

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

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**VULNERABILITY AND ADAPTATION OF LIVELIHOODS TO CLIMATE CHANGE
AND VARIABILITY IN RIVER OFFIN BASIN IN GHANA**

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April, 2009

**VULNERABILITY AND ADAPTATION OF LIVELIHOODS TO CLIMATE CHANGE
AND VARIABILITY IN RIVER OFFIN BASIN IN GHANA**

**A Thesis submitted to the Department of Fisheries and Watershed Management of the Faculty
of Renewable Natural Resources, Kwame Nkrumah University of Science and Technology, in
partial fulfillment for the requirements for degree of**

Doctor of Philosophy (PhD) in Watershed Management

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April, 2009

I hereby declare that this submission is my own work towards the MPhil/PhD and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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Abstract

Since 1960, temperature rises of over 1°C and reductions in rainfall of approximately 20% have been recorded in Ghana with significant declines in discharge of the country's major rivers. River Offin basin sustains livelihoods of many rural communities who are predominantly rain-fed crop farmers, majority of whom depend totally on River Offin and its tributaries for their water needs. River Offin also provides water to Kumasi and its environs through the Barekese and Owabi dams. The ability of the Offin basin to continue to sustain livelihoods of the people that depend on it is highly threatened by changes in climate, mainly temperature and precipitation. It is for the need to prepare for the future in terms of adaptation for the very vulnerable whose livelihoods depend almost completely on ecosystem goods and services that this study is undertaken. The goal is to contribute to the processes of adaptation to climate change through the assessment of vulnerability derived from the impacts of climate change on river basin and dependent communities.

The methodology combined empirical historical data with active community participation and indigenous knowledge. The study was to tap indigenous knowledge whilst ensuring active community involvement in appreciation of problems and finding solutions. Historical climate data from 1961 to 2006 was collected from the Ghana Meteorological Agency and analysed for trends using linear regression. Discharge data of River Offin was also collected from the Ghana Hydrological Services and analysed for trends and regressed against the climate parameters to establish the relationship between river discharge and climate parameters. Data on livelihoods of communities living in the River Offin basin were collected using questionnaires, interviews and focus group discussions. The current and future vulnerability of the communities were assessed based on the current livelihoods and projected climate changes for the semi-deciduous forest region of Ghana. The general assumption is that livelihood options in the Offin basin will not change drastically in the foreseeable future and there will still be heavy dependence on agriculture, River

Offin and other climate limiting natural resources-dependent livelihoods. Possible adaptation strategies for communities in the Offin basin were explored with active participation of the vulnerable communities, expert contributions and desk study.

Precipitation in the Offin basin has reduced by approximately 17% whilst maximum and minimum temperature has also increased by 1.3°C and 1.0°C, respectively. Rainfall pattern has also changed significantly between 2000 and 2006 with the beginning and end of the rainy seasons difficult to predict and the minor season recording more rainfall than the usual major season. Relative humidity in the basin has decreased by 2%, signifying reduction in moisture in the Offin basin whilst Bright Sunshine Duration has been varying. River discharge has also decreased by 6.941m³/s in 1957 to 3.797m³/s in 2006. It was found that discharge of River Offin is impacted heavily by changes in climate, especially precipitation, and projected changes in climate will add to the worsening of vulnerability of communities in the Offin basin. Increasing temperatures and decreasing precipitation has also had negative impacts on agriculture leading to crop failures, bad harvest and loss of income. Reduced river discharge has affected water availability to the communities. This can be seen in the drying of rivers, streams and wells during the dry season, an indication of reduction in underground water. Poor water quality and high temperatures have resulted in diseases that is affecting the productivity of the people and affecting income levels.

Communities in the Offin basin have coped well with the impacts of climate change on their livelihoods. However, projected changes in climate will need well planned community-based adaptation strategies which involve all stakeholders and fits into a national adaptation plan of action, if they are to affectively adapt to the potential changes. The last section of the thesis recommends some adaptation strategies for communities in the Offin basin.

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List of Abbreviations

AKT	– Agro-ecological Knowledge Toolkit
AR4	– Fourth Assessment Report
BSD	– Bright Sunshine Duration
CAZRI	- Central Arid Zone Research Institute
CIFOR	– Centre for International Forestry Research
CRISTAL	– Community-based Risk Screening Tool – Adaptation and Livelihoods
DFID	– Department for International Development
EPA	– Environmental Protection Agency
FAO	– Food and Agricultural Organisation
GCM	– General Circulation Models
GMA	– Ghana Meteorological Agency
GPRS	– Ghana Poverty Reduction Strategy
HADCM2	– Hadley Centre Model 2
IISD	- International Institute for Sustainable Development
IPCC	– Intergovernmental Panel on Climate Change
IUCN	- The World Conservation Union

LEK	– Local Ecological Knowledge
NADMO	– National Disaster Management Organisation
NAPA	– National Adaptation Plan of Action
NCCSAP	– Netherlands Government Climate Change Studies Assistance Project
SCM	– Simple Climate Models
SEI	- Stockholm Environmental Institute
SOC	– Soil Organic Carbon
SOM	– Soil Organic Matter
UKTR	– United Kingdom Meteorological Office Transient Model
UKHI	– United Kingdom Meteorological Office High Resolution Model
UNEP	– United Nations Environment Programme
UNFCCC	– United Nations Framework Convention on Climate Change
WRI	- World Resources Institute
WMO	– World Meteorological Organisation
WWF	– World Wildlife Fund

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1.0 INTRODUCTION

1.1 Background and Justification

Climate is usually described in terms of the mean and variability of temperature, precipitation and wind over a period of time, ranging from months to millions of years, the classical period being 30 years (IPCC, 2007). Climate Change and Climate Variability are two similar but different phenomena. Climate variability refers to the inter- and intra-annual variation of the climate whilst climate change refers to the significant long-term modification or variation of the climate due to anthropogenic activities (Niasse *et al.*, 2004). This modification adds to the natural variability of the climate. For the purpose of this study, and for clearer understanding, the two terms described above are put together, thus Climate Change and Variability. Therefore, Climate change and Variability is defined as any significant climate change or variation of natural or anthropogenic origin (Niasse *et al.*, 2004). This change should, however, be observed over a long period of time to merit being classified as a climate change or variability.

Climate changes occur as a result of both internal mechanisms and external influences, also referred to as “climate forcings”, which include natural phenomena such as volcanic eruptions and solar variations, as well as human-induced changes in atmospheric composition such as emission of greenhouse gases (IPCC, 2007). These greenhouse gases, including CO₂ and methane, have more than doubled since pre-industrial times. Others are nitrous oxide, sulphur dioxide and ozone (Schimel *et. al.* 1996). Greenhouse gas emissions are mainly driven by human activities. For example, land use and land cover changes such as the clearing and burning of biomass in agriculture and other industrial activities have led to CO₂ concentrations increasing by almost 30 percent since the 18th century (Eriksen, 2001). As the concentration of these gases increases, so does the radiative forcing, and global mean surface temperature. Surface temperature observations indicate that there

has been a global mean warming of 0.3 to 0.6 degrees centigrade over the past one hundred years (Schimel *et. al.* 1996), a very rapid rate of change compared to past changes in climate.

Even though Africa has contributed least to the Greenhouse gas emissions (WDM, 2007), the continent is the most vulnerable to impacts of climate change. This is because Africa lacks the economic and social resources to adapt to the long term effects of climate change (IPCC, 2001). Africa's problems of high population growth rate, wars, famine, debt and diseases, have further been compounded by the impacts of climate change. According to the World Development Movement (2007), 160 million people are already dying every year from climate change related diseases and billions will face drought, floods, starvation and diseases in the coming years. African Development Bank (2002) also predicts that increase in droughts, floods and other extreme events would add to stress on water resources, food security, human health and infrastructure, constraining development on the African continent as a result of Climate change and Variability.

Sub-Saharan Africa has experienced severe effects of climate change and variability over the past decades. Particularly in West Africa, issues of climate change and variability are not issues for the future since its effects are already manifesting in the sub region. In the 1970s for example, the mean annual rainfall decreased by 10% in the Wet Tropical Zone and more than 30% in the Sahelian Zone while the average discharge of the region's major river systems dropped by 40 to 60% (Niasse, 2005).

Climate change and Variability impacts include those on water quality and water availability, vegetation or flora and the fauna of the ecosystem. These impacts render communities that depend on natural resources vulnerable. The extreme effects of climate change and variability have been very prominent on the water resources of the sub region. The decline in rainfall has affected the discharge of major water courses. A classic example is the drying up of a major water body such as

Lake Chad. The area of Lake Chad which was estimated at over 20 000km² during the wet years before 1970s shrunk to less than 7000km² in the 1990s. The consequence of this situation is the splitting of the lake into two parts with only the southern part containing water perennially.

Although Ghana can be considered to be fairly well-endowed with water resources, there is a high variability in the amount of available water within the year and over several years. Also in Ghana, climate change and variability are no longer issues for the future since the effects are already being felt. Opoku-Ankomah and Amisigo (1998), through the evaluation of 40 years of rainfall and runoff records, concluded that there has been a significant reduction in rainfall and runoff in South-western Ghana, and linked that to the influence of climate change. River basins in Ghana are projected to experience marginal vulnerability by the years 2020 and 2050 (Ghana EPA, 2000), resulting in secondary impacts on health, nutrition and energy-based industrial activities, if proper adaptation options are not put in place.

Ghana started experiencing severe energy crises since 1998 and this is partly attributed to a reduction in volume of water in the Lake Volta which produces hydroelectric power for the country. Though several reasons have been proffered for the reduction in water volume in the Volta Lake, recent studies have however linked this to climate change and variability (Andah, 2003). Almost a decade afterwards, further reduction in water volume has exacerbated a national crisis in the energy sector resulting in electricity outage and rationing throughout the country. This has affected the country socially and economically, with the closure of major industries.

The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) observes that ‘scarce water resources are becoming increasingly critical for Africa’. Climate change therefore, poses great danger to water availability for sustainable livelihoods in the region. Especially, with changes in rainfall patterns and increased temperature, the discharge of many rivers, drinking water

supplies, and irrigation practices may be affected. This will in turn affect food security and income levels of many watershed-dependent communities. Ability to provide safe drinking water on a regular basis to communities has become a major pre-occupation of many societies today, and in some areas it is becoming a security threat. The United Nations (1997) also acknowledges that providing adequate water for irrigation to a growing population constitutes a major international security threat well in to the future. This is against the backdrop that world water resources are reducing at a time that population is also increasing. One account (WRI, 1998) shows that from 1950 to 1998, availability of freshwater reduced considerably from 16000 to 6700 m³/yr per capita, thus making it abundantly clear the vulnerability of the whole globe to water stress in the years to come.

Issues of climate change and its impacts continue to take centre stage at all major conferences. The sensitivity of the situation is seen in the increasing number of researches in climate change (Stanhill, 2001). Between 1965 and 1995 alone, the number of articles published yearly in atmospheric science journals tripled (Geerts, 1999). Worldwide, communities that depend on watersheds are very vulnerable to the effects of climate change and variability. Niasse *et al.* (2004) defines Vulnerability to climate change as the proneness of a human or natural system to be affected by the negative impacts of climate change, variability and extreme events.

It is from this global, regional, sub-regional and local backgrounds of climate change and variability, and the need to prepare for the future in terms of adaptation especially for the very vulnerable who depend almost totally on the natural resources such as rivers and forests for their survival that this study is undertaken.

The River Offin basin sustains the livelihoods of many rural communities and is also very crucial to residents of Kumasi and its environs. Whilst most communities within the Offin basin depend totally

on the river for their water needs, the river also provides all the water needs of Kumasi and its environs through the Barekese and Owabi dams. The ability of the Offin basin to continue to sustain the livelihoods of the many people that depend on it is highly threatened by changes in temperature and precipitation. The current state of the Offin River and its basin and the sustainability of its functions and the communities that depend on it need a critical look in the face of climate changes for the necessary adaptation actions to be planned and implemented.

This study is very important because it will bring more insight into the situation of rural natural resource-dependent communities and the vulnerability of their livelihoods to changing environmental conditions by highlighting the extent of current changes in climatic patterns in the Offin river basin, the probable future trends and the consequences of such changes on the livelihoods of the people and eventually plan adequately for such changes. The findings of this work will contribute to Ghana's debate and education of the population on effects of climate change and also aid the country's preparations towards adaptation to the effects of climate change and variability.

1.2. Research Questions

The study proceeded by trying answering four main research questions:

1. What is the extent of change in climate in the Offin River basin?
2. How vulnerable is the river basin and its functions to changing climate?
3. What are the implications of the impacts of climate change on the River Offin basin for livelihoods in the basin currently, and in the future?
4. What are the possible, sustainable and most suitable adaptation options for people living in the River Offin basin?

1.3. Main Objective

To contribute to the processes of adaptation to climate change through the assessment of vulnerability derived from the impacts of climate change on river basin and dependent communities.

1.4. Specific Objectives

1. To elucidate rainfall and temperature trends in the Offin River basin
2. To assess the vulnerability of River Offin and its basin communities to climate change and variability
3. To explore possible, sustainable and suitable adaptation strategies for livelihoods in the River Offin basin.
4. To analyse the effects of agricultural land use forms on soil organic carbon and its relevance for climate change and adaptation.

1.5. Structure of the thesis

The thesis is organised in six chapters. **Chapter 1** presents a background introduction to the dissertation including the key research issues and questions, as well as the study goal and objectives.

Chapter 2 presents a review of terminologies used in the study and existing literature and also presents a theoretical framework for the study. The theoretical framework gives an overview of the stages through which this study will progress.

Chapter 3 presents the methodological approach. It starts with basic socio-economic background information about the study area and why that area was chosen for the study. The different methods used in data collection and analysis are also presented in this chapter.

In **chapter 4**, the findings of the study are presented. Separate sections focus on results of climate trends in the Offin basin; the relationship between the different climate parameters; discharge pattern of River Offin; and relationship between discharge of River Offin and temperature and rainfall. Other sections present results on the livelihoods of the people, their assets and how they are affected by changing climate; future climate projections and potential effects on livelihoods. There is also a section on land use activities in the basin and soil carbon stocks in the Offin basin.

A detailed discussion of the results is presented in the **Chapter 5**. **Chapter 6** contains the conclusions made from the study. It also includes recommendations for adaptation at both the national and community level. National level adaptation recommendations examines policy interventions, institutional collaboration among others whilst community level adaptation strategies proposes strategies focusing on agriculture, income generation, high temperatures, etc.

2.0 TERMINOLOGY, CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

2.1 Terminology

The following terms have been adopted and used as working definitions for the study:

i. Climate change and Variability

Any significant climate change or variation of natural or anthropogenic origin observed over a long period of time (Niasse *et al.*, 2004).

ii. Vulnerability

The degree to which a system is susceptible; or unable to cope with adverse effects of climate change including climate variability and extremes. It is a function of the magnitude of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC, 2001).

iii. Adaptation

All adjustments in behaviour or economic structure that reduce the vulnerability of society to changes in the climate system (Smith *et. al.*, 1996)

iv. Adaptive Capacity

Ability of a system to adjust to climate change (including variability and extremes) to moderate potential damages, take advantage of opportunities, or cope with the consequences (IPCC, 2001).

v. Adjustment

A system's response to exposures that does not fundamentally alter it; commonly but not necessarily short-term and involve relatively minor system modifications (Kasperson, *et. al.*, 2003).

vi. Coping

The wide-ranging set of mechanisms used or actions taken (by ecosystems or people) in reaction to threats or impacts. Coping includes pre-emptive measures, as well as more reactive adjustments and adaptations (Kasperson, *et. al.*, 2002).

vii. Coping capacity

The potential of a system to reduce impacts from stresses, not necessarily the actual coping actions taken in response to a stress. Actual coping can be markedly less than the capacity for coping, depending on system goals and priorities, institutional and informational obstacles, and timely access to coping resources, all of which vary across the human and ecological components of the system. (Kasperson, *et. al.*, 2002).

viii. Pre-emptive measure

A type of coping mechanism utilized or action taken (by ecosystems or people) to reduce exposure or sensitivity to a stress or perturbation. Pre-emptive measures in human systems are anticipatory or preparedness actions (Kasperson, *et. al.*, 2002).

ix. Stress

Cumulating pressure on a system resulting from processes within the normal range of variability, but which over time may result in disturbances causing the system to adjust, adapt, or to be harmed. (Kasperson, *et. al.*, 2002)

x. Resilience

The ability of a system to absorb stresses without changes in its fundamental structure and function that would drive the system into a different state or extinction (Kasperson, *et. al.*, 2002).

xi. Perturbation

A disturbance to a system resulting from a sudden shock with a magnitude outside the normal range of variability. Perturbations may arise from human driving forces, ecological (natural) events, or combinations of the two. Perturbations may arise from within or outside of the exposure unit (Kasperson, *et. al.*, 2002).

xii. Sensitivity

The degree to which a system is affected, either adversely or beneficially, by climate-related stimuli (IPCC, 2001).

xiii. Exposure

The contact between a system or system component and a perturbation or stress. Exposure is a function of both the magnitude and scope of the perturbation, and of the system with which it comes into contact (e.g., its location) (Kasperson, *et. al.*, 2002).

xiv. Exposure unit

Any system or part of a system that comes into contact with a perturbation or stress. In practice these units include individuals, groups, economic sectors, places, and various parts of ecosystems (Kasperson, *et. al.*, 2002).

2.2. Conceptual framework for climate change vulnerability and adaptation study

Adaptation should be a dynamic process of planning at various levels involving local, district and national participation. A successful and effective adaptation strategy for impact of climate change on natural resource-based livelihoods depends on a thorough understanding of the livelihood structure of the community and careful selection of indicators to determine the vulnerability of livelihoods to current and projected climate changes. A conceptual framework for climate change vulnerability and adaptation designed for this study is presented in Table 2.1.

The framework has four main parts. The first stage is the ‘Pre-assessment Phase’ where concepts are defined, adapted and adopted to suit the study, and relevant information gathered. This is followed by the ‘Vulnerability Assessment Phase’ where the real data collection for the study begins. Indicators are carefully selected and the different vulnerable groups are identified.

The third phase of the framework involves assessing future climate risks and vulnerability, using overlays and projections of future climate and scenarios of possible future vulnerability of livelihoods.

The last stage of the framework is ‘Adaptation Strategies’. It involves exploring possible adaptation strategies based on current situation and future scenarios generated, with assistance from literature and expert judgement.

Table 2.1. Conceptual framework for climate change vulnerability and adaptation study

Assessment Phase	Task	Summary of activities
1. Pre-Assessment	1.1 Scoping 1.2. Information Gathering 1.3. Project Design	Defining and clarifying concepts of vulnerability, gathering relevant information adapting and adopting concepts to suit the Study. Making a design for the study.
2. Vulnerability Assessment	2.1. Indicator selection 2.2. Identifying vulnerable groups 2.3. Current climate baseline 2.4. Climate change vulnerability	Indicators are carefully selected as well as the groups that are vulnerable. Data collection for Vulnerability assessment begins
3. Assessing future Climate risks and vulnerability	3.1. Climate trends 3.2. Future climate scenario simulation 3.3. Future socio-economic Vulnerability projections	Overlays, projections and scenarios of future vulnerability
4. Adaptation Strategies	4.1 Exploring adaptation strategies	Exploring possible adaptation strategies based on the current situation and future scenarios generated with assistance from literature and Expert judgement

2.3. Driving Forces of Climate Change

This section reviews literature on issues that contribute to climate change such as change in vegetation cover and greenhouse gas emissions.

2.3.1. Change in vegetation cover

Model studies of interaction between land cover and climate (e.g. Franchito and Rao, 1992; Varejao-Silva *et al.*, 1998) indicate that climate is sensitive to vegetation changes (Kutzbach *et al.*, 1996), though the extent of the effect is uncertain, and the scale of change very regional (Chase *et al.*,

2000). Vegetation cover affects climate through alteration of the physical characteristics of the land surface (like albedo, roughness, water conductivity, evapotranspiration, etc.) and by changing atmospheric gas composition, for example, CO₂ and CH₄ (Brovkin, 2002).

The perception that desertification is a man-made process is partly based on studies, such as Charney (1975), which suggest that removal of vegetation cover affects the rainfall-producing convection circulation in West Africa, leading to a decline in rainfall over the Sahel. The rationale behind the process hypothesized by Charney is that as the vegetation and canopy cover decrease, the albedo (shortwave reflection coefficient) at the Earth's surface increases and evapotranspiration may be reduced. Increased albedo in turn leads to decreased net radiation at the surface and, in turn, reduced latent and sensible heat. However, Fuller and Ottke (2002) argue that albedo has a relatively minor role in land-atmosphere feedback.

Lowered rates of evaporation (as a result of deforestation) affect the levels of precipitation and ultimately climate in deforested areas by lowering the rate of evaporative transpiration or evapotranspiration, i.e. the process by which water is evaporated from within the leaves of plants. It is estimated that more than 70% of water reabsorbed in forested areas into the atmosphere for rain formation is through evapotranspiration and this is lost through deforestation. Deforestation also leads to reduced interception of rainfall and therefore a greater proportion of precipitation being lost from the local area as run-off (Henderson-Sellers *et. al.*, 1988) and less moisture being recycled back into the atmosphere through latent heat.

Ranganathan, (1949) observed that the Chota Nagpur region in India, which had a good area under forest towards the turn of the 21st century used to receive fairly frequent afternoon showers known as instability rain during summer. Consequent upon the destruction of private forests, in spite of no apparent reduction in the monsoon rainfall, the instability decreased drastically. In order to

determine the effects of deforestation, Meher-Homji (1980a, 1980b) selected two groups of meteorological stations with long records of rainfall and rainy days in the Western Ghats. One group of stations had undergone considerable loss of forests in their vicinity (in recent years); the other group was free of such devastation. A statistical comparison produced evidence of declining tendency of rainfall and rainy days becoming more apparent after large-scale deforestation (Meher-Homji, 1991).

In south-western Ivory Coast where large scale cultivation has replaced forest during the last three decades with attendant modification in evapotranspiration rates (Myers, 1988), some areas have their rainfall reduced so much that wells have even dried up. In similar documentation of the effects of forest clearing in various parts of Africa, Mann (1987) notes that in the Southern Province of Zambia tree cover has greatly decreased and grasslands have been converted into croplands, as a result of which the River Magoye is now completely dry. In Ghana the area under closed forest has been reduced by 64%; in Gambia the forest area declined from 28% in 1946 to less than 3% in 1968; and in northern Senegal forest cover in various areas declined by between 20 and 80% between 1970 and 1974 (Anon, 1974); and in all instances the result appears to be more erratic rainfall and increasing dust levels.

2.3.2. Greenhouse gas emissions

Increasing anthropogenic greenhouse gases (GHGs) has the largest effect on causing global warming (Hansen and Sato, 2001) and this is confirmed by different models (IPCC, 2001). This necessitated the Kyoto Protocol designed to slow emissions of several GHGs (Hansen, 2005). Greenhouse gas emissions into the atmosphere are closely linked with land use change and deforestation in particular and this review does not seek to isolate it. Tropical deforestation releases 1.5 billion tonnes of carbon each year into the atmosphere, and this accounts for nearly 20 per cent

of carbon emissions due to human activities. This is projected to release an estimated 87 to 130 billion tonnes of carbon by 2100, which is greater than the amount of carbon that would be released by 13 years of global fossil fuel combustion (CSIRO, 2007). DeFries *et al.*, (1999) estimate that land use change has contributed at least one third of the total carbon released into the atmosphere from human activities. Burning and decomposition of the forest biomass after deforestation also leads to a transient increase in atmospheric CO₂ (Henderson-Sellers 1988). Carbon usually stored in tissues of trees makes vegetation an important carbon sink and clearing of vegetation reduces the potential of trees as carbon sinks (Hulme and Kelly, 1993). As more greenhouse gases are released into the atmosphere, ambient temperatures increase and sea surface temperatures (SST) rise. Zheng and Eltahir (1998) state that sea surface temperatures may be a dominant factor influencing rainfall variability in general, and the Sahelian climate in particular (Rowell *et al.*, 1992).

Tropical terrestrial ecosystems across the African continent may play an increasing role in the global carbon (C) cycle with potentially significant climate change implications (Stephens *et al.*, (2007). In sub-Saharan Africa alone, the role of land use change in controlling CO₂ emissions and annual C budgets at regional and global scale may be more critical than in any other region (Houghton and Hackler, 2006). This observation by Houghton and Hackler (2006) may even be an under estimation because previous studies on the African continent C budget have usually focused only on either forests or conversion of forest to cropland (Houghton and Hackler, 2001, 2006) neglecting other human activities such as, fuelwood harvest and fertilization of farm lands. Other factors affecting net primary productivity also play a critical role in regional and global C budgets (Nemani *et al.*, 2003; Sankaran *et al.*, 2005; Reich *et al.*, 2006).

Forests serve as important sinks for GHG emissions. A study conducted in Ghana in 1994 estimated that CO₂ emissions by forest and grassland conversion amounted to 5738 Gg while the total CO₂ removals by the country's sinks was estimated at -25,618 Gg. This gives the net CO₂ removal by

sinks in the land use change and forestry sector as -19,878 Gg for 1994 (Ghana National Initial Communication to UNFCCC, Ghana EPA, 2000). The CO₂ removals by the country's sinks however reduced drastically from -40275 Gg to as low as -5411 Gg (1994) within about two decades. The sharp decline was attributed to circumstances such as; seasonal biomass clearings for farming; grazing lands; mining and settlements; charcoal and fuelwood use increasing over the years (approximately 2.3 times of wood harvested for timber in 1973); minimal restoration of deforested lands; high population growth leading to shortening of fallow periods; and falling stocking levels of timber in the high forest area.

Hansen and Sato (2001) argue for greater emphasis on the other greenhouse gases (Methane, troposphere ozone, black carbon or soot, reflective aerosols) aside carbon dioxide (CO₂), because the estimated methane (CH₄) forcing, for example, is half as large as that for CO₂. But although CH₄ is included in the Kyoto Protocol, it is given less attention compared with CO₂. From their argument, Hansen and Sato (2001) states although the sum of all “forcings” coincidentally is similar to that for CO₂ alone, knowledge of each of the forcings is needed for development of effective policies. They further single out CH₄ to deserve greater attention and maintain that it should not be lumped together with CO₂.

2.3.3. Deforestation in Ghana

Forests in Ghana can be classified into two broad ecological zones: the moist Tropical High Forest which comprises one-third of the country mostly in the South and the Savanna Woodland which occupies the remaining two-thirds (Kotey *et. al.*, 1998). The Tropical High Forest is sub-categorised into the Tropical Rain Forest and the Tropical Moist Semi-deciduous Forest (Antwi, 1999). These ecological zones follow the rainfall pattern of the country. The annual rainfall is as high as 2,000 mm in the south-western part of the country (Tropical Rain Forest) but decreases towards the

northeast, dropping to 1,000 mm at the northern border area (Savanna Woodland). The moist semi-deciduous rain forest has an average annual rainfall of less than 2000mm but not less than 1250 mm.

Deforestation is a major problem in Ghana. At the turn of the 20th century, Ghana had about 88 000 km² of forest. By 1950, the area had been reduced to 42 000 km² and at 1999 the closed forest stood at 15 000 km² with the rate of deforestation in Ghana estimated at 22 000 hectares per year (Fairhead and Leach, 1996). In 1992, IUCN estimated that only about 1.5 million ha of "intact closed forest" were remaining in Ghana (IUCN, 1992). Deforestation in Ghana reached a peak between the 1950s and the 1970s when about a third of Ghana's forest was estimated to have disappeared in the 17 years between 1955 and 1972 (Hall, 1987). The annual rate of deforestation was said to have slowed in the 1980s to about 22,000 ha (FAO, 1988; IUCN, 1992) and the area of Permanent Forest Estate (PFE) is an estimated 1.60 million hectares (ITTO, 2006 /1). Ghana's alarming deforestation rate was noted as early as 1908. Even within the reserved forests Hawthorne and Abu Juam (1995) indicated that just about half of the reserved forests, some 900,000 ha, was in "reasonable condition" and the remainder was "mostly degraded" or worse way back in 1993.

For many years, agricultural changes were partly responsible over many years for the forest loss, but recent evidence show that there are other driving forces and factors, which have influenced the face of forests in Ghana (Agyarko, 2000). For example, multinational players in the timber industry are usually not interested in the long-term management of the forest but in short-term profit maximisation. As a result they cut as many trees as they can with no regard for the future of the country in terms of the forest and climate change.

Agricultural activities, mainly unsustainable crop farming, have been responsible for many years for the forest loss. Farming has led to a considerable loss of Ghana's forest and, therefore, its biodiversity (Hawthorne and Abu-Juam, 1995). The area of land under agriculture increases every

year due to the extensive system of farming being practiced in the country, which also involves cutting of vegetation and rapidly increasing population growth. The farming systems involve slash and burn of forest and grassland before planting. However, due to population growth and pressure on the land, long fallow period necessary for the forest to regenerate fully is not possible. Agyemang and Brookman-Amissah (1987) attributed 70% of deforestation to shifting cultivation (bush fallow). Demand for subsistence agricultural cultivation has been compounded by demand for cash crops like cocoa, coffee, oil-palm, tobacco and for urbanization and infrastructural development (Agyarko, 2000).

Other factors driving deforestation in Ghana include logging, annual bushfires, surface mining and infrastructural development. Bushfires occur annually in the dry season and Hawthorne (1994) indicated that only about 20% of Ghana's forest zone was covered by forest which has not burnt regularly. Underlying these factors are forest policy failures, unrealistic forest fee regimes, external prices of timber and weak institutional structures. Clearing of land for expanding settlements constitutes a major problem in the forest sector of Ghana. The National Land Use Planning Committee estimated in 1990 that a unit increase in the urban population requires an additional land area of 33.3 ha for the provision of additional housing, infrastructure and other social services (Agyarko, 2000). This gives a clear indication that with increase in urban population, more land is required for technical and social infrastructure development. This depletion of surface cover has led to erosion in many parts of the country, which is accelerated wherever there is a depletion of vegetation cover (Nsiah-Gyabaah, 1994).

On average, the Annual Allowable Cut has been exceeded by more than 46% during the period 1990-1998 (Agyarko, 2000) and this is not good for the country. With the country's realization of the immense damage caused, measures are being undertaken to prevent excessive over-exploitation of forest resources. To this end, Ghana has introduced a new Timber Utilisation Contract system to

improve efficiency, transparency and accountability in forestry, particularly in forest production activities.

2.4. Climate trends

The section presents an overview of existing literature on observed global, regional, sub-regional and national climate trends as well as a summary of future projection.

2.4.1. Trends in Global Climate

The issue that the climate is changing is no longer subject to debate as several studies conducted by researchers all over the world confirm it. According to Hansen *et. al.*, (2001) global surface temperature increased in the past century by more than 0.5°C and NASA (2006) actually puts the warming over the past 100 years at 0.8° C or 1.44° F. The U.S. National Academy of Sciences confirms that the last few decades of the 20th century were the warmest in the past 400 years (National Research Council, 2006).

NASA scientists note 2005 as the warmest year since the late 1800s, and 1998, 2002, 2003 and 2004 followed as the next four warmest years (NASA, 2006). This means the five warmest years over the last century occurred in the last ten years. The 2005 atmospheric warming figures are very notable because until 2005, the 1998 warming was said to have been enhanced by the strongest El Nino of the century which added 2°C warmth to global temperatures (Hansen *et. al.*, 2006) and some researchers had used that to counter the claims of global warming. However global temperatures have returned to about the level of 1998 without the help of any El Nino. Over the past 30 years, the Earth has warmed by 0.6° C or 1.08° F and 0.8°C in the last century and Hansen *et al.*, (2006) concludes that there has been slow global warming, though with large fluctuations, over the past century until 1975 and subsequently the temperature has increased by 0.2°C per decade. Increase in

global temperatures is in response to increasing emissions GHGs and they are consistent with expectations (IPCC, 2001). Land surface precipitation has also increased over the same period in the mid- to high latitudes, but shows a decrease in the tropics and subtropics (IPCC, 1996) and overall areas of the world affected either by drought or excessive wetness have increased.

In Africa, atmospheric warming of 0.7°C over the 20th century has been observed which is a result of 0.05°C warming per decade through the 20th century as well as increased precipitation for East Africa (Hulme *et. al.*, 2001; IPCC, 2001)

2.4.2. Future Global Climate Projections

Identifiable trends in certain extreme climatic events, such as extremes in temperature or precipitation, adds to the body of evidence that there is appreciable human effect on the climate (IPCC, 2007), and potentially have important consequences on society and natural systems in the coming years (Easterling *et. al.*, 2000). The Earth has already warmed by 1.4 degrees Fahrenheit above pre-industrial levels and the consensus among scientists is that an increase of 3.6 degrees Fahrenheit could have disastrous consequences; if the status quo holds, the Earth will warm by 7.2°F by 2100 and more than 15°F by 2300 (US DoE, 2008). Hansen and Sato (2001), indicate that there has been remarkable deceleration in the growth rate of GHG climate forcing in the past 20 years mainly due to phasing-out of chlorofluorocarbons (CFCs) but notwithstanding this, it is suggested that global warming at a rate $+0.15 \pm 0.05^{\circ}\text{C}$ per decade will occur over the next several decades, judging from practical constraints on changes in emission. Although this predicted warming is moderate than in business-as-usual scenarios, if it is maintained for a century the Earth's temperature will approach that of the middle Pliocene (2.75 million years ago), when the world was about 2°C warmer than today and sea level was at least 25m higher (Dowsett *et al.*, 1996)

Due to improvements in climate modelling, it is now possible to make relatively accurate predictions of future climate. However, they are still characterized by systematic errors and limitations in accurately simulating regional climate conditions (Easterling *et al.*, 2000). However, after the IPCC Second Assessment Report (IPCC, 1996), there has been increasing agreements in climate change analysis and simulations from different sources (Hansen *et al.*, 2006). This is a sign of increasing confidence and credibility of the predictions but it must be added that agreement in models does not guarantee those predictions happening in real climate system or time (Easterling *et al.*, 2000).

The IPCC has projected that if greenhouse gas emissions, the leading cause of climate change, continue to rise, the mean global temperatures will increase between 1.4 and 5.8°C by the end of the 21st century (IPCC, 2001). Other studies predict increases in mean temperatures, more extreme high temperatures and fewer extreme low temperatures, with decreases in diurnal temperature range (Zwiers and Kharin, 1998) and increased intensity of precipitation events (Kothavala, 1997). Other models also predict a general drying of mid-continental areas during summer (Wetherald and Manabe, 1999) because of enhanced potential evaporation and strong temperature increases outweighing any precipitation increases, with an increased chance of drought (Kothavala, 1999). Drought is projected to affect the great grain-growing areas of Europe, North America and Russia, as well as the Middle East and Central Asia, North Africa and Southern Africa, Amazonia/Brazil, and Central America (Easterling *et al.*, 2000). The UK's Hadley Centre for Climate Prediction and Research concludes that the percentage of the Earth's land surface that suffers from extreme drought has trebled from just 1% to 3%, in less than a decade at the start of the twenty-first century. But the centre's climate model projects that this trend will continue until extreme drought conditions prevail over some eight per cent of the land surface by 2020 – and then accelerate until extreme drought affects no less than 30 per cent of the globe by 2090. Historically a total of 20% of the Earth's land

surface has been in drought at any one time, be it extreme, severe or moderate. This has now risen to 28% and is predicted to be 35% by 2020 and cover 50% – half the Earth's land surface and still rising – by 2090. The droughts will also be much longer in duration. Increased frequency of low summer precipitation, the probability of dry soil, and the occurrence of long dry spells has also been predicted by Gregory (1997). Kitoh *et al.*, (1997) also predicted an increase in inter-annual variability of the Indian monsoon, thus increasing the likelihood of droughts and floods in that region.

Although most models forecast a severe, overall drying pattern over the earth surface, certain areas will get much wetter. A wetter future is forecast for Central Africa, the Horn and East Africa and parts of coastal West Africa, China and Eastern Asia, and high Northern latitudes. Although higher rainfall could come equally in the destructive form of heavy inundations as well as beneficial rain, it raises the intriguing possibility of environmental refugees from a dehydrated Europe flooding into Africa by the mid-century. Projected warming for Africa ranges from 0.2°C per decade (low scenario) to more than 0.5°C per decade (high scenario), according to Hulme *et. al.*, (2001) and IPCC (2001).

2.4.3. Climate Trends in West Africa

The climate of West Africa has a unique feature of being highly variable (Hulme, 2001); varying from relatively stable humid areas with precipitation greater than 2000 mm per year through the sub-humid and semiarid zones as one moves from the south into the Sahelian north renowned for having one of the highest levels of climatic variability (spatial and temporal) in the world (Wang, 2004). In the recent past, the West African region experienced unusually high rainfalls in the 1930s and 1950s and this was followed by severe drought from the 1960s to 1990s. This 30 year period of drought actually observed mean annual rainfall drop by as much as 30%, from 512 mm (1931-60 average) to

410mm (1971-2000 average) and culminated in the devastating Sahelian droughts of 1973, 1984 and 1990. (L'Hote, 1995; Hulme, 2001; Nicholson, 2001; Le Barbe *et.al.*, 2002; Dai *et. al.*, 2004).

Knowledge on the current climate situation in West Africa is not conclusive. There are still gray areas in the climate data as a basis to make firm conclusions on the prevailing situation but even under such condition, there are indications in most parts of West Africa that rainfall has been gradually increasing since the mid-1990s, compared to the 30 year mean for the dry period of 1966-1997 (Nicholson, 2005; Dai *et. al.*, 2004). In a study of rainfall during the period of 1998 to 2003 in some parts of West Africa covering most of Mali and Burkina Faso and the most northerly part of Ghana, Nicholson (2005) concludes that while still being below the wetter conditions that prevailed in the region from 1930 to 1965, the data reveals a clear recovery in rainfall compared to the 30-year climatological “normal” for the very dry period 1968–97. The recovery was most marked in the western Sahel.

