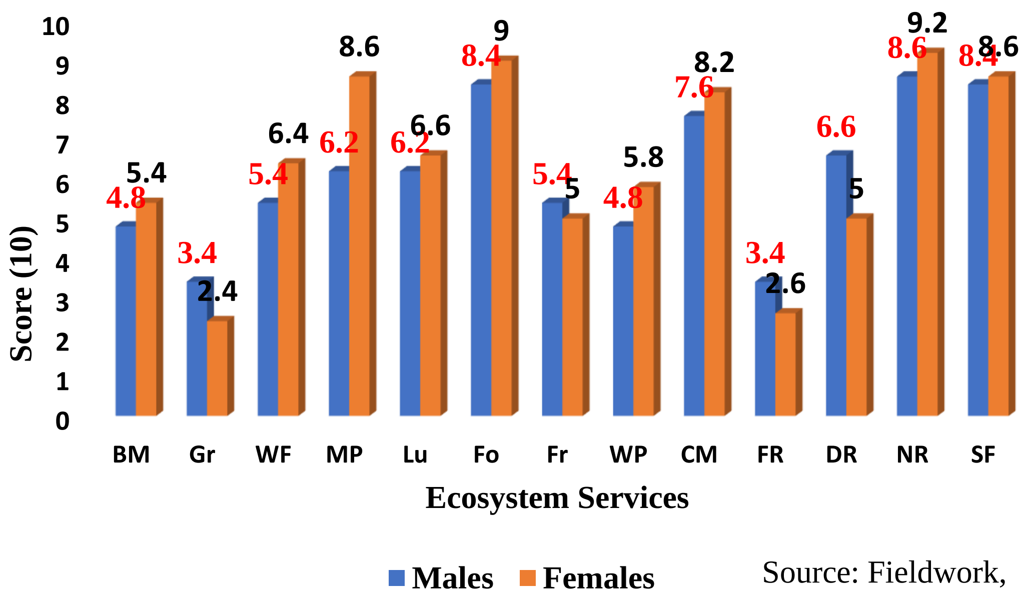
As shown in Figure 12, all respondent groups recognized regulating and supporting services over provisioning services. That is not to say provisioning services is less important to the communities. They analysed that, a combined functioning of regulating and supporting services will improve the supply of provisioning services. Again, respondents understood the relationship between these services in view of their farming activities and seasonal harvest or yield. The narration was connected to the necessity of nutrient recycling and soil formation in crop production. They observed a significant difference in crop production from in and off reserve farms. Farms in the reserve are rich soil nutrients that support crop production in terms of quality and yield. The climate and air modification (regulating) and soil formation (supporting) influenced the judgement. Global Forum (2004), upon commenting on the four ecosystem functions put forward by Groot et al., (2002) stated that “the regulating and habitat functions are essential for the maintenance of eco-systems, and without them the other two functions (i.e. provisioning and information) would not exist”. In this context, provisioning and cultural services rely on the performance of both supporting and regulating services. This habitat function is replaced by supporting services in the Millennium Ecosystem Assessment.



Source: Fieldwork, 2017

Figure 12: Valuation (importance) of Individual Ecosystem Services

Figure 13, summarizes the performance of males and females in valuating ecosystem services according to the level of importance. It was discovered that, the females scored the entire ecosystem 8.28 compared to the males' 7.92. Even though the difference was not huge, it is equally important to note that, the integration of gender perspectives in the current sustainable development discussions is recommendable.



Source: Fieldwork, 2017

Figure 13: Valuation on Gender Basis

How different communities valued the ecosystem was relevant to the study because the existing interaction between them and the forest ecosystem differs from one to the other. From figure 14, Abofour scored the ecosystem the highest value. Reasons could be related to the fact that the town is the biggest market center in the Offinso forest district. Almost all goods captured under provisioning services are sold in their market. Food stuffs like maize, banana, yam, groundnuts, plantain, cocoyam etc. are sold in the market. Considering the land use/land cover map of the area, it could be realized that, the forest at Asempanaye is fast depleting. It is either used for farming, settlement or recognized as unproductive farmland. Akofoa, Asuboi and Kwapanin are a bit farther from the market center and these areas are where farming activities are enormous.

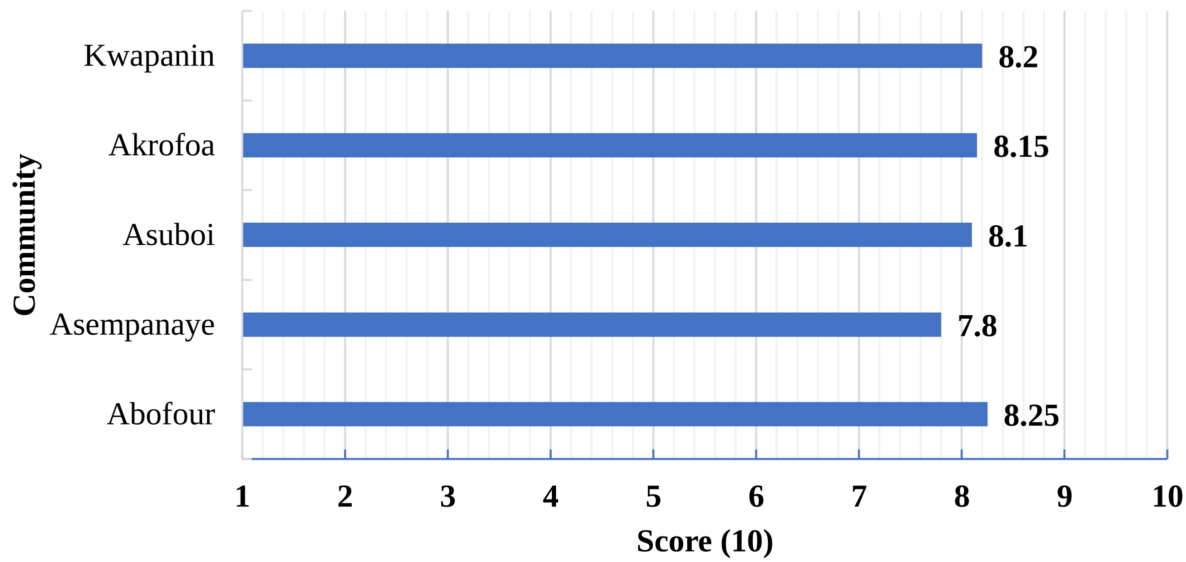
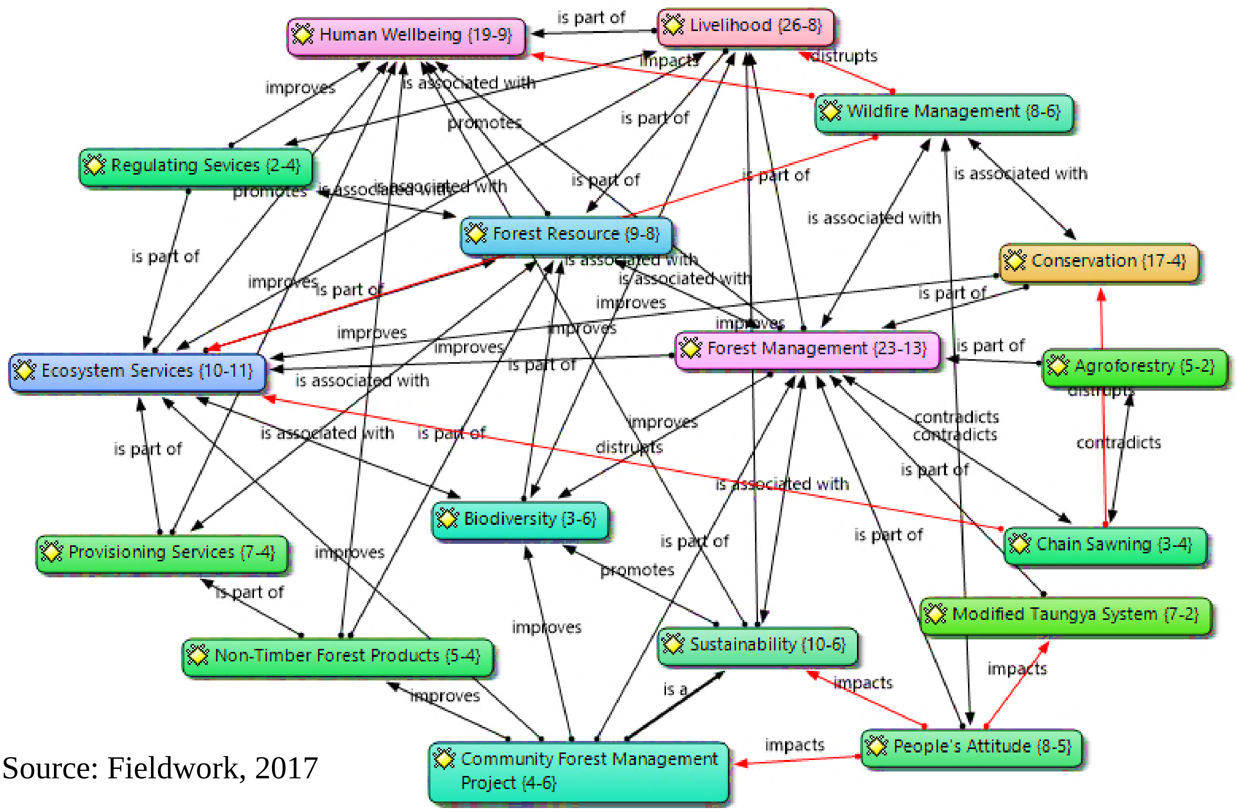


Figure 14 Valuation of ecosystem services by communities

4.1.5 Complexity of Population and Forest Synergy

The figure summarises the responses from the focus group discussions about the management of the forest ecosystem. The study explored that the interaction between population, especially fringe communities and the forest is a very complex one and the key component of these interactions is livelihood security. All focus groups settled on the fact that, livelihood diversification will improve their living conditions and translated into a healthy forest standing. Lessons from this figure can be traced by observing the definition of each interaction (represented by arrows) among different codes and the number of arrows pointing to each code. It shows that the interaction between ecosystem services, human wellbeing, livelihood, forest resource and forest management is such a complex one.



Source: Fieldwork, 2017

Figure 15: Complexity of forest-population interaction

4.2 Land use/land cover classification

4.2.1 Supervised classification of land use types

In view of vulnerability study in this research, the Afram Headwaters Forest Reserve (AHFR) was classified into three (3) classes, notably natural forest, plantation forest and bare land. A similar study on the potentials of the Taungya System in fostering species diversity in the forest, classified the AFHR into three classes – farmland, plantation and natural forest – when studying the (Boakye, 2011) . Table 8 contains the description of the land cover types.

Table 8: Land Cover Classes Description

	Land cover	Description
1	Natural forest	A multilayered vegetation unit dominated by tree whose combined strata have overlapping crowns and where grasses are generally rare.
2	Plantation forest	Forest plantations made up of Teak monoculture
3	Bare lands	Areas with no dominant vegetation.

The supervised image classifications of the study area for three periods (2000, 2010, and 2017) are found in Figures 16, 17 and 18. The kappa coefficients for the classified Landsat 7 images were 0.5663 (57%), 0.6097 (61%) and 0.7989 (79%) for 2000, 2010 and 2017. It implies that, for example, 57% of the classification is in accordance with the reference data for year 2000.

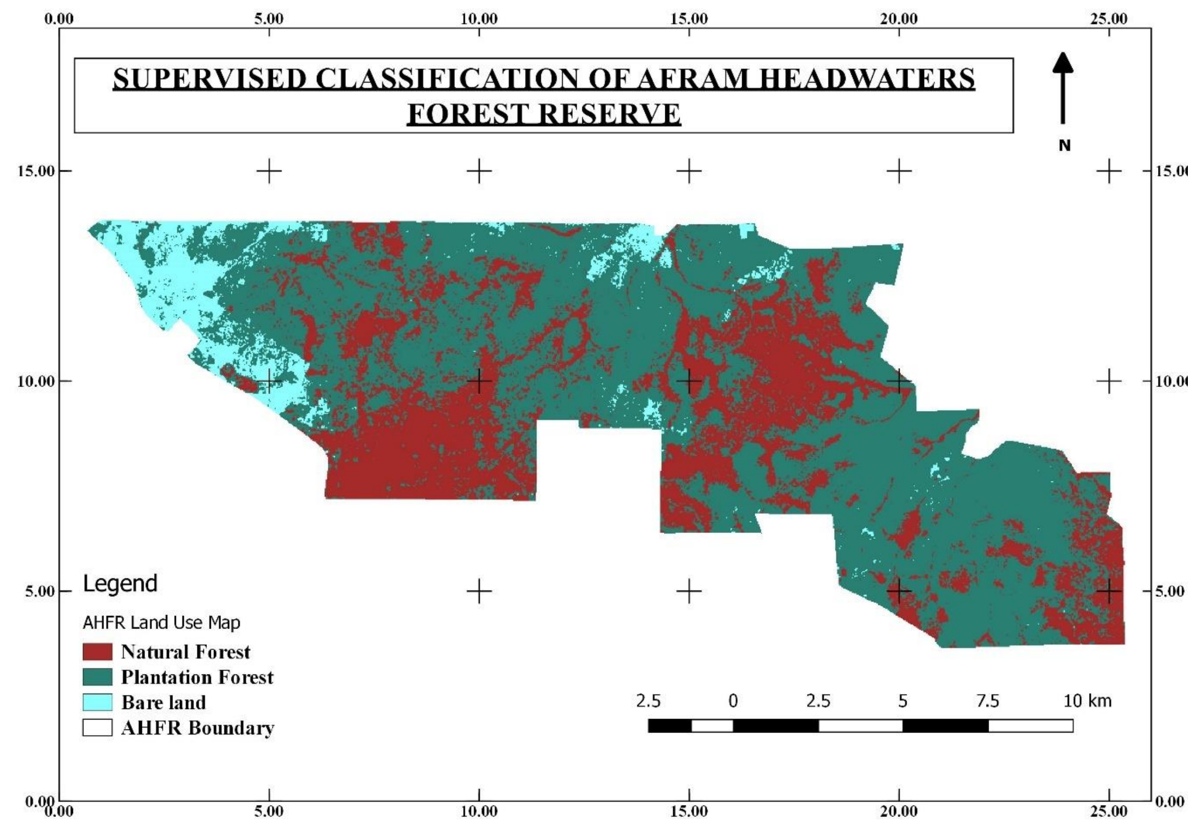


Figure 16: Land Use/Land Cover Classification (Landsat 2000)

Table 9: Accuracy Totals (Landsat 2000)

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy	Kappa
Natural Forest	33	25	22	66.67%	88.00%	
Plantation Forest	27	44	24	88.89%	54.55%	
Bare Land	21	12	12	57.14%	100.00%	0.5663

Overall Classification Accuracy = 71.60%

Table 10: Confusion Matrix for Landsat 2000

Classified Data	Natural Forest	Plantation Forest	Bare Land
Natural Forest	**22**	3	0
Plantation Forest	11	**24**	9
Bare land	0	0	**12**
Column Total	**33**	**27**	**21**

Table 10 details the number of the misclassified pixels from the three classes. For the natural forest, the total number of sampled pixels were 33 where 11 pixels were misclassified as plantation forest with no misclassified pixels for bare land. Again, for plantation forest, a total of 24 pixels out of 27 pixels were classified as plantation forest with three misclassified pixels for natural forest. With bare land, 9 out of 21 pixels were misclassified as plantation forests. The confusion matrices for Landsat 2010 and 2017 (Tables 18 and 19, respectively) are found at the appendices page.

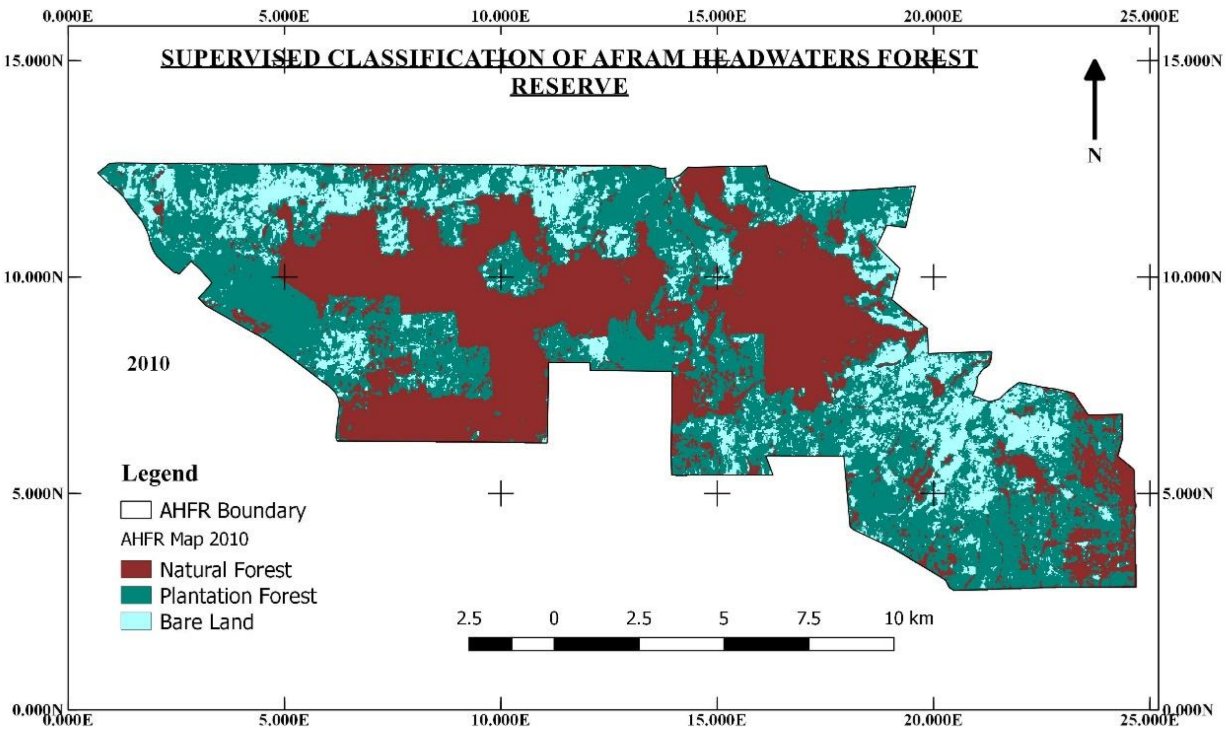


Figure 17: Land Use/Land Cover Classification (Landsat 2010)

Table 11: Accuracy Totals (Landsat 2010)

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy	Kappa
Natural Forest	45	46	41	91.11%	89.13%	
Plantation Forest	51	65	39	76.47%	60.00%	0.6097
Bare Land	49	35	28	57.14%	80.00%	
Total	145	146	108			

Overall Classification Accuracy = 73.97%

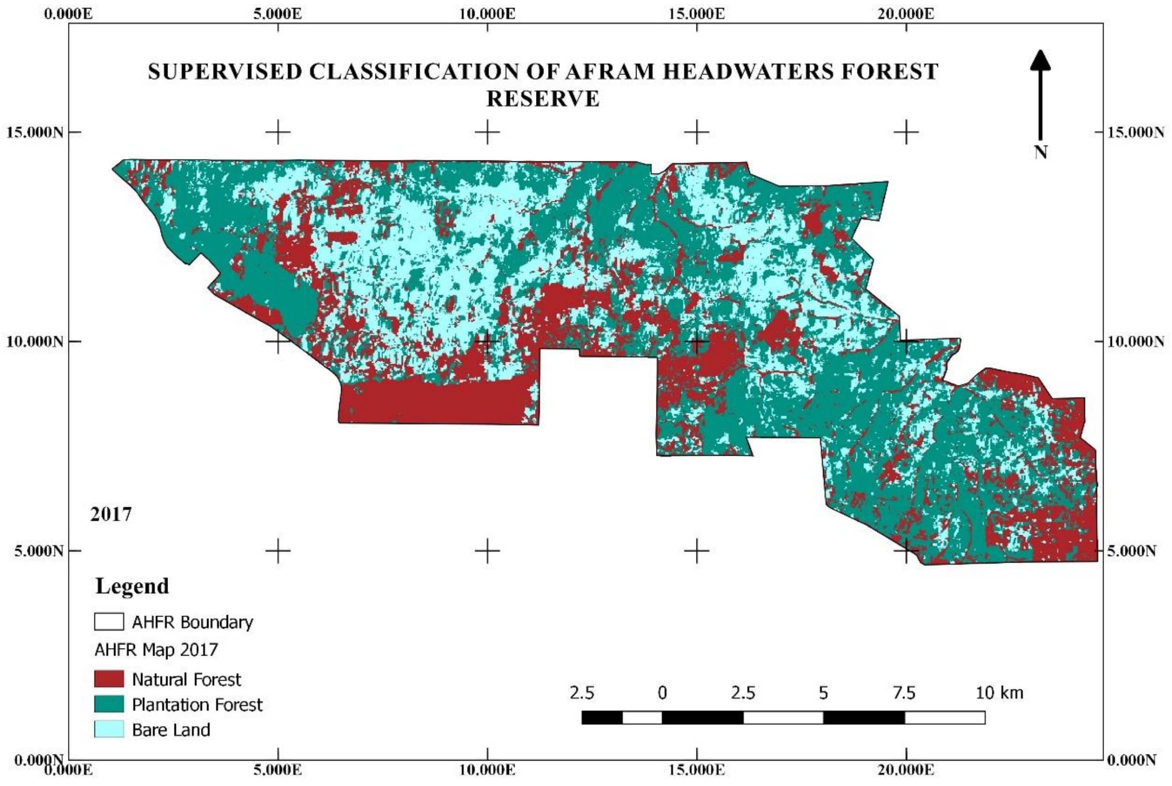


Figure 18: Land Use/Land Cover Classification (Landsat 2017)

Table 12: Accuracy Totals (Year 2017)

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users accuracy	Kappa
Natural Forest	41	38	36	87.80%	94.74%	0.7989
Plantation Forest	53	46	43	81.13%	93.48%	
Bare Land	21	31	21	100.00%	67.74%	
Totals	115	115	100			

Overall Classification Accuracy = 86.96%

4.2.2 Change Detection Analysis

Figure 19 and table 13 were used to analyse the change in forest cover in hectares from 2000 to 2017. It could be realised that, the natural forest cover for the past seventeen (17) years is been lost to deforestation and degradation. Plantation cover reduced from 63% in 2000 to 46.14% in 2010 and has fairly remained constant. However, Bare land has risen from 7.17% in 2000 to 16.25% in 2017, making this development a concern for forest ecosystem vulnerability discussions.