2.4.4. Future Climate Projections for West Africa

Regional climate models for West Africa are still inadequate to make major predictions on the future climate of West Africa with any accuracy or confidence based on current climate models (Hulme 2001, Brooks 2004; Boxel 2004). For example whilst models such as CCSR-98 and HADCM2 predict continuing aridification, other models (e.g. CSIRO and CGCM1) are anticipating more favourable trends of increasing rainfall. Jones (2005) gives an overview of the peculiar challenges and tries to give possible solutions associated with modelling local climate change in Africa. However, there have been attempts using various means to create future climate scenarios for West Africa, based on some assumptions such as atmospheric concentration of greenhouse gases, notably carbon dioxide, rising with associated climate changes.

Hulme (2001), using a range of greenhouse gas emission rates and other variables, generated continental scenarios ranging from increases of 0.2°C to over 0.5°C per decade. Thus by 2100, Africa could on average be from 2°C to 6°C hotter than present. This projected range of increased temperature, resulting from anthropogenic greenhouse gas emissions, is now universally accepted (IPCC 2001, 2007; Brooks, 2004). Paeth and Hense (2004) suggest that southern West Africa will become wetter into the 21st century but are less clear about northern Sub-Saharan Africa. The models examined by Hoerling *et al.*, (2006) show this trend intensifying in future decades. They project that the Sahel monsoon will be some 20% to 30% wetter by 2049 compared to the 1950-99 average (Hoerling *et al.*, 2006).

Wang and Eltahir (2002) predict increases in rainfall as CO₂ levels rise and have also accurately simulated the 30 year drought period of the late 20th century, with sea surface temperatures (SST) as the primary driver. They find that an increase of CO₂ concentration and SST causes the regional biosphere-atmosphere system to become wetter and greener, with the radiative effect of CO₂ and improved plant-water relation dominant in the Sahelian grassland region and the direct enhancement of leaf carbon assimilation dominant in the tree-covered region to the south. They also show that biosphere-atmosphere systems under constant SSTs at higher CO₂ level are more resilient to drought-inducing external forcings. This finding suggests that the regional climate in Sahel, which tends to alternate between dry and wet spells, may experience longer (or more frequent) wet episodes and shorter (or less frequent) dry episodes in the future than in the past (Wang, 2004). However, recent research by Held *et al.*, (2005), using new global climate model, also simulates the 20th century drought years but predicts a significantly drier Sahel by the end of the 21st century, due primarily to greenhouse gases. From the above discourse, it is evident that how rainfall will be in West Africa in the future is not very certain (IPCC, 2007).

2.4.5. Climate Trends in Ghana

One very recognisable feature of rainfall in Ghana is its seasonal character and very high year to year variability. Rainfall in Ghana rarely prolongs for more than 3 hours in all parts of the country. In the dry months, rainfall duration would not reach 10 hours in a month and even in the wet seasons, the average total duration of rain is only about 30 to 40 hours in a month. Temperatures in Ghana are generally high, with little variation from year to year. Annual mean temperatures also show only small variations across the country. From 1961 to 1990, temperature rise of about 1°C and reductions in rainfall of approximately 20% were recorded in Ghana (Ghana Initial National Communication to the UNFCCC; EPA, 2000).

2.4.6. Future Climate Projections for Ghana

Both maximum and minimum temperatures are projected to increase in all agro-climatic zones of Ghana with the highest increases (3°C) expected in the Sudan savanna where temperatures are normally high, and 2.5°C in all other agro-climatic zones (EPA Ghana, 2000). The mean daily temperatures will increase by about 2.5°C to 3.2°C, if the mid-range atmospheric sensitivity of 2.5°C is assumed, over the 1961 to 1990 baseline temperatures by the year 2100. This is higher than the global average of 2°C over the same period (IPCC, 2007). A 2°C rise in temperature is very significant because even if a 1°C rise in temperature is attained by 2100 above current mean temperatures, it would be larger than any century time-scale trend for the past 10,000 years.

Mean annual rainfall is projected to decrease by 170 mm in the Sudan Savanna Zone, 74 mm in the Guinea Savanna Zone and 99 mm in the Semi-Deciduous Rainforest Zone, respectively by the year 2100. The only exception to these rainfall decreases was observed in the High Rainforest Zone where the mean annual rainfall is projected to increase by 1105mm by the year 2100. The predicted trend in rainfall in all regions is similar to the observed trend during the baseline period. However,

the observed rate of decrease in rainfall of about 5.4% per decade between 1961 and 1990 is larger than the average predicted rate of decrease of about 4% per decade between 2000 and 2100, due to the projected increases in the high rainforest. Projected changes in rainfall are also subject to uncertainty mainly due to the uncertainty in the way the atmosphere will respond to increased concentrations of greenhouse gases.

The Ghana National Initial Communication to the UNFCCC also projects average solar radiation to increase by 1.95MJ/m² in the forest-savanna Transition Zone, and the Semi-Deciduous Rainforest Zone, 1.0MJ/m² in the Guinea Savanna Zone, and 0.75MJ/m² in the High Rainforest Zone, by the year 2100.

2.5. Impacts of climate change

This section presents a review of literature on how climate change will affect critical sectors of human endeavour. The sectors reviewed are water resources, food security, poverty, health and energy needs.

2.5.1. Water resources

Among the various effects of climate change, increase in global mean temperature and changes in rainfall is likely to be the most hydrologically important (Linhares, 2007). Complete disappearance of Kilimanjaro glaciers by 2015 – 2020 at current global warming rates has been projected by Thompson *et al.*, (2002). The impacts of climate change on water resources are closely linked with changes in land cover and land use and have on some occasions been difficult to isolate. This is so because human-induced land cover and land use changes constitute a major source of anthropogenic influence that can independently cause both significant hydrological and climate changes through its

direct effects on the hydrological cycle and greenhouse gas emission respectively. Reduction in water availability has been linked to thermocline circulation collapse and accelerated climate change. It must be noted that both thermohaline circulation collapse and accelerated climate change not only alter the annual volume of runoff, but in large regions change the timing of streamflow through the year – and this change in timing can have very significant impacts on resource availability and reliability (Arnell, 2006).

In Africa, warm sea surface temperatures may lead to increased droughts in equatorial and subtropical Eastern Africa (Funk *et al.*, 2005). Less precipitation during already dry months can lead to drought and increased desertification (IPCC, 2001b). Some major rivers will be highly affected by climate reductions. From Arnell (2006), accelerated climate change increases the numbers of people with an increase in water resources stress by 2055 from around 1 billion to approximately 1.3 billion, with most of the increase occurring in Europe, North and Central America, and West Africa. Although the effects are not expected to be the same across the globe, accelerated climate change is expected to have relatively little effect on the numbers of people with an apparent decrease in water resources stress.

2.5.2. Food security

The impacts of climate change on food security depend on changes in the seasonal timing of temperature and water availability, changes in CO₂ concentrations, and changes in the prevalence of pests and diseases and their effects on crop productivity (Arnell, 2006). Agriculture, especially crop production, has a long history of its fair share of negative climatic impacts. Ranganathan (1949) observed that the Chota Nagpur region (India) used to receive fairly frequent afternoon showers known as instability rain during summer which favoured tea plantations but a significant reduction

in these instability rains has led to a disappearance of the tea gardens. This signifies a reduction in the food availability to the Chota Nagpor region.

The greatest reductions in food productivity is expected in the equatorial and tropical regions where crop growth is usually rain-dependent and temperature-limited (Arnell, 2006), as is currently being experienced in Africa (IPCC, 2001). Increased heat stress during extreme events can also reduce productivity in temperate regions, and effects of pests and disease depend on local climatic limits (Arnell, 2006). Although increases in CO₂ concentration are known to increase productivity of most key food crops due to the important role of CO₂ in photosynthesis, interaction with other factors such as changes in temperature, water availability and nutrient status (Arnell, 2006) may negate any expected positive impact of increased atmospheric CO₂ since warm temperatures may also lead to faster depletion of the limited oxygen supply, negatively affecting fisheries, and limiting lake overturn (Fick *et al.*, 2005)

Some studies (e.g. Parry *et al.*, 2004) argue that since gradual climate change would result in a general shift in world food production to higher latitudes, increases in production of cereals in developed countries could possibly compensate for reductions in developing countries but all scenarios developed indicate that crop prices would rise, leading to an increase in risk of hunger, particularly in Africa. Accelerated climate change would exaggerate this pattern, leading to greater increases in food prices (Arnell, 2006). Warming temperatures may also negatively affect fisheries production (Roessig *et al.*, 2004).

2.5.3. Poverty

The World Bank President Robert Zoellick is reported to have stated at the United Nations Climate Change Conference in 2007 in Bali that climate change is a “development, economic, and investment challenge” (Agrawal, 2008). Earlier writings on climate change had tended to focus

more on its links with biodiversity loss (WWF, 2006), spread of pathogens and diseases, land use planning, and ecosystem change (Easterling and Apps, 2005; Tompkins and Adger, 2004). Most economies in developing countries, however, are heavily dependent on natural resources and agriculture, and are mostly sidelined in climate change discussions. In recent years the development implications of climate is beginning to receive the needed attention and has been referred to as the defining development challenge of our generation.

There is a strong link between climate and livelihoods. Africa depends heavily on rain-fed agriculture making rural livelihoods and food security highly vulnerable to climate variability such as shifts in growing season conditions (IPCC, 2001b). Changing climate has had lots of negative impacts on many households in Africa. Climate change affects agriculture, forest productivity, biodiversity and other natural resources which is the main base for economic activity for most households in Africa. Significant declines in rainfall in south-western Ivory Coast is reported to have led to some cocoa plantations being abandoned (Myers, 1988) and these cocoa farms have been the major source of income for many households and also the backbone of that country's economy.

2.5.4. Health

Climate change is expected to increase the incidence of diseases in most parts of the world because the expected changes may create conducive environments for the growth and distribution of disease vectors (Arnell, 2006; WWF, 2006). The biological activity and geographic distribution of the malarial parasite and its vector, for example, are sensitive to climatic influences, especially temperature and precipitation (Martens *et al.*, 1995; Zhou *et al.* 2004). The spread of malaria is seasonal and limited to the warm and rainy months; however, changing climate conditions, such as the persistence of warm and rainy days for more of the year can increase the incidence of malaria

events (Craig *et al.*, 2004). Among the factors that govern the distribution and population dynamics of malaria, Martens *et al.*, (1995) state that, the abiotic are stronger than the biotic factors and rainfall and temperature are the most important of the possible abiotic influences. While other factors, such as topography and health preparedness can influence the spread of malaria, scientists have found a correlation between rainfall and unusually high maximum temperatures and the number of malaria cases (Githeko and Ndegwa, 2001; Zhou *et al.*, 2004).

Rainfall may influence malaria transmission by providing the medium for the aquatic stages of the mosquito life cycle, while temperature acts as a regulatory force (Martens *et al.*, 1995). Rainfall may also increase the relative humidity and hence the longevity of the adult mosquito because between certain limits the longevity of a mosquito decreases with increasing temperature and increases with increasing relative humidity (Molineaux, 1988; Zhou *et al.*, 2004; Craig *et al.*, 2004). It must be added, however, that the relationship between changing temperature, precipitation, and relative humidity are complicated and the processes affecting atmospheric humidity suggest only a small change in relative humidity as the atmosphere gets warmer (Mitchell and Ingram, 1992)

Overall, human-induced climate change is expected to cause a change in the distribution and incidence of malaria (WHO, 1990; Doll, 1992; McMichael, 1993; Kai, 1994). Globally, a widespread increase of risk due to expansion of the areas suitable for malaria transmission and the predicted increase is most pronounced at the borders of endemic malaria areas (Martens *et al.*, 1995) especially in Africa where it is common knowledge that malaria accounts for most of clinical cases and deaths, especially in children. An estimated 182 million people might die from disease associated with climate change by the end of the century in sub-Saharan Africa (IPCC, 2007b), especially from malaria. In the highly endemic malarial areas of tropical Africa, the incidence of malaria and consequently the number of years of healthy life lost due to malaria may increase. In the malarial areas of lower endemicity, the incidence or infection is far more sensitive to climate

changes (Martens *et al.*, 1995). Therefore, anthropogenic climate change may have substantial effects on years of life lost in such areas.

Both cold and hot spells lead to an increase in mortality, through exacerbation of respiratory and circulatory problems, with effects depending on climatic conditions and degree of acclimatisation and adaptation (Arnell, 2006). In northern Europe, for example, excess mortality is greater in winter than in summer, whilst in southern Europe most heat-related deaths occur during hot spells in summer. Increased mortality in summer in northern Europe under higher temperatures would therefore be offset to a large degree by reduced mortality in winter; in contrast, higher temperatures in southern Europe would result in increases in summer mortality far greater than reductions in winter mortality (Arnell, 2006)

2.5.5. Energy

Virtually all of the literature on future energy demand is concerned with the effects of different economic growth rates, the extent of innovation and changing patterns of energy use: there is relatively little quantitative information on the implications of climate change for energy demand. The main effects of climatic variability are on the demand for space heating fuels and the amount of electricity used for air conditioning and refrigeration (Arnell, 2006).

Climate change has five broad impacts on energy production: it affects the viability of renewable resources, energy from biomass schemes, the availability of cooling water, the extraction of offshore oil and gas, and the physical infrastructure associated with production and transmission of energy. The key renewable resources affected by climate change are hydropower (affected by the volume and timing of river flows) and wind. Scenarios for change in wind are highly uncertain, so it is not possible to project changes in wind generation potential. The viability of energy from biomass depends on biomass productivity, which for the species most frequently used depends on

temperature through the year and, particularly, the length of the growing season. Thermal power generation (whether fossil or nuclear) requires cooling water from rivers or the sea; changing river flows (and water temperatures) will affect reliability of access to cooling water. Both the extraction of offshore oil and gas and, more generally, infrastructure involved in the production and distribution of energy are exposed to changes in extreme climatic events, such as the occurrence of ice storms (Arnell, 2006).

2.6. Livelihoods

The definition of ‘livelihood’ has been extensively discussed among academics and development practitioners. Livelihoods generally refer to the financial means whereby one lives, means of earning a living, or source of income covering the range of activities and programs that work toward and enhance self-reliance. Livelihood is basically means of support or subsistence. The common thing in all definitions of livelihoods is that it involves people and their resources and how the resources are used. The most widely accepted definition of livelihoods is by Chambers and Conway (1992) who defined livelihood as ‘comprising the capabilities, assets (including both material and social resources) and activities required for a means of living’.

2.6.1. Rural Livelihoods

Rural livelihoods are mostly natural resource dependent; mainly on smallholder agriculture as farmers, labourers, marketers and processors of produce. Even other activities such as supplying non-agricultural services are paid for by households whose income is principally agriculture-derived (Kydd, 2002). Consequently, slight changes in environment that also affect agriculture have immense effect on rural livelihoods. When this happens, the easiest and usually more touted option

is diversification of rural livelihoods away from agriculture. Ellis (1999) defines rural livelihood diversification as ‘the process by which households construct a diverse portfolio of activities and social support capabilities for survival and in order to improve their standard of living’.

Reardon *et al.*, (2000) has observed that rural livelihood diversification away from agriculture has often involved poor people crowding into a competitive sub-sector supplying a limited market. The diversification is often in less advantageous labour markets than the better-off, i.e. in casual, part-time and unskilled work compared to full-time work or substantive self-employment (Ellis, 1999). According to Reardon *et al.*, (2000), this results in returns to labour in these sub-sectors, which is already low, falling further.

In 1998, Institute of Development Studies (IDS) provided an analytical framework for sustainable rural livelihoods (Scoones, 1998) which highlighted five interacting elements: contexts; resources; institutions; strategies; and outcomes. Access to land for example, being an obvious important natural resource, is a key condition for rural livelihoods. If land property rights and rights to use agricultural produce from land are not secure and regulated, the vulnerability of households increases and will influence their strategies (Bekele, 2003). Sustainable rural livelihoods focuses not on the needs of the rural poor, but rather, builds on the existing assets of the poor, both at the village level, and individuals (Fouracre, 2001).

2.6.2. Sustainable livelihoods

According to DFID (2001), a livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base. This concept of sustainable livelihoods reflected in a shift in thinking towards a more people-centred approach to international development. The paradigm shift was led by NGOs with analytical support from researchers, and later was widely

adopted by governmental agencies; e.g., the Brundtland Commission report in 1987 and the first UNDP Human Development Report in 1990.

Chambers and Conway (1992) offered a framework for development thinking that was both normative and practical. According to Chambers and Conway (1992), in achieving sustainable development, there is the need for 1) enhancing capability – in facing change and unpredictability, people are versatile, quick to adapt and able to exploit diverse resources and opportunities; 2) improving equity – priority should be given to the capabilities, assets and access of the poorer, including minorities and women; and 3) increasing social sustainability – the vulnerability of the poor should be minimised by reducing external stress and shocks and providing safety nets.

A combination of activities make up a livelihood strategy and these set of activities are referred to as ‘livelihood portfolio’ (Fouracre, 2001). Such portfolio is diversified over time, and between households, communities and generations. In pursuing livelihood strategies, both the access to assets and the use to which they can be put are mediated by social factors (social relations, institutions, organisations) and by exogenous trends (e.g. economic trends) and shocks such as drought, disease, floods, pests (Ellis, 1999).

Diverse livelihood systems are less vulnerable than undiversified ones; they are also likely to prove more sustainable over time precisely because they allow for positive adaptation to changing circumstances.

2.6.3. DFID’s Sustainable Livelihoods Approach

DFID’s Sustainable Livelihoods Approach (SLA) was part of the British government’s decision to refocus international development efforts on the elimination of poverty and encouragement of economic growth which benefits the poor through support for international sustainable development

targets and policies that create sustainable livelihoods for poor people, promote human development and conserve the environment (DFID, 1997). Several studies on sustainable livelihoods (Singh and Kalala, 1995; Rennie and Singh, 1996; Leach et al., 1997a, 1997b, 1999); Farrington et al., 1999) have contributed to the current state of the concept of SLA. The concept of SLA had been tested both intellectually and empirically by researchers and practitioners (Solesbury, 2003). Its goal is to help poor people to achieve lasting improvements against the indicators of poverty that they themselves identify, and from a baseline they define (DFID, 2003).

In essence the DFID's SLA is a way of putting people at the centre of development. Although the SLA framework does not and cannot provide an exact representation of reality, it provides a way of thinking about the livelihoods of poor people that will stimulate debate and reflection, thereby improving performance in poverty reduction (DFID, 2003). The approach views people as operating in a context of vulnerability. The DFID's SLA has evolved over time and its origin can be traced to the Brundtland Commission Report of 1987. The report defined sustainable development as development that meets the needs of the present without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development 1987). This was the first appearance in policy debate of what was conceptualised later as SLA. The first Human Development Report from the United Nations Development Programme (UNDP, 1990) buttressed the views of the Brundtland Commission report of 1987. From this point, the focus of development issues drifted from the macroeconomic bias of earlier development thinking to individual and household health, education and well-being.

Key components of the SLA framework for analysing the livelihoods of individuals and the community are their capital assets, their vulnerability context and the transforming structures (layers of organisations both in the private and government sectors) and processes (laws, policies,

incentives) which shape and influence the livelihood strategies which they adopt (DFID, 1999). The DFID identifies and groups the capital assets as follows:

Natural Capital: The natural resource stocks from which resource flows useful for livelihoods are derived (including land, water, wildlife, biodiversity, environmental resources)

Social Capital: The social resources upon which people draw in pursuit of livelihoods (i.e. networks, membership of groups, relationships of trust, access to wider institutions of society).

Human Capital: The skills, knowledge, ability to labour and good health important to the ability to pursue different livelihood strategies.

Physical Capital: The basic infrastructure (transport, shelter, water, energy and communications) and the production equipment and means which enable people to pursue their livelihoods.

Financial Capital: The financial resources which are available to people (whether savings, supplies of credit or regular remittances or pensions) and which provide them with different livelihood options.

The vulnerability context within the SLA framework indicates the nature of trends, shocks and culture, and the ability of the poor to withstand their impact. The different structures and processes which define people's livelihood options are critical in determining, who gains access to the various assets, and in influencing the effective value of each asset.

2.7. Vulnerability to climate change

In the Second Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) defines vulnerability to climate change as “the extent to which climate change may damage or harm a system and this depends not only on a system’s sensitivity, but also on its ability to adapt to new climatic conditions” (Watson *et. al.*, 1996). Vulnerability, therefore, is a function of the magnitude of climate change, the sensitivity of the system to changes in climate and the ability to adapt the system to changes in climate. Hence, a highly vulnerable system is one that is highly sensitive to modest changes in climate and one for which the ability to adapt is severely constrained (IPCC, 2000a). Olmos (2001) also defines vulnerability to climate change as the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. It is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.

From a natural hazards perspective, Blaikie *et. al.*, (1994) define vulnerability as “the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard”. Blaikie *et. al.*, (1994) continues to argue that vulnerability “is a measure of a person or group’s exposure to the effects of a natural hazard, including the degree to which they can recover from the impact of that event”.

2.7.1 Climate Change Vulnerability Assessment

Vulnerability assessment is not unique to climate change since it has been used in several fields previously and continues to be used in fields such as risk/hazards impact assessments; ecological resilience; and food security. The emerging field of global change vulnerability assessment draws heavily from these research fields. One consensus from the ever growing literature on Vulnerability assessment (e.g. Dow, 1992; Bohle *et. al.*, 1994; Cutter, 1996; Ribot *et. al.*, 1996; NRC, 1999;

Downing, 2000; Kelly and Adger, 2000; Golding, 2001; Kasperson, 2001; McCarthy *et. al.*, 2001; Kasperson *et. al.*, 2003) is that vulnerability is such a complex and variable characteristic that no one method or set of methods should be prescribed for conducting vulnerability research. However, based on a shared understanding of what types of questions should be asked and general classes of techniques for answering them (Downing *et. al.*, 2001; Polsky *et. al.*, 2003), a methodological framework can be made for vulnerability assessment.

According to Polsky *et. al.* (2003), to produce a successful global change vulnerability assessments, the knowledge base engaged for analysis should be varied and flexible; vulnerability research and assessments should be “place-based”; the stresses examined should be recognized as multiple and interacting instead of unique or multiple and independent; the research must allow for differential adaptive capacity; and the information must be both prospective and historical.

2.7.2. Africa’s Vulnerability to Climate Change

Africa’s climate, especially in the semi-arid regions, has been quite erratic from year to year and over longer periods and this situation seems to have delayed Africa’s awareness of changing climate (IPCC, 2007b). Some have even argued that the success or failure of one rainy season, or even several, cannot be attributed to climate change (Magrath, 2006). However, now the signs are too clear to ignore: the continent as a whole is warmer by 0.5°C than it was 100 years ago and the six warmest years in Africa have all been since 1987 and globally, 2005 is the hottest year on record. (IPCC, 2001a)

One’s ability to withstand shocks and negative changes mainly depends on its adaptive capacity and this makes Africa the most vulnerable of all to the negative effects of climate change (Handmer *et. al.*, 1999; IPCC, 2001b). Too much or too little rain can be a matter of life or death in Africa and at different times and in different places across the continent, climate change threatens both (Magrath,

2006). It is now very well established that climate change, mainly through increased extremes and temporal/spatial shifts, will worsen food security in Africa (IPCC 2001b; 2007b)

Watson *et al.*, (1998) argues that the vulnerability of a region depends, to a greater extent, on its wealth, and that poverty limits adaptive capabilities. Vulnerability of a region also depends on the level of economic development and institutions and it is well known that socio-economic systems are more vulnerable in developing countries where economic and institutional circumstances are less favourable (Watson *et al.*, 1996). FAO statistics indicate that with the exception of Latin America, developing countries would face a decrease of GDP from agriculture due to climate change (FAO, 2007). Asia (-4% for high emission scenarios) and Africa (-2 – -9% for 3 of out the 4 GCMs) would generally be the most negatively affected.

2.7.3. Ghana's Vulnerability to Climate Change

The current assessment of Ghana's vulnerability to climate change (Ghana EPA, 2000) concentrated on how changes in climate may affect some important sectors of the national economy which includes water resources, coastal resources and some agricultural crops. The assessments consisted essentially of analysing the scope and severity of the potential effects of climate change, as a result of probable temperature rise, decreased precipitation and rise in sea level.

Runoffs or discharges of all the river basins in Ghana are sensitive to changes in precipitation and temperature; a 10% change in precipitation or a 1°C rise in temperature can cause a reduction in runoff in excess of 10% (Ghana EPA, 2000). Projected climate change scenarios indicate reduction in river flows between 15-20% and 30-40% for the years 2020 and 2050 respectively in all the basins. Similar reductions in ground water recharges between 5% and 22% by the year 2020, and 30 and 40% were projected for 2050. This would result in serious constraints for water for irrigation; hydropower generation; secondary impacts on health, nutrition and energy-based industrial activities

(Ghana EPA, 2000). The Ghana National Initial Communication to the UNFCCC concludes that by the year 2020 and 2050, all river basins will be marginally vulnerable and the country will face water management problems.

Food production is also projected to decline. Using the projected climate scenarios and CERES model, it was projected that the yield of maize would decrease in the forest-savanna transition Zone from 0.5% in the year 2000 to 6.9% in the year 2020. The yield of millet however was not affected by the projected climate change because millet is more droughts tolerant and therefore insensitive to temperature rise.

2.8. Adaptation to climate change

Adaptation to climate change is one of the critical issues in climate studies because from all indications, climate change is real and living with it requires planned activities that will reduce its effects and make life possible. The great need for adaptation is given attention in Article 4.1.b of the United Nations Framework Convention on Climate Change (UNFCCC) which provides that all countries must formulate and implement national or regional programmes containing measures to facilitate adequate adaptation to climate change (Art. 4.1. b). Adaptation to climate stimuli includes adaptive responses to extremes, variability from year to year, and to changes in long-term mean conditions, both independently and as they relate to each other (Smit *et al.*, 2000).

Adaptation to climate change has been given several definitions and at different times have meant differently from author to author and this, according to Smit *et al.*, (2000), requires a need for users of the term to specify adaptation in what, and to what. There are several definitions of Adaptation to climate change (e.g. Burton, 1992; Smit, 1993; Stakhiv, 1993; Smith *et al.*, 1996; Watson *et al.*,

1996) but they all refer to adjustments in a system in response to climatic change, or/and variability. The IPCC defines 'Adaptation to Climate Change' as a process by which strategies to moderate, cope with and take advantage of the consequences of climate events are developed and implemented (IPCC, 2001b).

According to Easterling (1996) adaptation can be either autonomous (reaction of individuals to changing climate) or planned (conscious policy options or response strategies). Similarly, Smit (2000) groups adaptations into passive, reactive or anticipatory; and spontaneous or planned. Stakhiv (1993) groups adaptive strategies according to the time frame of the stimulus: long range, tactical, contingency, and/or analytical and Smithers and Smit (1997) differentiate adaptations on the basis of intent or purposefulness, the role of government, the spatial and social scale, duration, form and effect.

2.8.1. Who needs to adapt to climate change?

Climate change effects are not for a single group of people, although they are expected to be higher in tropical regions (Thomas and Twyman, 2006). However, the need and extent of adaptation varies within and between locations. Climate change and variability are among the most important challenges of Least Developed or developing countries because of their strong economic reliance on natural resources and rain-fed agriculture (FAO, 2007). Of the developing countries, many in Africa are seen as being most vulnerable to climate variability and change (Slingo *et al.*, 2005). Observational records show that Africa has been warming through the 20th century at the rate of between 0.26 and 0.50°C per century, and there is evidence that this warming trend will significantly accelerate in Africa (IPCC, 2007). According to the IPCC Fourth Assessment Report (2007) a medium-high emission scenario would see annual mean surface air temperatures expected to increase between 3°C and 4°C by 2080 (IPCC, 2007). Moreover, most of Africa, particularly sub-

Saharan Africa, relies on rain-fed agriculture and as a result it is very vulnerable to changes in climate variability, seasonal shifts, and precipitation patterns. This high vulnerability of Africa to climate change requires the formulation of effective adaptation strategies but this is hindered by lack of resources.

In effect, resource-poor communities who depend mostly on natural resources for their livelihoods, such as peasant crop farmers in Africa, are particularly critical when it comes to formulating adaptation strategies but they also have the lowest capacity to adapt (Thomas and Twyman 2006). FAO (2007) makes it clear that countries with limited economic resources and insufficient access to technology will be least able to keep up with the changes.

2.8.2. Proposing adaptation strategies

Proposing adaptation strategies in any given area must be considered holistically, including trade-offs among biophysical and socio-political factors (FAO, 2007), because of the multi-sectoral effects of climate change. In formulating adaptation strategies, it is very necessary to define the system to which the adaptations pertain (Smit *et al.*, 2000). This brings into focus the questions of whether we are dealing with an individual or a community, a region or a nation. A system's ability to adapt is a crucial basis in formulating adaptation strategies and various terms such as "sensitivity", "vulnerability", "coping range or adaptive capacity", "resilience" (Klein and Tol, 1997; Smithers and Smit, 1997a; Sprengers *et al.*, 1994) has been used, sometimes interchangeably, to explain this situation. The resilience of a system may influence the type of adaptation strategy to propose.

There cannot be one adaptation strategy proposed globally or for a region or sub-region because whilst climate change is noticed everywhere, its impacts vary from region to region and adaptation is also expected to vary. West Africa, for instance, with its diverse climate ranging from the arid

regions in the Sahel north to humid tropical rainforests of the south, economic disparity among countries, cultural diversity, and the socioeconomic activities undertaken by the different populations directly affect their adaptation strategies. Adaptation strategies need full implementation to have the desired effect and farm level analyses have confirmed that large reductions in adverse impacts from climate change are possible when adaptation is fully implemented (Mendelsohn and Dinar, 1999).

2.9. Soil organic carbon and climate change

The bulk of carbon in terrestrial ecosystems is stored in soils as soil organic matter and this storage is highly impacted by agriculture which causes a great reduction in the carbon storage (Eswaran *et al.*, 1993). Increase in atmospheric carbon in the form of release of CO₂ gas into the atmosphere (Schlesinger, 1984) is one of the leading causes of climate change. This means any process that keeps or locks carbon and prevents it from getting released into the atmosphere is a sure way of combating climate change. Therefore growing crops that can lock vast amounts of carbon up in the soil is a means of mitigating climate change (Carbon Coalition, 2008).

Osher *et al.*, (2003) have proved that total organic carbon stored in soils varied as a result of management practices. Soil also represents the largest carbon sink over which we have control (Carbon Coalition, 2008) and strategies must be put in place for effective soil carbon sequestration.

2.9.1. Determining changes in soil organic matter

Soil organic matter (SOM) consists of various functional pools that are stabilized by specific mechanisms with specific turnover rates (von Lutzow *et al.*, 2007) and changes in such soil organic matter pools can be an indicator of changes in the quantity of soil organic carbon stored in the soil

and also how much carbon is being sequestered by the soil. According to von Lutzow *et al.*, (2007), one way of predicting changes in soil organic matter pools is through the use of mechanistic models which involve quantifying and characterizing SOM pools through fractionation procedures. Fractionation procedures can either be physical separation of SOM into aggregate, particle size, and density fractions and fractions according to their magnetic susceptibility; or various wet chemical procedures that fractionate SOM according to solubility, hydrolysability, and resistance to oxidation or by destruction of the mineral phase. There can also be combinations of fractionation.

SOM pools have been named differently, depending on the authors: active, intermediate or slow and passive or inert (McGill, 1996; Smith *et al.*, 1997) but in all instances they have been defined by their different turnover times and pool sizes. The active SOM pool with turnover rates <10 years may best be represented by the soil microbial biomass and the light fraction (<1.6–2 g cm⁻³) obtained by density fractionation (if black carbon contents are considered). Turnover rates (k) may be determined by different methods such as decomposition studies; natural labelling of SOM using stable ¹³C tracers; in situ labelling of SOM with ‘bomb’ ¹⁴C; and the ¹⁴C-dating technique.

2.9.2 Physical Fractionation

Physical fractionation methods are based on the premise that the association of soil particles and their spatial arrangement play a key role in SOM dynamics, because bio-accessibility is a prerequisite for decomposition. This can be done by either the application of various degrees of disaggregating treatments (dry and wet sieving, slaking); dispersion (ultrasonic vibration in water); density separation; and sedimentation (Elliott and Cambardella (1991) and Christensen (1992; 2001). Christensen (1992) further states that physical fractionation methods in the strict sense include size and density separation of primary organo–mineral complexes in whole soil. In effect, aggregates are not considered in physical fractionation and the primary organo–mineral complexes

are released only after ‘complete’ disaggregation. Therefore, the effectiveness of soil disaggregation (dispersion) procedures is crucial for both particle size fractionation and density fractionation.

2.9.3. Aggregate fractions

Aggregate fractions can easily be obtained physically by dry or wet sieving and slaking. Whilst aggregates less than 2 μm even survive ultrasonic treatment (Chenu and Plante, 2006), aggregates less 20 μm are very stable and are only disrupted by ultrasonic treatment (Oades and Waters, 1991).

The organic matter content of various aggregates differs depending on location. Whilst in most temperate soils, macro-aggregates ($>250\ \mu\text{m}$) often contain more organic matter than microaggregates ($<250\ \mu\text{m}$), because the former include microaggregates plus organic matter serving as an intra-macroaggregate binding agent (Cambardella and Elliot, 1993; Jastrow *et al.*, 1996; Puget *et al.*, 1995; Six *et al.*, 2000a), it is usually not the case in some tropical soils, where other cementing agents stabilize macroaggregates (Oades and Waters, 1991; Six *et al.*, 2000b; Zotarelli *et al.*, 2005).

In a study by Jastrow *et al.*, (1996), nearly 90% of soil organic carbon (SOC) in surface soils was found to be located within aggregates with 20–40% of SOC as intra-microaggregate SOC (Carter, 1996). The degree of decomposition increases with decreasing aggregate size, since chemical compound classes representing plant components or ^{14}C -labelled plant residues decrease from macro- to microaggregates (McLauchlan and Hobbie, 2004; Monreal *et al.*, 1997). Furthermore, C/Nitrogen (N) ratios decrease from about 20 to 8 with decreasing aggregate size (Aoyama *et al.*, 1999; Buyanovsky *et al.*, 1994; Gregorich *et al.*, 2003). Angers *et al.* (1997) directly traced C and N in macro- and microaggregates during decomposition of $^{13}\text{C}^{15}\text{N}$ -labelled wheat straw under field conditions and observed a redistribution of ^{13}C from macroaggregates to microaggregates with time. This clearly indicates that C occlusion in microaggregates only happens after occlusion at the

macroaggregate scale. Consequently, microaggregate OM is usually older and in a more decomposed state than macroaggregate OM on average.

2.9.4. Particle size fractions

Particle size fractionation is based on the concept that SOM associated with particles of different size and therefore also of different mineralogical composition differ in structure and function (Christensen, 1992). While quartz particles that dominate the sand fraction exhibit only weak bonding affinities to SOM, the clay-sized particles (e.g. sesquioxides, layer silicates) provide a large surface area and numerous reactive sites where SOM can be sorbed by strong ligand exchange and polyvalent cation bridges (Sposito *et al.*, 1999). Assuming from the above arguments that sorption is an important stabilization mechanism, SOM within the sand fraction is allocated to the active pool and SOM in silt and clay fractions to the intermediate and passive pool. Jenkinson *et al.*, (1987), Kleber *et al.*, (2004), Saggar *et al.*, (1996), Wattel-Koekkoek and Buurman, (2004) and Wattel-Koekkoek *et al.*, (2003), all concludes that the effect of clay mineralogy on surface reactivity was important for C storage and stability.

2.9.5. Density Fractions

According to von Lutzow *et al.*, (2007), the intention of density fractionation is to achieve active, intermediate and passive soil organic matter pools. It is applied to isolate SOM that is not firmly associated with soil minerals (light fraction) from organo–mineral complexes (heavy fraction). Associations of SOM to mineral surfaces like e.g. phyllosilicates are most often characterized by a density greater than $1.6\text{--}2\text{ g cm}^{-3}$. Lighter fractions (LF), a term often used as a synonym for particulate SOM (POM) (Sikora *et al.*, 1996; Vanyushina and Travnikova, 2003), with a density of less than $1.6\text{--}2\text{ g cm}^{-3}$ consist mostly of pieces of plant residues, i.e. POM, either free (fPOM) or occluded in aggregates (oPOM) (Christensen, 1992). Gregorich *et al.*, (2006), however, cautions

that although POM and LF are similar, they are not equivalent fractions (e.g. different C-, N-, O-alkyl contents), and therefore should not be used as synonyms. POM has been isolated by size alone (Gregorich *et al.*, 2006) or by a combination of size and density fractionation (Balesdent *et al.*, 1998).

Despite differences in fractionation methods and turnover measurements (^{13}C , ^{14}C), the stability of OM is observed to increase from fLF/fPOM to oLF/oPOM and further to mineral-associated SOM (von Lutzow *et al.*, 2007) and Janzen *et al.* (1992) also provides evidence that the LF with a turnover time <10 years is a useful indicator of the active OM pool. They found a significant correlation between soil respiration rates and SOC stored within the LF.

Like aggregate and particle size fractionation, the density fractionation makes only a rough differentiation of active and passive OM. While the free light fraction is a good representation of the active pool (except in soils with black C), the heavy fraction is too heterogeneous and contributes to the intermediate and passive pool. However, when used as a pre-treatment, density fractionation is seen as a useful tool for further differentiation of functional fractions (von Lutzow *et al.*, 2007).

3.0. METHODOLOGY

3.1. Study Area

River Offin is an easterly-flowing river in Ghana (latitudes 4.5°N and 11.5°N and longitude 3.5°W and 1.3°E) which takes its source from the Ashanti uplands and flows through the Ashanti region and joins the River Pra in the Central Region of Ghana. River Pra then enters the sea at Shama in the Western region.