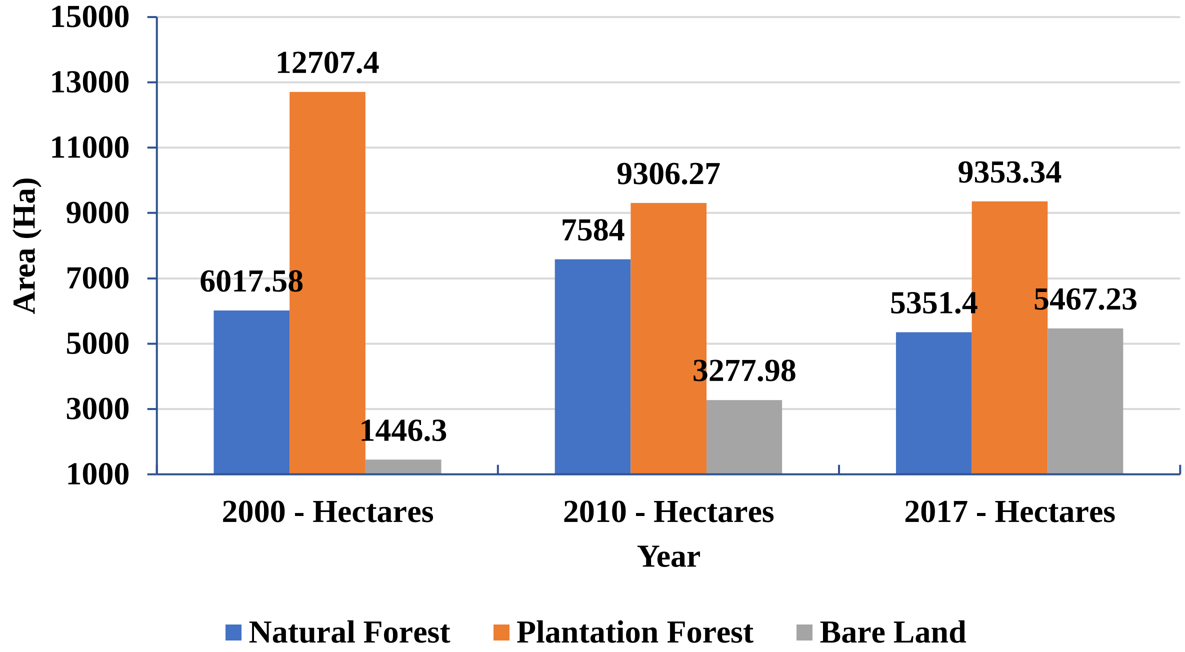


Figure 19: Area of Classified Land Use/Land Cover Types

Table 13: Area of Classified Land Use/Land Cover Types

Class Name	**Hectares in 2000**	**%**	**Hectares in 2010**	**%**	**Hectares in 2017**	**%**
Natural Forest	6017.58	29.83	7584	37.60	5351.40	26.53
Plantation Forest	12707.40	63	9306.27	46.14	9353.34	46.37
Bare Land	1446.30	7.17	3277.98	16.25	5467.23	27.10

Again, the map below (Figure 20) shows a 50% increase or decrease in change of the classified land use types between 2010 and 2017. All areas in green have witnessed a 50% increase in change of vegetation cover. There is no area which showed a 50% decrease in change.

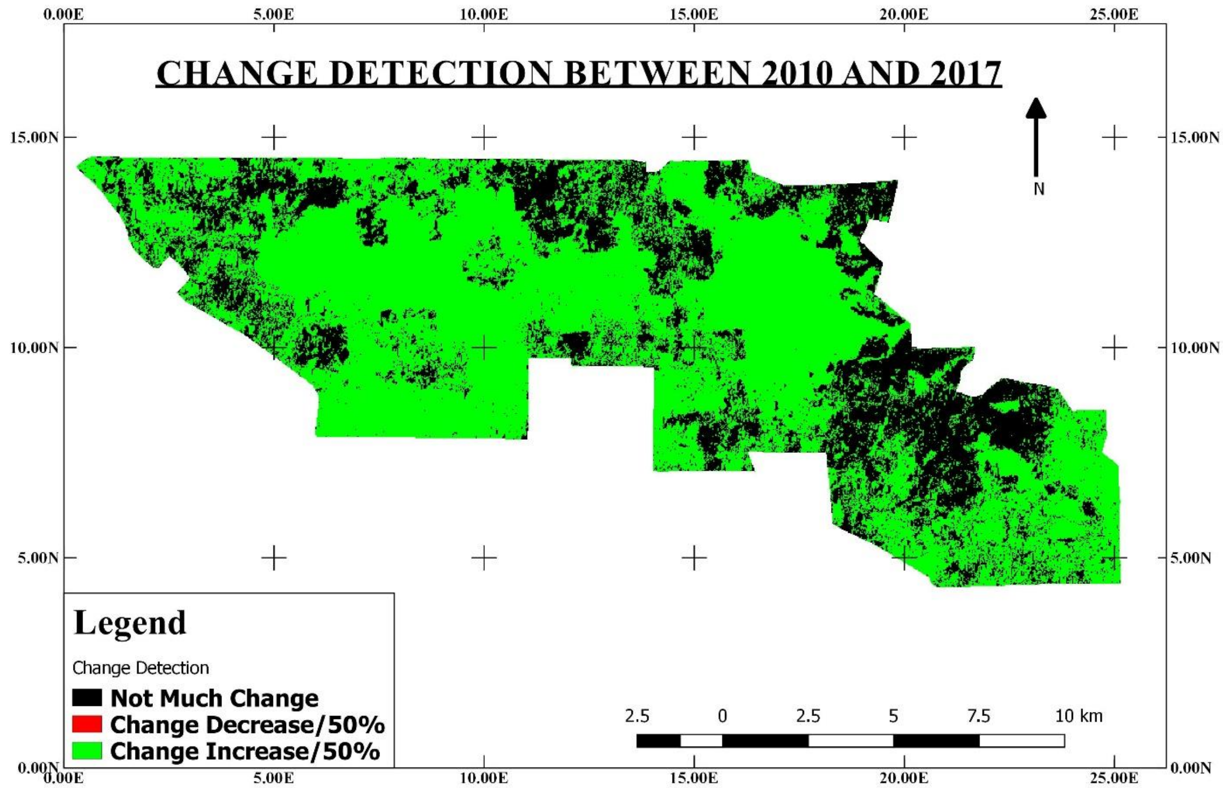


Figure 20: Change Detection Map

4.3 AHP Model Processing

The factors that influence the vulnerability of the forest ecosystem were evaluated by experts who have knowledge about ecosystem and familiar with its management. In this study, the AHP was structured on physical, environmental and anthropogenic criteria. The weights of the individual factors are here in described as the level of influence in view of the vulnerability of the resource.

4.3.1 AHP Stressor Map

The mapping of the stressors to which the forest is exposed took into consideration physical (elevation and slope), environmental (precipitation and temperature) and anthropogenic factors (land use, population density and wild fire). In this study, stressors are referred to as factors that influence vulnerability. The degree of susceptibility and exposure of the ecosystem to the stressors defines its vulnerability. The representation of the factors in Tables 14, 15 and 16 is explained as: Elevation (E), Slope (S), Precipitation (Pr), Temperature (T), Land use (Lu), Population Density (Pd) and Wildfire (Wf). The stressor map will show the level of vulnerability of various compartments of the forest. These weights assigned to the factors by the AHP determine the extent to which a particular stressor influences the ecosystem vulnerability. The figures generated through the expert judgement were used to calculate the weight or eigenvectors [B] of the factors. Table 15 contains the weights [B] assigned to each stressor factor on the comparison matrix.

Table 14: Stressor Matrix

CR Value = 0.05			**OK**				
Factor	**E**	**S**	**Pr**	**T**	**Lu**	**Pd**	**Wf**
E	1	1/3	1/5	1/9	1/9	1/5	1/7
S	3	1	1/5	1/5	1/7	1/5	1/9
Pr	5	5	1	1	1/5	1/7	1/7
T	9	5	1	1	1/7	1/7	1/9
Lu	9	7	5	7	1	1	1/5
Pd	5	5	7	7	1	1	1/7
Wf	7	9	7	9	5	7	1
SUM	39.00	32.33	21.40	25.31	7.60	9.69	1.85

Table 15: AHP Standardisation Table

	E	**S**	**Pr**	**T**	**Lu**	**Pd**	**Wf**	**[A] = ΣRows**	**[B] = [A]/7**
E	0.03	0.01	0.01	0	0.01	0.02	0.08	0.16	0.02
S	0.08	0.03	0.01	0.01	0.02	0.02	0.06	0.22	0.03
Pr	0.13	0.15	0.05	0.04	0.03	0.01	0.08	0.49	0.07
T	0.23	0.15	0.05	0.04	0.02	0.01	0.06	0.57	0.08
Lu	0.23	0.22	0.23	0.28	0.13	0.1	0.11	1.3	0.19
Pd	0.13	0.15	0.33	0.28	0.13	0.1	0.08	1.2	0.17
Wf	0.18	0.28	0.33	0.36	0.66	0.72	0.54	3.06	0.44

Table 16: Consistency Index and Ratio

	E	**S**	**Pr**	**T**	**Lu**	**Pd**	**Wf**	**[C] = ΣRows**	**[D] = [C]/[B]**	**λmax, CI, CR**
E	0.02	0.01	0.01	0.01	0.02	0.03	0.06	0.17	7.52	λmax = Σ[D]/7 = **7.40**
S	0.07	0.03	0.01	0.02	0.03	0.03	0.05	0.24	7.51	
Pr	0.12	0.16	0.07	0.08	0.04	0.02	0.06	0.55	7.91	CI = (λmax – 7)/6 = **0.067**
T	0.21	0.16	0.07	0.08	0.03	0.02	0.05	0.62	7.66	
Lu	0.21	0.22	0.35	0.57	0.19	0.17	0.09	1.79	9.64	
Pd	0.12	0.16	0.49	0.57	0.19	0.17	0.06	1.33	7.76	CR = CI/RI = **0.05 CR < 0.1**
Wf	0.16	0.29	0.49	0.73	0.93	1.20	0.44	1.66	3.81	
SUM									51.81	

The consistency ratio for the judgement was 0.05 which is less than 0.1. This is acceptable according to Saaty (1980). Table 15 reveals that wildfire has the highest weight (44%), denoting its significant influence on forest ecosystem vulnerability and risk as compared to the other factors or elements. Land use and population density followed with 19% and 17% respectively.

The method of Inverse Distance Weighting in ArcGIS was employed to generate maps for the seven layers. It should be noted that, the entire study area was represented by the annual rainfall amount for precipitation and mean temperature for temperature, which definitely had only a pixel when rasterised. The maps of these two factors were not shown here but were included in the Raster Calculation. The maps of the other factors are shown below:

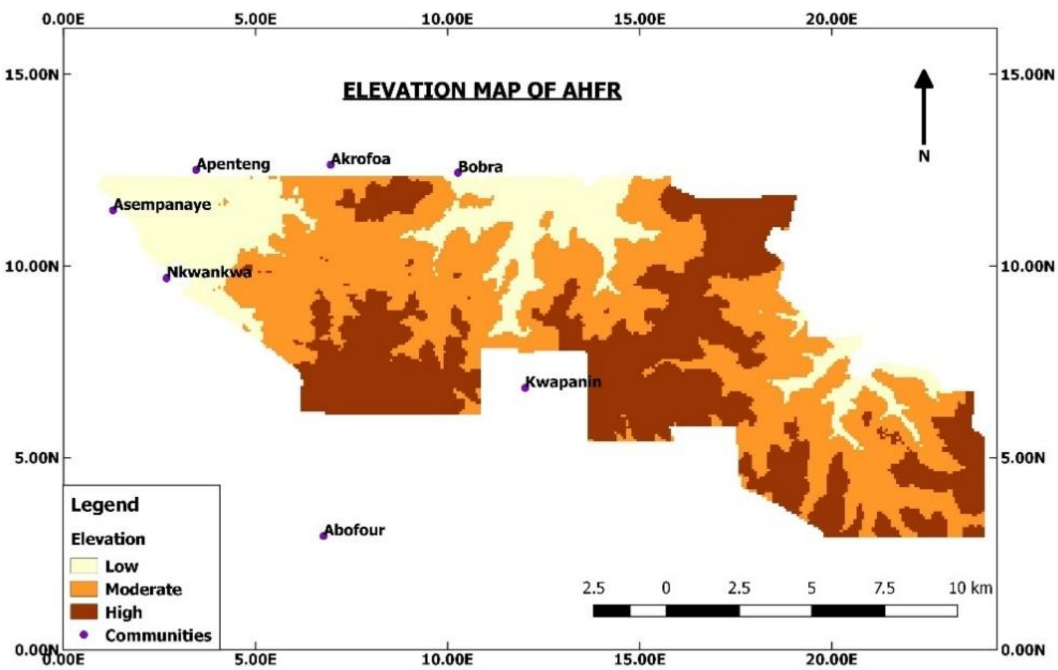


Figure 21. Elevation map

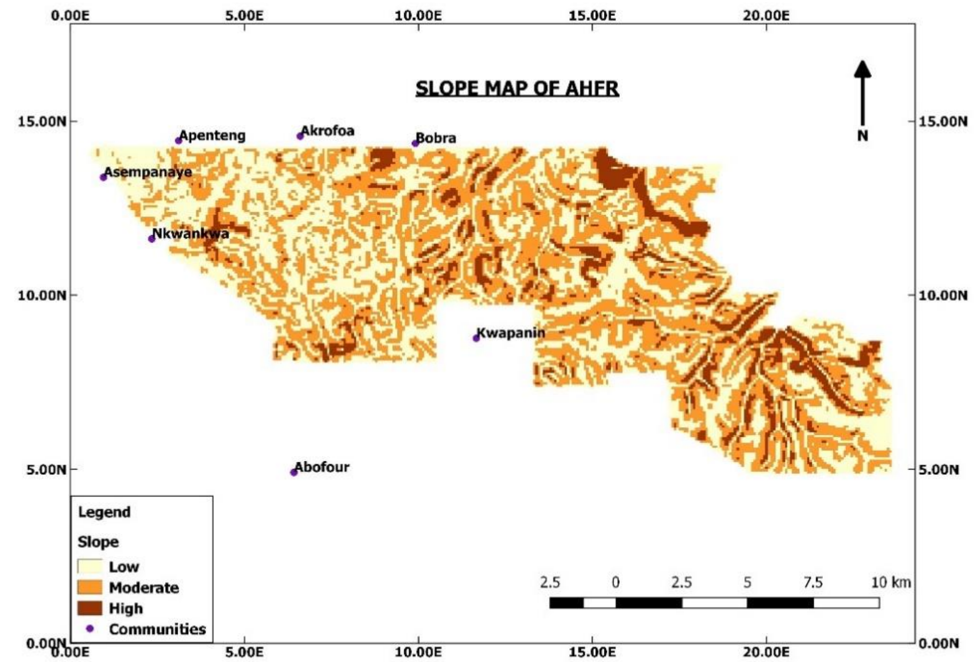


Figure 22. Slope map

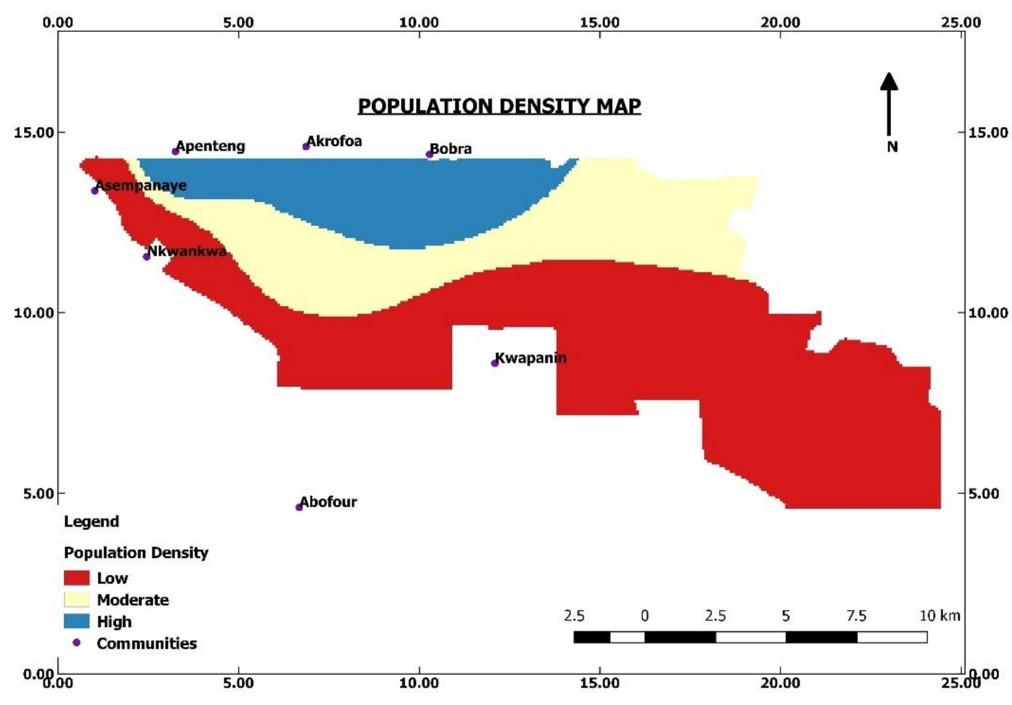


Figure 23. Population density map

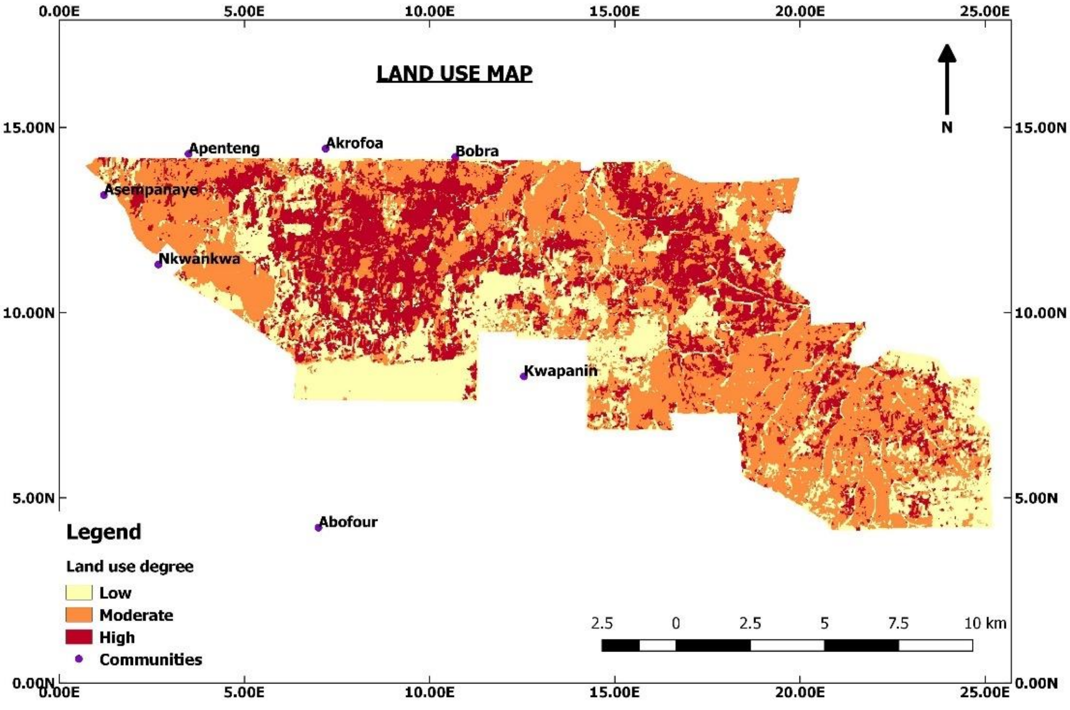


Figure 24. Land use map

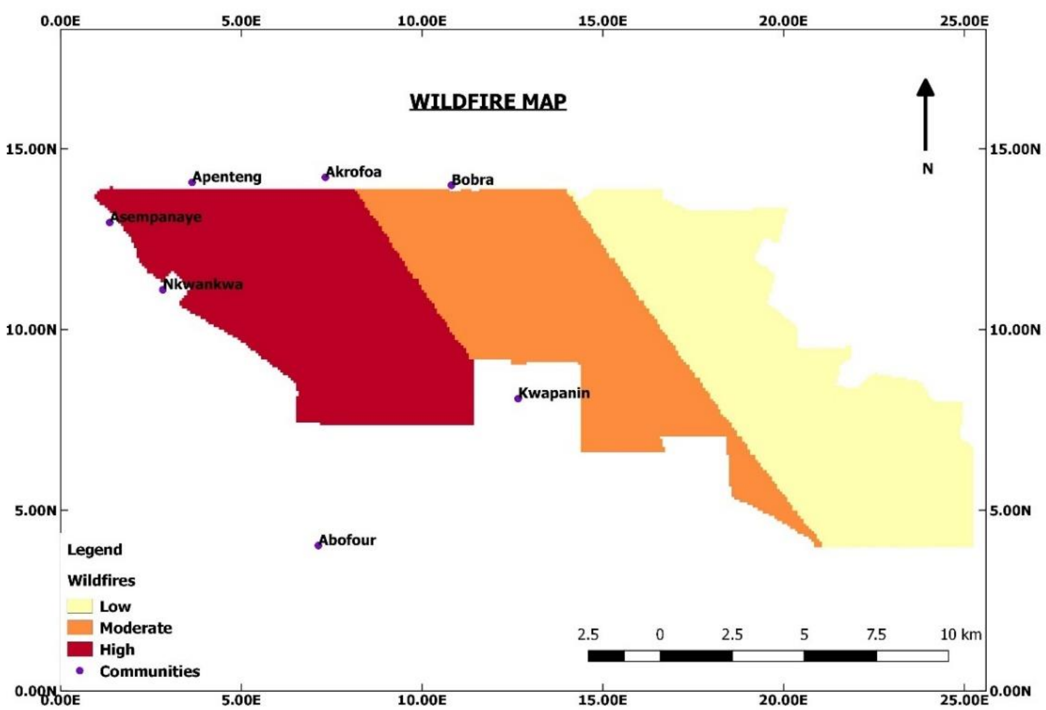


Figure 25. Wildfire map

4.3.1.1. Ranking of Stressor Factors

The natural break classification tool in ArcGIS and aided in rating the factors and used for estimating the environmental vulnerability index of the forest.