3.1.1. Vegetation and climate

The major part of the River Offin basin is found in the Ashanti region within the moist semi-deciduous forests of Ghana. The basin has a bimodal rainfall pattern: a main peak in May to June and a trough in July to August and a secondary peak September to October. Temperatures throughout the basin are generally high. The mean annual temperature is above 24°C,

3.1.2. Socio-economic Structure

Most communities in the River Offin basin are rural and predominantly crop farmers who depend directly on the natural resources of the area such as the river and the forests for their livelihoods. Their livelihoods are therefore directly affected by any changes in the natural resources or environment. Communities which were covered in the study include Adiembra, Oboase, Offinso, Akataniase, Esaase, Nkrumah Nkwanta, Nnerebehi, Nwabi, Maase and Mmofranfadwen. The rest are Nyamebekyere, Fufuo, Koforidua, Adubinsu, Adumasa, Akoboro, Anyinamso, Breme, Yawbarimakuro and Amangoase.

Most of these communities have no access to treated pipe-borne water and depend on the River Offin and its network of streams for their water needs for drinking, irrigation of farms, sources of fish

for the communities, transportation of humans and farm produce, and water for other domestic and industrial activities.

3.1.3. Why the River Offin basin was chosen for the study

River Offin is a very important river in Ghana providing all the potable water needs of the Kumasi metropolis and its environs through the Barekese and Owabi dams constructed on the river. The Barekese dam produces 80% (18 million gallons) and Owabi dam produces the remaining 20% of potable water daily to the Kumasi metropolis. Aside the production of treated water, the river and its tributaries also provides the water needs of many rural communities who depend on it directly and also support many rural livelihoods. Majority of communities in the River Offin basin are rural and their livelihoods are natural resources-dependent. Any environmental changes that may negatively affect the River Offin and its functions would have serious negative repercussion on the many people that live in the basin. It is, therefore, necessary to study the possible effects of changing climate on the basin and develop the necessary adaptation strategies to ensure that livelihoods in the basin can continue in the face of possible climatic changes whilst taking advantage of any positive effects such changes might bring.

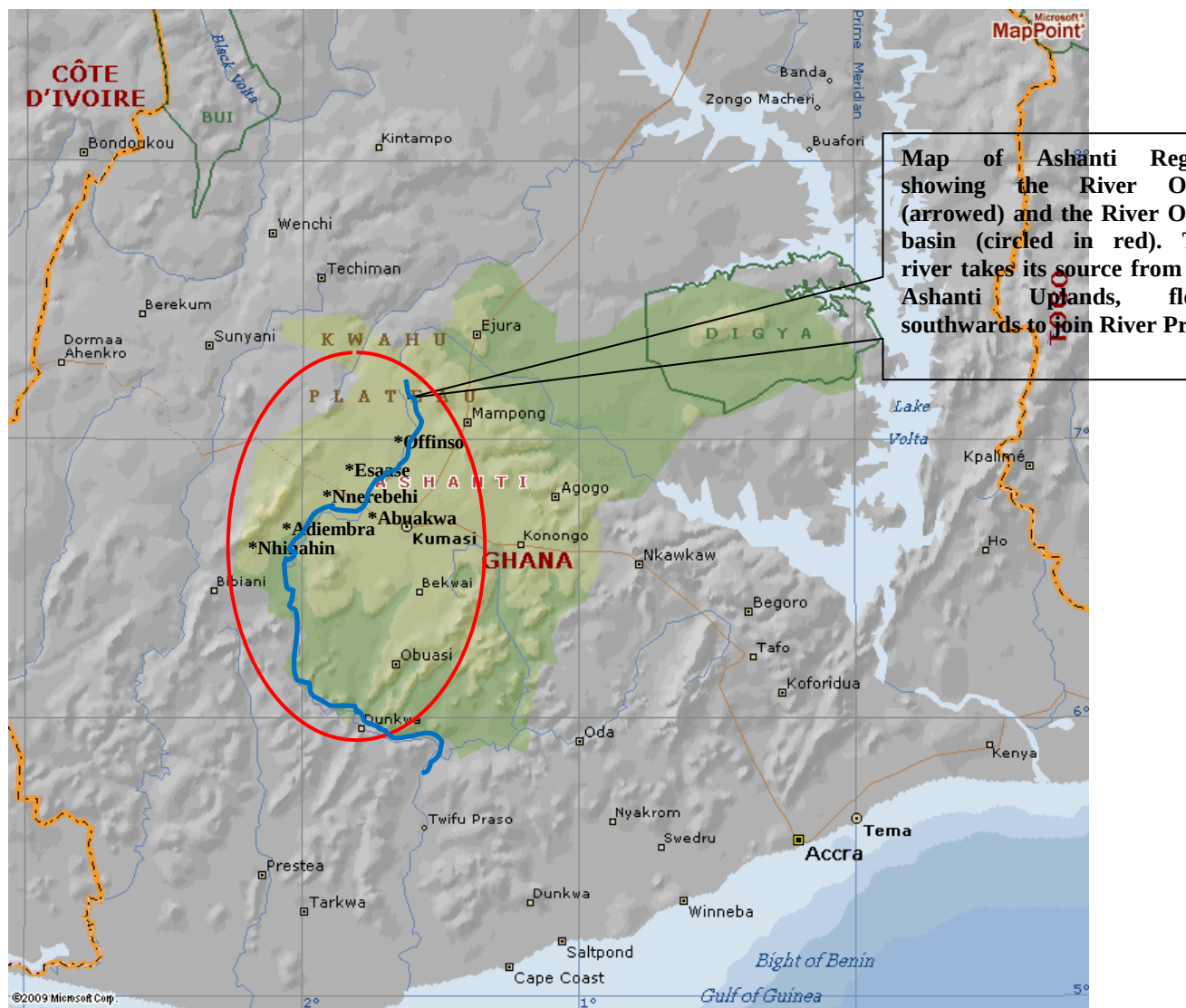


Fig.3.1. The Offin basin in Ghana showing some dependent communities

3.2. Data Collection and Analysis

Process of data collection and analysis for the study is presented in the sections that follow.

3.2.1. Climate Trends

The initial stage of the work analysed the climate situation in the Offin river basin to establish a trend. The intention was to use historical climate records to elucidate the future trends and to avoid

the uncertainties and generalisations involved in regional climate predictions which usually overlook local variability.

Forty-six years (1961-2006) of historical climate data were collected from Ghana Meteorological Agency for trend analysis. The selected parameters were:

- i. precipitation
- ii. maximum and minimum temperature,
- iii. maximum and minimum relative humidity
- iv. sunshine duration

Temperature and precipitation are the major climatic parameters of interest as they are the climatic variables which reveal significant changes in extreme values in the tropics and frequently show variation.

The climate data was analysed using linear regression to establish the following:

- Historical trends and patterns, i.e. whether the climate parameters are increasing or decreasing over time.
- The percentage increase and decrease as well as the rate of change of the parameters
- Seasonal and annual variability in the parameters
- Mean, minimum and maximum values recorded for precipitation, air temperature, relative humidity and bright sunshine duration between 1961 and 2006.
- For air temperatures, the warmest and coldest periods (decades, years, seasons), over the 46 year period was determined.
- The wet and dry periods (decades, years, and seasons) were also determined for precipitation.

3.2.2. Trends in discharge of River Offin

In the absence of a long historical river discharge records on the River Offin, river height measurements at two different stations; Adiembra station (downstream) and Offinso station (upstream) from 1957 to 2006 were collected from the Hydrological Agency of Ghana office in Kumasi for analysis. Discharge measurements of River Offin at the Adiembra station from 2002 to 2006 were available and used to construct a rating curve for the Offin River. The rate equation was used to estimate the discharge of the river at the recorded river heights from 1957 to 2006. From this data, the trend in discharge of the River Offin over the last forty years was established. Long periods of unrecorded data were excluded from the analysis to avoid biases in the calculation since the missing periods were too long to favour reliable estimation of the values. Estimation of long periods of missing data usually introduces errors and unreliability of data.

The technique of linear regression was used in analysing the trend in river discharge of the River Offin, as well as percentage increase or decrease in flows between 1957 and 2006; and the monthly, seasonal and annual variability of the flow of River Offin. Peak flows, minimum and average flows/discharges were also analysed.



Photo 1. River Offin at Adiembra

3.2.3. Modelling climate parameters and river discharge

The relationship between the climatic variables (temperature, rainfall) and river discharge and the influence of the two climatic variables on river discharge and on each other were explored using regression.

* Response Variate = Discharge

* Fitted terms = Temperature and precipitation

- Regressing discharge against temperature and precipitation
- Regressing discharge against precipitation only
- Regressing discharge against temperature only
- Regressing precipitation against temperature

From the regression, the following equation was arrived at in estimating discharge of the River Offin in relation to precipitation and temperature.

* Estimated Discharge = Constant x Coefficient (precipitation) + Coefficient (temperature)

3.2.4. Future Climate Change Scenarios

Climate change scenarios for the River Offin were based on scenarios developed for the moist semi-deciduous zone of Ghana by the Ghana National Communication to the United Nations Framework Convention on Climate Change (Ghana EPA, 2000). The “Linked Model” approach was used, involving the Hadley Centre Model 2 (HADCM2), the UK Meteorological Office Transient Model (UKTR) and the UK Meteorological Office High Resolution Model (UKHI) to generate future climate change scenarios on temperature and rainfall. The baseline climate data from which the

projections were made were the rainfall and temperature records from 1961 to 1990. Projected values of temperature and rainfall were estimated for years 2000 and 2050. The predictions were also compared with projections of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4).

3.2.5. Climate and livelihoods vulnerability

Extracting information on the relationship between climate and livelihoods was done through a multi-faceted approach. The methodology used was a result of a review, adoption and adaption of three (3) different frameworks used in collecting data on livelihoods, especially in developing countries. These are;

1. CRISTAL 3.0 (Community-based Risk Screening Tool - Adaptation & Livelihoods), developed by IISD, IUCN, SEI-B and Intercooperation. The CRISTAL 3.0 has two modules and the module 1 which is used for synthesizing Information on Climate and Livelihoods was found very relevant for the study. It helps in collecting data/information on anticipated impacts of climate change; current climate-related hazards affecting the project area; the impacts of these hazards; and coping strategies being used by the victims to deal with these impacts.

2. The Sustainable Livelihoods Approach (SLA) developed by the Department for International Development (DFID). The SLA was used in identifying which resources were available to the communities and were important to their livelihoods. The SLA looks at these resources under 5 main thematic areas:

- a) Natural resources – these include land, forests, rivers/streams, wildlife, etc.
- b) Physical resources – infrastructure such as roads, hospitals, buildings, bridges, etc.
- c) Social resources – local institutions, membership in organizations and groups, family, etc.

- d) Financial resources – sources of income, remittances, savings, etc.
- e) Human resources – knowledge and expertise of the people, etc.

3. The Agroecological Knowledge Toolkit (AKT5) developed by the University of Wales, Bangor, UK, in conjunction with the Department of Artificial Intelligence at Edinburgh University. It is designed to provide an environment for knowledge acquisition in order to create knowledge bases from a range of sources. The AKT5 system is primarily concerned with gathering local ecological knowledge (LEK), i.e., what people know about their natural environment, based primarily on their own experience and observation.

All the above approaches emphasises the importance of active local community participation and this was given priority in this study as the local people were facilitated to put forward their knowledge, perceptions and experiences of climate variability and change.

Local knowledge was used to set the climate and livelihoods contexts of the communities in the River Offin basin. The synthesizing was done in two steps; setting the climate context and setting the livelihoods context.

3.2.5.1. The climate context

In setting the climate context, current climate hazards and impacts of the hazards and climate change in Offin basin, particularly on local livelihoods, were identified. The process involves facilitation of the researcher for the communities to come out with the climate hazards as they have observed over the years.

3.2.5.2. The livelihoods context

Secondly, setting the livelihoods context involves identifying the natural, physical, social, financial, and human resources of communities in the Offin river basin. The extents to which these resources help the people to earn and secure their livelihoods and cope with impacts of climate changes were assessed. This formed the baseline for the vulnerability of the communities to potential climate change and variability.

Interviews, questionnaires and focus group discussions (FGD) were used in the data collection.

Focus group discussions:

Four (4) focus group discussions were held in four communities to collate their views on climate change and how they are coping with the changes.

Questionnaire administration:

Approximately two hundred structured questionnaires were administered in over 20 communities covered in the study. Respondents to questionnaires were carefully selected to make sure only people who can respond adequately to the questions were sampled. Selected respondents had to be forty years old and above and should have lived in the community for at least twenty years. The assumption was that such respondents would have enough knowledge of changes that have occurred in the environment; younger people may not have observed and experienced enough change in climate in their lifetime to make good judgement. The questionnaires were primarily aimed at getting as many views independent from other views as possible from the people without the respondents being influenced by others when done in a group.

The questionnaires and FGD helped to identify current observed climate changes and impacts of such changes particularly on local livelihoods; livelihood resources, i.e., natural, physical, social, financial, and human resources of communities in the Offin river basin; and the extents to which these resources help the people to earn and secure their livelihoods and cope with the impacts of climate change.

In-depth interviews:

Through the focus group discussions and questionnaire administration, individuals were selected for in-depth interviews. The selected individuals were in different categories:

- i. People who showed great knowledge in their environment and could demonstrate their awareness of changes that are occurring
- ii. Local farmers who were directly affected by climate change
- iii. Traditional leaders and opinion leaders involved in decision making and administration of the communities.



Photo 2. Interview with chief of Adumasa



Photo 3. Focus Group Discussion at Akoboro

3.2.6. Future socio-economic vulnerability projections

Projections of future vulnerability of livelihoods of people living in the River Offin basin were done based on the Livelihoods vulnerability assessment done earlier in the study. The future socio-economic projections takes into consideration the current livelihoods options of the people; how the livelihood options are being impacted by recent climate situation; and the projected climate changes and how it is likely to influence or affect livelihoods of the people. The projected vulnerability was also based on comparisons with case studies in literature from other parts of the world especially sub-Saharan Africa and other countries in the developing world under similar conditions as the Offin River basin and also on expert contributions.

3.2.7. Exploring possible adaptation strategies

Although climate change is global, adaptation to the effects of climate change must be inevitably local: this was a basic principle in exploring possible adaptation strategies for communities in the Offin basin. The greatest challenge for this exercise was insufficient data and inadequate resource.

The adaptation strategies were aimed at prescribing intervention to address the following:

1. Increasing mean temperatures
2. Decreasing rainfall with increased variability and unpredictability in rainfall pattern
3. Reduction in stream flow and water shortages
4. Increased deforestation and frequent wildfires
5. Enhanced land degradation crop failure and food shortages
6. Heat and health problems
7. Loss of income

Exploring suitable and sustainable community-based adaptation strategies was done through:

i. Community Assessment

A general assessment of the communities under study was undertaken. This involved the following areas: the cultural context; decision making and implementation; the social structure of the communities: homogenous or heterogeneous, communal or independent; vulnerability of different groups such as households in the same community to climate impacts; links with extended families, social groupings or networks. The assessment also considered the communities' environmental awareness and their dependence on and value of nature.

ii. Adaptive Capacity

This looked at the ability of the communities to adapt to the changes occurring in their environment based on their assets, sources of income, livelihood options, occupation, diversity of resources, knowledge base, availability of alternative sources of water, food sources, and sensitivity of the communities to changing climate.

A major feature of the assessment of adaptive capacity of the communities is the review of current coping strategies already in place and being practiced by the people at different levels to enable them go on with their life in the face of major changes in their environment.

iii. On-going mitigation/adaptation projects assessment

There was also an assessment of on-going programmes or projects in the basin aimed at mitigating or helping the communities to adapt to climatic changes

iv. Focus group discussions and in-depth interviews

Eight focus group discussions (FGD), two (2) per community, were conducted in four communities to get the input of selected groups on what they think will better help them to adapt to the changing

climate and its effects on their livelihood options. The identified groups were traditional leaders and opinion leaders in the community; only women; the youth; and farmers. In-depth interviews were conducted with selected people who were identified during the FGDs or were recommended by their peers as being very knowledgeable in specialised areas such as agriculture and herbal medicine. This helped to collect any information which was not captured due to time constraints, presence of influential personalities and cultural norms.

v. Desk study and expert contributions

A desk study of adaptation strategies implemented elsewhere in communities that have similarities with the Offin River basin was carried out. The research looked at the processes involved in arriving at the adaptation strategies, which strategies have worked and which ones have not, how the local people have responded to the strategies, and lessons learnt from the various approaches.

Experts in the area of climate change and adaptation such as natural resources managers, agriculturists, natural and social scientists, development workers and non-governmental organisations were also consulted for their experience and views on which strategies are feasible and are best suited for the communities under study.

3.2.8. Soil Sampling and Analysis

Soil samples were taken based on the process developed by Anderson and Ingram (1993). Soil samples were taken from five (5) plots (treatments) with each plot (treatment) having three replicates. Soils from each plot (treatment) were collected in April 2007 from a depth of 0-15 cm using two 8 cm diameter replicate cores.

The three replicates were taken at different locations within the same treatment at a depth of between 5cm and 10cm of the top soil with a cylindrical auger of the dimension 5cm x 5cm. The treatments are as follows:

1. Soil under a natural vegetation estimated to have existed for about 30 to 40 years. The land is at a higher altitude than the surrounding lands.
2. Soil under a cocoa farm of about ten 10 years old. Land is covered by dried cocoa litter.
3. Soil from plantain/cassava/maize inter-crop farm system under cultivation for 1 year. Until the cultivation, the land was part of the natural ecosystem described in (1) above.
4. Soil under part of the natural vegetation which has recently been cleared for cultivation. After clearing the forest, the debris is burnt as part of the land preparation before farming.
5. Soil taken from under an oil palm plantation of about 10 years old.

Soil analysis was done at the laboratories of the Soil Research Institute (SRI) of the Council for Scientific and Industrial Research (CSIR), Ghana, at Kwadaso in Kumasi. The soil was analysed for: soil nutrients, organic carbon, bulk density, percentage base saturation, soil textural class, exchangeable acidity and soil carbon stocks.

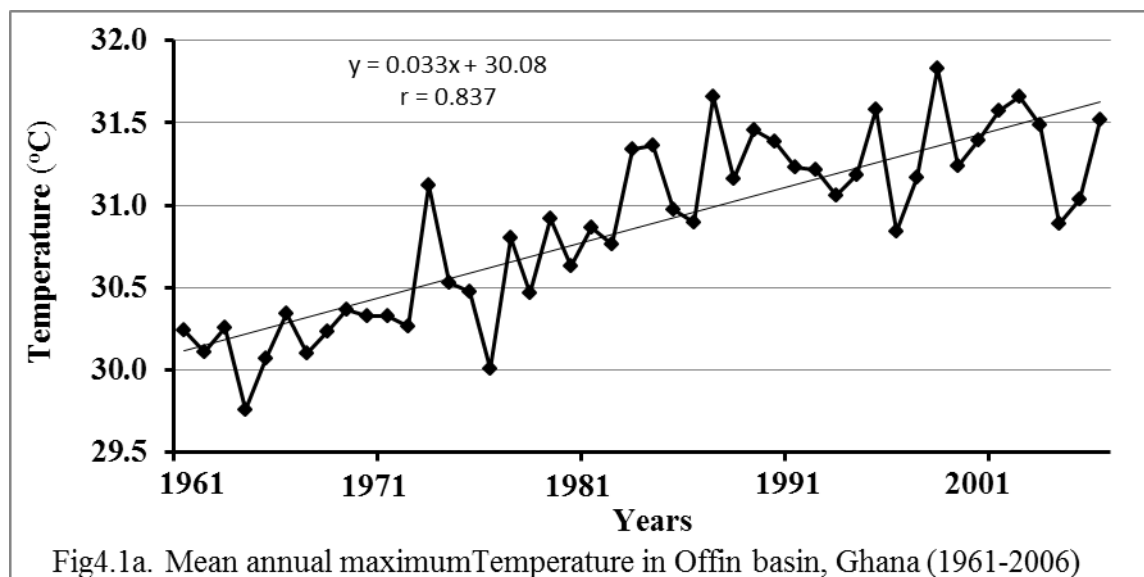
4. RESULTS

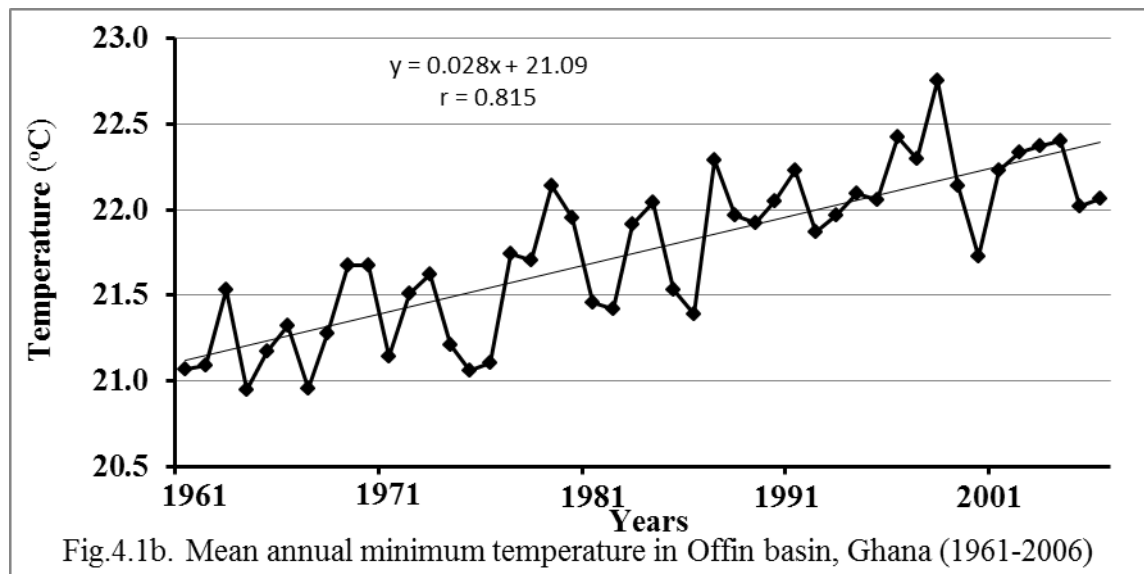
4.1. Climate trends in Offin basin

Analyses of climate trends in the River Offin basin are presented in the sections that follow.

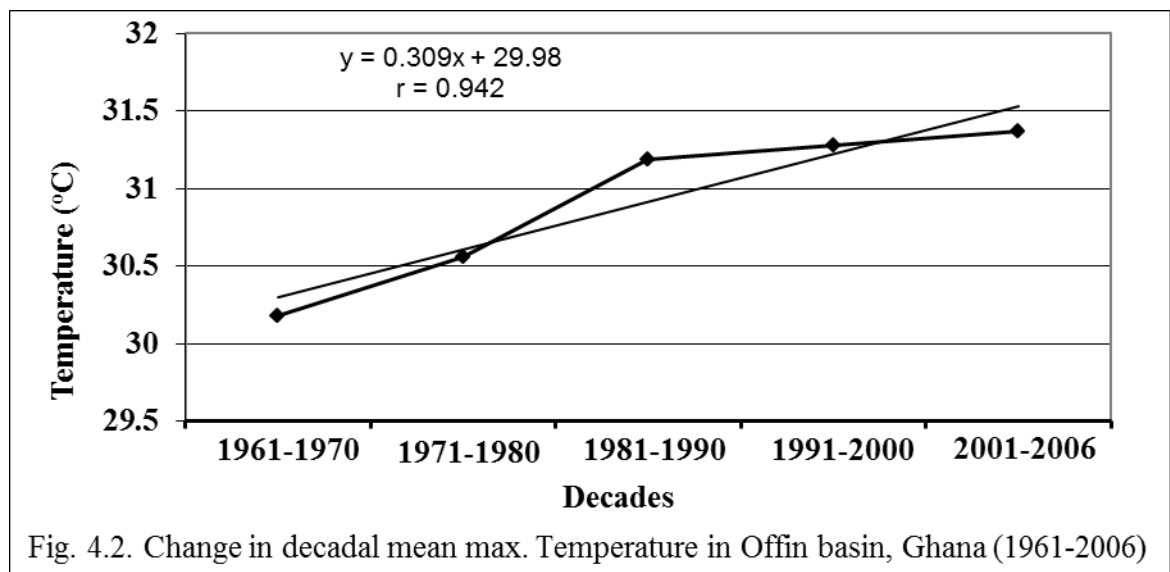
4.1.1. Temperature

Changes in air temperatures in the River Offin basin generally reflect warming (Fig. 4.1a and Fig.4.1b). Analysis of mean air temperatures showed that maximum air temperatures (Fig.4.1a) have risen by 4.3% over the period from 1961-2006. From an average temperature of 30.2 °C in the first decade, 1961 – 1970, the average maximum temperature for 2001 to 2006 was 31.5 °C, an indication of a 1.3 °C or 4.3% rise in mean maximum air temperatures. There has also been a 1.0 °C (4.7%) rise in minimum air temperature in the Offin basin from 1961 to 2006 (Fig.4.1b). The warmest year recorded over the study period (1961 to 2006) was 1998 (31.8 °C) and the coldest was 1964 (29.8 °C).



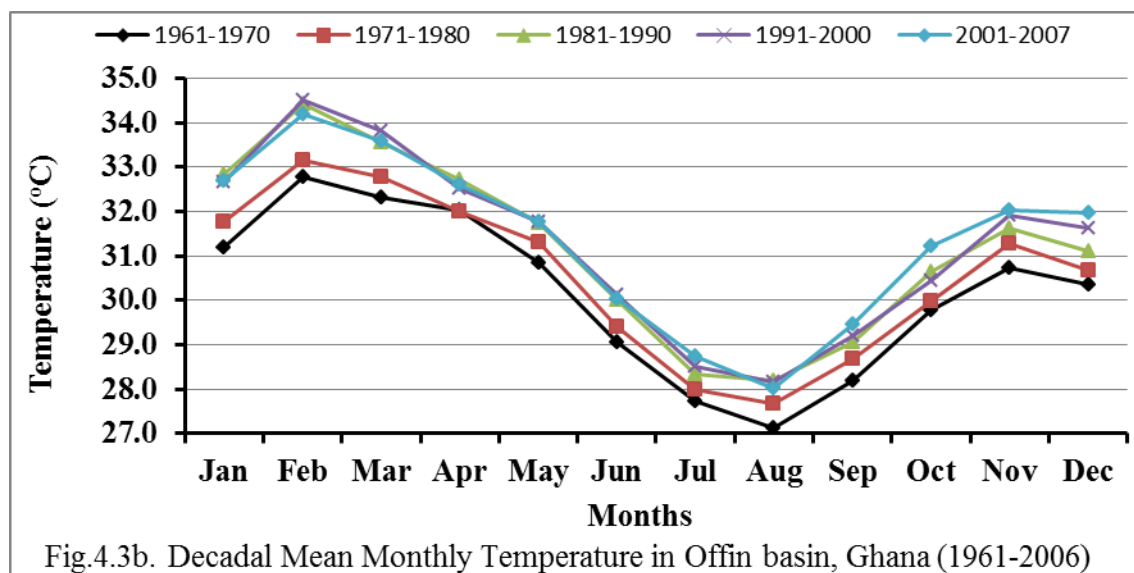
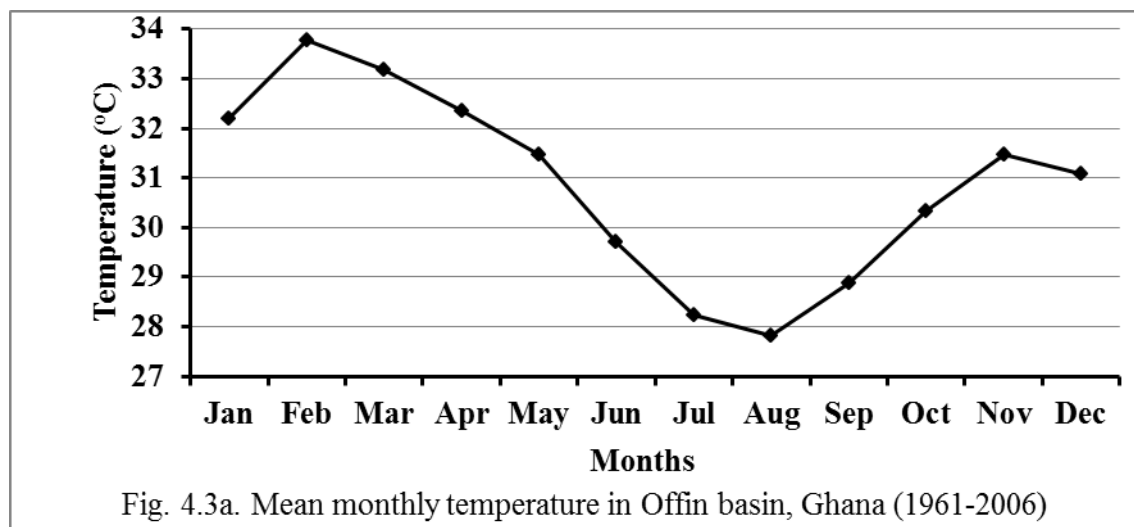


Breakdown of the temperature rise into ten year averages (Fig.4.2.) using maximum temperature readings show a gradual but consistent increases of 0.4°C (1.32%) from 1961-1970 to 1971-1980; a 0.6°C (1.96%) increase in temperature from 1971-1980 to 1981-1990; 0.1°C (0.32%) from 1981-1990 to 1991-2000 and finally another 0.1°C (0.32%) increase from 1991-2000 to 2001-2006. Decadal average increases indicate a 3.92% increase in mean maximum temperature.



Monthly analysis of air temperature in the Offin River basin shows November-May as the warmest period and June - October is relatively colder. February is the warmest month and August is the

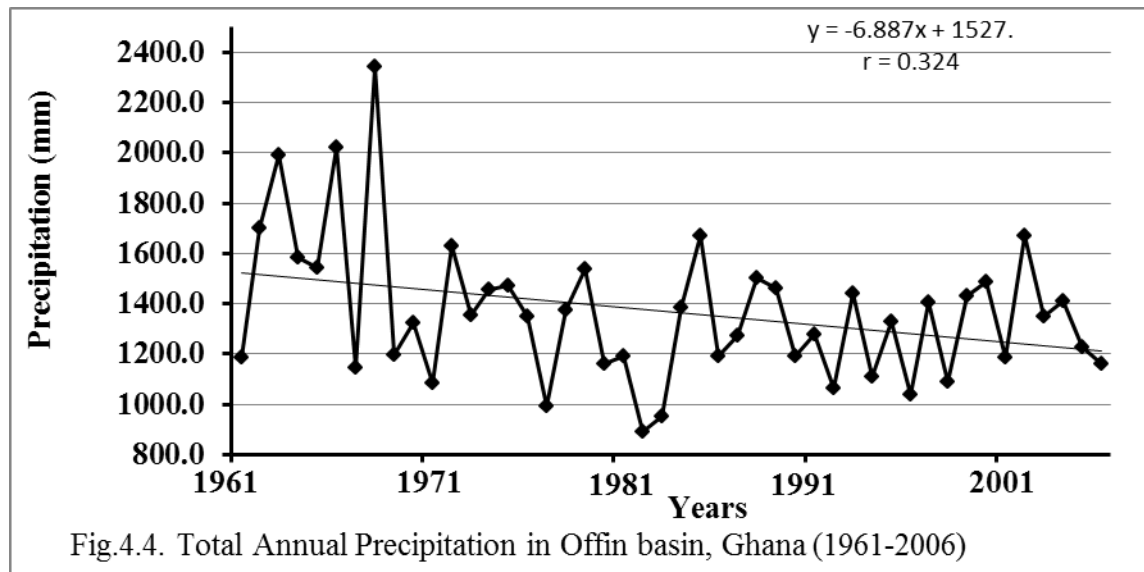
coldest (Fig.4.3a). The highest monthly temperature of 36.1°C was recorded in February 1995 whilst the lowest monthly temperature of 26.4 °C was recorded in August 1961. The monthly trend has continued without much variation over the last 4 decades but there have been consistent increases in monthly temperatures in the decadal analysis (Fig.4.3b).



4.1.2. Precipitation

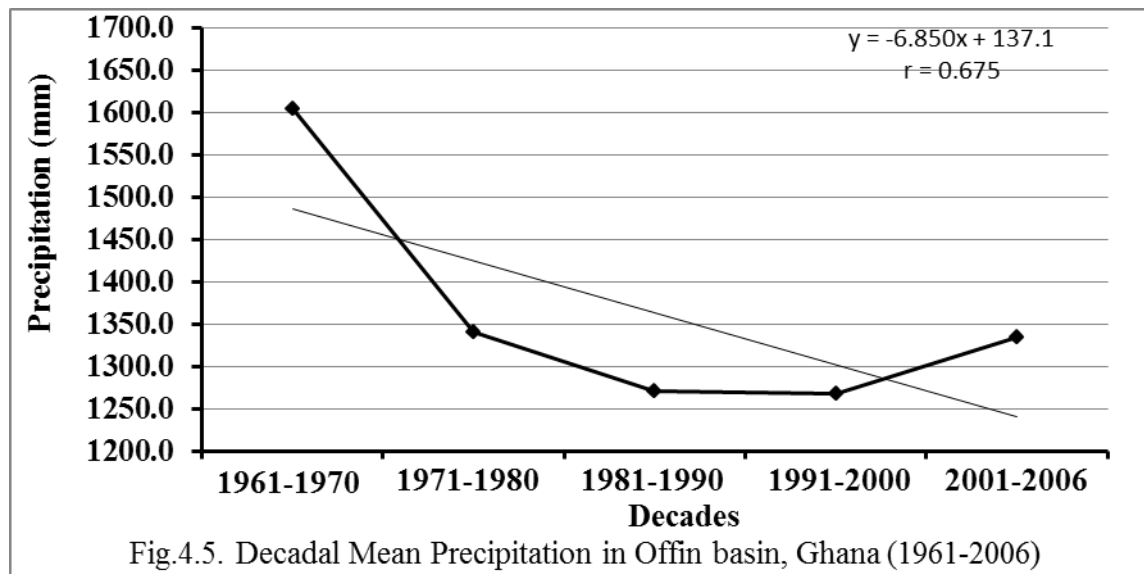
Mean annual precipitation for Offin basin from 1961 to 2006 has been 1366 mm. The least annual rainfall of 891.5 mm was recorded in 1982 whilst the highest annual rainfall of 2343.7 mm was

recorded in 1968. Mean annual precipitation has generally decreased by 17%, i.e., 1603.8 mm in 1961-1970 and 1333.9 mm in 2001-2006 (Fig.4.4).

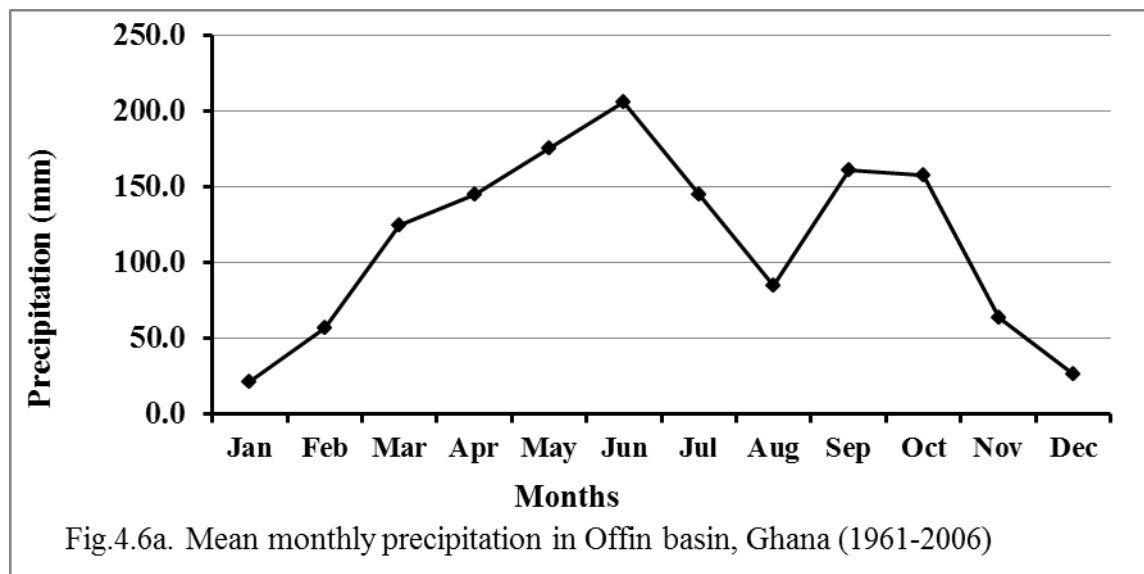


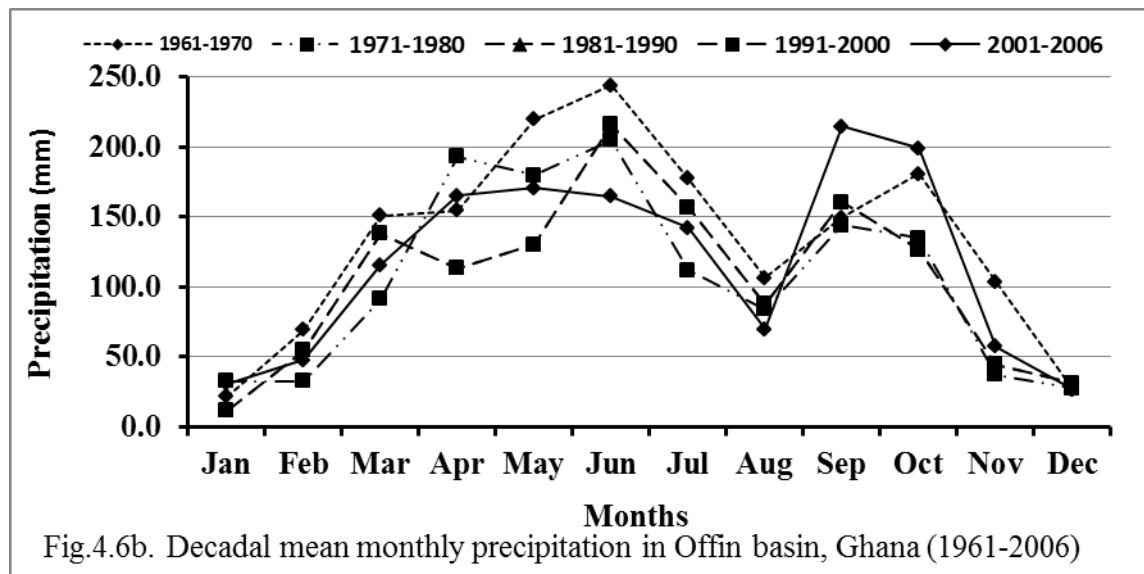
Between 1961 and 2006, 45.65% of the years recorded rainfall above the annual mean of 1366mm and these are referred to as the wet years. Decadal analysis of wet and dry years shows that 1961-1970 had 60% of the years being wet; 1971-1980 had 50% wet and 50% dry years; and after this the third and fourth decades, 1981-1990 and 1991-2000 respectively, both had 40% wet years and 60% dry years. Between 2001 and 2006, the percentage of dry years increased to 66.7% whilst the wet years reduced to 33.3%. Closer analysis reveals that 55% and 45% of the years before 1980 were wet and dry years respectively, compared to 38.5% and 61.5% of the years after 1980 being wet and dry years respectively. This makes the years before 1980 relatively wet and the years after 1980 have been generally dry.

Analysis of decadal average mean precipitation recorded over the last four and a half decades show a sharp decrease of 16.37% between 1961-1970 and 1971-1980 and further decreases of 5.24% from 1971-1980 to 1981-1990 and 0.29% from 1981-1990 to 1991 to 2000. There was a slight increase of 5.26% between the decade of 1991-2001 and 2001-2006, as seen in Fig.4.5.



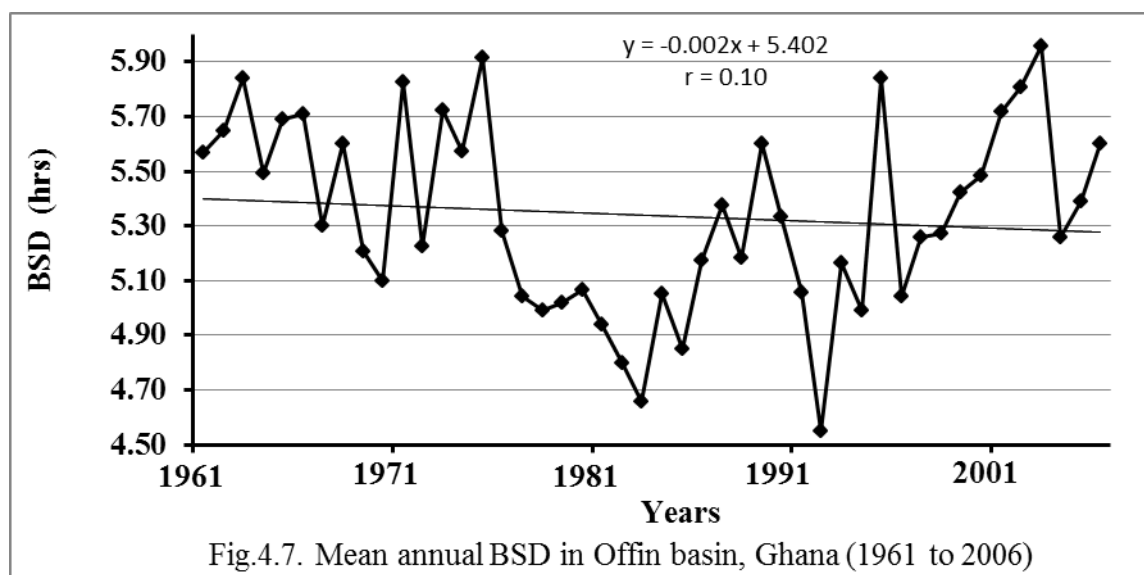
Monthly precipitation in the Offin basin follows a bimodal pattern: main peak in May-June, a trough in July-August and a secondary peak September –October (Fig.4.6a). Generally, the rainfall pattern is showing significant shifts in recent years (2000 to 2006), with clearly observed changes in the beginning of the rainy season. Analysis of monthly rainfall data for the year 2000 to 2006 shows that the minor season (September – October) actually recorded more rainfall than the major season, i.e., May – June (Fig.4.6b).



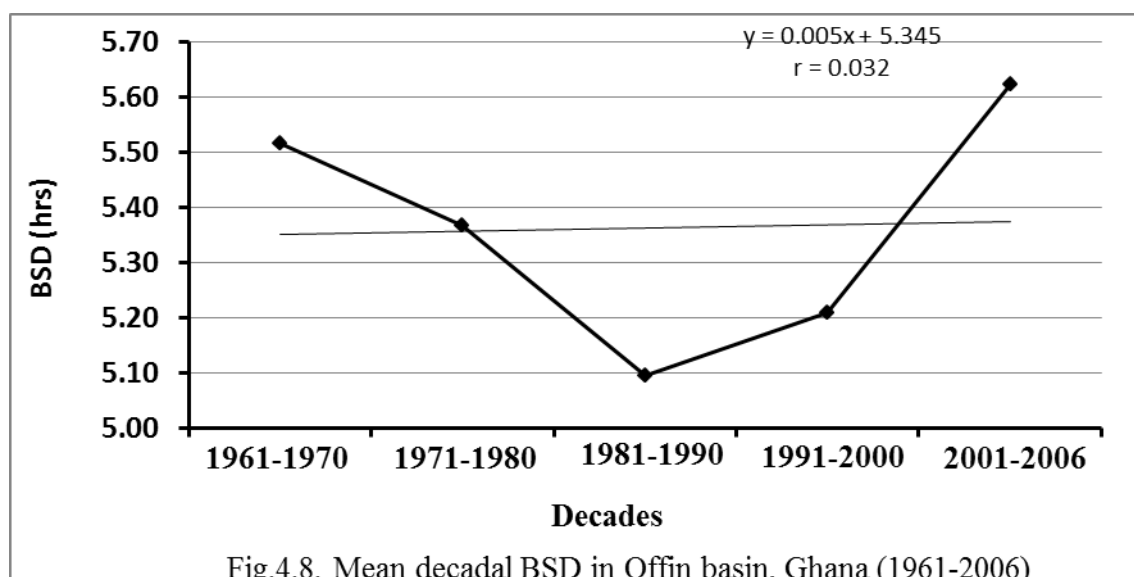


4.1.3. Bright Sunshine Duration (BSD)

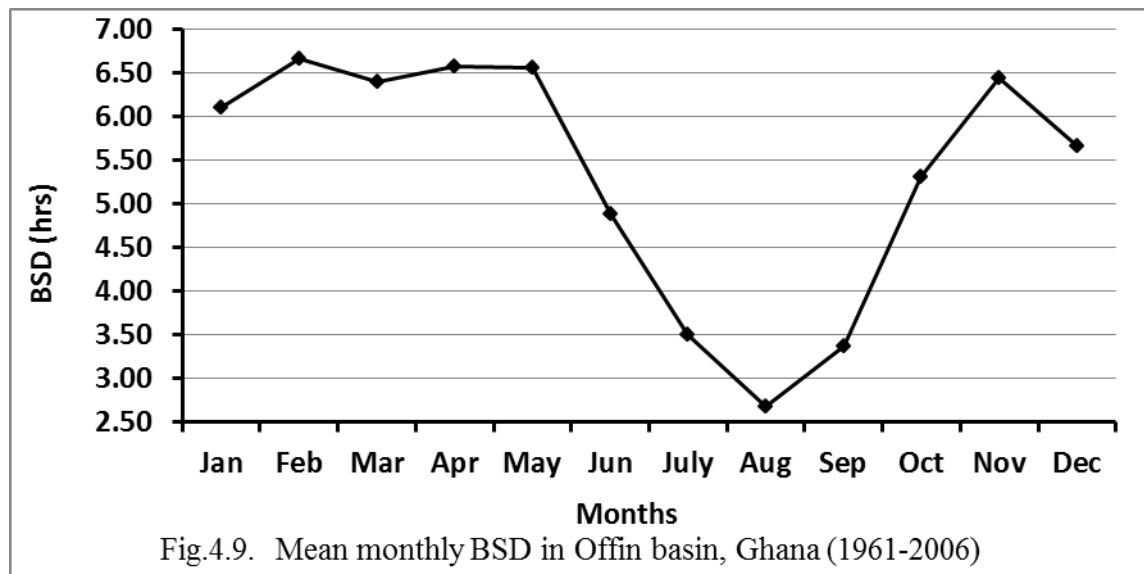
Bright Sunshine Duration (BSD) in the River Offin basin shows a high variability (Fig. 4.7). The lowest mean daily duration of bright sunshine recorded for the period of 1961 to 2006 is 1.40 hours and the highest is 8.10 hours but the average mean daily duration of bright sunshine is 5.34 hours. Year 2003 recorded the highest annual average daily bright sunshine duration of 5.96 hours whilst 1992 recorded the least average daily duration of bright sunshine of 4.55 hours.



The analysis of decadal averages in BSD shows some clear trends (Fig.4.8). The 1961-1970 decade recorded an average daily BSD of 5.52 hours and this decreased by 2.72% to 5.37 hours in the 1971-1980 decade. From 1971-1980 to 1981-1990, mean daily BSD decreased by a further 5.03% before it started increasing by 2.2% from the 1981-1990 decade to 1991-2000. In the last decade of the study period (2001-2006), mean daily BSD has increased sharply by 7.87% from 5.21 hours in the 1991-2000 decade to 5.62 hours in 2001-2006.

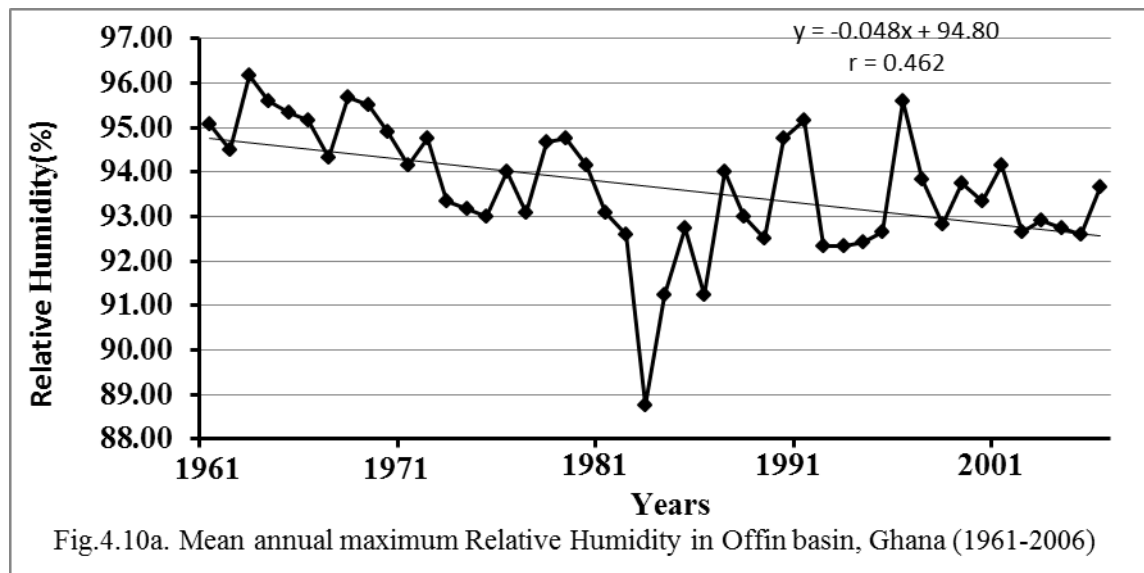


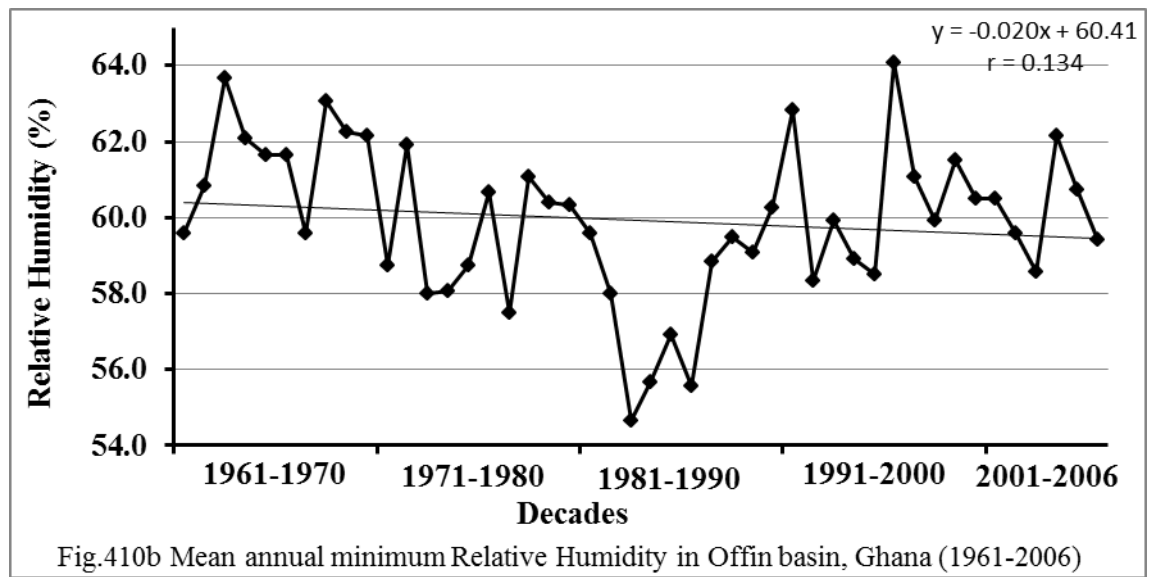
There are also clearly visible trends in mean monthly BSD recorded in Offin basin (Fig.4.9). The first five months of the year (January to May) records the highest duration of bright sunshine and there is not much variation between the months, ranging from 6.11 hours to 6.66 hours. After May, sunshine duration begins to decline until it reaches the lowest of 2.67 hours of daily bright sunshine in August. After August, daily duration of bright sunshine increases until it reaches that of the early part of the year (January to May) in November, declines slightly in December and continues the trend from January.



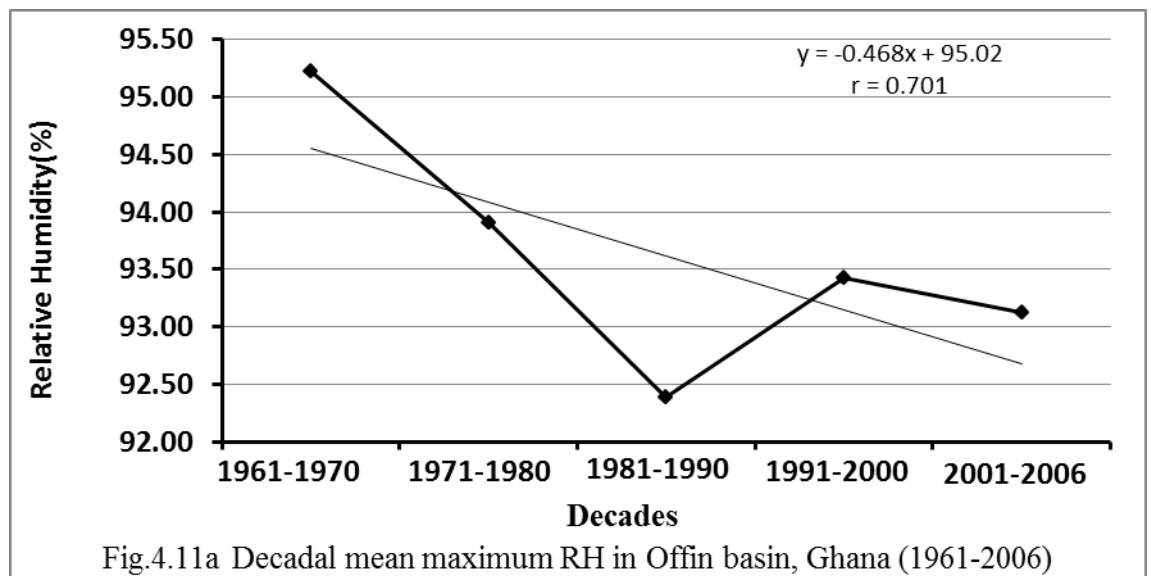
4.1.4. Relative Humidity (RH)

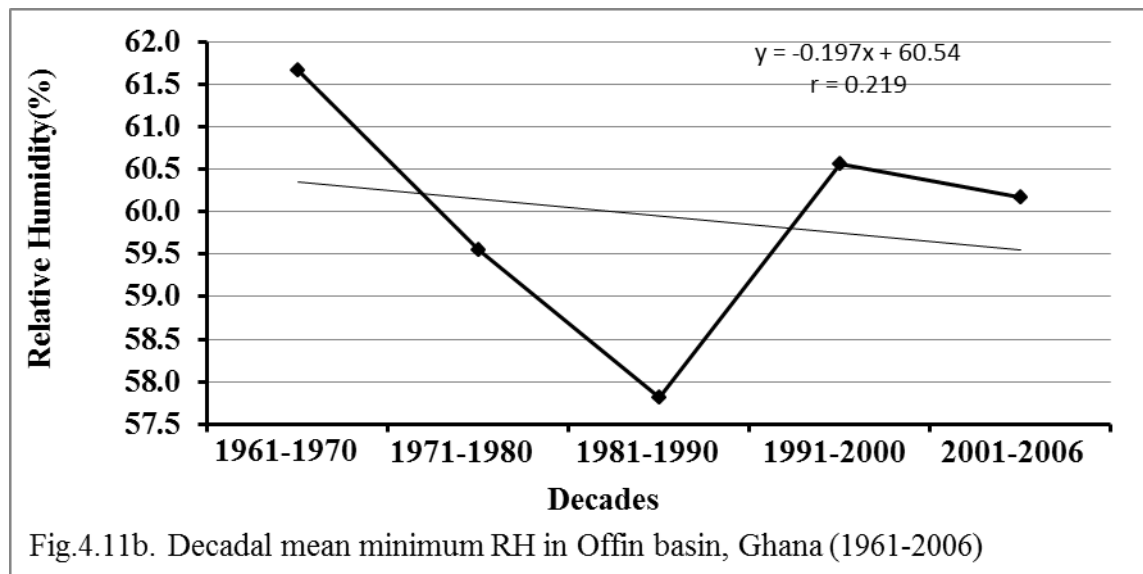
The mean annual maximum and minimum RH recorded at 06:00 hours and 15:00 hours respectively, for the Offin basin shows a gradual decline, as shown in Figs.4.10a and 4.10b.





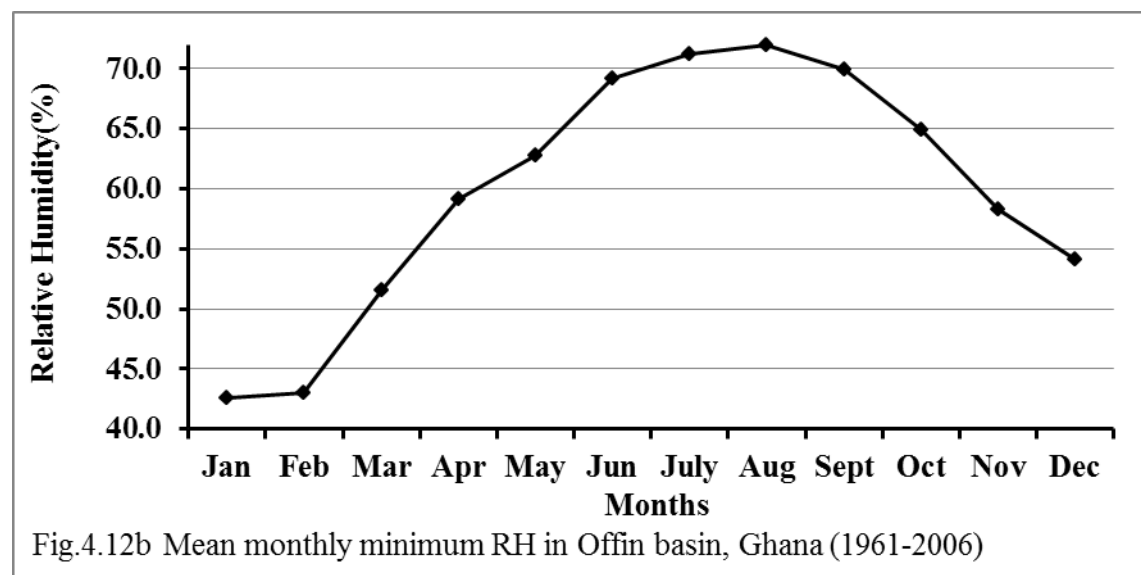
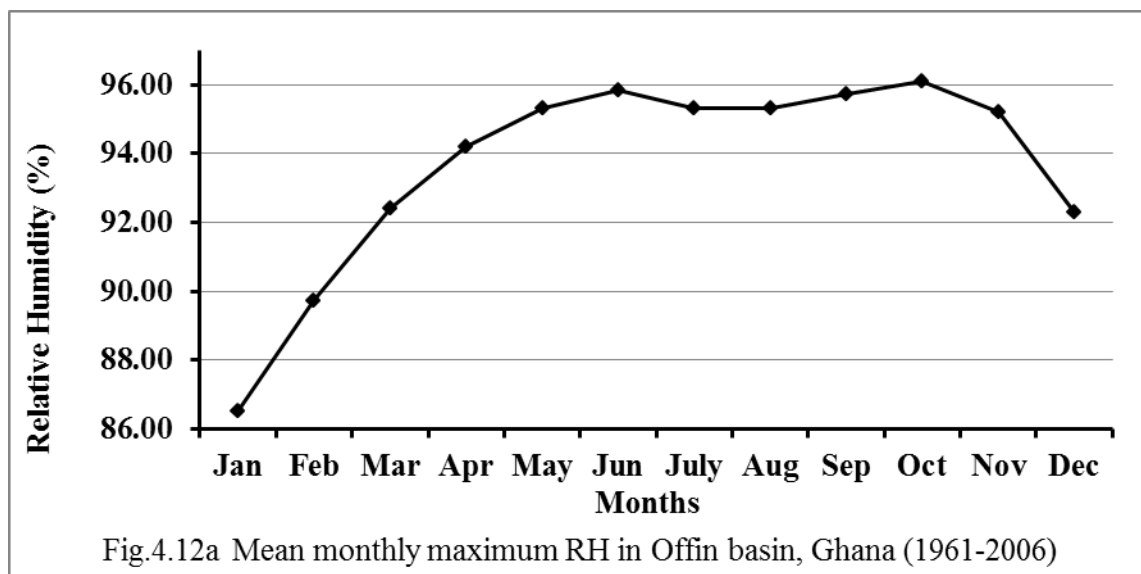
On the average, mean maximum and minimum RH has reduced by 2.2%, i.e., 2.18% and 2.24% respectively between 1961 and 2006. From Fig.4.11a, between the first two decades (from 1961-1970 to 1971-1980), the mean maximum RH declined by 1.37% and there was a further decline of 1.62% from the second to the third decades. There was, however, an increase of 1.13% in the maximum RH recorded from 1981-1990 to 1991-2000 and a marginal decrease of 0.32% from the 1991-2000 decade to the 2001-2006 decade.





The decadal trend for the mean annual minimum RH (Fig.4.11b) also follows a similar pattern of decrease from the first decade until the third decade where there is an increase and finally a decrease till 2006, as that of the maximum RH. However, the percentage decreases and increases are relatively higher. Between 1961-1970 and 1971-1980, the minimum RH declined by 3.4% which is higher than that of the maximum RH; 3.02% reduction from 1971-1980 to 1981-1990; an increase of 4.84% from 1981-1990 to 1991-2000 and finally a reduction of 0.66% from 1991-2000 to 2001-2006.

Monthly mean maximum RH values recorded ranges from follows a very weak bimodal pattern (Fig.4.12a) The decline in maximum RH begins from November and reaches its lowest in January, from where it begins to increase gradually till June. There is a very slight drop in the RH in July and August and begins to increase again till it reaches the peak in October then the decline starts, as seen in Fig.4.12a. The mean minimum RH, however, does not follow the same weakly bimodal pattern as that of the maximum relative humidity, as shown in Fig.4.12b. It increases gradually from January till it reaches the peak in August and starts declining from September.

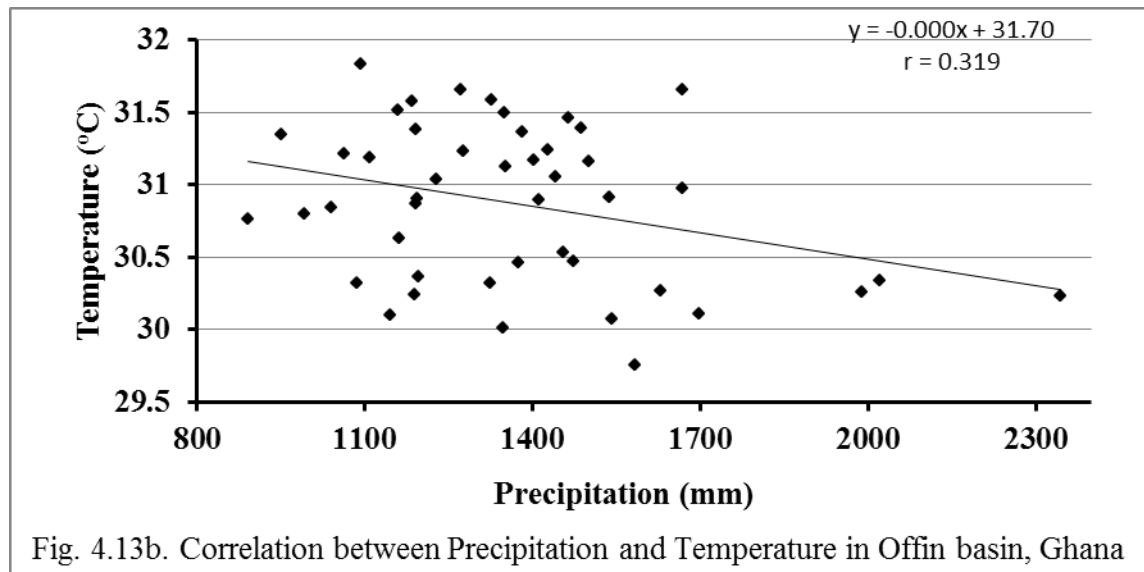
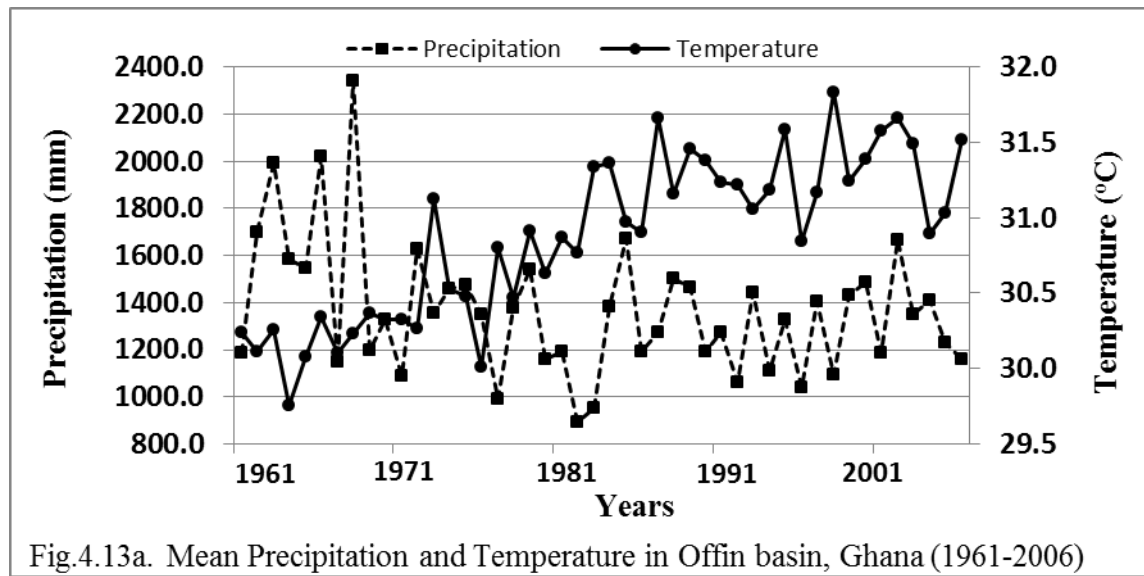


4.2. Relating climate parameter trends

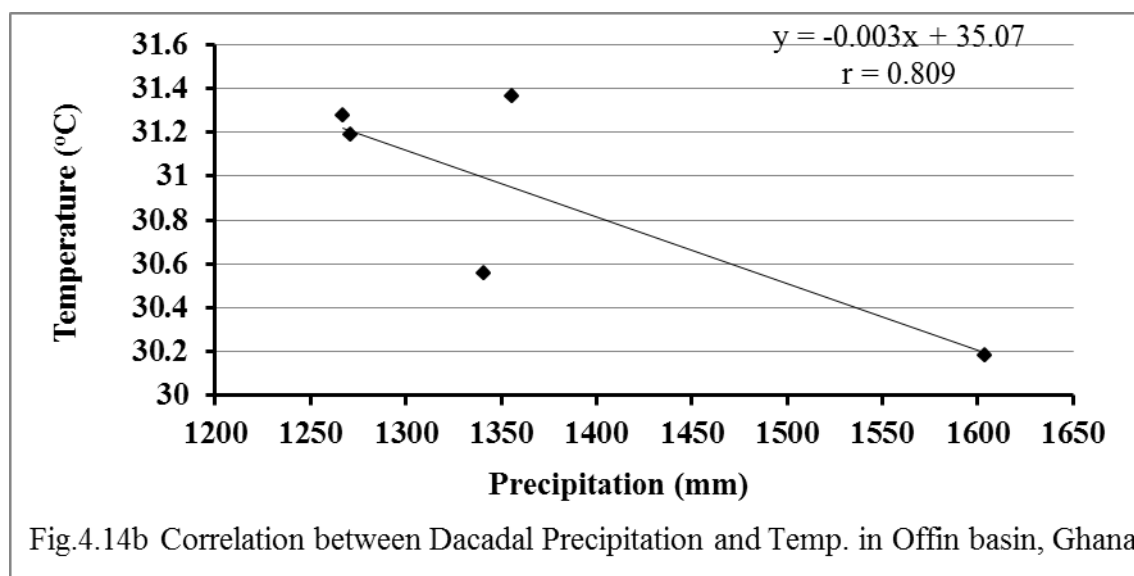
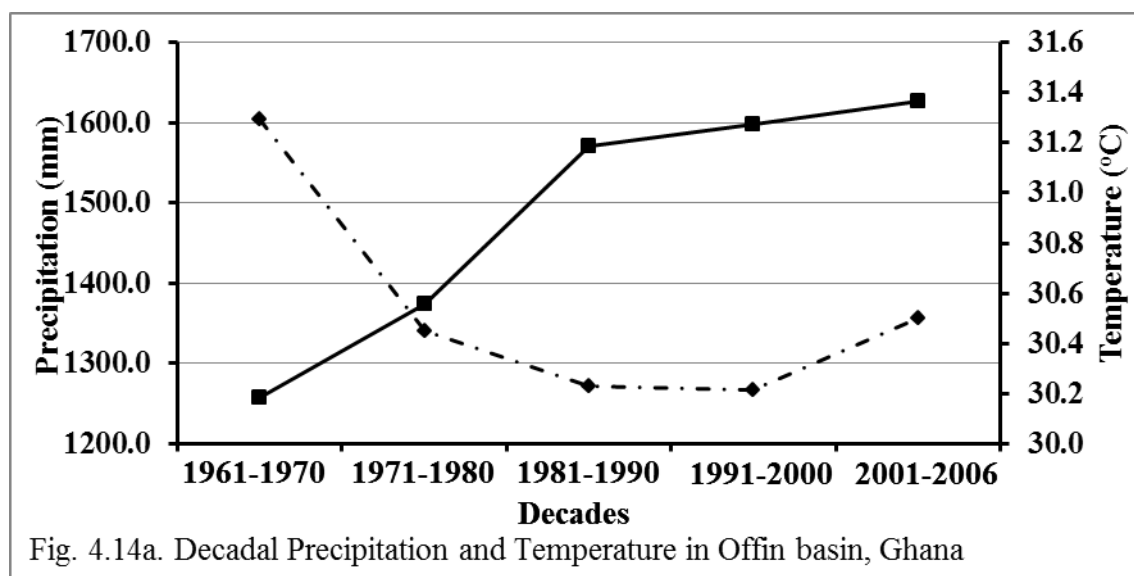
The section below presents comparisons between the various climate parameters analysed in Offin basin.

4.2.1. Temperature and Precipitation

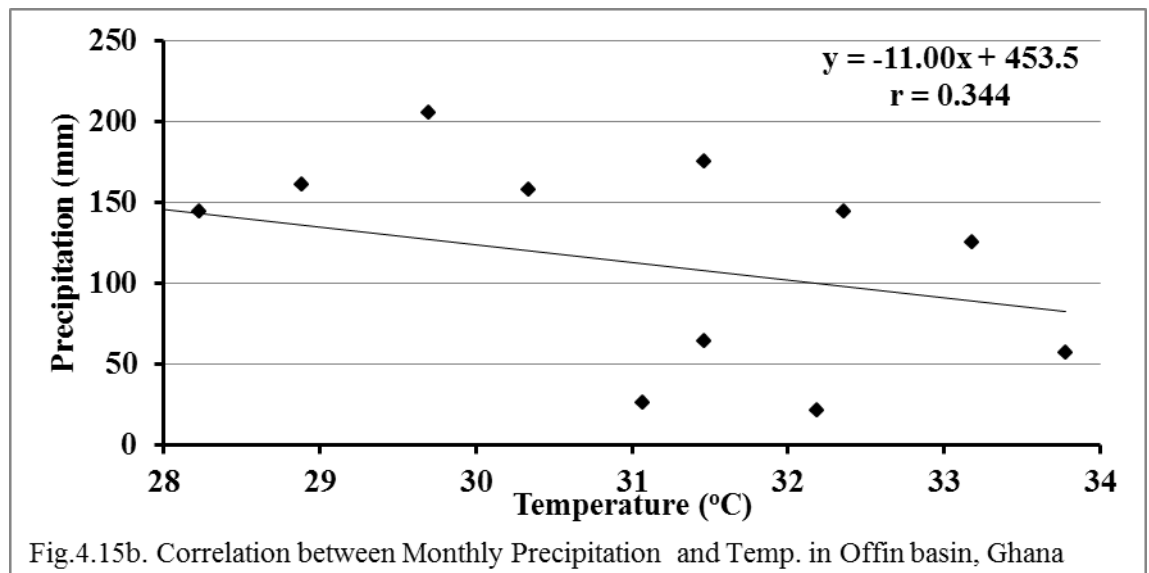
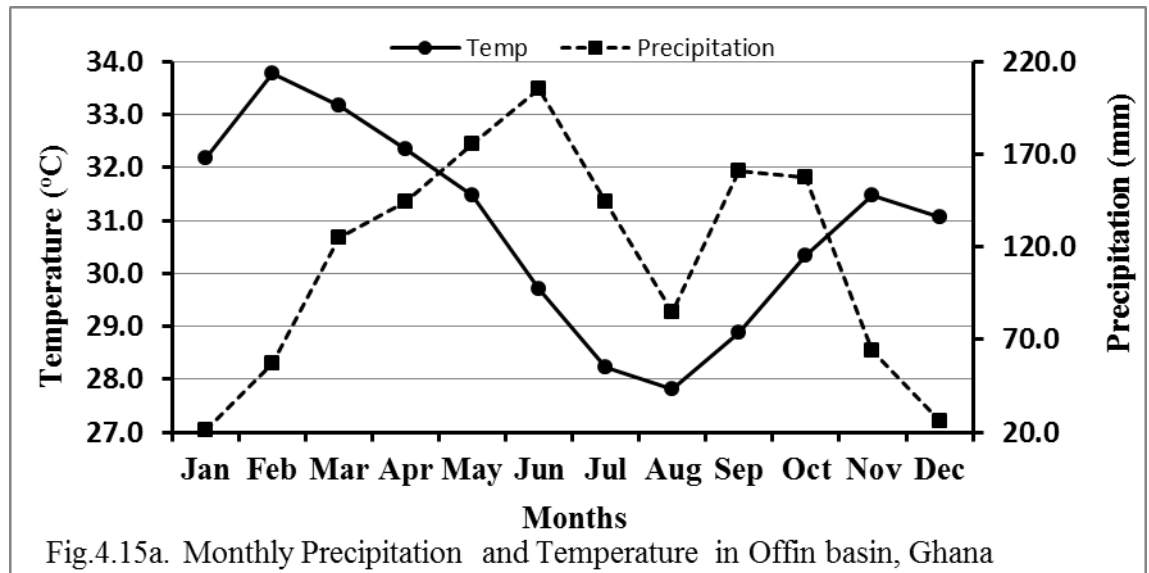
Between 1961 and 2006, mean temperature trends have generally increased whilst precipitation trends have shown a gradual decline (Fig.4.13a). There is a negative correlation between annual temperature and precipitation (Fig. 4.13b). For any given year, as temperature increased, there is about a 30% probability that precipitation will decrease and vice versa.



The negative correlation between temperature and precipitation becomes very evident in the decadal analysis (Fig. 4.14a). A very strong negative correlation is seen between the two parameters in the decadal analysis (Fig. 4.14b).