Table 17: Ranking of Factors

S/No.	Factor	Condition	Rating
1	Elevation	Low	1
2	Slope	Low	1
3	Rainfall	High	3
4	Temperature	Moderate	2
5	Farm lands	Moderate	2
6	Population density	Moderate	2
7	Wildfires	High	3

From table 17 and equation 7, the Environmental Vulnerability Index is calculated:

EVI = 0.02*1 + 0.03*1 + 0.07*3 + 0.08*2 + 0.19*2 + 0.17 *2 + 0.44*3

EVI = 2.46

The natural breaks classification was used to divide the environmental vulnerability into three grades: low (1), moderate (2) and high (3). From the calculated EVI, the forest ecosystem could be said to be moderately vulnerable. To generate the vulnerability map of the study area, (equation 6) was utilised. The maps were overlaid in ArcGIS by Raster Calculator as shown below.

$$\boldsymbol{SI = \sum_{i=1}^{7} 0.02 * E + 0.03 * S + 0.07 * Pr + 0.08 * T + 0.19 * L + 0.17 * Pd + 0.44 * W}$$

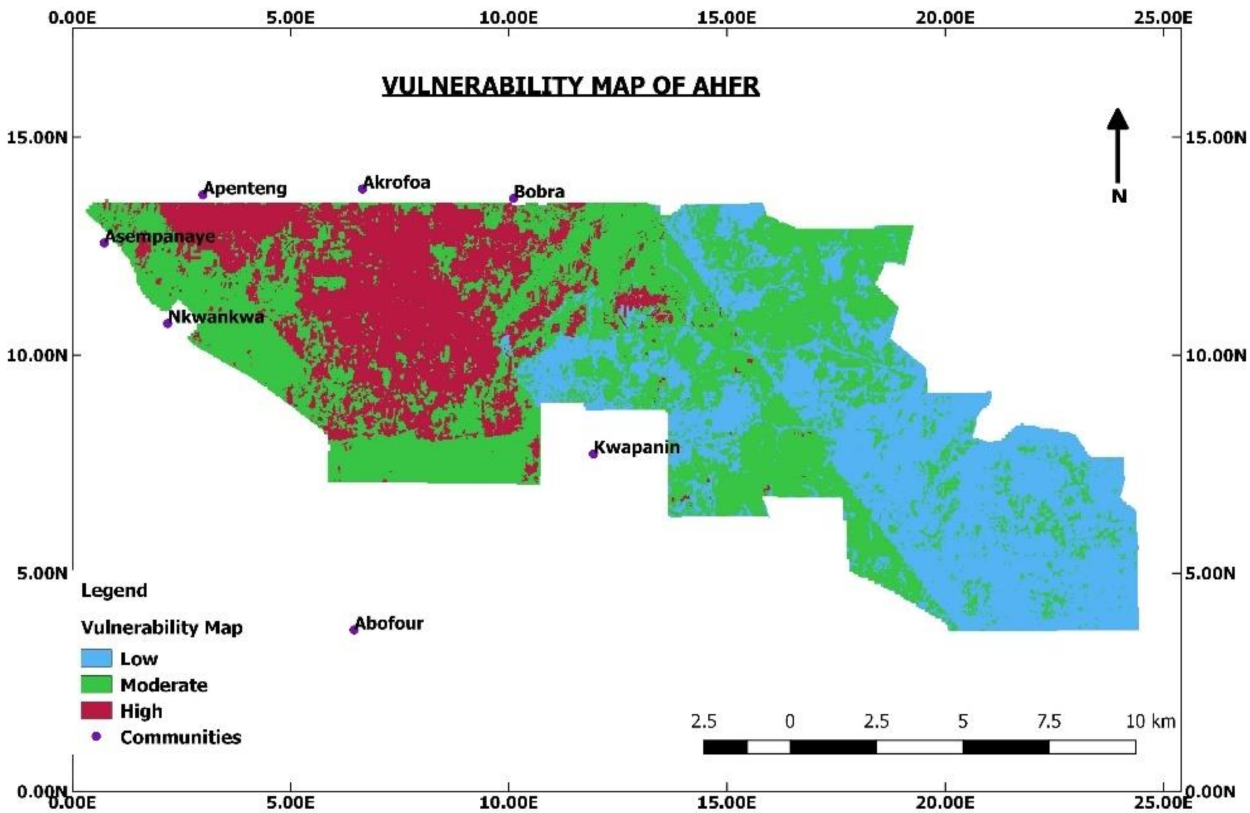
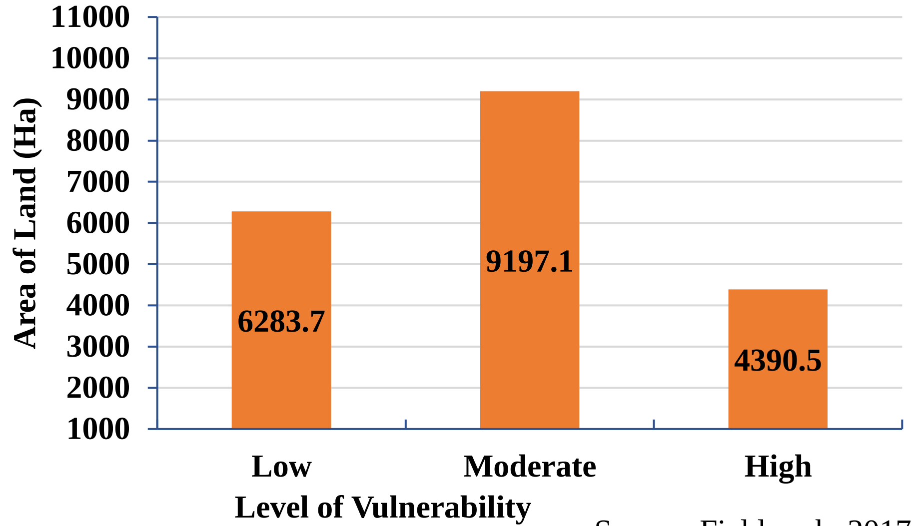


Figure 26: Vulnerability Map

4.31.2 Vulnerability Distribution

The vulnerability of a system varies from one place to the other due to underlying adaptive capacities and the magnitude of the exposure to stressors. Different compartments of the forest the forest naturally possess different characteristics. From Table 18 (appendix 4) and Figure 27, 9197.1 ha of the land area, representing 46% is moderately vulnerable, 6283.71 ha (31.62%) is less vulnerable and 19871 ha (22.09%) is highly vulnerable.



Source: Fieldwork, 2017

Figure 27: Vulnerability Distribution

4.4 Discussion

4.4.1 The Usefulness of AHP

The combination of AHP with GIS method in the assessment of ecological vulnerability paved way to consider a lot of factors. The evaluation results and the ecological vulnerability pattern of the forest reserve could be studied for environmental management. Despite the subjective nature of the method, it is still useful to analyse complex situations like the aim of this research work. As confirmed by Ying et al., (2007), the method could be very useful to policy makers concerned with forest restoration and environmental management. It improves the knowledge of decision makers about the current status of the ecosystem, stressors influencing its vulnerability, and which should be addressed with immediate effect.

4.4.2 Ecosystem Services Identified in the Forest by Local People

The respondents engaged from different livelihood types, genders and role in the communities prioritised supporting and regulating services over provisioning services. Bush meat, grass, wood fuel, medicinal plant, lumber, food and fruits are the main products obtained as provisioning services from the forest ecosystem. With the exception of grass (2.9) and flood regulation (3.0), all other ecosystem services were valued above 5.0 – bush meat (5.1), food (8.7), medicinal plants (7.4), wood fuel (5.9), lumber (6.4) and fruits (5.2) on the scale (1-10). The higher values for food and medicinal plants is consistent with the essence of good health and survival. Apart from the need for food and medicine for growth and survival, food production have also helped to save many people from poverty (MA, 2005). Values placed on these goods and services by respondents were done with deep thoughts, displaying the essence of the goods in the development and sustainability of their livelihoods. Several others fetch non-timber forest products (NTFPs) such as honey, mushroom and termites to serve as food and poultry feed, and preparation of herbal medicines are used in families and/or sold to generate income.

Clearly, respondents demonstrated a high knowledge of the importance of the forest ecosystem services not only as major sources of livelihood but also the health benefits, the sense of belonging and the level of prestige attached to the “ownership” of a forest resource. From their stay in the respective communities for more than thirty years, they were able to identify and draw the dependence of one ecosystem service on the other and the cascading impacts that are likely to be registered upon the alteration of one ecosystem function. The people were critical and explicit with the sudden change in climatic conditions in the area. Their knowledge about carbon sequestration may be limited but that of heightened temperatures and distorted rainfall distribution and pattern in the area over the years was undisputable. The indiscriminate felling of trees coupled with wildfire incidences reduce the canopy cover by the forest, leading to a reduction in humidity and growing trend of species extinction. Realising the reduction in forest cover, farmers have observed seasonal changes – short rainy season and extended dry season – which affect crop growth and yield.

Regulating services assessed included water purification, climate modification, flood regulation and disease control. Many people perceived that, unlike the olden days, rivers and streams flowing currently in the reserve are polluted and hence farmers usually carry their gallons of water along to their farms. The few ones left dry up during the dry seasons due to the fast depletion of the forest. Flood incidences are rare in the area; breathing disorders and mosquito breed are linked to the depletion of the forest. This explains why flood regulation scored 3.0.

The supporting services that got much recognition are nutrient recycling (8.9) and soil formation (8.5). The local people in the selected communities stated emphatically that, there is better crop yield from farms in the forest reserve in quantity and quality as compared to that from the off-reserve. It is common practice and knowledge that, the shed tree leaves in the forest boost the soil’s organic content and provide a favourable atmosphere for microorganisms to aerate and moisten the soil for plant growth. In a related study by Kalame et al., (2011), the benefits of farming in the forest reserve include reduction of soil erosion and land degradation. Respondents shared that, though provisioning services have direct impact on their economic power, it is dependent on the performance of both regulating and supporting services. This informed why the latter were rated highest in the forced decision matrix. Regulating and supporting services were most recognised by the focus groups across communities. Similar results were obtained in the study of the involvement of local farmers in the rehabilitation of forests. About 72% of respondents cited the soil fertility as reasons for participating in the MTS (Blay et al., 2014).

4.4.3 Placing "importance value" on Ecosystem Goods and Services

There is an undeniable need for economic valuation of ecosystem goods and services to fundamentally understand not only the functionality of different ecosystem management approaches but also the basis for the sustainability of alternative courses of action (Bauhus, et al., 2010). Yet, people from different geographic areas certainly will not put the same degree of importance on the goods and services they enjoy from an ecosystem. In this study, the goods and services were valued in different communities and also along gender perspectives. Substantially, economic valuation of ecosystem services builds on the biophysical knowledge to estimate people's preferences for the benefits from ecosystem processes (UNEP, 2008). However, the study brought an understanding that, people do not place economic value on these goods and services beyond their purchasing power and/or income. It is worth sharing that, the adoption and use of economic value is widely accepted but concentrating more on the relevance of the goods and services, their importance to the development of human wellbeing and livelihood supports are what the study sought to achieve.

4.4.3.1 The Assessment of Gender Perspectives in Valuing the Ecosystem Services

Valuation of the ecosystem services in terms of gender revealed females giving a greater value to the ecosystem, though they had low representation. Out of the 100 respondents, there were 59 males and 41 females. Women are identified in the use of goods and benefits, especially from provisioning services due to their business and livelihood orientation in the society; they are the major buyers and sellers of the products. Females relatively scored bush meat (5.4), wood fuel

(6.4), food (8.7), climate modification (8.2), nutrient recycling (9.2) and soil formation (8.4) higher values than men – all are related to ecosystem services.

Women are involved much in farming activities in the area and this is heightened by the growing emigration of people from the Northern Region of Ghana (GSS, 2014b). The vast arable land and good climatic conditions of the area make it profitable for farming activities. The study aimed at ensuring extensive and balanced involvement of women literature reports of women's application of sustainable management practices that contribute to the maintenance, protection and development of ecosystems and biodiversity (Kelemen et al., 2016). The outcome of the gender-based valuation confirmed the validity of the existing knowledge that women and men have different needs; they construct different livelihoods for themselves according to their interests and abilities and make different choices based on their physiological make-up. Individuals' access to ecosystem services, benefits, positions in decision making processes are influenced by gender differences (Kelemen et al., 2016). This may explain why the "hunters" recorded no female in the group and only one female in all the selected communities actively participated in wood logging. Similar results were discovered when bushmeat trade in Techiman, Ghana was studied (Swensson, 2005). The study recorded no female hunter. Their feminism nature and/or human physiology is also a weakness for them to play such roles.