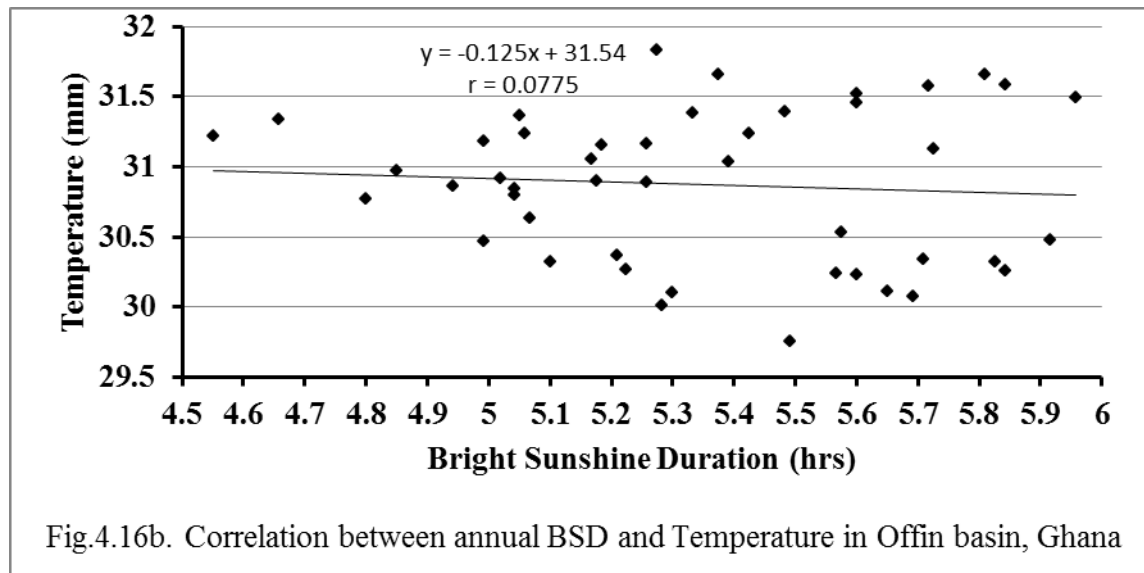
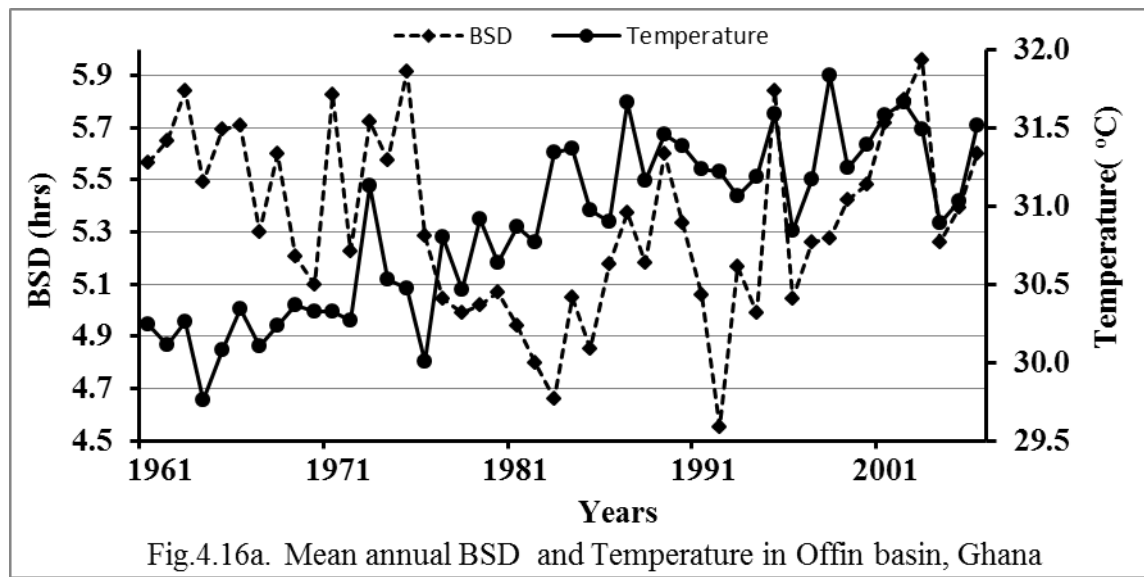


The monthly trends of temperature and precipitation shows generally a reduction in ambient temperatures during the rainy periods (Fig.4.15a) and the negative correlation between the two climate variables is still evident (Fig. 4.15b).



4.2.2. Bright Sunshine Duration and Temperature

There is not any significant correlation between annual BSD and Temperature between 1961 and 2006 (Fig.4.16a and 4.16b).



Monthly records of BSD and temperature, however, follow a similar pattern (Fig. 4.17a) and show very strong positive correlation (Fig. 4.17b) of over 90%. As BSD increased in the month, temperature also increased and same is observed with decreases in monthly BSD and temperature.

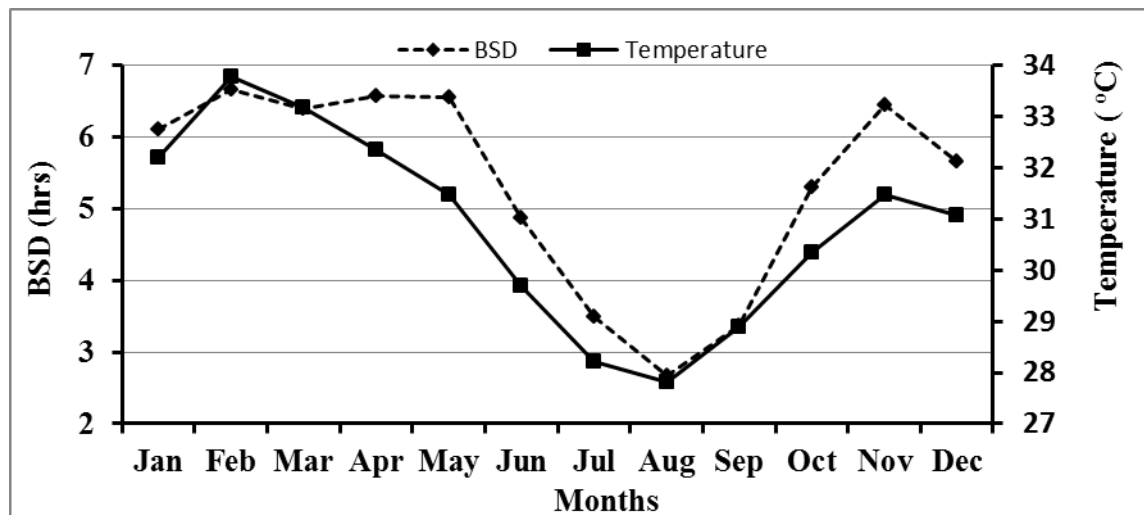


Fig. 4.17a. Monthly BSD and Temperature in Offin basin, Ghana

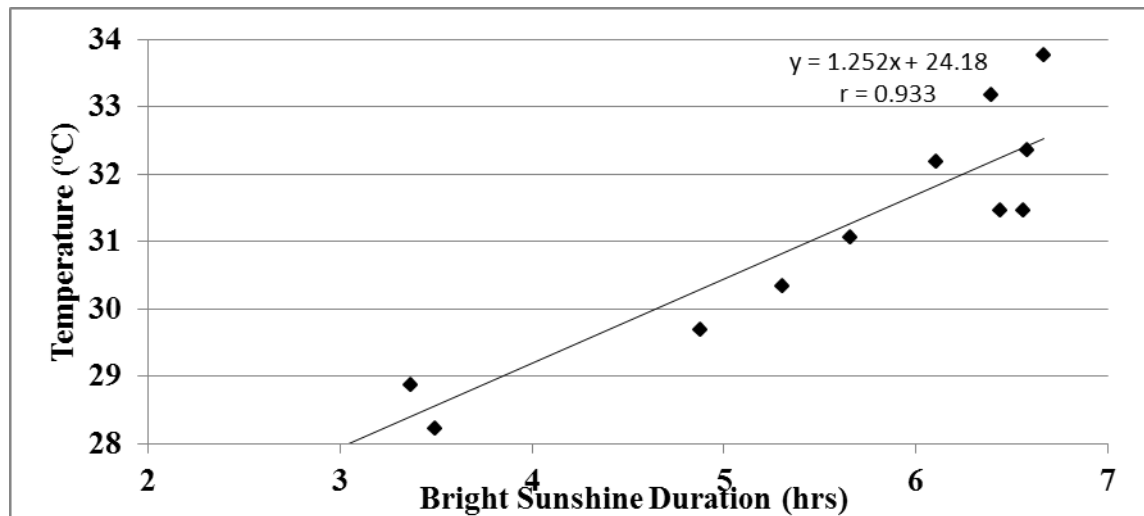
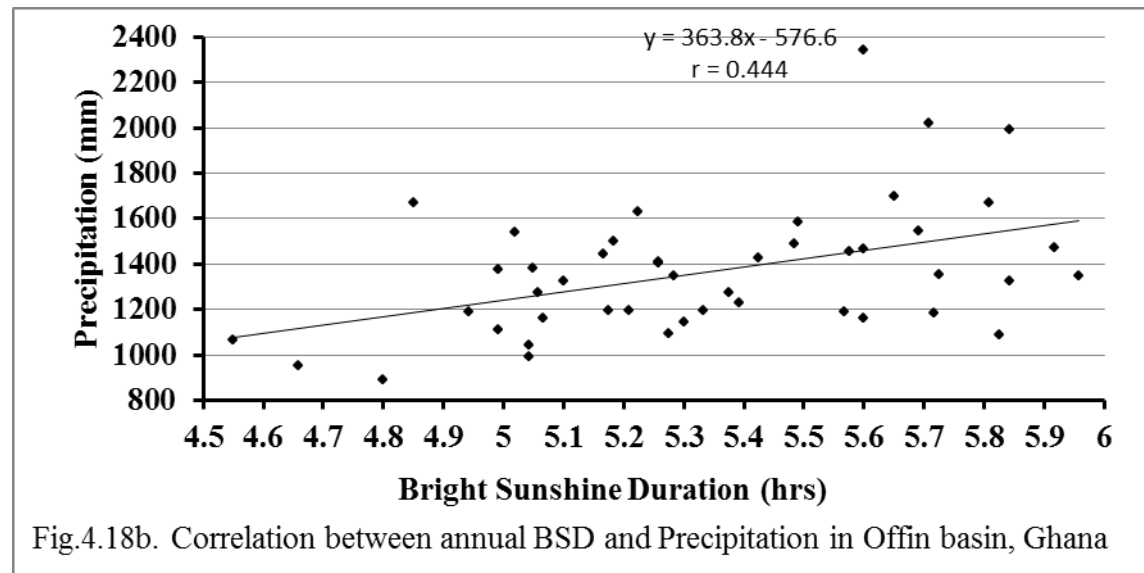
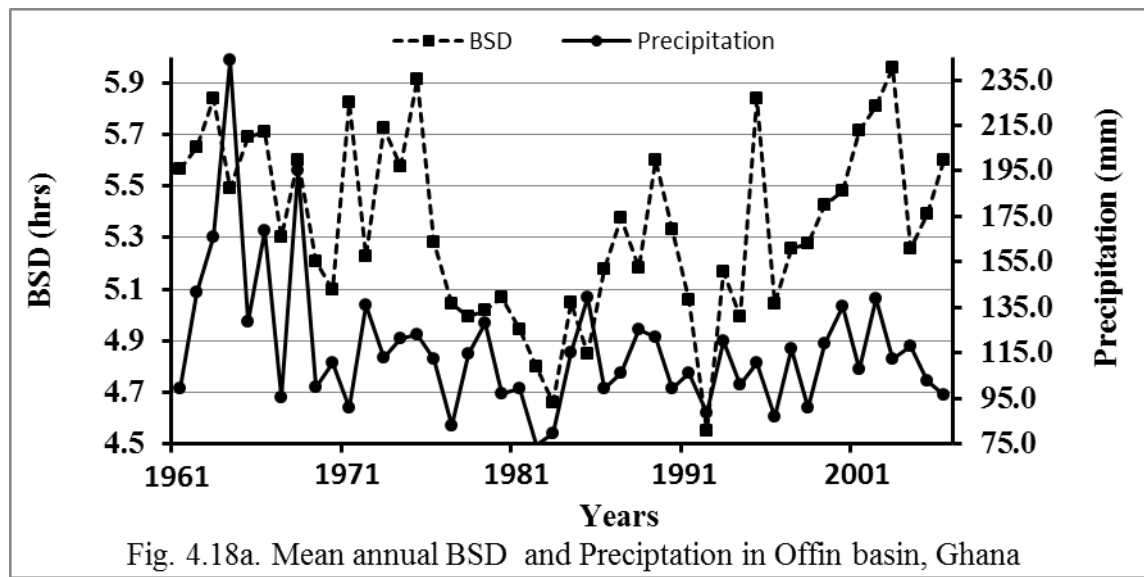


Fig. 4.17b. Correlation between monthly BSD and Temp. in Offin basin, Ghana

4.2.3. Bright Sunshine Duration and Precipitation

The relationship between the trends for precipitation and BSD (Fig.4.18a) shows a positive correlation, though not very strong (Fig. 4.18b).



Monthly trends for both precipitation and duration of bright sunshine show clear trends. The rainy season begins to peak in May as the duration of bright sunshine begins to decline from May to August which coincides with the major rainy season from April to June (Fig.4.19a). August records both the least duration of bright sunshine as well as precipitation. After August, the minor rainy season (September to October) coincides with an increase in bright sunshine duration which continues till May with a slight reduction in December. But the two variables show a weak negative correlation (Fig. 4.19b).

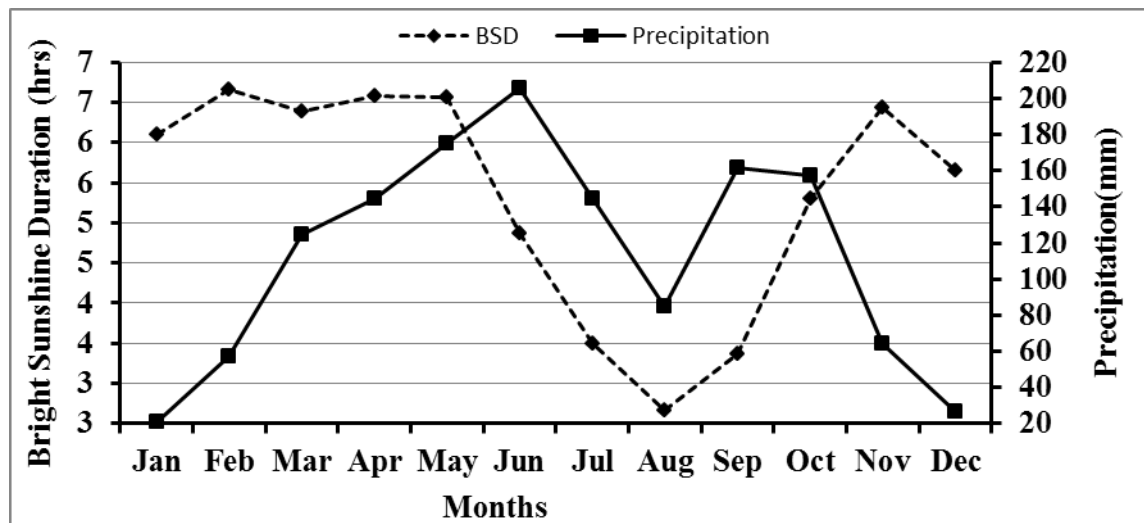


Fig. 4.19a. Monthly BSD and Precipitation in Offin basin, Ghana

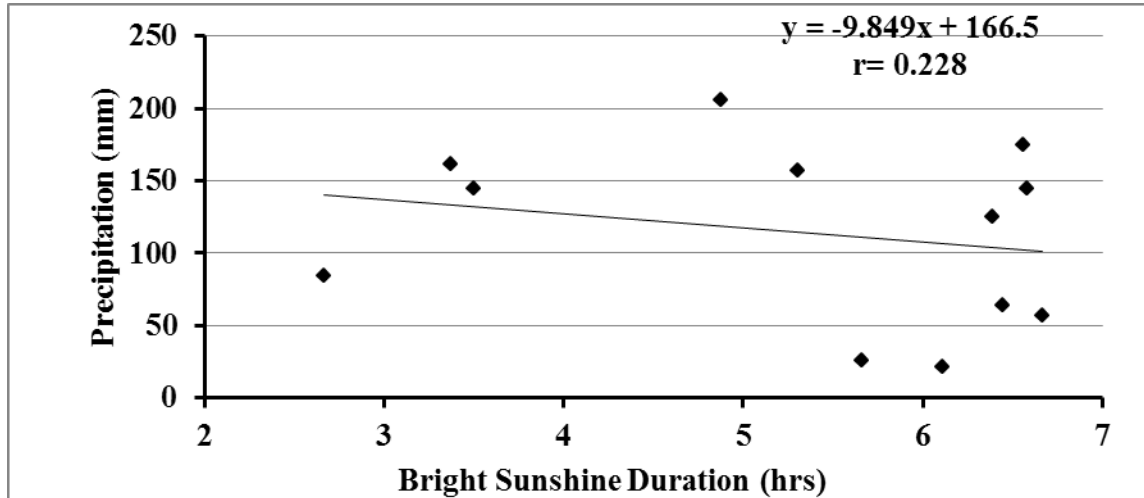
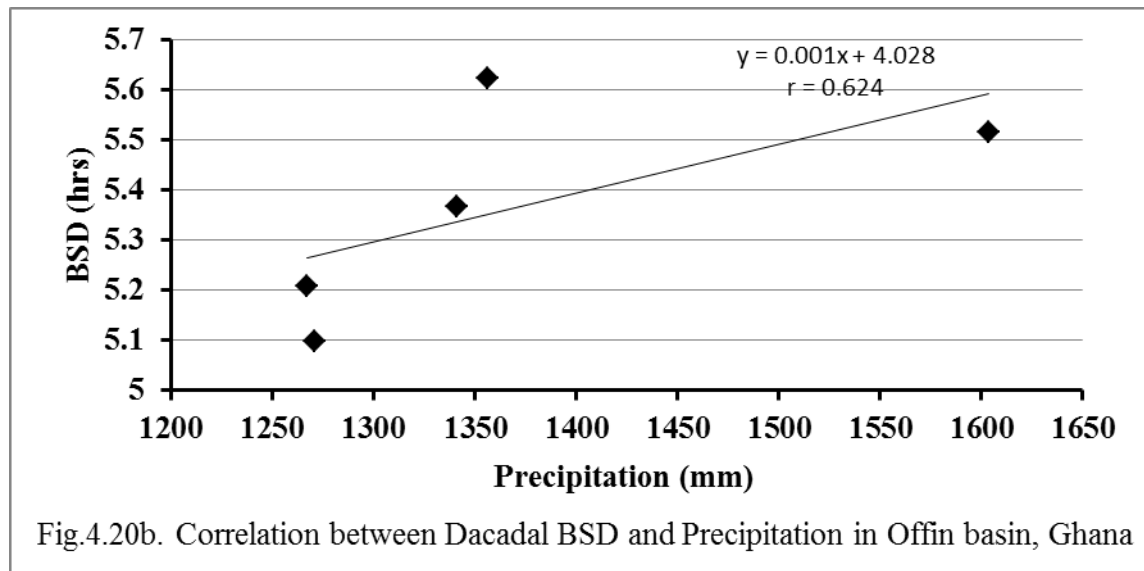
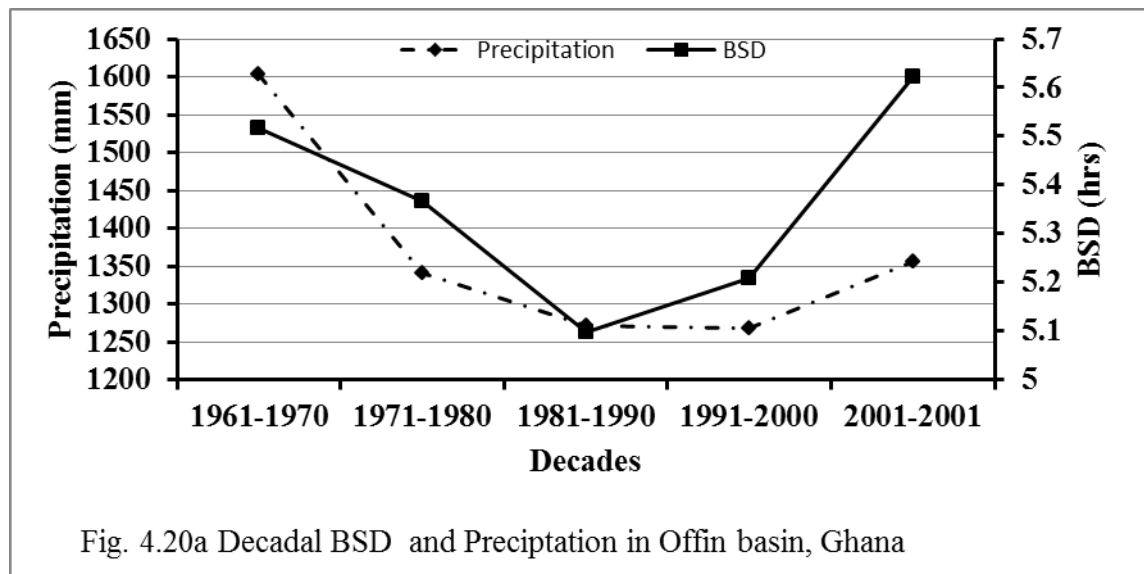


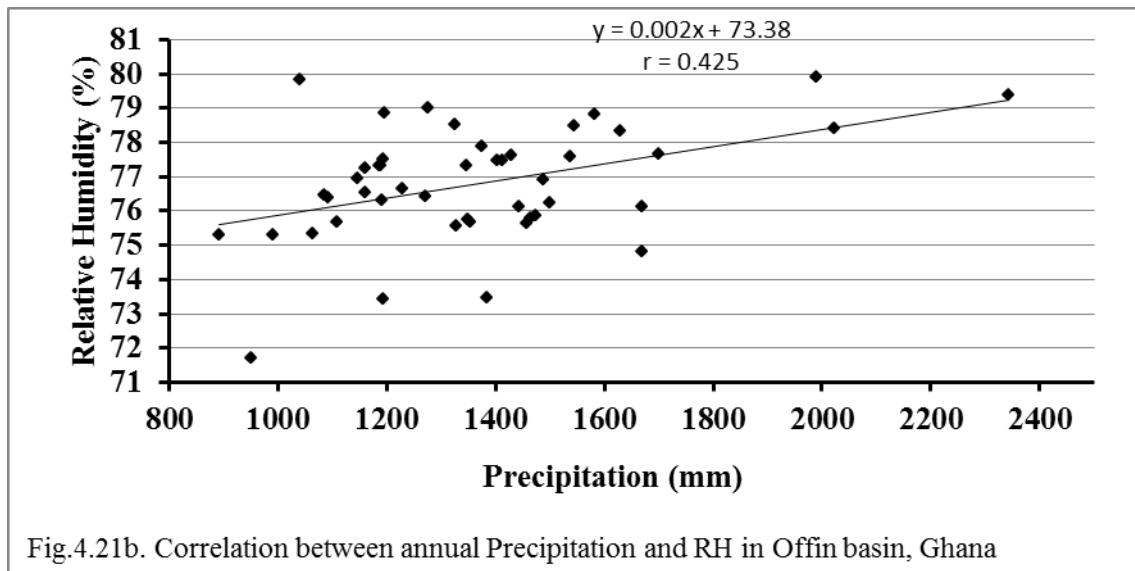
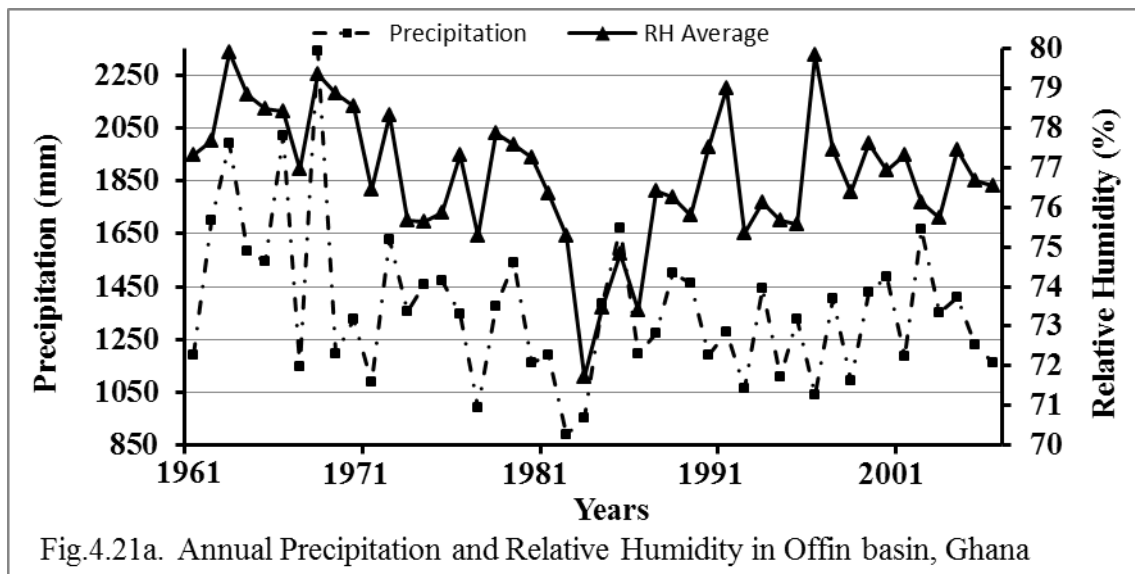
Fig. 4.19b Correlation between monthly BSD and Precipitation in Offin basin, Ghana

There is, however, a strong correlation between the decadal trends of BSD and precipitation in the Offin basin (Figs. 4.20a and 4.20b)

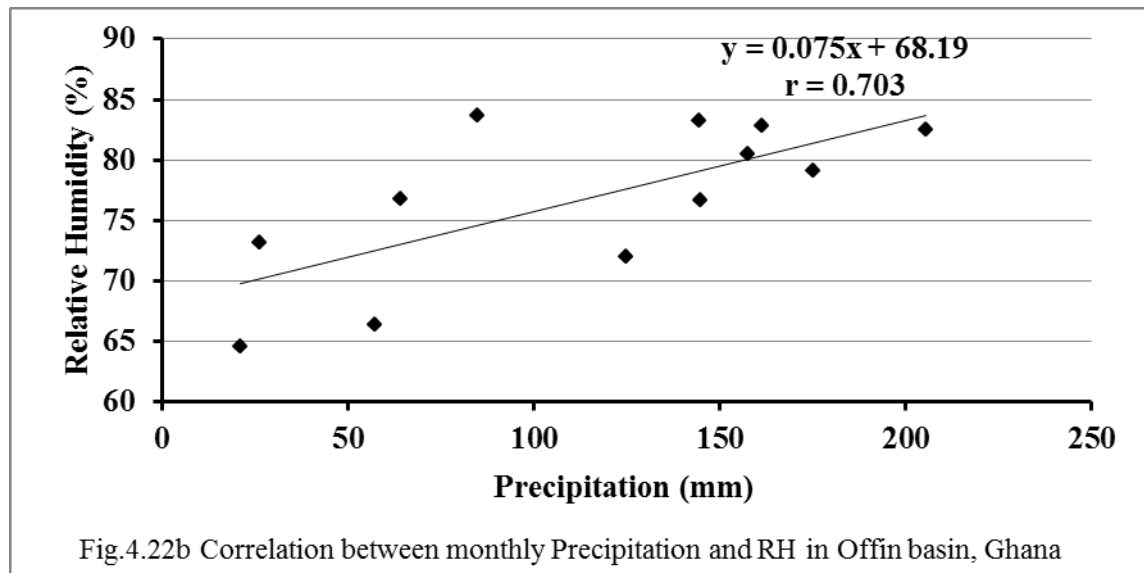
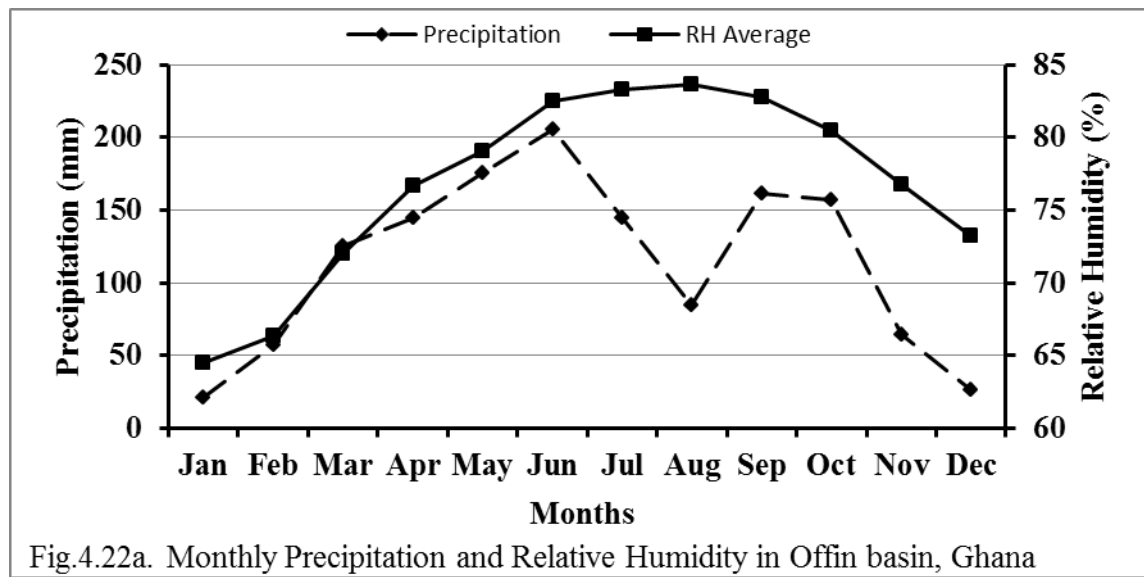


4.2.4. Relative Humidity and Precipitation

Annual mean relative humidity shows a similar trend like precipitation (Fig. 4.30a) and shows a positive correlation (Fig. 4.20b). For every given year, RH increases as precipitation increases.



The positive correlation between the two variables in the Offin basin is even stronger in the monthly trends (Fig. 4.22b). However, unlike precipitation, mean monthly RH does not show a strong bimodal pattern (Fig. 4.22a).



An even stronger correlation between precipitation and relative humidity is seen in the decadal trends (Figs. 4.23a and 4.23b)

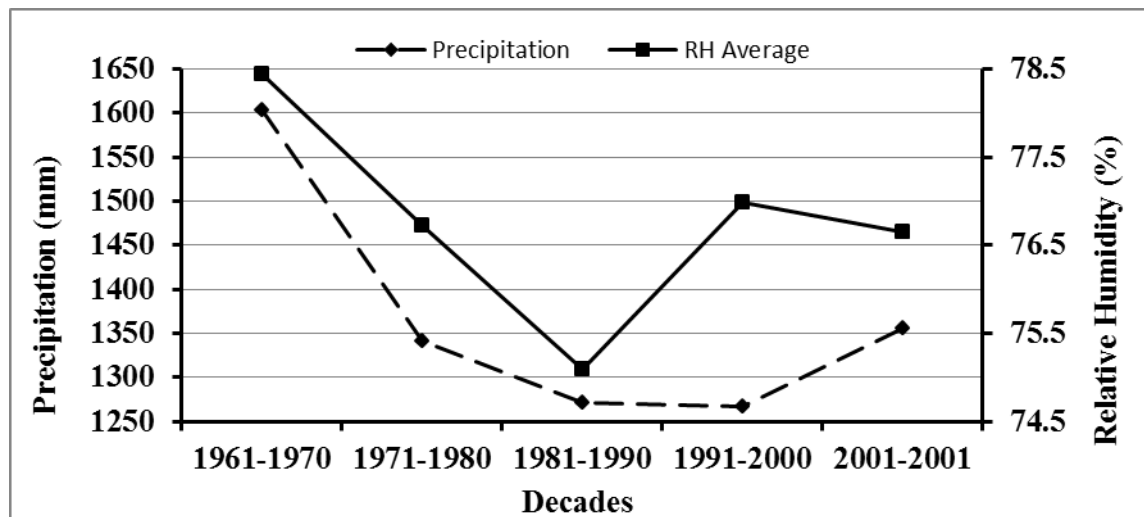


Fig.4.23a Decadal Precipitation and Relative Humidity in Offin basin, Ghana

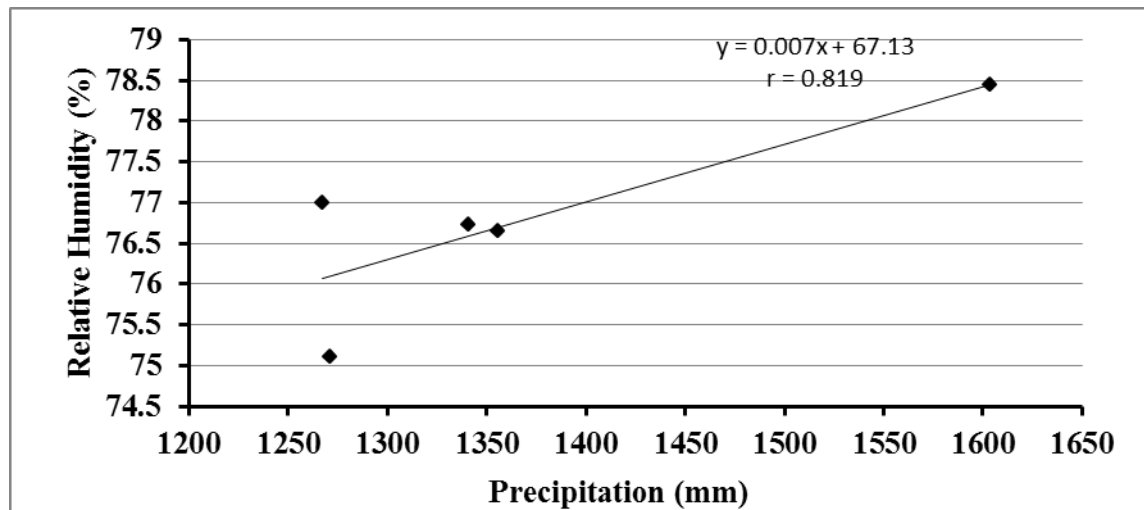
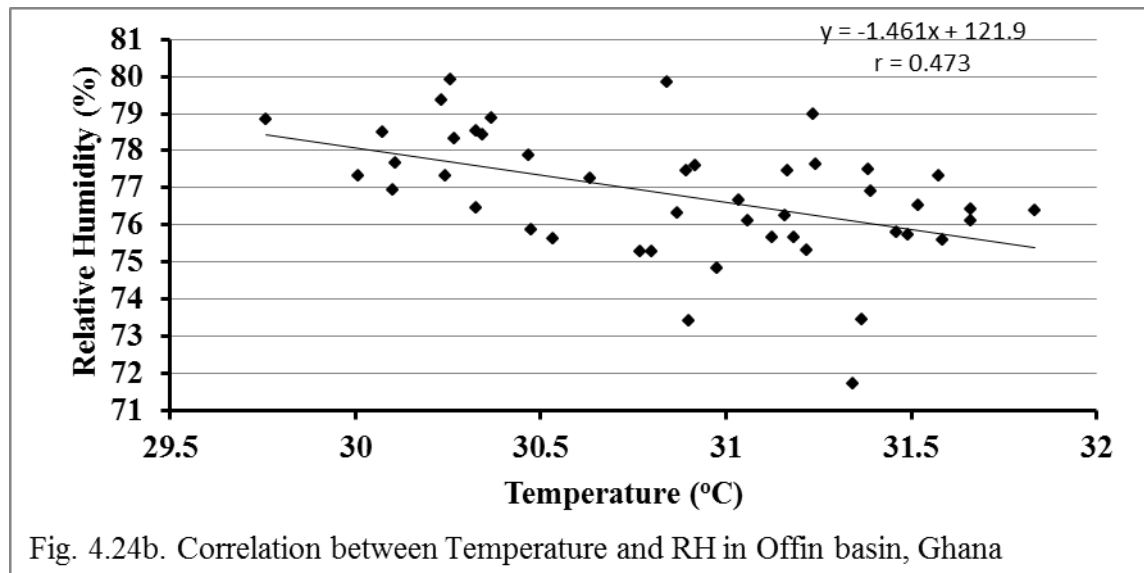
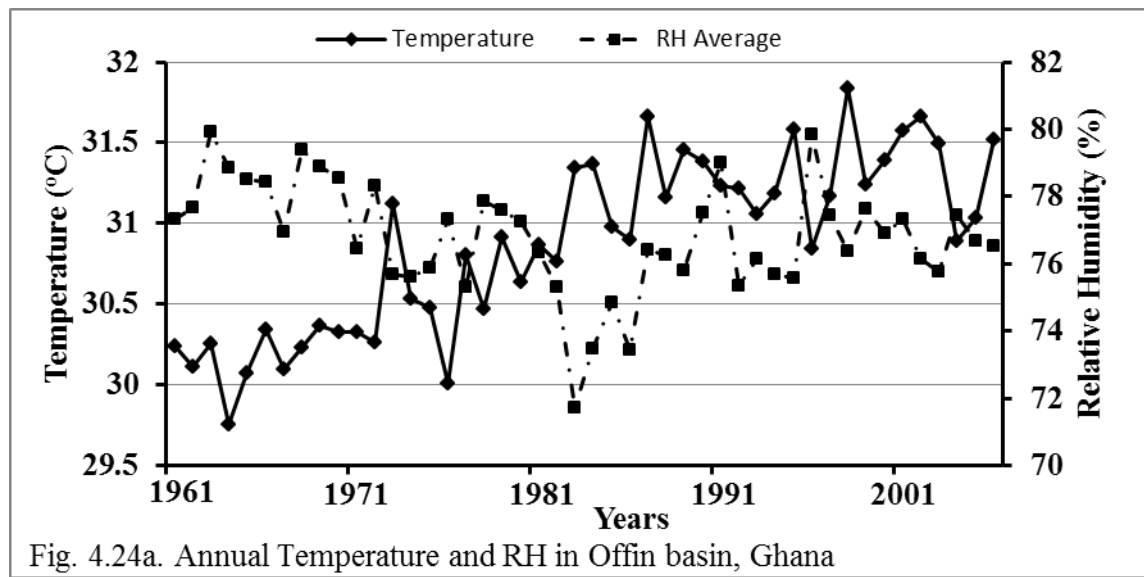


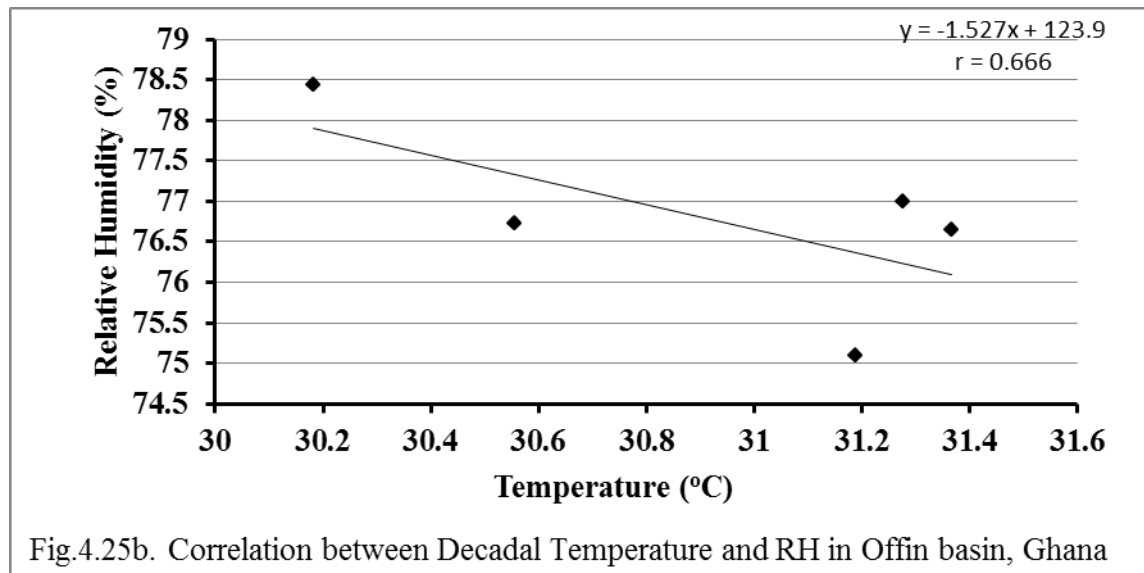
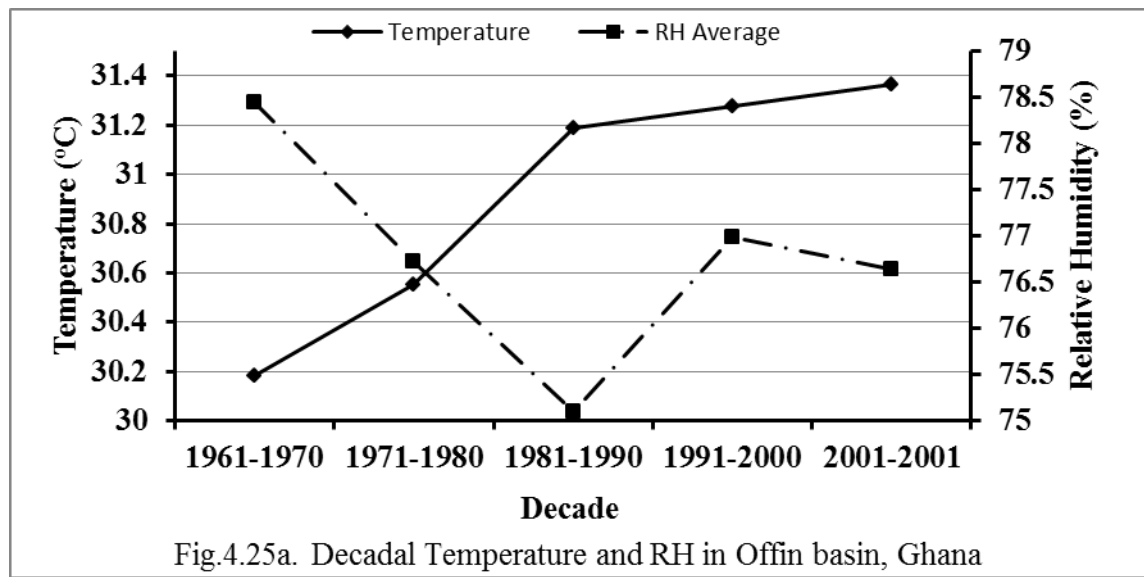
Fig.4.23b. Correlation between Decadal Precipitation and Rel. Humidity in Offin basin

4.2.5. Relative Humidity and Temperature

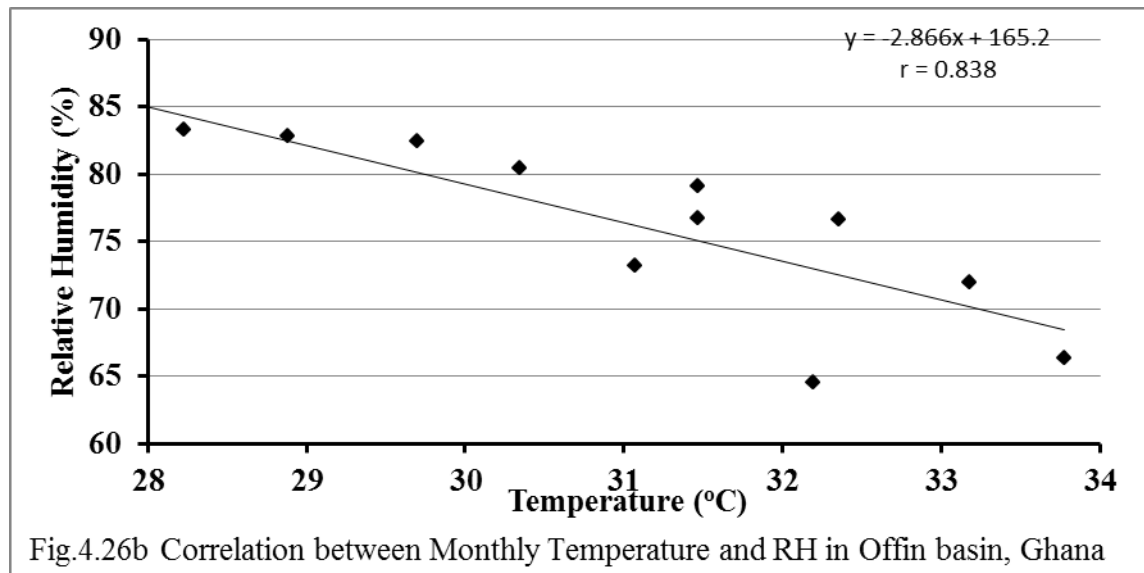
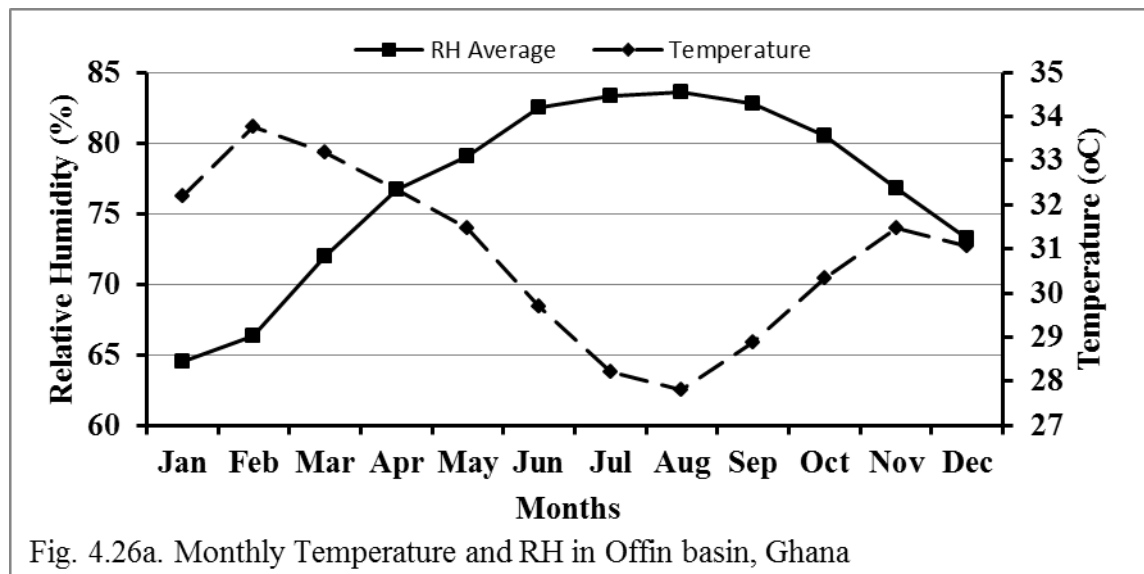
There is almost a 50% a negative correlation between relative humidity and temperature in the Offin basin and this is seen in the annual trends (Fig. 4.24a). As temperature increases, relative humidity decreases (Fig. 4.24b).



The negative correlation between RH and temperature in the Offin basin is even stronger in the decadal trends (Fig. 4.25a) where for any particular decade RH decreased at a correlation of over 60% as temperature increased (Fig.4.25b).

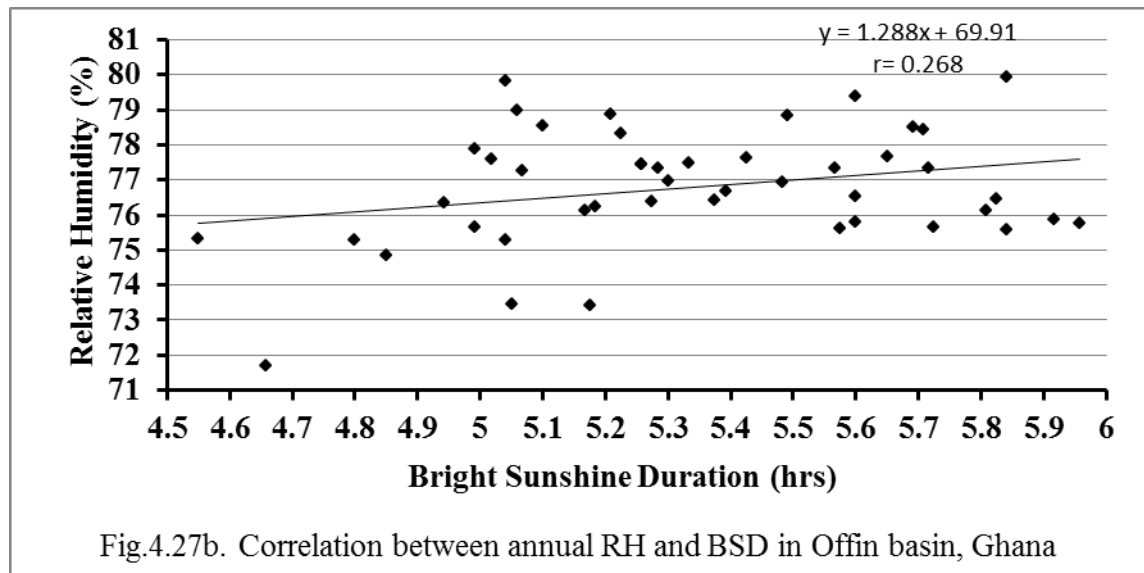
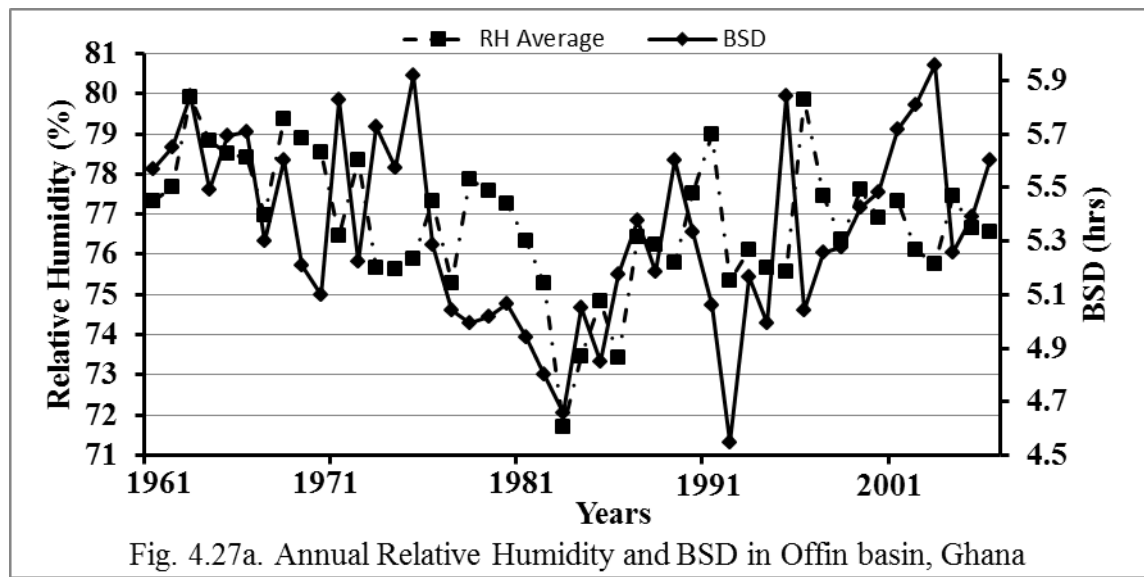


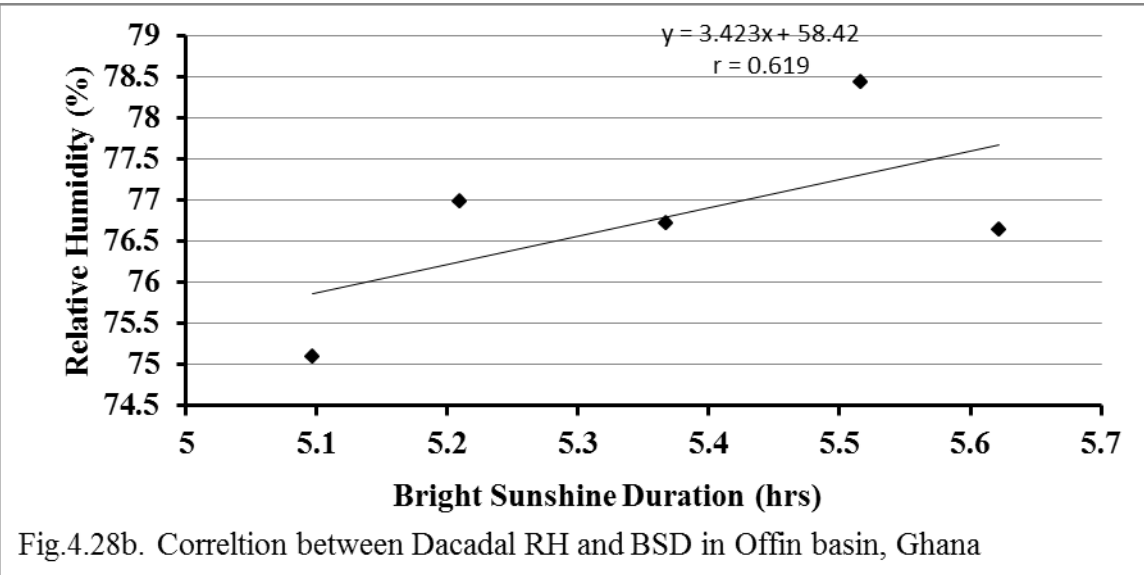
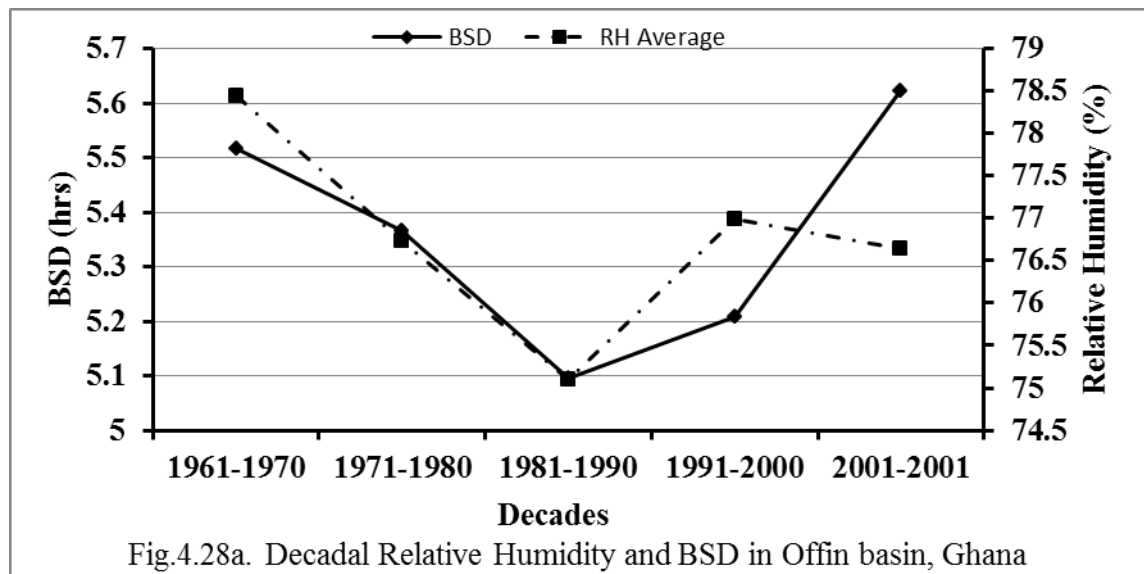
The monthly trends of RH and Temperature (Fig. 4.26a) show an even stronger negative correlation ($r = -0.838$) (Fig. 4.26b).



4.2.6. Relative Humidity and Bright Sunshine Duration

Comparison of annual trends in relative humidity and bright sunshine duration (Fig. 4.27a) show a very weak positive correlation (Fig. 4.27b). Decadal trends in RH and BSD show a very strong positive correlation (Figs. 4.28a and 4.28b). However, the monthly trends show a very strong negative correlation (Figs 4.28a and 4.28b).





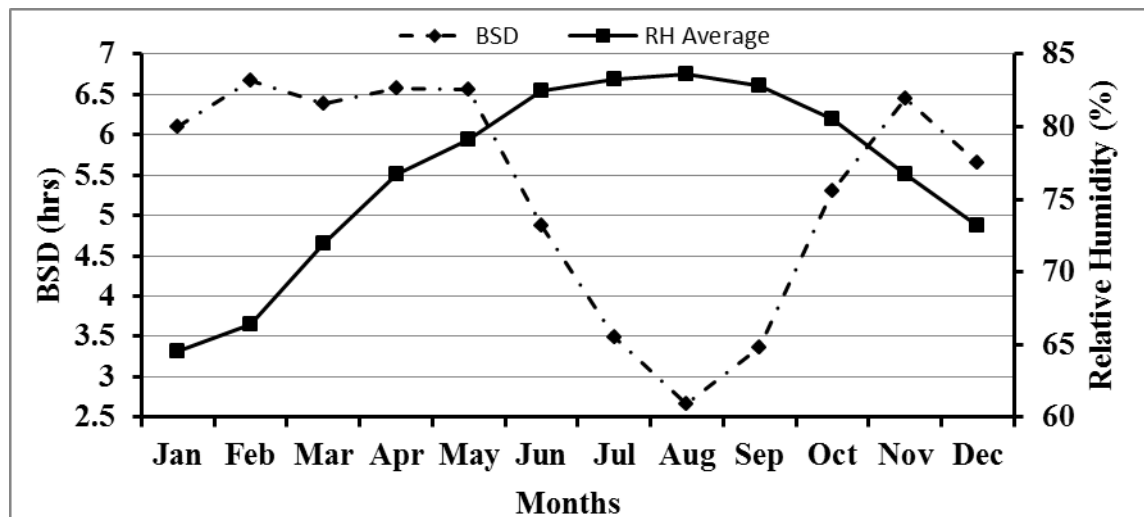


Fig.4.29a Monthly Relative Humidity and BSD in Offin basin, Ghana

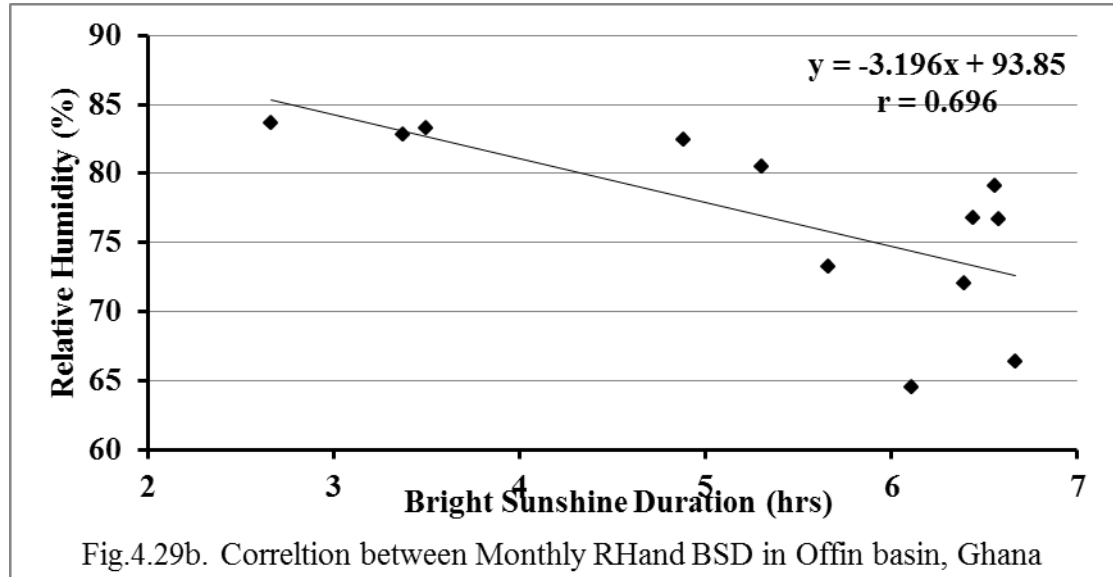
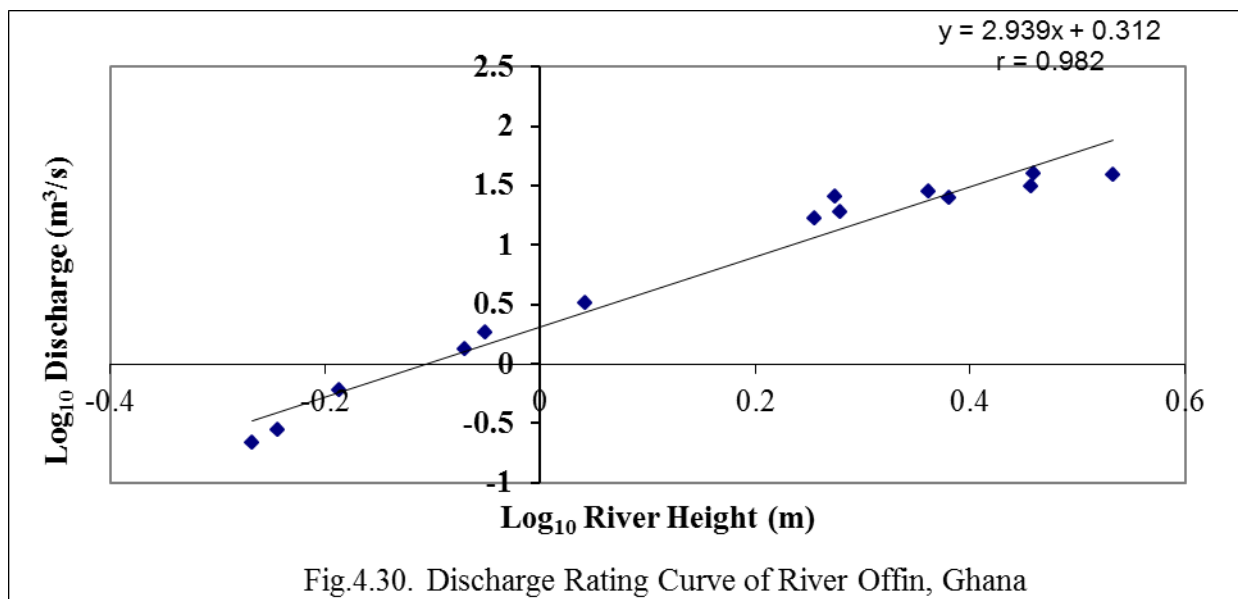


Fig.4.29b. Correlation between Monthly RH and BSD in Offin basin, Ghana

4.3. Discharge pattern of River Offin from 1957 to 2006

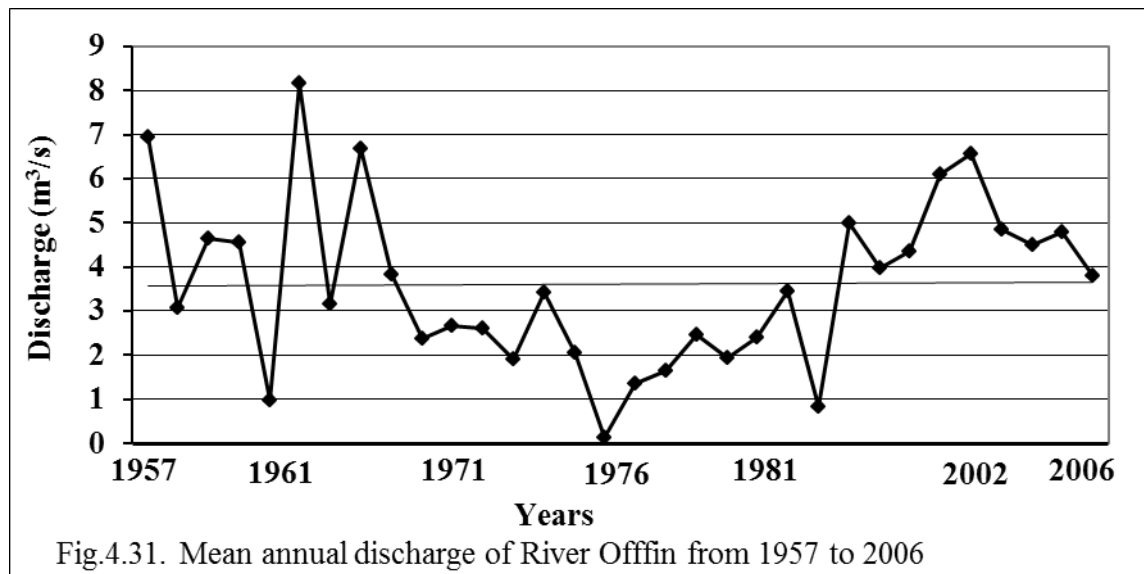
In the absence of a long period of river discharge record on the River Offin, historical river height measurements on the River Offin at two different stations; Adiembra station (downstream) and Offinso station (upstream) from 1957 to 2006 were collected from the Hydrological Agency of Ghana office in Kumasi for analysis. River discharge measurements of River Offin at the Adiembra

station from 2002 to 2006 were available and used to construct a rating curve for the Offin River, as shown in Fig.4.30. From the rating curve (Fig.4.31), the rate equation ($y = 2.939x + 0.312$) was used to estimate the discharge of the river at the recorded river heights from 1957 to 2006. From this data, the trend in discharge of the River Offin over the last forty years was established.

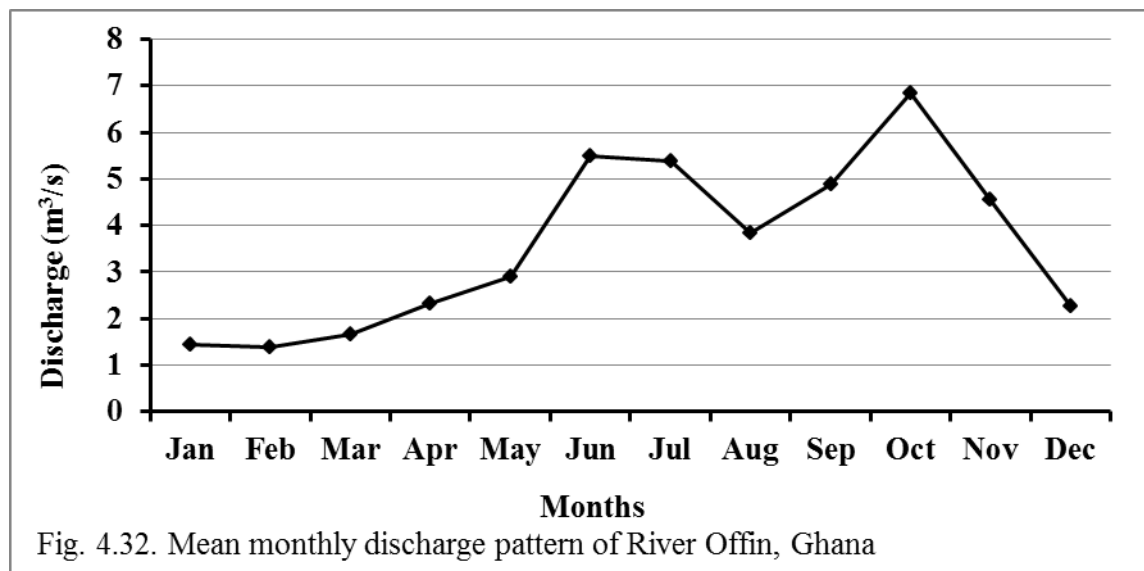


There was, however, several years of unrecorded data between 1957 and 2006 and those years were excluded from the analysis in order to minimise the errors that may be introduced by estimation of missing values. The exclusion of the “years of no data” accounts for the irregularity of the scale of the “X” axis.

From 1957 to 2006, discharge of River Offin has shown great variability, as seen in Fig.4.31. Highest discharge of 8.177m³/s recorded in 1963 and the lowest discharge of 0.139m³/s in 1976 (during the Ghana droughts). Generally, from 6.941 m³/s of discharge in 1957, the discharge of River Offin at 2006 was 3.797m³/s indicating a 3.144 m³/s (45.3%) reduction in river discharge or flow rate.



Monthly discharge of River Offin (Fig.4.32) has followed almost the same bi-modal pattern as that of precipitation.



4.4. Relationship between discharge pattern of River Offin and climate parameters

This section presents results of analyses of the relationship between temperature and precipitation in the River Offin basin and discharge of River Offin.

4.4.1. Discharge of River Offin against temperature and precipitation

A summary of Regression Analysis of Discharge of River Offin against Temperature and Precipitation is presented in Tables 4.1a and 4.1b.

Response Variate: discharge

Fitted terms: Constant, Precipitation (rainfall), Temperature

Percentage variance accounted for = 29.0. Standard error of observations = 1.63.

Table 4.1a. Regression of Discharge of River Offin against Temperature and Precipitation

	Degree of freedom (d.f.)	Sum of squares (s.s.)	Mean Square (m.s.)	f-statistic estimated (v.r)
Regression	2	34.58	17.292	6.52
Residual	25	66.28	2.651	
Total	27	100.86	3.735	

Table 4.1b. Estimates of regression coefficients

	Estimate	standard error (s.e.)	t(25)
Constant	-0.62	1.74	-0.36
Precipitation	0.0445	0.0129	3.46
Temperature	-0.0296	0.0277	-1.07

Amount of error accounted for is 29.0 and this shows that the model is good. This means only 29%, i.e. less than 50% is accounted for. Actual Error or Standard Error of observations is estimated to be 1.63. Having large standardised residual means there was greater difference between the estimated

value and actual value. From the above information it can be concluded that the coefficients of precipitation and temperature contributes more to the model compared to the constant term. The formulae for calculating the estimated discharge from the regression analysis will then be:

$$\text{Discharge} = -0.62 \times 0.0445(\text{precipitation}) + -0.0296(\text{temperature})$$

The Mean Square of the Regression (explained variation) is bigger than the Mean Square of the residual (unexplained variation) which makes the model good or a good correlation was established.

4.4.2. Discharge of River Offin and Temperature

Discharge of River Offin and air temperature recorded in the Offin basin was subjected to a regression analysis and a summary of the Regression Analysis of Discharge of River Offin against Temperature is presented (Table 4.2a and 4.2b).

Response variate: Discharge

Fitted terms: Constant, Temperature

Residual variance exceeds variance of Y variate and standard error of observations is 1.94

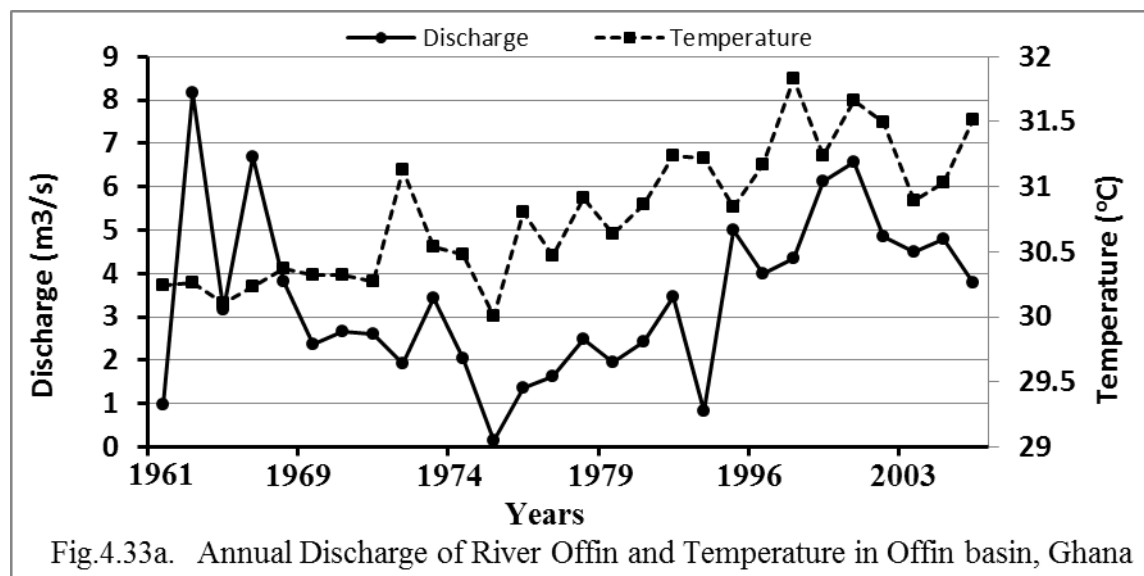
Table 4.2a. Regression of Discharge of River Offin against Air Temperature

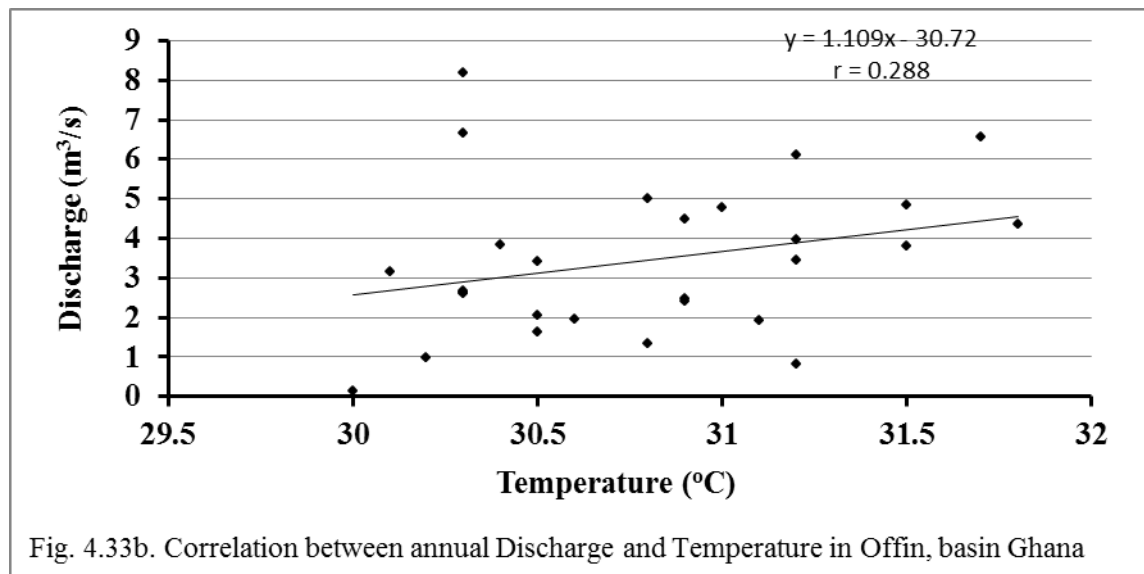
	d.f.	s.s.	m.s.	v.r.
Regression	1	2.92	2.925	0.78
Residual	26	97.93	3.767	
Total	27	100.86	3.735	

Table 4.2b. Estimates of regression coefficients

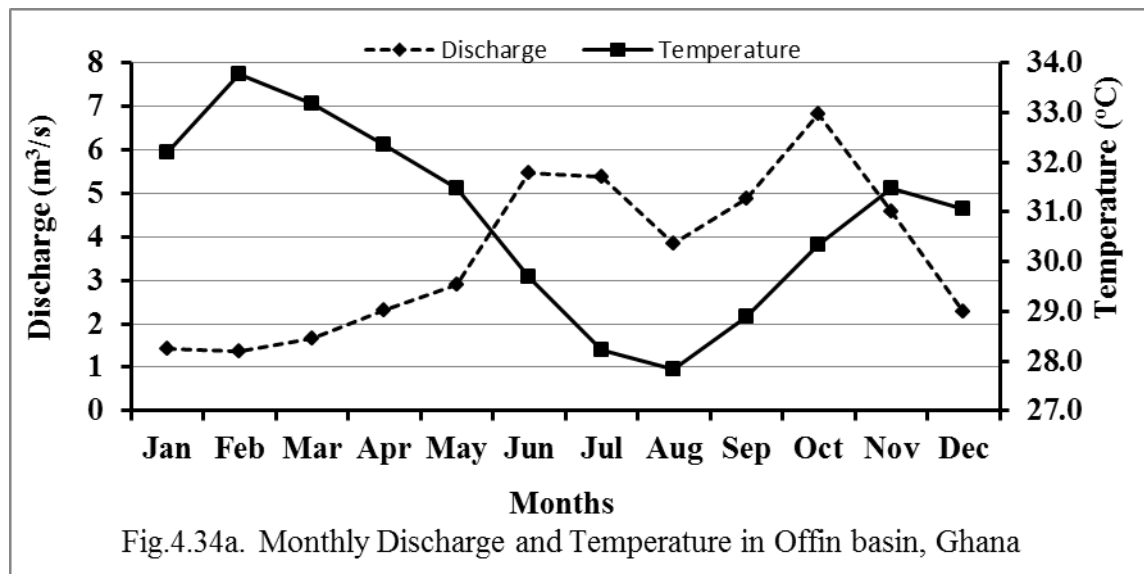
	Estimate	s.e.	t(26)
Constant	4.39	1.15	3.82
Temperature	-0.0291	0.0331	-0.88

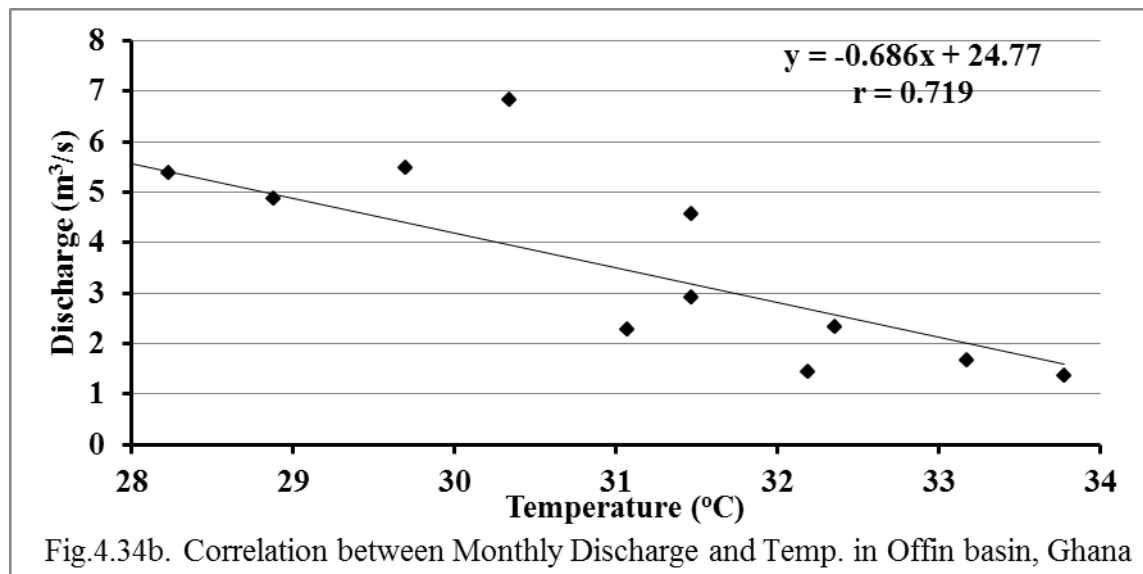
From the regression analysis of discharge of River Offin against air temperature, temperature is not having any major effect on the annual discharge and this is also shown figures 4.33a and 4.33b. The correlation between annual temperature and discharge is weak.