4.4.3.2 The Contribution of Focus Group in Ecosystem Valuation, their Criteria and Indicators

The use of Focus group discussion in the study of environmental issues provided a platform for participants to share deeper experiences and thoughts of the matter under discussion. Mazur & Bennett,(2008) employed the method to establish bounds of willingness to pay for environmental policy (WTP) design and improvement. They stressed that, it is advantageous to use when detailed observation of diverse opinions about an issue or problem are under examination or investigation. The degradation of the Afram Headwaters Forest Reserve and the history of past and present strategies towards improving the quality and quantity of goods and services really needed to identify specific people for their contribution. UNEP (2008), shared the possibility and advantage of valuing ecosystem services in biophysical terms basically due to the broaden understanding of ecological "production functions" and the availability of sufficient data. But in this study, it was an objective to include the experiences and views of local people to potentially capitalise on local knowledge for the management of the forest ecosystem. The inclusion of hunters, wood loggers, farmers, herbalists and charcoal producers provided an avenue to assess and map the ecosystem services in order to obtain a fair view of how vulnerable the forest resource is and to what stressor. It then translates that local people are key and important stakeholders in forestry and the management of forest ecosystems. This description is consistent with the modified definition of stakeholders from Hein et al., (2006): “any group or individual who can affect or is affected by the ecosystem’s services”. Whereas the ecosystem affects humans through its ecological functions, it is affected largely by humans’ capacity to convert the forest into a farmland or built area. The discovery of wildfire by this study as a major factor that influences the ecosystem’s vulnerability recalls IPCC’s assertion of anthropogenic cause of environmental challenges.

4.4.4 Sustainable Forest Management

All respondents realised the contribution of the forest resource to livelihoods and human survival, almost all fringe communities are actively involved in the Modified Taungya System (MTS) initiated and commenced in 2002 by the Government of Ghana. Respondents recognised the forest-based strategy to improving not only their livelihoods but also the restoration of the forest’s health and the production of timber for domestic use and export for foreign exchange. This has been confirmed in the assessment of the contribution of the MTS to the wellbeing of fringe communities in Worobong South Forest Reserve in Ghana (Asare-Kissiedu, 2014). In the study, livelihood improvement came next to assess to farm land as reasons why fringe communities signed the MTS contract. Livelihood benefits enjoyed from the Afram Headwaters Forest Reserve include income, food and non-forest timber products (NTFPs), bush meat etc. The MTS is a system of forest management where local members grow, nurture and manage planted tree species whilst growing their crops on the same piece of land. Apart from having total ownership over the crops, farmers involved in this system also receive some financial benefits (40%) when the trees, usually teak are harvested at maturity; the Government of Ghana also receives 40%; the traditional council (15%) and the remaining 5% goes to the community hosting the project. This mechanism, according to the Forestry Commission, was initiated to motivate and upscale the involvement of local people in the management of forest ecosystems. However, the many challenges confronting the system are related to the indiscriminate felling of trees, poor management of the plantation, inadequate support and delay in paying benefits to farmers and indiscriminate use of pesticides in MTS farms, recounted respondents. These constraints have demotivated farmers. They reiterated that, the present dilapidated nature of the forest isn't only linked to wildfire occurrences but also the lukewarm attitude put up by farmers as a response to the treatment meted out to them. A report on the successes of pilot projects, later challenges and difficulties stated that when institutional support was withdrawn from the communities, project beneficiaries were left to their own fate (Nutakor et al., 2014). Though the intangible benefits of farming through the MTS are but not limited to soil fertility and increased pollination; trees serving as wind brakes are noticed, the fast depletion of the forest is accounted to the same program. This participatory approach to managing the forest brings a sense of belonging and responsibility towards the development and protection of the forest resource. Upon this, the Forestry Commission classifies the MTS as traditional because of the reliance on the capacities, the assistance and the involvement of the local farmers to rehabilitate the forest. This becomes good news to the realisation of the protection, restoration and promotion of sustainable use of terrestrial ecosystem as enshrined in the Goal 15 of the Sustainable Development agenda.

There is a great deal of knowledge locked up in local communities; their synthesis and synchronization with scientific knowledge will provide enough pieces of information and tool to effectively design, formulate and implement policies that are sustainable. The Forestry Commission alone has over the years rolled out several policies and programs with the intention of reducing human pressure and safeguarding the forest but their implementation saw little or no contribution from the communities – the people for which the programs are meant for. A good example is the Community Forest Management Project (CFMP) which was similar to the MTS but the former came with livelihood support programs. In this project, the local people were trained in a number of skills and business ventures including rabbit and sheep rearing, snail and beekeeping, mushroom growing as alternative livelihood support. But according to them, the program lacked traditional or local inclination; all raw materials, including the animals were imported from elsewhere and they couldn't survive the test of weather and some other conditions.

4.4.5 Delineation of AHFR Using Land Cover Map

An unsupervised classification of the forest ecosystem revealed five main land cover types in the area namely: built up, forest, grass, teak plantation and farmland. But for the purpose of this study that focused on forest ecosystem vulnerability assessment, a supervised image classification resulted in three (3) classes which comprised Natural forest, Plantation forest and Bare land. It should be noted that, the Normalised Difference Vegetation Index (NDVI) for farmlands, bare lands and built up produced similar reflectance values and this resulted in categorising them as bare land. However, having noticed that, different land cover types produce varied ecosystem services, the land cover map was used as the elementary spatial information and/or boundary for the ecosystem services valuation and also as the boundary for the ecosystem.

The supervised image classifications of the study area for three periods (2000, 2010, and 2017) as found in Figures 16, 17 and 18 show the health of the forest. A strict comparison of the images over the period revealed a gradual reduction in the natural or dense forest cover compared to the growing hectares of plantation and bare land. The plantations are dominated by teak (*Tectona grandis*) which are harvested and exported for foreign exchange.

4.4.6 Forest Cover Change, Vulnerability and Human Security

The Millennium Assessment in 2005 reported of the ecosystem services degradation as a significant causative factor of harm to human well-being. The framework (Figure 1) provides the components of human well-being as the basic material needs for a good life, health, good social relations, security, and freedom of choice and action. Quoting a response from a participant on why people subject the forest to activities that render it vulnerable and depleted, the answer was tied to livelihood and the urge to improve their standard of living. He opined that "when a cutlass lays bare by one's side, he/she doesn't allow a snake bite"; to wit, "they can't certainly stay hungry or poor when the forest has all what it takes to provide them food and income".

The results of the forest cover change analysis (Figures 19 and 20) revealed different trends as well as variations in the rate of cover change between the years. Comparing the periods, it was disclosed that, deforestation took place massively from 2010-2017. Natural and plantation forest covers have been transformed from closed canopy forest to open canopy forest over the years. With the introduction of the Modified Taungya System in 2002, the gains were visible in 2010 but got deteriorated in the second period (2010-2017). Statistics from the 2010 Population Census held by the Ghana Statistical Service identified that, population in all fringe communities has increased significantly. The MTS enhanced the migration of people from the Norther regions to the area to capitalise on the fertile soil for farming (GSS, 2014b). It has been remarked that rapid population growth and governance challenges are closely related to and exacerbate the depletion process of natural resource and growing desertification threats (Kalame et al., 2011).

The vulnerability index of the AHFR stood at 2.46 which is fairly high but different parts of the forest had different vulnerability conditions. From figure 27, a combination of the moderately and highly vulnerable regions of the forest is a major issue of concern and agrees and this reflects the meaning of the index. From the study, the present vulnerability status of the forest is largely influenced by wild fires (44%), land use options (19%) and population density (17%). The combined impact of anthropogenic factors (wild fires, land use and population density) considered in this research work on the vulnerability of the forest stood at 80%. The environmental factors (precipitation and temperature) contributed 15% and a little of 5% from physical factors (elevation and slope). The issue of wild fires in the catchment places a toll on the biodiversity component of the forest. Apart from plants which face extinction upon been burnt, slow-moving animal species such as snails, tortoise etc. are equally vulnerable. The establishment and management of fire belts around the forest and near-by farm lands could do better to save the forest from this predicament. It was discovered that, heavy logs that are not able to be transported to the house are used to produce charcoal in the heart of the forest (appendix 8). This could only happen when there is poor supervision and surveillance from Forest Rangers and Field Officers from the Forestry Commission.

CHAPTER 5. CONCLUSION AND POLICY RECOMMENDATION

5.0 Summary of findings

The main objective of this study was to assess the ecological vulnerability of the Afram Headwaters Forest Reserve. This was carried out through, among others the application of GIS and Analytical Hierarchy Process (AHP) to allow for the quantification of the ecosystem's vulnerability. Moreover, the views of some focus groups – hunters, farmers, charcoal producers, wood loggers and herbalists in five fringe communities were sought on issues on forest ecosystem services supply and their value.

The study discovered that, the cultural services supplied by Afram Headwaters Forest Reserve is less recognised. Supporting and regulating services were prioritised over provisioning services. Despite the reduction in the supply of ecosystem services by the forest, respondents valued it at 6.2 over the 1 to 10 scale. Respondents were very particular about supporting services because of their livelihood orientation. All the respondents had farms and the question of crop production and yield was of great interest to them. Based on the informant interviews and focus group discussions it can be concluded that three criteria were considered in the valuation exercise.

1. Availability: The continuous supply of goods and services by the ecosystem formed a key component in placing a value.
2. Accessibility: A specific good and/or service may be available but the ways and means of getting it may be the challenge.
3. Importance: How useful, beneficial or needed a service is influence its value.

Again, the results of the study indicated that, the forest cover in AHFR has transformed over the years with growing hectares of bare lands. From the land use/land cover classification maps, the natural forest cover in general recorded a gain of 7.8% from 2000 to 2010 and a 11.1% drastic reduction 2010-2017. The notable change in the first period is attributed to the introduction of the Modified Taungya System in 2002. Plantation forest increased within this time frame at 63% but had dropped to a little of 46% from 2010 to 2017. Bare lands son the other had witnessed marginal increase over the years – from 7.17% in 2000 to 27.10% in 2017. The reduction in the supply of ecosystem services commensurate with the decline in forest cover. All these were confirmed in the change detection analysis, where over one-third of the entire forest had witnessed a 50% increased change in cover. From the expert judgement, the factors that influence the vulnerability of the forest ecosystem, wild fire contributed 44% whilst land use options and population density made 19% and 17% contribution respectively. The current plight of the AHFR is largely due to these anthropogenic factors; physical and environmental factors made little contribution. It is therefore envisaged that restoration programmes are capable of replenishing the forest cover but sustainable management of wild fires, land use choices and population growth are critical.

Furthermore, the combined analysis of AHP and GIS produced an environmental vulnerability index of 2.46. The value was interpreted on the natural breaks classification (low – 1, moderate – 2 and high – 3) as moderately vulnerable. The environmental vulnerability map also showed that 9197.1ha (46.3%) of the forest was moderately vulnerable, 6283.7ha (31.6%) and 4390.5ha (22.1%) were less and highly vulnerable respectively. Areas which recorded 50% increase in change from the change detection analysis have either moderate or high vulnerability. The biodiversity and genetic pool of the forest face extinction and these are concerns for discussion in the food and environmental security fraternity.

5.1 Conclusion

The assessment of threats from potential stressors to the forest resource offers chance of off-setting future risk. Vulnerability assessment play major roles in many facets of national and social development. Characterising the concept as a critical component of sound human and environmental security policies and practices, the conduct of periodic assessment, cataloguing assets and capacities and sustainable implementation of strategies are important.

In all these, the quantification or at least the ranking of vulnerability of a particular area influences decision-making and the distribution of capacities and resources in view of forest restoration. With about 70,895 people from the Offinso Municipality interacting directly and/or indirectly with the forest, the resource's vulnerability status will foster restoration programs. The relationship spans from agricultural activities in and off the forest reserve through livelihood developments to general ecosystem services.

Finally, the vulnerability of the forest is a human security issue. The loss of livelihood to forest degradation will cause people to lose the tangible and non-tangible elements necessary for them to pursue their self-interests and design a dignified lifestyle for themselves. Again, with the observed growing population and the fast depletion of the forest cover, there is the likelihood of intense competition for forest products and goods, including accessibility to fertile lands for crop production. The complexity of forest-population interactions and the management of the forest as observed in Figure 15 calls for a proactive approach in the management of the ecosystem, the services it supplies, human wellbeing and livelihoods.

5.2 Limitation

1. Time could not permit the zoning of the study area and mounting rainfall and temperature plots to effectively discuss that vulnerability is location specific. A single annual mean temperature and rainfall amount was interpolated.
2. There was a great challenge in determining the adaptive capacity of the forest and presenting it in a raster format. Further research need to be carried on to include this feature, including sensitivity analysis.

5.3 Recommendations

The forest-population synergy is not only a complex one but also sensitive. The study reiterates that, forestry is about people and not only tree and animal species and offers the following recommendations for policy makers for consideration:

1. Sustainable alternative livelihoods: Sustainable rural livelihoods must be developed, encouraged and even supported by stakeholders and government. The development and implementation of these alternatives must be done through a bottom-up approach where beneficiaries are involved or engaged from the conception stage to the implementation level. Forest dwellers must be integrated in the decision-making process, restoration and management programs. Beekeeping, animal husbandry and mushroom cultivation are noted to be viable ventures but will be sustainable if the value addition is highly upscaled.
2. Review of the Modified Taungya System: The aim of this restoration program will be fully achieved upon comprehensive review of terms and conditions to reward farmers even before trees are harvested. Most farmers who signed the contract lost their lives before the trees matured, demotivating several others from participating in the program. A system may be created for the Forestry Commission to properly supervise and appraise MTS farmers' work done, and remunerate them financially.
3. Wild fire management: The involvement of fringe communities in wild fire surveillance and management is in order. The capacity – education, livelihoods, resources – of forest

dwellers must be built to enable them take responsibility of the resource. Elsewhere, drones are used to monitor wild fire incidences which quickens response to the menace. Apart from this, the maintenance of green belts around the forest is commendable. A well-managed green belt has the potential of minimizing the spread and impact of wild fires on the forest ecosystem.

References

Adger, W. N. (2006). Vulnerability. *Global Environmental Change*, *16*(3), 268–281. http://doi.org/10.1016/j.gloenvcha.2006.02.006

Agyemang-Bonsu, W. K. (2007). *GHANA'S NATIONAL DEFINITION OF FOREST*. Retrieved from https://cdm.unfccc.int/DNA/cdf/files/2008/1706_ghana.pdf

Asare-Kissiedu, E. (2014). Contribution of Modified Taungya System to Forest cover and Livelihoods of Forest-Fringe Communities: A Case Study of Worobong South Forest Reserve in Ghana, (10362346).

Baatuuwie, N., & Leeuwen, L. Van. (2011). Evaluation of three classifiers in Mapping Forest stand types using Medium Resolution Imagery : a case study in the Offinso Forest District , Ghana. *African Journal of Environmental Science and Technology*, *5*(January), 25–36.

Barker, T. (2007). *Climate Change 2007 : An Assessment of the Intergovernmental Panel on Climate Change*.

Bauhus, J., Van der Meer, P., & Kanninen, M. (2010). *Ecosystem goods and services from plantation forests*.

Berkes, F., Colding, J., & Folke, C. (2003). Navigating Social - Ecological Systems: Building Resilience for Complexity and Change. *Cambridge University Press*, 1. http://doi.org/10.1017/CBO9780511541957

Bishaw, K. (2012). Application of GIS and Remote Sensing Techniques for Flood Hazard and Risk Assessment: The Case of Dugeda Bora Woreda of Oromiya Regional State, Ethiopia. *2012 Berlin Conference on the Human Dimensions of Global Environmental Change*, 1–17.

Blay, D., Appiah, M., Damnyang, L., Dwomoh, F. K., Luukkanen, O., & Pappinen, A. (2014). Involving local farmers in rehabilitation of degraded tropical forests : Some lessons from, (May), 1–17. http://doi.org/10.1007/s10668-006-9077-9

Boakye, E. A. (2011). DOES TAUNGYA FOSTER WOODY SPECIES DIVERSITY IN GHANA ? A case of the Afram Headwaters Forest Reserve DOES TAUNGYA FOSTER WOODY SPECIES DIVERSITY IN GHANA ? A case of the Afram Headwaters Forest

Reserve, 68.

Boughton, D. A., Smith, E. R., O'Neill, R. V. (1999). Regional vulnerability: a conceptual framework. Ecosyst. Health;5:312–22.

Brien, K. O., & Leichenko, R. (2008). *Human Development Report 2007 / 2008: Human Security , Vulnerability and Sustainable Adaptation*.

Care International. (2009). *Climate Vulnerability and Capacity Analysis Handbook*.

Castanedo, S., Juanes, J. A., Medina, R., Puente, A., Fernandez, F., Olabarrieta, M., & Pombo, C. (2009). Oil spill vulnerability assessment integrating physical, biological and socio-economical aspects: Application to the Cantabrian coast (Bay of Biscay, Spain). *Journal of Environmental Management*, *91*(1), 149–159. http://doi.org/10.1016/j.jenvman.2009.07.013

De Lange, H. J., Sala, S., Vighi, M., & Faber, J. H. (2010). Ecological vulnerability in risk assessment - A review and perspectives. *Science of the Total Environment*, *408*(18), 3871–3879. http://doi.org/10.1016/j.scitotenv.2009.11.009

Dowsett-Lemaire, F., & Dowsett, R. J. (2011). Comments on selected forest reserves visited in SW Ghana in 2008-2010 : wildlife (especially birds) and conservation status, *82*.

Dwomoh, F. K. (2009). Forest fire and carbon emission from burnt tropical forest : The case study of Afram Headwaters Forest Reserve. *Geo-Information Science*, 1–62.

FAO. (2010). *The definition of forest*.

FAO/IAEA. (2009). *Quality Control of Pesticide Products.*

Fianko, J. R., Donkor, A., Lower, S. T., & Yeboah, P. O. (2011). Agrochemicals and the Ghanaian Environment, a Review. *Journal of Environmental Protection*, *02*(May), 221–230. http://doi.org/10.4236/jep.2011.23026

Fussel, H.-M., & Klein, R. J. T. (2006). Climate Change Vulnerability Assessments:, 301–329. http://doi.org/10.1007/s10584-006-0329-3

Global Forum. (2004). *An Integrated Approach to Forest Ecosystem Services*.

Golden, N. H., Rattner, B. A. (2003). Ranking terrestrial vertebrate species for utility in biomonitoring and vulnerability to environmental contaminants. Rev Environ Contam Toxicol;176:67-136.

Groot, R. de, Wilson, M., & Boumans, R. (2002). A Typology for the Classification Description and Valuation of Ecosystem Functions , Goods and Services, (February). http://doi.org/10.1016/S0921-8009(02)00089-7

GSS. (2014a). *Population and Housing Census 2010: Offinso North District Analytical Report*.

GSS. (2014b). *Population and Housing Census: District Analytical Report, Offinso Municipality*.

Halpern, B. S., Selkoe, K. A., Micheli, F., Kappel, C. V. (2007). Evaluating and ranking the vulnerability of global marine ecosystems to anthropogenic threats. Conserv Biol;21:1301–15.

Hammill, A., Brown, O., & Crawford, A. (2016). *Natural Disasters and Human Mobility*. http://doi.org/10.1017/CBO9781107415324.004

Hein, L., van Koppen, K., de Groot, R. S., & van Ierland, E. C. (2006). Spatial scales, stakeholders and the valuation of ecosystem services. *Ecological Economics*, *57*(2), 209–228. http://doi.org/10.1016/j.ecolecon.2005.04.005

Hou, K., Li, X., Wang, J., & Zhang, J. (2016). Evaluating ecological vulnerability using the GIS and analytic hierarchy process (AHP) method in Yan???an, China. *Polish Journal of Environmental Studies*, *25*(2), 599–605. http://doi.org/10.15244/pjoes/61312

ICIMOD. (2012). *Value of Forest Ecosystem Services: A quantitative estimation from the Kangchenjunga landscape in eastern Nepal*.

IIED. (2015). *Sustainable Development Goals and Forests: A summary of UNECE*.

Ippolito, A., Sala, S., Faber, J. H., & Vighi, M. (2010). Ecological vulnerability analysis: A river basin case study. *Science of the Total Environment, The*, *408*, 3880–3890. http://doi.org/10.1016/j.scitotenv.2009.10.002

Kalame, F. B., Aidoo, R., Nkem, J., Ajayie, O. C., Kanninen, M., Luukkanen, O., & Idinoba, M. (2011). Modified taungya system in Ghana : a win – win practice for forestry and adaptation to climate change ?, *4*. http://doi.org/10.1016/j.envsci.2011.03.011

Kelemen, E., Potschin, M. B., Martín-López, B., & Pataki, G. (2016). Ecosystem services: A gender perspective. *OpenNESS Ecosystem Services Reference Book*, *1*, 1–5. Retrieved from www.openness-project.eu/library/reference-book

Kenter, J. O., Jobstvogt, N., Watson, V., Irvine, K. N., Christie, M., & Bryce, R. (2016). The impact of information, value-deliberation and group-based decision-making on values for ecosystem services: Integrating deliberative monetary valuation and storytelling. *Ecosystem Services*, *21*(April), 270–290. http://doi.org/10.1016/j.ecoser.2016.06.006

King, J.G., and Sanger, G.A. (1979). Oil vulnerability index for marine oriented birds. In: Bartonek JC, Nettleship DN, editors. Conservation of Marine Birds of Northern North America: Wildlife Research Report 11. Washington DC: Fish & Wildlife Service;. p.227–39.

Kulhavý, J., Suchomel, J., & Menšík, L. (2014). *Forest Ecology*.

Li, A., Wang, A., Liang, S., & Zhou, W. (2006). Eco-environmental vulnerability evaluation in mountainous region using remote sensing and GIS - A case study in the upper reaches of Minjiang River, China. *Ecological Modelling*, *192*(1-2), 175–187. http://doi.org/10.1016/j.ecolmodel.2005.07.005

Millenium Ecosystem Assessment (2005). *Ecosystems and Human Well-being*.

Marfo, E. (2010). *Chainsaw Milling in Ghana: Contexts, drivers and impacts*. Retrieved from www.chainsawmilling.org

Mazur, K., & Bennett, J. (2008). Using focus groups to design a choice modelling questionnaire for estimating natural resource management benefits in NSW, (March).

Ministry of Environment and Science (2002). National biodiversity strategy for Ghana.Ministry of Environment and Science.

Nutakor, E., Samar, B. S., Marfo, E., & Oduro, K. A. (2014). *Barriers to Sustainability of Alternative Livelihoods A Case Study of a Forest Reserve in Ghana*.

Ojoyi, M. M., Mutanga, O., & Odindi, J. (2015). An analysis of ecosystem vulnerability and management interventions in the Morogoro region landscapes , Tanzania, *8*(3), 662–680.

Ollinger, S. V. (2002). Forest Ecosystems. *Encyclopedia of Life Sciences*, 1–10.

Ouma, Y. O., & Tateishi, R. (2014). Urban Flood Vulnerability and Risk Mapping Using Integrated Multi-Parametric AHP and GIS: Methodological Overview and Case Study Assessment, 1515–1545. http://doi.org/10.3390/w6061515

Özkan, U., & Gökbulak, F. (2017). Catena Effect of vegetation change from forest to herbaceous vegetation cover on soil moisture and temperature regimes and soil water chemistry. *Catena*, *149*, 158–166. http://doi.org/10.1016/j.catena.2016.09.017

Parliament of Ghana. Forestry Commission Act , 1999 (1999).