However, monthly trends of temperature and discharge (Fig. 4.34a) show a very strong negative correlation (Fig. 4.34b) which signifies that as monthly temperature increases, monthly discharge decreases.





4.4.3. Discharge of River Offin and Precipitation in the River Offin basin

A summary of Regression Analysis of Discharge of River Offin against Precipitation is presented in Tables 4.3a and 4.3b:

Response variate: Discharge

Fitted terms: Constant, Precipitation

Percentage variance accounted = 28.7. Standard error of observations = 1.63

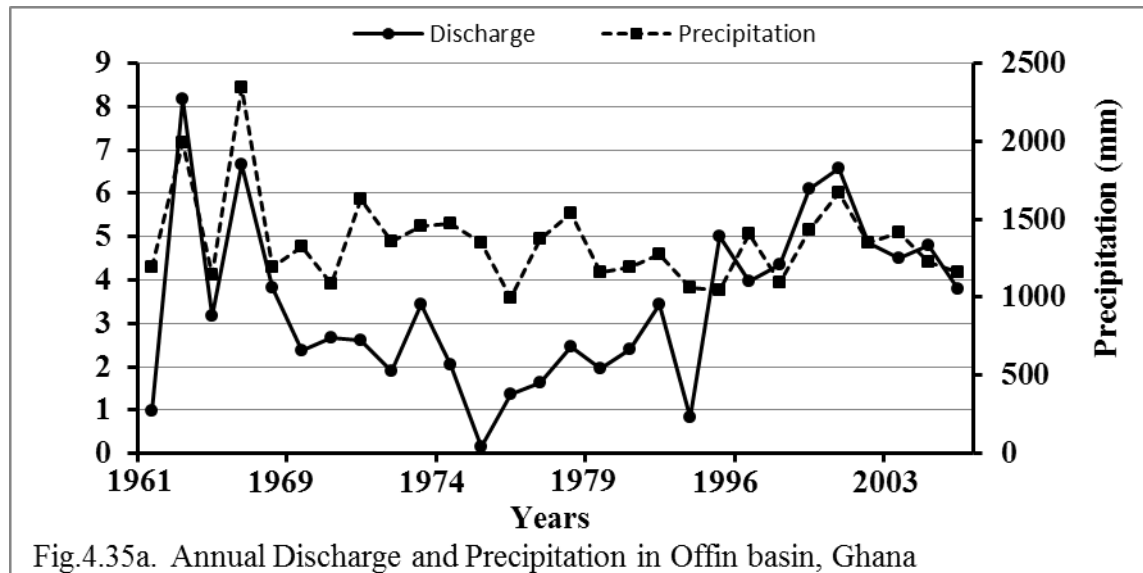
Table 4.3a. Regression of Discharge of River Offin against Precipitation

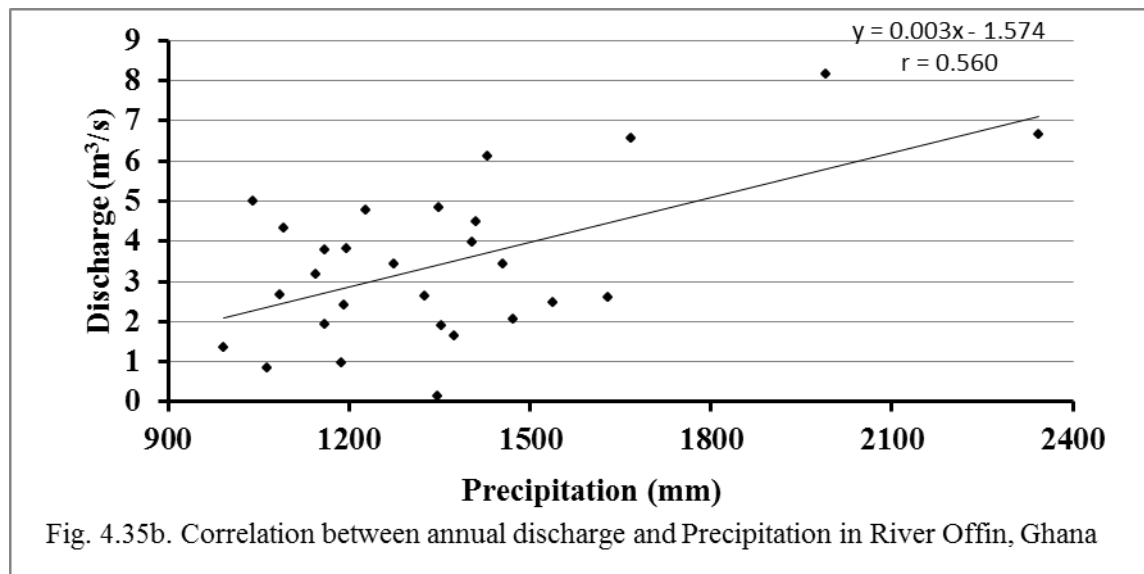
	d.f.	s.s.	m.s.	v.r.
Regression	1	31.57	31.571	11.85
Residual	26	69.29	2.665	
Total	27	100.86	3.735	

Table 4.3b. Estimates of regression coefficients

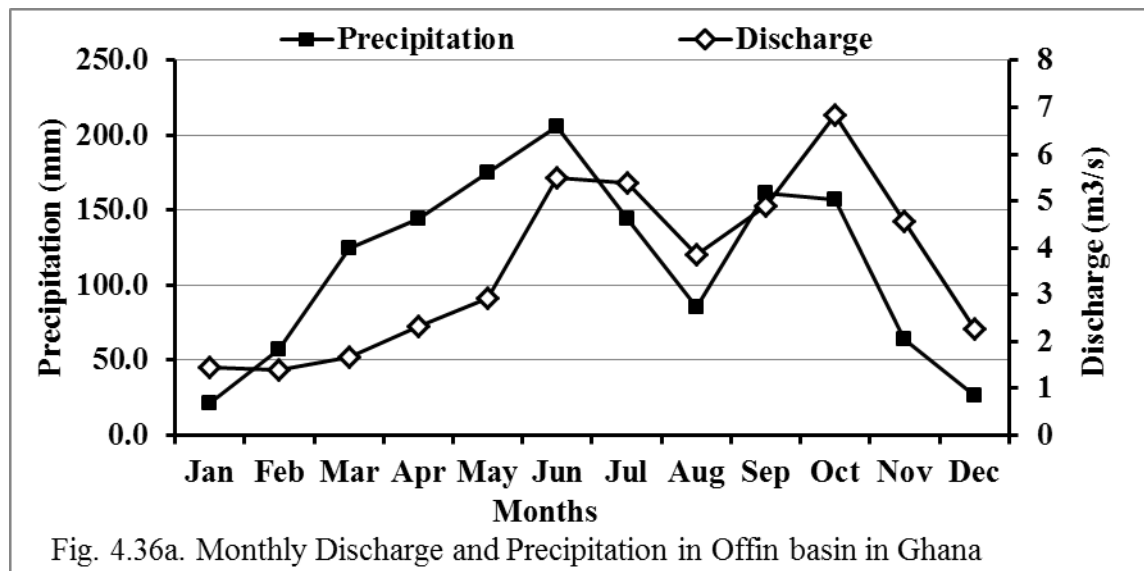
	estimate	s.e.	t(26)
Constant	-1.59	1.49	-1.06
Precipitation	0.0444	0.0129	3.44

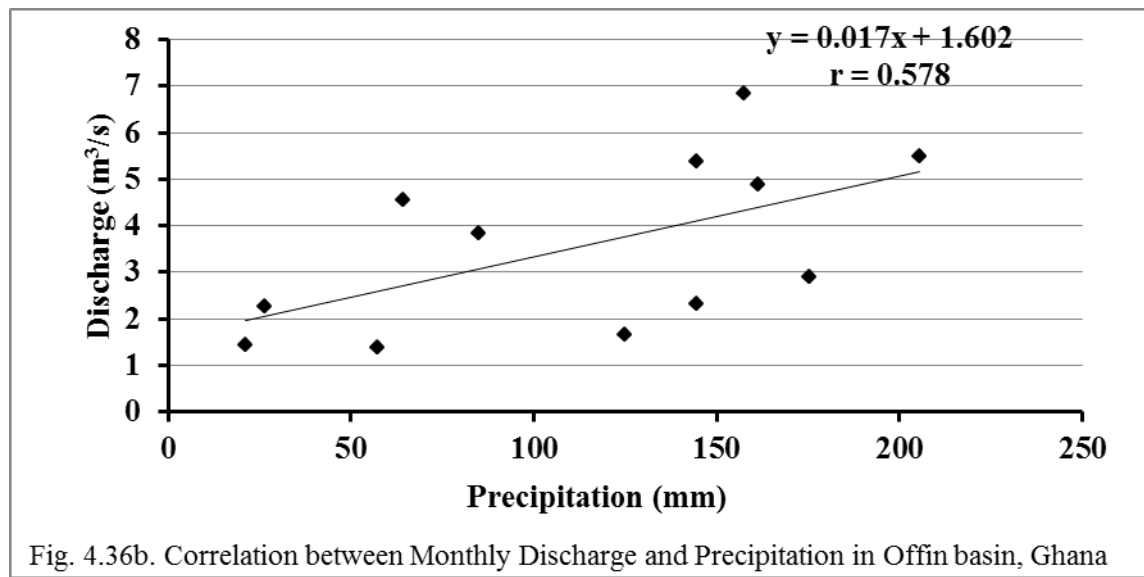
From the regression of discharge against precipitation, all the values show that, precipitation has a stronger effect on the discharge of River Offin. Precipitation is explaining most of the variation in the model. This relationship between discharge of River Offin and Precipitation is seen clearly in the annual trends (Fig.4.35a and Fig. 4.36b) as well as the monthly trends (Fig.4.36a and Fig. 4.36b).





But unlike precipitation, the major and minor peaks for monthly discharge of River Offin occurred in October and June, respectively; directly opposite to precipitation, as shown in Fig.4.36a.





4.5. Climate change and Livelihoods

This section presents results on the effects of changes in climate on the livelihoods of communities in the River Offin basin. The findings here are from answers given by the local people to questions asked on how they see and perceive climate change to be affecting them.

4.5.1. Vulnerability of livelihoods in Offin Basin to Climate Change

In the analysis the guiding principles were that:

- i. Each hazard was of equal weight and none was seen as more critical than the other
- ii. Once a relationship between a negative effect on a respondent and observed climate changes could be established, it was considered as a climate hazard.

Because of the above principles, the focus was not on how many believe mention a particular situation as a climate hazard but all real and accepted climate hazards were considered. Information

gathered through the questionnaires, interviews and focus group discussions were grouped under three main headings. These are;

- **Prolonged and inadequate rainfall:** this represented responses that described a situation of delayed rainfall more than was expected, rains not coming on time or when the rains came it was not in the quantity expected
- **Drought:** responses that referred to very long periods of no rainfall were grouped under droughts. Drought were separated from prolonged inadequate rainfall upon discussion with respondents who clearly differentiated between periods where rains did not come in due season and delayed or received too little rains from periods where the rain did not come at all or just traces were observed for a very long period.
- **Extreme heat:** responses referring to abnormally high temperatures were grouped under the heading ‘extreme heat’.

Using the Sustainable Livelihoods framework as a guide, communities were facilitated in identifying important resources that help them to secure their livelihoods. Under each of the five assets/resources (natural, human, financial, physical and social), communities were asked to mention the top three important resources available to them. The important livelihood resources identified by the communities are presented below:

- Natural Resources - Forest products, Aquatic resources (River Offin) and Land
- Human resources - Indigenous knowledge, agricultural skills/training, water management skills/training
- Financial Resources - Remittances, Savings from sale of farm produce
- Physical Resources - Wells, bridges, roads
- Social Resources - Local Community based organizations, Local Governance Institutions

The effects of the climate hazards identified by the communities on their livelihoods were, however, grouped into two. It was realised that the effects of prolonged inadequate rainfall and the effects of droughts on livelihoods of the people were similar and in most cases overlapped; so such effects were grouped under a broader sub-heading of ‘prolonged inadequate rainfall and droughts. The other group of climate effects on livelihoods were as a result of extreme heat.

1. Effects of prolonged inadequate rainfall and droughts on livelihoods:

- Affects the quantity, quality and flow of water in rivers and streams
- Wells dry up during the dry season
- People, especially children and women, spend more time looking for water
- Water in River Offin gathers in pools and quality of water deteriorates
- Water related diseases like bilharzia and diarrhoea are often reported
- Land hardens, develop cracks, soil becomes dry and does not support crops
- Crop failure due to no rains and altered rainfall pattern
- Financial resources are spent on replanting failed farms, buying sachet water
- Wild fires and bushfires increase, especially from November to March



Photo 4. River Offin at Adiembra in the rainy season



Photo 5. River Offin at Adiembra in the dry season



Photo 6. Land hardens as a result of no rains



Photo 7. Borehole with hand-pump has no water in the dry season

2. Effects of extreme heat on livelihoods

- Heat related diseases such as shingles, malaria and other skin debilitations
- More financial resources spent on medical treatment
- Wilting and drying of crops
- General uncomfortable feeling

4.5.2. Coping with Climate Change in River Offin basin

The effects of climate hazards on the livelihoods of the people were mapped to the different means by which the people are coping with these effects and trying to secure their livelihoods in the face of these climatic effects. The coping strategies adopted by the local people in coping with the effects of climate change are presented in this section.

4.5.2.1. Coping with droughts, inadequate rainfalls, reduced water quantity and quality

Coping strategies against effects of climate change on water resources in the Offin basin include:

i. Water rationing:

Due to the difficulty in getting water, especially in the dry season, areas that are worst hit by the water shortages have adopted strategies where water collected can be used for more than one purpose. Water which previously would have been thrown away after being used for one purpose, such as washing of clothes, are now kept and re-used as irrigation water for backyard gardening.

ii. Rainwater harvesting:

Most homes have big containers or barrels which are used to collect rainwater during rainfall and stored for future use. This strategy is very widespread in all the communities studied and it is only useful during the rainy season.



Photo 8. Rainwater harvesting from roof of building using barrels (1) and PVC pipes (2)

iii. Construction of wells and boreholes:

Communal and private boreholes and wells are being constructed in most of the areas studied in order to get water during prolonged rainfalls and dry season. Most private wells are shallow and easily dry up during severe dry season. The private wells are normally for just one household and the entire community is only allowed access during extreme water shortages. The community or government assisted boreholes are usually deeper and fitted with hand-pumps for drawing water.

iv. Purchasing sachet water for drinking:

Buying of bagged/sachet water for drinking is more popular in the peri-urban areas compared to the very rural areas. This becomes necessary especially during the peak of the dry season when there is no water and the available sources are muddy or dirty.

v. Tree planting programmes and water protection awareness campaigns:

A lot of effort is going into water protection awareness campaigns by the traditional leaders and the local government. The people are educating themselves on practices which are destroying their sources of water and finding solutions to their problems. Tree planting programmes are also being embarked upon especially in areas where the riparian vegetation has been destroyed by deforestation.

vi. Indigenous knowledge in water management, forbidden days, taboos, and bye-laws:

People in the study communities are increasingly realising the importance of some previous interventions of their forefathers in the form of sacred groves, forbidden days and taboos. Sacred groves are places, usually thick forested areas, which were left untouched. Farming activities are not allowed in such groves and felling of timber was also prohibited by traditional laws. Most of these sacred groves were located around sources of streams and they helped to protect the streams from drying or siltation resulting from clearance of riparian vegetation. Such sacred groves, according to the chief of Adumasa, were usually rich in medicinal plants and were ways that their ancestors used to protect such plants of great value. There were also forbidden days when no one was allowed

access to the river. For example, Tuesday is regarded as a taboo day for the River Nwabi which is a tributary of the River Offin and no one is allowed to visit the river. According to traditional folklore, the river goddess was born on a Tuesday and it rests on that day and needs no disturbance. In addition are other days of the year set aside as forbidden days where no one either visits the farm, forest or river.

4.5.2.2. Coping with crop failure and loss of income

Findings on coping strategies against crop failure and loss of income are presented in this section.

i. Indigenous knowledge in weather prediction, agriculture

Farmers in the Offin basin have been coping with the adverse effects of climate change on their crop farming by using their knowledge in weather prediction. The old farmers are able to predict when the rains are likely to come and plan their farming operations to coincide with the rains. They also know which crops can survive under which conditions and have started changing the crops they grow to suit the climate pattern. Cocoa, which used to be widely grown as a very major cash crop, is gradually fading out because of unsuitable climate among other factors. One farmer at Adiembra remarked, ‘platforms that we used to dry our cocoa are now being used to dry cassava because the cocoa is no longer doing well; the weather has changed’

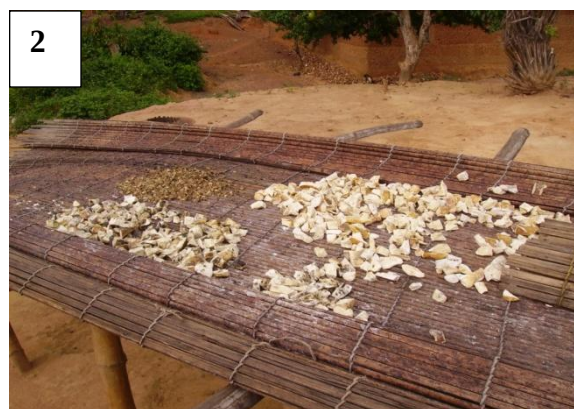


Photo 9. Platforms for drying cocoa (1); now either empty or used to dry cassava (2)

ii. Replanting of failed farms

One other obvious means of coping with the changes have been replanting of failed farms. Though this is costly in terms of energy, time and resources, farmers are left with little choice since that is their major source of income.

iii. Remittances from relations and personal savings

The people rely on their personal savings when they lose the expected income from their farming activities. Remittances from relations living in the big cities of Kumasi and Accra or outside the country are also a major source of income in times of difficulty when their expected income from their farms fails.

iv. Petty trading

The women and young men also resort to petty trading to augment their income from farming. They usually trade in basic goods that are needed by the people in the community such as soaps, sugar, groceries, etc. Communities living by the main Kumasi road also resort to selling of foodstuffs, oranges, boiled corn and fried yams by the roadside to travellers to and from Kumasi.

4.5.2.3. Diseases

To cope with diseases, the people resort to medical attention both from traditional medical practitioners and orthodox medicine from hospitals.

4.6. Future climate projections for River Offin basin

Future climate projections for the River Offin basin presented in this section are based on regional climate projections by the Intergovernmental Panel on Climate Change's Fourth Assessment Report

(AR4) (IPCC, 2007) and Ghana's first national communication to the United Nations Framework Convention on Climate Change (UNFCCC).

4.6.1. Temperature

From the IPCC's Fourth Assessment Report, all of Africa is very likely to continue to warm up in the coming years and the warming is very likely to be larger than the global annual mean throughout Africa and in all seasons, with drier subtropical regions warming more than the moister tropics. Mean temperature increases in Africa is expected to be between 3°C and 4°C, roughly 1.5 times the global mean response. Minimum temperatures are very likely to increase, resulting in more warmer and fewer cold nights.

According to Ghana's first communication to the UNFCCC, mean maximum temperature is expected to increase by 2.5°C in the semi-deciduous rain forest zone by the year 2100. Average minimum temperature is also expected to increase by 2.5°C in the Semi-Deciduous Rainforest Zones by the year 2100. From the Vulnerability and Adaptation Assessment of Ghana under the Netherlands Climate Change Studies Assistance Programme Phase 2 (NCCSAP2), mean annual temperature changes will rise by 0.8, 2.5 and 5.4°C in the semi-deciduous forest zone in 2020, 2050 and 2080, respectively.

4.6.2. Precipitation

According to IPCC, Fourth Assessment Report, it is generally unclear how rainfall in the Sahel, the Guinean Coast and the southern Sahara will evolve, although decreases in precipitation are projected in many regions adjacent to the tropics. Increases in tropical precipitation are projected during rainy seasons (e.g., monsoons). A general increase in the intensity of high-rainfall events, associated in part with the increase in atmospheric water vapour, is expected in Africa. In regions of mean drying,

there is generally a proportionally larger decrease in the number of rain days. Increase in the number of extremely wet seasons in West Africa is expected, increasing to roughly 20% (i.e., 1 in 5 of the seasons are extremely wet, as compared to 1 in 20 in the late 20th century).

From the Ghana initial communication to the UNFCCC, mean annual rainfall would decrease by 99 mm in the Semi-Deciduous Rainforest Zone in Ghana by the year 2100. Mean annual rainfall values in the semi deciduous forest zone of Ghana is expected to decline by -2.8, -10.9 and -18.6% in year 2020, 2050 and 2080 respectively for the semi-deciduous forest zone of Ghana, according to the NCCSAP2. A summary of climate projections relating to the Offin basin in the moist semi-deciduous zone of Ghana are presented in table 4.4.

Table 4.4. Climate projections relating to River Offin basin in Ghana

Source	Variable	Projections			
		2020	2050	2080	2100
West Africa (IPCC)	Min. Temperature				Increase
	Mean Temperature		+3°C – 4°C		Increase
	Max. Temperature				Increase
	Precipitation				Uncertain
Ghana Communication To UNFCCC (Semi-deciduous zone)	Min. Temperature	+0.9°C			+2.5°C
	Mean Temperature				+2.5°C
	Max. Temperature	+0.8°C			+2.5°C
	Precipitation	-33mm			- 99mm
NCCSAP 2 (Semi deciduous zone)	Min. Temperature				
	Mean Temperature	+0.8°C	+2.5°C	+5.4°C	
	Max. Temperature				
	Precipitation	-2.8%	-10.9%	-18.6%	

4.7. Future livelihoods vulnerability projections

Future livelihood vulnerability projections for communities in the Offin basin, based on their current livelihood vulnerability and projected changes in climate are explored and presented in the sections that follow. Some major assumptions made are that dependence on rainfall for agriculture; the river system for water needs; and a natural resource based economy will continue in the foreseeable future.

4.7.1. Water Needs

The River Offin and the other streams and the Offin basin are very crucial for livelihoods in the basin. Water demand is expected to increase due to several factors including an increase in population and the need for improvement in socio-economic conditions. Discharge or flow rate of rivers as well as the groundwater recharges is very sensitive to rainfall and with projected reductions in rainfall the discharge of River Offin and other streams in the Offin basin are expected to decline. This will affect the water available to the people living in the River Offin basin for their domestic, agricultural and industrial needs.

Rainwater harvesting will be severely affected when there is little rainfall in the rainy season. Scenarios developed under the Netherlands Government Climate Change Studies Assistance Project (NCCSAP) for vulnerability assessment studies for water resources in Ghana observed flow reductions of between 15-20% and 30-40% for simulations using climate change scenarios for years 2020 and 2050 respectively and reduction in groundwater recharge was between 5-22% by 2020 and 30-40% by 2050. The shallow wells in the River Offin basin are likely to dry out earlier than they currently do as a result of projected reductions in groundwater recharges, and the water needs of the people will be severely affected.

4.7.2. Agricultural vulnerability

Agriculture in the River Offin basin is mainly rain-fed so farmers depend on knowledge of the rainy season to plan their planting operations. They clear their land and prepare the land to coincide with the onset of the rainy season. So, with the rainfall pattern becoming increasingly unreliable farmers will find it difficult planning their planting operations to coincide with the rainy season in order to derive optimum benefits in terms of rainfall for their crops. The projected reduction in rainfall will also affect the water available for the crops throughout their growth cycle. This will affect the growth and yield of crops grown in the Offin basin.

Another projected effect of the changing climate change on the livelihoods of the people is the incidence of intense sunshine and increasing temperature on crops. These changes coupled with prolonged rainfall shortages may cause the wilting of crops. Bright sunshine duration is increasing and becoming very intensive. Exposure of crops to intense and prolonged sunshine and high temperatures may cause crops to wither as well as vegetables to ripen prematurely. These projected effects of climate change may prevent the farmers from getting the expected income from the sale of their produce. This is a major loss to the farmers and puts a big drain on their financial resources.

As the climate changes, crops which hitherto were very suitable to the area and grew well may no longer do well in the basin and this may require shifts in the type of crops grown in the region. Dry season farming will also be heavily affected as some vegetable farmers usually farm closer to the streams and rivers during the dry season so that they can easily fetch water from the stream to irrigate their crops. In effect irrigation water demand could be affected considerably by projected changes in climate change. Expected increase in climate extremes such as high intensity of rainfall or storms will also have negative impacts on agriculture in the basin. Farms may be destroyed by projected strong rains or storms as well as strong winds that usually accompany the storms.

4.7.3. Socio-economic vulnerability

Projected increases in the intensity of rainfall or storms, in addition to destroying farms and causing food scarcity, may also cause major disasters such as buildings collapsing or roofs of buildings being ripped off during storms. Heavy runoff from storms may also cause serious erosion of lands in the communities creating galleys and land degradation. Major disasters will put a strain on the finances of the people as they have to rebuild their homes or fix their roofs.

Changes in temperature and rainfall may also have secondary impacts on the health of the people living in the Offin basin. Extreme heat from increasing temperatures may also cause skin debilitations and other heat related diseases that will affect the health of the people as well as put a strain on the financial resources of the people. Other heat and water related diseases such as malaria may see increases in reported cases as the people try to sleep in the open or with windows open due to high temperatures at night thereby exposing them to mosquitoes and eventually malaria. Incidence of malaria may also increase primarily due to optimum conditions being created as result of the projected changes in climate.

Prolonged inadequate rainfalls may also affect the quality of water in the streams as the streams get stagnated and muddy during the dry season as people struggle for the limited water available in the streams. Drinking from dirty water may also have health implications for the people through water related diseases such as cholera and diarrhoea.

Due to crop failure/loss, money spent on land preparation and planting as well as income from the sale of farm produce is lost and household savings are spent to replant farms. Nutrition of the people living in the River Offin may also be affected when there is crop failure since most households are into subsistence agriculture and depend on the crops they grow to feed themselves.

4.8. Climate Change and soil carbon storage in Offin basin

A survey and analysis of soil properties and effect of land use systems on soil carbon storage is presented in the section that follows.

4.8.1. Soil physical properties.

The soil bulk density of the landuse systems ranged from 1.25 g/cm³ under the recently cultivated soil to 1.50 g/cm³ under the Natural forest. The soil under the oil palm and cocoa plantations was silt loam in texture with the rest of the landuse system showing sandy loam textural class (Table 4.5).

4.8.2. Soil carbon stocks

The landuse systems showed a high degree of heterogeneity in soil carbon stocks. Soil carbon stocks to a depth of 15cm across the landuse systems ranged from 18Mg C ha¹ under the oil palm plantation to 39 Mg C ha¹ under the Cassava/maize /plantain intercrop system. The soil carbon stocks reflect the differential resource management in the landuse systems of the study site.

4.8.3. Soil chemical properties:

Table 4 shows some physical and chemical properties of the landuse systems at the time of sampling. The pH of the soils under the different landuse systems indicates a strongly acid to moderately acid conditions and ranged from 4.2 to 5.4. This low pH will require liming to support high crop productivity. Most crops grow best if soil pH is between 6 and 7.5. The low pH of the soils under the different landuse systems could be due to the sandy nature of the soils. Sandy soils have low amount of reserve acidity due to low cation exchange capacity (CEC). In such cases, a light application of lime (1 to 2 t/ha) may suffice to neutralize soil acidity (Marx *et al.*, 1999). The organic carbon content was also low and the values are typical of soils of the semi-deciduous forest

zone of Ghana. Soil available phosphorus was low and ranged from 1.82 ppm to 11.23 ppm. Inorganic phosphorus application is therefore essential to support productive agriculture in the study area. Excessive phosphorus application however should be avoided as high soil phosphorus combined with surface runoff can cause excessive growth of plants and algae in surface waters damaging aquatic ecosystems. Exchangeable calcium was low under the Oil palm, Cocoa and natural ecosystems but showed medium concentrations under the recently cultivated and the cassava/ maize/plantain intercropped systems. The relatively high Ca under the recently cultivated soil and the Cassava/Maize/Plantain intercrop landuse system is likely due to burning of the sites after land clearing. Biomass burning is a common practice of land preparation in the study area. The extractable magnesium was 2.94, 2.80 and 2.40 mg/100g respectively under the recently cultivated field, the cassava/plantain/maize intercrop systems and the cocoa plantation. The high extractable magnesium under the cocoa plantation could be due to concentration of the nutrient in the cocoa pod.

4.8.4. Land-use effects on native Soil Organic Matter (SOM) dynamics

Generally, conversion of natural forest to an agroecosystem results in profound changes in the biological and chemical processes at the plant-soil interface. The accumulation of soil organic matter under the natural forest in this study was found to be lower than recently cultivated soil and the cassava/plantain/ maize intercrop system even though total C accumulation in biomass is expected to be higher under the natural ecosystem. The lower SOM under the oil palm plantation may be due to lower litter production rate.

4.8.5. Fractionation results

The wet sieving shows the large macro-aggregate across land use systems had more aggregates by proportion of the total soil mass.

Table 4.5. Physico-chemical properties of soil under different landuse systems

Soil parameter	Landuse system				Natural Ecosystem
	Oil Palm	Cocoa	Recently cultivated	Cassava/Maize/Plantain intercrop	
pH (1:1 H ₂ O)	4.2	4.5	5.1	5.4	4.2
Org C (%)	0.82	1.15	2.08	1.86	1.19
% N	0.06	0.09	0.18	0.16	0.09
Available P (mg/g)	4.41	1.82	11.23	4.64	3.00
Ca (meq/100g)	2.14	3.47	7.21	6.94	2.67
Mg (meq/100g)	0.27	2.4	2.94	2.8	0.53
Na(meq/100g)	0.02	0.08	0.07	0.09	0.06
K(meq/100g)	0.09	0.2	0.49	0.52	0.24
Available K (ppm)	120.52	184.12	241.04	174.09	160.7
Exchangeable acidity	0.7	0.35	0.2	0.2	0.45
% Base saturation	78.26	94.62	98.17	98.1	88.61
% Sand	41.96	16.5	65.66	60.08	67.64
% Silt	54.02	73.44	30.29	33.86	28.27
% Clay	4.02	10.06	4.05	6.06	4.09
Textural class	Silt loam	Silt loam	Sandy loam	Sandy loam	Sandy loam
Carbon stocks	17.55	22.91	38.94	39.41	25.07

5. DISCUSSION

5.1. Climate trends in River Offin basin

The climate trends in River Offin basin generally indicates reduction in conditions that favour increased rainfall whilst both minimum and maximum temperatures continue to rise steadily. These observations conform to other studies of climate in West Africa (Nicholson, 2001; 2005; IPCC, 2007; Shanahan *et al.*, 2009).

5.1.1. Precipitation in River Offin basin

Climatic variability observed in the Offin basin is not different from what has been observed in most parts of West Africa; general decreases in rainfall, shifts in the beginning and end of seasons, which has resulted in a significant decrease in water resources (Le Borgne, 1990; Servat *et al.*, 1997; Brou, 1998). The significant decreases in precipitation in Offin basin follows the general trends observed in West Africa since the late 1960s when, according to Nicholson (2005) and Hulme *et al.*, (2001), decline in rainfall levels became very significant. Some researchers even concluded that the decline in rainfall was so drastic to suggest a significant change in the normal regional climate (Farmer and Wigley 1985).

The slight increase in rainfall in the Offin basin (in the 2000s) should not be seen as an end of the decline in rainfall in the basin because it may just be reflective of the West African trend. Nicholson *et al.*, (1996) reported a little break in the decline of rainfall in West Africa in 1994, the wettest year in West Africa since 1960 but after this break the decline continued (Horton and Parker 1997). What is seen in the Offin basin, though very good and encouraging, cannot be concluded that the rainfall pattern has changed to a wetter regime because analysis of historical rainfall in other parts of West Africa by Ozer *et. al.*, (2003) shows that statistical tests respond with a relatively long time lag to

strong variations. Ozer *et. al.*, (2003) suggests that a little time of about a further ten years is allowed to elapse before inferring any conclusion about the rainfall regimes.

Another important feature of the rainfall is the seasonal variability. Rainfall pattern in the Offin basin has changed and is highly unpredictable which not the case was previously. People in the basin have always predicted the inception of rains with some level of accuracy and planned their farming activities accordingly but the rainfall pattern can no longer be predicted. Heavy rains come when they are least expected and there are no rains when rains are expected. This has negatively affected crop production since the farmers depend on rains for growing their crops.

5.1.2. Temperature in River Offin basin

That there are changes, and in particular, increases in ambient temperatures in the Offin basin and that this change has been pronounced in the last years and seem to be following a particular global trend is a matter of both common experience and scientific knowledge. Temperatures in Offin basin has steadily increased from 1961 to 2007 and follows the global and regional trends of surface air temperature change as analysed routinely by bodies such as the Hadley Centre for Climate Research, Goddard Institute for Space Studies (GISS), and the National Climatic Data Centre. Although all the analysis have been based on basically the same observations, different ways of handling data problems such as incomplete spatial and temporal coverage, urban influences on station environment, and other factors affecting data quality (Karl *et al.*, 1989, 1994; Jones, 1995; Easterling and Peterson, 1995) compensates for various levels of uncertainties that may be introduced by one approach or the other. These different analytical approaches usually produce generally very little differences among the global mean temperature changes of the order of 0.1°C (IPCC, 1996, 2001a).

The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (IPCC, 2007) states that global mean surface temperatures have risen by $0.74^{\circ}\text{C} \pm 0.18^{\circ}\text{C}$ when estimated by a linear trend over the last 100 years (1906–2005) with the rate of warming over the last 50 years almost doubling that over the last 100 years. Some other authors also indicate global surface temperatures increased in the past century by more than 0.5°C (Hansen *et al.*, 2001; Jones *et al.*, 1999). Global analysis of surface temperatures also indicate that eleven of the last twelve years of the study (i.e., 1995 to 2006) – the exception being 1996 – rank among the 12 warmest years on record since 1850 (IPCC, 2007). Increases in mean temperatures in Offin basin are similar in both maximum and minimum temperatures and this agrees with the IPCC assertion that from 1979 to 2004, both maximum and minimum temperatures rose at similar rates. The two warmest years in the instrumental record of global surface temperatures are 1998 and 2005, with 1998 ranking first in one estimate, but with 2005 slightly higher in the other two estimates. It is therefore not a coincidence that the warmest year recorded in the Offin basin was 1998.