Penghua, Q., Songjun, X., Genzong, X., Benan, T., Hua, B., Longshi, Y. (2007). Analysis of the ecological vulnerability of the western Hainan Island based on its landscape pattern and ecosystem sensitivity. Acta Ecol Sin;27:1257–64.

Robinson, L. A, Rogers S., Frid, C. L. J. (2009). Methodology for assessing the status of species and habitats at the OSPAR Region scale for the OSPAR Quality Status Report 2010. (Contract No: C-08-0007-0085 for the Joint Nature Conservation Committee). Lowestoft: University of Liverpool, Liverpool and Centre for the Environment, Fisheries and Aquaculture Science;. 30 pp.

Saaty, T. L. (1977). A Scaling Method for Priorities in Hierarchical Structures. *Journal of Mathematical Psychology*, *281*, 234–281.

Saaty, T. L. (1980). How to make a decision: the analytic hierarchy process. *European Journal of Operational Research*, *48*(1), 9–26.

Saaty, T. L. (1990). *The analytic hierarchy process*.

Steele, J. K. (2007). Influence of Elevation on tree species distribution in the southern Appalachian Mountains, *0*(0), 1075.

Swensson, J. (2005). Bushmeat Trade in Techiman, Ghana, West Africa. *Environmental Conservation*, *31*(1), 333. http://doi.org/10.1080/03066150310001691340

Talib, F., Rahman, Z., & Qureshi, M. N. (2011). Prioritising the practices of total quality management: An analytic hierarchy process analysis for the service industries. *Total Quality*

Management & Business Excellence, *22*(12), 1331–1351. http://doi.org/10.1080/14783363.2011.625192

Timmerman, P. (1981). *Vulnerability, Resiliece and the Collapse of Society: A Review of Models and Possible Climatic Applications*.

Tortell, P. (1992). Coastal zone sensitivity mapping and its role in marine environmental management. Mar Pollut Bull;25:88–93.

UNEP. (2008). *The Economics of Ecosystems and Biodiversity (TEEB)*.

Westoby, J. (1989). The purpose of forests. *N. Z. Forestry*, 1.

White, K. S., Ahmad, Q. K., Anisimov, O., & Arnell, N. (2001). *Climate Change 2001 (Technical Summary) : Mitigation, Impacts, Adaptation, and Vulnerability*.

Williams, L., & Kapustka, L. (2000). Ecosystem Vulnerability: a complex interface with technical components. *Environmental Toxicology and Chemistry*, *19*(4), 1055–1058. http://doi.org/10.1002/etc.5620190435

Wilson, M. A., & Howarth, R. B. (2002). Discourse-based valuation of ecosystem services : establishing fair outcomes through group deliberation, *41*, 431–443.

World Bank. (2004). *Sustaining Forest: A Development Strategy*.

Yang, Y., Watanabe, M., Li, F., Zhang, J., Zhang, W., & Zhai, J. (2006). Factors affecting forest growth and possible effects of climate change in the Taihang Mountains, northern China. *Forestry*, *79*(1 SPEC. ISS.), 135–147. http://doi.org/10.1093/forestry/cpi062

Ying, X., Zeng, G. M., Chen, G. Q., Tang, L., Wang, K. L., & Huang, D. Y. (2007). Combining AHP with GIS in synthetic evaluation of eco-environment quality-A case study of Hunan Province, China. *Ecological Modelling*, *209*(2-4), 97–109. http://doi.org/10.1016/j.ecolmodel.2007.06.007

Zereini, F., & Hötzl, H. (2008). Climate Changes and Water Resources in the Middle East and North Africa. *Environmental Science and Engineering*, 1–558.

ANNEXES

Appendix1: Questionnaire

QUESTIONNAIRE ON ECOSYSTEM SERVICES AND VALUATION ON AFRAM HEADWATERS FOREST RESERVE (AHFR)

Study Objective: This study aims at mapping ecosystem services provided by the AHFR and valuation of the services.

This exercise is a component of a master research work entitled "**Ecological vulnerability assessment: A case study on Afram Headwaters Forest Reserve in Ghana"** and meant to answer research questions under objective 1. Identify, map the types of ecosystems and their services based on people's perspectives over the past 27 years (1990 – 2017).

The information that will be obtained will be used for academic purposes and not for political gains. The participants of the Focus Groups Discussion will be assured of confidentiality of the information they will supply.

Researcher's Name: Richard Asante

Researcher's Affiliation: West African Science Service Center on Climate Change and Adapted Land use, University of Lomé, Togo.

1. PRELIMINARY

a. Name of Village………………………………..

b. Date of Interview………………………………

c. Name of interviewer……………………………

2. ECOSYSTEM SERVICES

a. When you think about forest, what is the first thing that comes to mind?

……………………………………………………………………………………………….

b. What do you like best about or in the forest?

……………………………………………………………………………………………….

c. Do you collect forest products (besides wood) which you did not plant? If yes, what do you collect (5 important products)? And for what purpose? (If for selling, ask the price)

……………………………………………………………………………………………….

d. What are the threats to forest maintenance?

…………………………………………………………………………………………….....

e. Which one (in e) do you think needs much attention?

……………………………………………………………………………………………………

f. ECOSYSTEM SERVICES VALUATION

f2. How much are you willing to pay at each collection?

	Goods	Uses	Source	Value (1-10)
	PROVISIONING			
1	Bush Meat			
2	Grass			
3	Wood fuel			
4	Medicinal plants			
5	Lumber			
6	Food			
7	Mushrooms			
	REGULATING			
8	Water Purification			
9	Climate Modification			
10	Air Regulation			
11	Disease Regulation			
	SUPPORTING			
12	Nutrient Recycling			
13	Soil Formation			

f3. Do you presently get enough of these goods as compared to the past?

i. YES { } NO { }

ii. If "NO", how is the reduction rate?

Small { } Huge { } Very Huge { }

iii. What could have caused this?

……………………………………………………………………………………………………

iv. Are you actively involved in efforts to prevent decrease in the number (population) of hunted and harvested plant and animals? If yes, please explain the preventive activities that you do? If not, why?

v. Do you report to someone if you find changes in the animal and tree population mentioned in (iv)? If yes, to whom? What information is shared?

vii. What are some ways to increase benefits from forest products?

……………………………………………………………………………………………………

g2. If we obtain these goods and services from the forest, in your own view, why do people subject the forest to this treatment?

………………………………………………………………………………………………
………………………………………………………………………………………………

3. FOREST CONSERVATION/ SUSTAINABLE ECOSYSTEM SERVICES PROVISION

a. Are there any plant and animal species you are prohibited from taking from the forest? Is there a season for not hunting/harvesting these species? How often do you hunt/harvest during this season?

b. Is there any time limitation when you can hunt the animals mentioned in (a)? (E.g. forbidden to hunt during a particular season, etc.). Please explain.

c. Are there commonly understood rules for hunting and harvesting in the forest? Are these rules produced by the village community or the government? What is the present management scheme?
………………………………………………………………………………………………
………………………………………………………………………………………………

f. For the above-mentioned rules, are there any sanctions if someone violates them?

g. Do you take/implement any action toward Forest Conservation? Yes { } No { }

h. If "NO", can you explain why (three main reasons)?
....

…………………………………………………………………………………………

i. If "YES", what types of actions do you implement to conserve the forest?

....

j. Your thoughts about continuous/long term ecosystem services provision:

- Is it important? Yes { } No { }

- Could you explain/justify your answer (three main reasons?

………………………………………………………………………………………………

………………………………………………………………………………………………

……………………………………………………………………………………………

Appendix 2: Respondents

Table 16: Number of respondents and their characteristics

Community	Hunters		Wood loggers		Farmers		Charcoal Producers		Herbalists		To	Gender	
	M	F	M	F	M	F	M	F	M	F		Male	Female
Abofour	3	0	2	0	3	4	1	2	3	2	20	12	8
Akrofoa	2	0	2	0	5	4	1	1	3	2	20	13	7
Asempanaye	2	0	3	1	3	5	2	2	1	1	20	11	9
Asuboi	2	0	2	0	4	4	2	2	2	2	20	12	8
Kwapanin	2	0	1	1	3	5	2	1	3	2	20	11	9
TOTAL	11	0	10	2	18	22	8	8	12	9	100	59	41

M – Male F – Female

Appendix 2. Confusion Matrices of Landsat 2010 and 2017

Table 17: Confusion matrix (Landsat, 2010)

Classified Data	Natural Forest	Plantation Forest	Bare Land
Natural Forest	**22**	3	0
Plantation Forest	11	**24**	9
Bare Land	0	0	**12**
Column Total	**33**	**27**	**21**

Table 18: Confusion Matrix (Landsat 2017)

Classified Data	Natural Forest	Plantation	Bare Land
Natural Forest	**36**	2	0
Plantation Forest	3	**43**	0
Bare Land	2	8	**21**
Column Total	**41**	**53**	**21**

Appendix 3: Ecosystem Services Valuation

Table 19: Valuation of ecosystem services by communities

	Abofour		Asempanaye		Asuboye		Akrofoa		Kwapanin		Average	
	M	F	M	F	M	F	M	F	M	F		To
Bush Meat	4	6	3	5	8	1	5	9	4	6	5.1	
Grass	5	3	2	3	4	2	4	1	2	3	2.9	
Woodfuel	4	8	4	8	7	4	7	5	5	7	5.9	
Medicinal Plant	8	10	3	6	7	10	5	8	8	9	7.4	
Lumber	7	9	5	7	6	3	7	6	6	8	6.4	
Food	5	9	10	8	9	10	8	9	10	9	8.7	
Fruits	6	5	4	5	5	7	8	2	4	6	5.2	5.9
Water Purification	5	4	6	5	4	5	4	7	5	8	5.3	
Climate Modification	6	8	8	10	9	10	9	8	6	5	7.9	
Flood regulation	4	3	4	1	2	4	3	2	4	3	3	
Disease regulation	5	5	7	5	8	3	7	5	6	7	5.8	5.5
Nutrient recycling	9	10	10	9	8	10	8	8	8	9	8.9	
Soil formation	9	8	8	10	8	8	10	8	7	9	8.5	8.7
Average/10	7.7	8.8	7.4	8.2	8.5	7.7	8.5	7.8	7.5	8.9		

Table 20: Scoring Ecosystem Services according to Gender Perspectives

Benefit	Males	Females	Mean	% Score
Bush Meat (BM)	4.8	5.4	5.1	51
Grass (Gr)	3.4	2.4	2.9	29
Wood fuel (WF)	5.4	6.4	5.9	59
Medicinal Plant (MP)	6.2	8.6	7.4	74
Lumber (Lu)	6.2	6.6	6.4	64
Food (Fo)	8.4	9	8.7	87
Fruits (Fr)	5.4	5	5.2	52
Water Purification (WP)	4.8	5.8	5.3	53
Climate Modification (CM)	7.6	8.2	7.9	79
Flood regulation (FR)	3.4	2.6	3	30
Disease regulation (DR)	6.6	5	5.8	58
Nutrient recycling (NR)	8.6	9.2	8.9	89
Soil formation (SF)	8.4	8.6	8.5	85
Mean	6.09	6.37	6.23	62.31

Appendix 4: AHP Comparison Matrix for Stressors

Table 21: Vulnerability Distribution

Condition	Area (Ha)	Percentage (%)
Low	6283.71	31.62
Moderate	9197.1	46.28
High	4390.47	22.09
Total	19871.28	100

Appendix 5: Pictures from Focus Group Discussion

Appendix 6: Wood sawing activities in the forest

Appendix 7: Photos of the forest

Appendix 8: Wild fire Hotspots