Based on current trends and projections, Hansen and Sato (2001) predict global warming for several decades at a rate $0.15 \pm 0.05^{\circ}\text{C}$ per decade and they maintain that although this warming is moderate than in business-as-usual scenarios, if it is maintained for a longer period, say a century, the Earth's temperature will approach that of the middle Pliocene (2.75 million years ago), when the world was about 2°C warmer than today.

One other factor worth noting is the fact that due to the increasing temperatures in the Offin basin, even minimum temperatures are becoming so high that they are not very different from the maximum daily temperatures. This has decreased the Diurnal Temperature Range (DTR) in the Offin basin as has been experienced over much of the globe during the past few decades (Karl *et al.* 1993b; Horton 1995; Easterling *et al.* 1997). As a result of the reduction in the DTR, even night time

temperatures in the Offin basin which hitherto was low, has risen thus making rooms warm and uncomfortable for sleeping at night when the windows are closed.

5.1.3. Bright Sunshine Duration (BSD) in River Offin basin

The duration of sunshine per day has been varying in the Offin basin but decadal analysis show a sharp increase in duration of sunshine in the Offin basin. The effect of longer duration of bright sunshine on the activities of people in the basin who work daily on their farms is negative as the farmers are unable to spend more time on their farms when the sun is high up and scorching. There is a positive relationship between intensity and duration of sunshine (Kaiser and Qian, 2002) as the farmers do not only complain about the duration of the sun but also the intensity as it scorches, withers, dries and kill their crops.

5.1.4. Relative Humidity in River Offin basin

Relative humidity (RH) is an indication of the amount of moisture in the atmosphere and it is seen from the analysis of maximum and minimum relative humidity in the Offin basin that, RH has generally decreased by 2%. High relative humidity, meaning higher moisture content in the atmosphere is a good signal of the possibility of rains. For example, a reading of 100 percent relative humidity means that the air is totally saturated with water vapour and cannot hold any more, creating the possibility of rain. The decline in RH in the Offin basin only further buttresses the fact that moisture levels in the basin are going down and drying may ensue. Studies have shown that decreases in summer precipitation in continental and southeastern Europe were mainly associated with thermodynamic factors which included reduced relative humidity resulting from larger continental warming (Rowell and Jones, 2006). This is a likely situation expected in the Offin basin since temperatures are expected to increase.

Reduced relative humidity, with the expected impacts on rainfall will also indirectly affect the flow of River Offin. At higher RH, there is more water in the atmospheric system and this also reduces evaporation which is major source of water loss.

5.2. Driving forces of Climate Change in Offin basin

Increase in atmospheric greenhouse gas (GHG) concentrations is noted to be the single biggest factor in global temperature rise (Ladislaw *et al.*, 2008) and CO₂ is the most significant greenhouse gas. Deforestation contributes to the build-up of CO₂ in the atmosphere by reducing the rate at which the gas is removed from the atmosphere and also by the decomposition of dead vegetation and burning of the biomass (Mastrandrea and Schneider, 2005). In Africa and Ghana in particular where industrialization is still very low, deforestation remains a major source of CO₂ emissions. Moreover, attempts by some authors such as McKittrick and Michaels (2004) and De Laat and Maurellis (2006) to link geographical patterns of warming trends over land with geographical patterns of industrial and socioeconomic development, have been proven to be statistically insignificant (IPCC, 2007).

Tropical forests, apart from their role as reservoirs, sinks and sources of carbon, also provide numerous additional ecosystem services including maintenance of elevated soil moisture and surface air humidity, reduced sunlight penetration, weaker near-surface winds and the inhibition of anaerobic soil conditions (Betts, 1999) which directly or indirectly influence climate. Although there is no recorded data on deforestation rates specifically for Offin basin, deforestation data available for Ghana aptly reflects the situation in the Offin basin which is in the forest region of Ghana and is experiencing a lot of deforestation. Deforestation rate in the Offin basin might even be higher than the country average. Between 1990 and 2005, Ghana lost 25.9% of its forest cover, or around 1,931,000 hectares at 2% per annum (FAO, 2007).

Deforestation in the Offin basin and Ghana in general has been driven mainly by agriculture and logging. The timber industry in Ghana has been very vibrant since pre-independence days and was even intensified after independence in an attempt to be economically self-reliant, whilst more forests were also cleared for cocoa farms and mining concessions have even been granted within some of Ghana's forest reserves (UNEP, 2008) with serious implications for Ghana's forests. The world's forest ecosystems are estimated to store more carbon (carbon sinks) than the entire atmosphere (Greenfacts, 2007), an indication of the strong relationship between deforestation and CO₂ emissions. From 1990 to 2000 and to 2004, CO₂ emissions in Ghana have increased steadily from 0.2419 to 0.3075 and to 0.326 metric tonnes per capita, respectively (UNEP, 2008). This is very much expected where deforestation rate is high and 'slash and burn' agriculture is widely practised, as in the Offin basin. At current rates of deforestation, tropical forests such as that of the Offin basin will eventually be a major source of carbon emissions in the near future rather than sinks. Tropical forests could generate an unprecedented source of carbon, even in the absence of additional anthropogenic deforestation (Cox *et al.* 2000; Cramer *et al.* 2001) as deforestation rates and future productivity in untouched or sustainably managed forests is strongly influenced by economic development (since most tropical forests are in developing countries) and climate change (Cranmer *et. al.*, 2004).

5.3. Climate and hydrology of River Offin

Drainage of most rivers including the River Offin is a function of mean annual rainfall as shown in the relationship between precipitation in the River Offin basin and discharge of river Offin (Section 4.4.3). Even a little drop in rainfall will have significant effects on the drainage of the River Offin. Precipitation and catchment characteristics such as land use, topography, soil type, geology and stream patterns have major effects on the discharge of rivers (Hamlyn and Wright, 1978). Rainfall naturally contributes to river flow/discharges through the surface runoff and base flow. The time

taken for surface flow and base flow to manifest in river discharge varies considerably and a single rainfall event which will have immediate effect on surface run off may have a delayed effect on the base flow contribution to the discharge. This delay also varies depending on the catchment characteristics and also the water available for river flow/discharge is a function of precipitation and the amount lost by evaporation. Some level of evaporation occurs during or immediately after rainfall but majority occurs as evaporation from the upper layers of the soil (Hamlyn and Wright, 1978). When there is enough moisture in the upper layer of the soil, the extent of evaporation can be reduced and this is where the importance of the catchment characteristics, particularly land uses, soil type and geology, is realised. Where there is underlying impermeable rock, most of the contribution to river flow is by surface runoff and in such places river flow drops rapidly during the dry season. Such is the situation of the Offin basin which is underlain with pre-Cambrian impervious Tarkwaian and Birrimian rocks (Dickson & Benneh, 1980). But in places where the underlying rocks are permeable with good vegetative cover and organic matter content, the soil is able to absorb the water and the water gradually infiltrates and percolates to the water table and emerges later as base flow to join the river discharge. In such basins, it takes a longer period for low rainfall to reflect in low river discharges.

Communities living in the River Offin basin, like any part in Africa, are not free from vulnerability to water scarcity. Recent evidence suggests that the River Offin cannot be truly called perennial after all as it has started showing clear signs of succumbing to any potential major changes in climate. In 2006, portions of the river, especially in areas where people live closer to the river and depend on the river for their water needs such as Adiembra, dried up to bare ground. According to the local people, this has been quite the case in the recent past and drying usually occurred at the peak of the dry season (from December to January). Even bigger rivers in Africa have suffered and continue to suffer this fate. For example, the Orange River which is the fifth largest river in Africa

and one of the fifty largest ones globally (Bremner *et al.*, 1990), experienced at least 5 instances of this river running dry between 1862 and 1912 (before any damming schemes); in 1903 the river stopped flowing for 2 months, showing that even one of the continent's biggest rivers cannot be truly called perennial (van Warmelo, 1922). Water shortages in central South Africa in late 2004 led to virtually no water being released from the dams on the Orange River causing the lower reaches of this river, where it forms the border of Namibia, to reach a very low level indeed (de Wit and Stankiewicz, 2006). It must be noted that the relationship between discharge of rivers and precipitation is, however, non-linear (De Wit and Stankiewicz, 2006) and other factors such as vegetation, population, geology and catchment area characteristics are involved. However, with the River Offin precipitation has been found to be the significant factor affecting its discharge.

A discernible dependence of precipitation on vegetation has been simulated and/or discussed in several papers (e.g., Dickinson 1980; Anthes 1984; Avissar 1992; Sud and Fennessy 1982, 1984). Removal of vegetation in any typical region can lead to reduction of evapotranspiration and/or land surface roughness and thereby to a decrease in rainfall (e.g., Sud and Smith 1985; Sud and Molod, 1988; Walker *et al.* 1995). Therefore, increasing deforestation in the Offin basin will affect precipitation in the basin and eventually discharge of the River Offin. Research findings already suggest that deforestation along the southern coast of West Africa (e.g., in Nigeria, Ghana and Ivory Coast) may result in complete collapse of monsoon circulation, and a significant reduction of regional rainfall (Zheng and Eltahir, 1998).

5.4. Climate change and livelihood options in River Offin basin

Livelihoods in the Offin basin are primarily climate dependent. The people are predominantly crop farmers and depend on rainfall to irrigate their crops and also the river for their water needs. Any reduction in rainfall has significant effects on their water needs and agricultural production.

5.4.1. Livelihood resources and climate hazards in River Offin basin

Observed climate changes have resulted in serious effects on natural resources in the Offin basin. There have been low discharges in all waterbodies in the Offin basin with some streams becoming extinct. This is mainly in response to the reduction in rainfall since it is the source of water for the streams/ivers in the basin. River Offin has been experiencing very low flows in the dry seasons to the extent that the river bed could be seen during recent dry seasons. To ensure availability of water all year round, wells are dug by the communities but some wells dry up during the dry periods, indicating a possible reduction in ground waters.

Recent crop failure in the basin has been attributed to low rainfalls, prolonged rainfall shortages and changes in rainfall patterns. Agriculture in the basin is rain-fed and farmers have over the years perfected the art of predicting the onset of the rainy season. Farmlands are cleared and prepared in anticipation for the rains to start the cropping season. This has, however, become difficult during recent years due to significant changes in the rainfall pattern. The beginning of the rainy season is no longer predictable, and during times that it has started on time, there may be an unexpected long break before the rains resume. This makes it difficult for farmers to plan their cropping activities to coincide with the rains; resulting in crop failure and low crop yield. Money spent on land preparation and planting, as well as income from the sale of farm produce is lost and household savings are spent to replant farms. Occasional bad harvests are tolerable but consistent crop failures have serious negative effects on livelihoods.

Another effect of climate change on agriculture in Offin basin is the effects of longer sunshine duration increasing temperature on crops. These changes coupled with prolonged rainfall shortages causes wilting of crops. Some farmers, notably cocoa growers, narrated incidence of cocoa trees withering as a result of exposure to intense and prolonged sunshine. This situation was also reported

by other farmers such as vegetable growers who claim that the high temperatures causes their vegetables to ripen prematurely and as such not getting the expected income from the sale of their produce.

Heat and water related diseases such as malaria; diarrhoea, bilharzias, shingles and other skin debilitations are becoming common in the basin. Malaria has been mainly due to people's exposure to mosquitoes while sleeping in the open or with windows open due to high temperatures at night. During dry seasons and prolonged rainfall shortages, water becomes scarce, stagnant and contaminated and cases of diarrhoea and bilharzias reported. Shingles and other skin debilitations are also common during periods of high temperatures. Previously, according to the communities, some skin diseases were rare in the communities but such diseases are becoming predominant in recent years.

5.4.2. Indigenous knowledge and coping with climate change

Traditional or indigenous knowledge, defined by Bebbington (1991) as a changing system, where western knowledge has a place, has played significant roles in solving problems including climate change. Indigenous people, who live close to natural resources, observe activities around them and are first to identify any changes and adapt to them. Appearance of certain birds, mating of certain animals, or the flowering of certain plants are all important signals of changes in time and seasons that are well understood by traditional knowledge. Biodiversity have been used as a buffer against variation, change, and catastrophe; in the face of plague, if one crop fails, another will survive (Salick and Byg, (2007).

Communities in the Offin basin have invented array of strategies ranging from diversification of economic activities and changes in land use patterns to modification of agricultural systems in order to cope with changes in climate. Because of the complex and intertwined relationships between

human activities-environment-climate, the perceptions and strategies of indigenous people can bring significant insight to a broader understanding of the impacts of climatic variability. Moreover, the dynamic nature of the impacts is noticeable since as people react to climatic change, they are likely to modify the environment in some way, which in turn may further affect the climate.

Indigenous people may not understand the concept of global warming or climate change but they rightly observe and feel its effects. The observations of indigenous people in the Offin basin were in agreement with the recorded climate parameters in the Offin basin from 1961 to 2006. Indigenous people are an important source of information on climate change and there is the need for close collaboration between scientists and indigenous people to document indigenous knowledge. Currently, most published reports on indigenous observations of climate changes come from the Arctic regions where co-operation between scientists and indigenous people is strongest (Salick and Byg, 2007).

5.5. Future climate projections and livelihoods vulnerability in Offin basin

All projections point to a very changed climate in Offin basin in the coming years. Temperature is expected to continue rising and precipitation patterns are also expected to continue to show increased variability. These projected changes will have several effects on the livelihoods of the people living in the basin whose livelihood activities depend on the natural resources available to them, mainly depending on agriculture.

5.5.1. Water Needs

Water availability in the River Offin basin is already a crucial issue and in the coming years it can only be expected to get worse under a “business-as-usual” scenario. Due to the dependence on River

Offin and its tributaries as well as shallow wells and boreholes for their water needs, communities living in the River Offin basin will be very much hit by water shortages in the event of reduction in rainfall and surface runoff, river discharges and groundwater recharges. Climate change, however, will not be solely responsible for the water scarcity being projected but other factors such as increasing population, changes in catchment land cover, construction of dams or upstream reservoirs, and pollution from domestic, agricultural and industrial sources will also impact on water availability and quality. Climate change will add to worsen an already bad water situation in the Offin basin. Already, rise of global population and increased human activities have progressively reduced the world run-off per capita, from 40,000 m³ per person in 1800 to 6,840 m³ in 1995 and this is estimated to fall further to 4,692 m³ by 2025 (Nsiah-Gyabaah, 2001). Arnell (2004) also reports that approximately 1.4 billion people currently live in watersheds with less than 1000 m³ of water per person per year, even without the effects of projected climate change.

The reduction in water resource availability in the Offin basin is likely to cause diseases leading to deaths and depletion of financial resources in treating diseases, ecosystem disturbance and social disorders in the form of conflicts on water use. These effects have been felt in Ghana before during the drought of the early 1980's and 2001 in the semi-arid and semi-humid parts of Ghana. This drought exposed the vulnerability of poor households to weather changes and scarcity of water. The reliance on wells during the dry season will be severely affected as groundwater recharges decline and the water table goes down

5.5.2. Agriculture

Communities in the Offin basin feed on the crops they grow as well as sell some to earn income but agriculture in the basin will be severely affected as crops grown by the people are suited to the prevailing climate in the area. Any effects of climate on agriculture will also affect the nutrition and

health of the people as they grow what they eat, for example cassava and cocoyam, which are very important components of “fufu”, a staple food of the people. Other crops grown include maize, vegetables, fruit crops, oil palm and cocoa. The farmers have realized that changing climate is already impacting on the crops they grow but other factors like species or cultivar and the soil type (Sagoe, 2006) may also affect the growth of crops in the Offin basin, aside the change in climate.

In an assessment of the effects of climate change on root crops production, Sagoe (2006), using 1990/1991 growing season as the base year and assuming rainfall amounts remain the same, increasing temperature in 2020, 2050 and 2080 by 0.6°C, 2°C and 3.9°C respectively reduced cassava yields. The rate of reduction in cassava yields increased with an increase in temperatures and projects that cassava yields would decrease by 13%, 23% and 58% (observed Kumasi yields) and 3%, 13.5% and 53% (predicted yields) in 2020, 2050 and 2080 respectively. Percent reductions in cocoyam productivity at the same projected conditions for temperature and precipitation are 11.8%, 29.6% and 68% in 2020, 2050 and 2050 respectively. Such a reduction in production of these staple crops with an estimated per capita consumption of 151.4 kg of cassava and 56 kg of cocoyam, accounting for 58% of the per capita food consumption would not only have a direct impact on the local farmer but also on the national economy. Root and tuber crops as part of the agriculture exports generate about 75% of government earnings and employs 70% of the population. Already, farmers in the River Offin basin have started moving from the cultivation of these tubers due to low yield and are moving into vegetable production.

Maize has a very high crop water requirement (CEEPA, 2006) and the reduction in water availability in the Offin River basin will have serious consequences on maize production because crop water use, in general, is directly related to the crop yield; this holds for all crops. In a study of five crops (maize, millet, sorghum, groundnuts and bean) in selected countries across Africa, CEEPA (2006) found out that among the selected crops, maize is the least drought resistant and the

most sensitive to water stress. In the case of rain-fed maize, actual yield increases from 0.8 tons/ha when actual crop water use is 212mm to 2.26 tons/ha when actual crop water use is 381mm, showing the important role of water in rain-fed maize production. The findings from CEEPA (2006) corroborates the well-known fact that water is among the main limiting factors in several African farming systems including that of the Offin River basin. Invariably, a situation where water available for the cultivation of maize reduces, yield of maize will also reduce. This, unfortunately, is likely to be the real situation if no immediate steps are taken to address the situation as de Wit and Stankiewicz (2006) predict that by the end of this century 25% of Africa will have reduced surface flows owing to decreasing rainfall.

Growing of cocoa as a cash crop has been the major source of income for the people but this is gradually and unfortunately diminishing due to the highly sensitive nature of cocoa to climate change in terms of bright sunshine duration, evapotranspiration, rainfall/precipitation, temperature and relative humidity. The changing climate does not seem favourable for cocoa production and the yields being recorded are decreasing in the basin. This turn of events will become very terrible for the smallholder rain-fed cocoa farmers for whom cocoa contributes about 70-100% of their annual household incomes (Anim-Kwapong and Frimpong, 2006). Cocoa is highly susceptible to drought, as all farmers in the basin attested to and also confirmed by (Anim-Kwapong and Frimpong, 2006). The pattern of cropping of cocoa is related to rainfall distribution in Ghana and usually most cocoa seedlings die during the establishment phase when there are prolonged dry conditions. According to Anim-Kwapong and Frimpong (2006), water deficits result in lower yields and an increase in the level of mirid (capsid) damage in adult plantings particularly from September to March when moisture deficit is high and the insects are most active.

One major problem that the farmers mentioned as a result of climate change is intense and longer duration of sunshine which scorches and kills their crops. This concern raised by the local farmers is

corroborated by Anim-Kwapong and Frimpong (2006) that the photosynthetic rate of cocoa decreases if the photosynthetic apparatus is exposed to light intensities exceeding 60% of full sunlight that is $1800 \mu \text{mol m}^{-2} \text{s}^{-1}$, while prolonged exposure to high light intensities damages the photosynthetic mechanism of the leaves.



Photo 10. Intense sunshine destroys cocoa tress



Photo 11. Farmer shows effect of sun on cocoa trees

5.5.3. Diseases

Several studies have clarified the links between climate change or variability and diseases (van Lieshout *et al.*, 2004; Epstein and Mills, 2005; McMichael *et al.*, 2006; Pascual *et al.*, 2006; Patz and Olson, 2006). The role of rainfall variability and its effects on water resources and eventually diseases is also clearer now. About a quarter of the population of Africa already experience high water stress which is a catalyst for the spread of water borne diseases particularly cholera and malaria (Few *et al.*, 2004; IPCC, 2007). Water stress also impedes the ability of people to recover from malaria and it is therefore not by coincidence that Africa accounts for 90% of global cases of malaria. An estimated 700,000 to 2.7 million people die of malaria each year and 75% of those are African children (see <http://www.cdc.gov/malaria/>; Patz and Olson, 2006).

People living in the Offin basin claim there has been increased incidence of malaria and although there is not any recorded long term data to scientifically prove this, it cannot be totally discounted. Schreck and Semazzi (2004) work in the northern sector of East Africa state that in areas that have two rainy seasons – March to June (MAMJ) and September to November (SON) – more rain falls in SON than previously experienced. They contend that the SON period is relatively warm, and higher rainfall is likely to increase malaria transmission because of a reduction in larval development duration. This condition is similar to that of the Offin basin in Ghana which is generally warm all year have two rainy seasons – the major season from April to July (AMJJ) and minor season from September to October). Seasonal rainfall analyses in River Offin basin also remarkably show more rainfall in the minor season (September-October) in recent years than previously experienced. Further research on this issue is important to really confirm or reject the local people's perception of increased malaria incidence. Ghana has always been a malaria prone area and as results from the "Mapping Malaria Risk in Africa" project (MARA/ARMA) show, there is likely to be increased incidences in some areas while others decrease depending on location of climatically suitable areas for malaria by 2020, 2050 and 2080 (Thomas *et al.*, 2004).

Other water related diseases such as cholera also have the tendency of increasing in the study areas due to water stress. Usually in the dry season, there is no rainfall, rivers are dry and wells also dry up. Any available source of water becomes good in absence of better. Families without private wells or cannot afford to purchase sachet water for use are forced to ration poor quality water. This is a major problem and can lead to increases in water borne diseases. While diseases such as cholera are being eradicated in other parts of the world, they are re-emerging in Africa (IPCC, 2007). As the link between more diseases such as meningitis and climate change/ variability are being established, it is worth noting that in Ghana these diseases have been associated with the dry parts of Northern Ghana and the trends in climate variability in the Offin basin may just be closing in on creating

favourable conditions for its outbreak. Already, about 162 million people in Africa are said to live in areas with a risk of meningitis (Molesworth *et al.*, 2003) and although factors that predispose populations to meningococcal meningitis are still poorly understood, dryness, very low humidity and dusty conditions are factors that need to be taken into account (IPCC, 2007).

5.5.4. Other socio-economic activities

The summary of all the negative effects of climate change and the vulnerability of water-dependent livelihoods is the loss of income which would have been earned or saved if there was enough water available to ensure the success of their livelihood activities. Savings are spent to replant farms which have failed as a result of the lack of rainfall whilst the money which would have been earned should the crops have grown to maturity, is lost. Money is spent by those who can afford to buy sachet water for drinking, where they are available. Those who cannot afford to buy sachet water would eventually spend more money on medication as a result of water-related diseases and malaria.

5.6. Coping with Climate Change in the Offin basin

The people realised that water shortages are a major threat to their survival and there are several strategies to adapt to this new phenomenon. One of such strategies is water rationing. For example, “waste water” from washing clothes, utensils and other activities are also used for watering backyard gardens and nurseries. Households also try to reduce the water use per person per day in an attempt to conserve water. This strategy needs to be part of a behavioural change and not during periods of water shortage. Adaptation is not just a climate change issue; education on water conservation should be an on-going process.

Rainwater harvesting, an old traditional way of collecting and storing water where every household had at least two big barrels placed at strategic places in the house where rainwater is directed from the roof of buildings into those barrels for storage, is actively being revived and advocated in most communities. This has become necessary following prolonged rainfall shortages and drying of previously perennial streams that provided water all year round, at a time where more water is needed by the communities due to increase in population. But in all the over 20 communities covered under the study, not enough rainfall is harvested because the harvesting technology is not good, i.e. out-dated and inefficient under the current climate regime. The type of houses constructed and the roofing system does not support efficient rainwater harvesting. Only a small percentage of the rains can be harvested with the majority going waste.

The traditional and local authorities identify clearing of riparian vegetation along their river banks as a major factor affecting their streamflows and are putting on measures to remedy the situation. Some of the measures are creating awareness on the effects of deforestation around water bodies, sensitizing the communities to prevent bush fires, community based management of forests, imposition of fines, etc. These measures by the traditional authorities are not yielding much because the communities, though still rural in terms of development and infrastructure, have become very cosmopolitan or heterogeneous in composition and allegiance to traditional authority is not absolute. There have been settler farmers who have moved into some of these communities and the communal nature of the communities is breaking down and people now think more of themselves than of their collective well-being.

There are also forbidden days or taboo days when nobody is expected to go to the riverside. Previously, the use of taboos was very effective in controlling community behaviour and the traditional leaders see it as an effective alternative in protecting their waterbodies. The question then is, why does it need a re-introduction since such tradition has not at any point been abolished? These

taboos have been ineffective for several reasons including modernisation, heterogeneity of the communities, and influx of other religions including Islam and Christianity. For example, since most of the people are now Christians compared to previous years when almost everyone adhered to traditional way of worship, traditional authorities have been undermined and their directives on issues such as forbidden days and taboos are seen as fetish and not adhered to. Although some traditional authorities do believe in the re-introduction and strict enforcement of taboos and forbidden days, they may not have the desired impacts under the current dispensation. Religion is a very delicate issue in these communities and although re-introduction and enforcement of some of the traditional laws will be very useful, it needs a very cautious approach.

Indigenous knowledge in agriculture and water management, acquired over many years of practice, has helped the communities to cope very well with water shortage, droughts, and crop damage/losses. The farmers are able to predict, quite well, when the rains will come and plan their planting season to coincide with the rains. This has, however, become difficult in recent years due to changing rainfall pattern. To this, the farmers are adapting by changing the type of crops they used to grow. Crops which thrive well under the current prevailing conditions are increasingly being planted in areas which, hitherto, did not support their cultivation. A case in point is shifting from cocoa cultivation to drought resistant crops such as cassava. Vegetable growers are also gradually moving into the river plains to grow their crops since they do not get enough water in the places they previously grew their vegetables. This is a form of adaptation but, obviously, not sustainable. The money which they previously earned from the sale of cocoa, for example, was a major source of income which supplemented the upkeep of families and even in buying agricultural inputs and expanding their farms. Clearing of the riparian vegetation and use of chemicals so close to the rivers/streams, as is being done by the vegetable growers has its own hazards.

Farmers, especially cocoa farmers, who complained most about the effects of intense sunshine on their crops see the best way to adapt is to have a means of providing shade for the crops. Though some farmers already have trees on their farms or are planting trees to provide shade, the practice does not seem appealing to most farmers. In Ghana, all timber trees found on any land belong to the Government and the Government decides when an area of land is given as concession to a timber company for felling. This has resulted in some farmers, having in the past, deliberately killed trees on their farms to prevent timber merchants from coming to cut their trees, destroy their farms and pay little or no compensation. This policy has been a major disincentive to adaptation. Although the Timber Resource Management Amendment Act 2002 (ACT 617) provides that the right to harvest trees and extract timber from a specified area of land shall not be granted if there are farms on the land, unless the consent of the owners of the farms has been obtained or if there is timber already grown or owned by any individual or group of individuals on the land, not much has changed in terms of the relationship between timber merchants and farmers. Due to the inability of farmers to show clear proof of ownership of trees on their farms (either planting the tree or tending the tree till maturity), lack of education in forest laws and the financial strength of the timber merchants, the farmers are still being exploited. To stop this exploitation and enhance adaptation of rural farmers, there must be sustained education programmes to get the farmers informed of their rights and empower them to protect their farms and most importantly, plant more trees.

5.7. Current Vulnerability and Future Changes in Climate

Decreasing the vulnerability of socio-economic sectors and ecological systems to natural climate variability through a more informed choice of policies, practices and technologies will, in many cases, reduce the long-term vulnerability of these systems to climate change. (IPCC 2000a)

While members of the scientific community and policy-makers are particularly concerned about adaptation to climate change, some authors (e.g., Burton 1992) have argued that attention should be given to adaptation to current climate. Bohle *et al.*, (1994), for example, argued that a full understanding of current vulnerability is necessary for developing strategies to coping with future climate change. This school of thought stresses the potential benefits and enhanced resilience that can result from practices and infrastructure that are well suited to the current climate. Given the uncertainties about future climate under various scenarios, efforts to assess adaptation to current climate can be useful as improved adaptation to current climate may be a crucial step in reducing vulnerability.

Burton (1997) argued that for developing countries it makes sense to focus on current problems that affect the economy rather than on uncertain changes that will only be manifested at some point in the “distant” future. It is in this context that current vulnerability is likely to be most relevant. The same author points to the need for more convergence between the scientific communities studying adaptation to current climate and extreme weather and those studying longer-term changes (e.g., ISDR) —advice which seems to have been taken by the IPCC. From the point of view of “the person on the ground” (i.e., those adversely affected by climate change), distinctions between “normal” climate and climate change might be irrelevant.

There may be some merit in following Burton’s (1997) suggestion about “integrating” the study of adaptation to current variability (i.e., extreme events) and that of long-term changes in climate. The projected increased frequency of extreme events, and the related reduction in recovery time, “would greatly affect the effectiveness of adaptation options” (Smit et al. 1999).

5.8. Soil and land management and climate change

Soil organic matter makes up the bulk of carbon in terrestrial ecosystems (Delaney *et al.*, 1997; Eswaran *et al.*, 1993; Schlesinger, 1997) and this storage of carbon is heavily affected by land use changes (Houghton *et al.*, 1999; Paustian *et al.*, 1997). For example, conversion of forest lands to agricultural lands is known to reduce carbon storage in soils (Solomon *et al.*, 2002) as it enhances microbial decomposition of organic carbon and affects carbon storage by changing redox conditions, soil solution chemistry or the amount of water flowing through soils (Osher *et al.*, 2003). The lost carbon gets into the atmosphere (Schlesinger, 1984), causing atmospheric warming.

5.8.1. Land Management Practices and Soil Organic Matter

Soil organic matter (SOM) improves and stabilizes the soil structure so that soils can absorb higher amounts of water without causing surface run off, which could result in soil erosion. The improvement in water absorption capacity of the soil also helps the soil to remain moist during extended drought and this is critical for climate change adaptation since agricultural cropping systems requires a higher resilience against both excess of water (due to high intensity rainfall) and lack of water (due to extended drought periods).

As conversion of cultivated land to forest resulted in increased aggregation and a greater soil organic carbon (SOC) stock (Six *et al.*, 2002), the general and normal expectation is for total C accumulation in biomass to be higher under natural forest ecosystem than under agricultural cultivation (Davidson and Ackerman, 1993; Yoneyama *et al.*, 2001; Solomon *et al.*, 2002). On the contrary, accumulation of soil organic matter under the natural forest in this study in the Offin River basin was found to be lower than recently cultivated soil and the cassava/plantain/maize intercrop system. This, however, agrees with some studies (Garcia-Oliva *et al.*, 1994; Feigl *et al.*, 1995; Moraes *et al.*, 1996) which found that conversion of tropical forests to pasture, for instance, resulted

in gain of total soil carbon as a result of increased carbon storage in subsurface horizons (Osher *et al.*, 2003).

Low SOC in the natural forest ecosystem in the Offin basin may also be due to some reasons such as vegetation type (Rhoades, 1997) and physical properties of the soil, notably soil mineralogy (Parfitt *et al.*, 1997; Veldkamp, 1994) because there are soils which have naturally low occurring SOC. This low SOC content of such soils can, however, be greatly enhanced by a combination of cropping systems and the type of crops grown as shown by Purakayastha *et al.*, (2008) in a study of carbon Sequestration in Native Prairie, Perennial Grass, No-Till, and Cultivated Palouse Silt Loam". Purakayastha *et al.*, (2008) concluded that neither no tillage (NT) nor conversion to perennial vegetation would attain the soil organic carbon (SOC) found in Native Prairie (NP) over 10 to 30 yr; but medium duration of NT (10 yr) combined with short intervals of conventional inversion tillage (CT) (3 yr) followed by NT might increase SOC compared with continuous long-term NT under annual cropping.

While intensive soil tillage reduces soil organic matter through aerobic mineralization, low tillage and the maintenance of a permanent soil cover (through crops, crop residues or cover crops and the introduction of diversified crop rotations) increases soil organic matter. A no- or low-tilled soil conserves the structure of soil for fauna and related macrospores (earthworms, termites and root channels) to serve as drainage channels for excess water. Surface mulch cover protects soil from excess temperatures and evaporation losses and can reduce crop water requirements by 30%. The FAO, therefore, promotes low tillage and maintenance of permanent soil cover that can increase soil organic matter and reduce impacts from flooding, erosion, drought, heavy rain and winds. The lower SOM under the oil palm plantation may be due to lower litter production rate.

5.8.2. Soil organic matter and carbon stocks

Soil organic matter plays an important role as a pool of terrestrial C, in ecosystem productivity, in the functioning of agro-ecosystems and in crop land fertility. While the global society is facing the challenge of climate change due to rapidly increasing CO₂ accumulation in the atmosphere, accumulation of SOM, and hence, C sequestration have not been given much attention as a climate change mitigation option at global scale (FAO, 2001). Carbon sequestration however, is an important option not only to mitigate climate change but also to enhance soil fertility and the productivity of ecosystems (Janzen, 2006).

The high carbon stocks under the Cassava/maize/plantain landuse systems (Table 4.5), demonstrate, under agricultural systems, the “win-win” benefits from soil C accumulation. The high C stocks is significant for climate change mitigation and in addition, provides nutrient reserves for crop yields increases, thereby helping to enhance global food security. Reduction in soil erosion and biomass addition from maize stover and cassava leaves may account for the high soil carbon stocks under the cassava/maize/plantain intercrop system. With decreasing availability of arable lands in developing countries, intercrop systems can be used as climate change mitigation and food security measures.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

It is now well accepted both scientifically and politically that climate change is occurring (Ladislav *et al.*, 2008) and most studies point to the fact that poor, natural resource-dependent rural households will be the worst hit by adverse climate impacts (Kates 2000; Mendelsohn *et al.* 2007; Thomas and Twyman 2006). Currently, adverse impacts of climate change are being felt in several parts of the globe and the worst affected are the rural poor (Adger *et al.* 2005, Adger *et al.* 2007). Habitats are changing in some areas, leading to species range shifts and changes in plant diversity, affecting indigenous staple foods and medicinal plant availability. FAO (2007) estimates that with the exception of Latin America, developing countries would face a decrease of GDP from agriculture due to climate change, and Asia and Africa would generally be negatively affected and further estimates that for Africa, 25%–42% of species habitats could be lost, affecting both food and non-food crops.

The issue of climate variability in the Offin river basin may not be a new thing and the communities have coped with the effects of the varying weather conditions on their livelihoods for a long time. However, the magnitude of recent changes in climate is what is of major concern. If the changes in rainfall and temperature continued to be very marginal as it had been previously, the people would have continued to cope quite well with their indigenous knowledge and practices and their limited resources without any major problems. Current and projected changes in climate are far beyond what can be called negligible. True changes in climate are occurring in the River Offin basin and the effects on ecosystems and people living in the basin are already being felt. This brings to the fore the urgent need for assistance to these communities to enable them adapt to the changes. Due to the lagged relationship between greenhouse gas emissions and their future impacts, past and current

emissions have already committed the earth to appreciable changes in climate and no matter the level of interventions to mitigate the effects of greenhouse gas emissions, adaptation is necessary to reduce the impact of committed changes in climate (Agrawal, 2008). This calls for proper planning and implementation of adaptation strategies.

A well planned and implemented climate adaptation strategy increases knowledge about future impacts of climate change (IPCC, 2007b); existing experience of historical forms of adaptation provides strategic lessons about the suitability of different forms of adaptation in different contexts (Adger *et al.* 2005); and also without proper adaptation strategies, the costs of potentially adverse effects of climate change will increase. The United Nations Framework Convention on Climate Change (UNFCCC) provides that all Parties formulate and implement national or regional programmes containing measures to facilitate adequate adaptation to climate change (Art. 4.1.b) and lists specific areas in particular need of adaptation as coastal zones, water resources, agriculture, and areas affected by drought and desertification, as well as floods.

Because usually the people most affected by climate changes are the poor and marginalised, their ability to adapt is also limited due to the same poverty. Adaptation measures may be outlined for the local communities but the success of it depends on the implementation and that is where the government, civil societies, NGOs, international agencies and everybody in a position to help is needed. The effects of climate change cut across territories. The government needs to develop a holistic National Adaptation Programme of Action (NAPA) which would ensure effective implementation of adaptation strategies.

6.2. Recommendations for adaptation

The recommendations in this work are in the form of proposed adaptation strategies which when implemented can enhance the communities' adaptation strategies to the effects of climate change.

There is no argument about whether the climate is changing or not. The planet has already been committed to some form of change through greenhouse gas emissions and what is needed is for us to adapt to the coming changes (adaptation) whilst we find means of preventing further high levels of greenhouse gas emission.

The great diversity of the people in the Offin basin and differences in resources available to them and generally the diversity of situations encountered with each individual may require that different adaptation strategies are developed for each household but in the midst of all the diversity, some common grounds were found upon which adaptation options are developed for communities in the Offin River basin. Even before this strategy is implemented it must be noted that there must be flexibility in its application to changing situations.

Although this document may make references to Mitigation because it believes that there is a need to reduce the emission of greenhouse gases and stop the worsening of the climate, the central focus is Adaptation because climate change cannot be totally avoided, and already the people are feeling the negative impacts of climate change. Moreover, mitigation measures may take time to become effective because the climate system is already set in a particular direction, some greenhouse gases are already in the atmosphere.

It is important to highlight that the relationship between a changed climate system (e.g., higher temperatures, altered precipitation regime, etc.) and impacts on human systems is not necessarily linear—as early approaches used in climate impact studies (e.g., crop yields research and various analyses of land and regional production potentials—as applied in studies of agricultural impacts of climate change) seemed to imply. Human agencies and institutions can play a crucial role in minimizing the adverse impacts of—and in seizing opportunities resulting from—climate change. In

particular, the role of adaptation (whether reactive or anticipatory, spontaneous or planned, etc.) is crucial for assessments of potential impacts of climate change (Smit *et al.* 2000).

The proposals for adaptation strategies are made at two main levels: National and Community levels. Most of the community level adaptation strategies being proposed can work best when implemented within a national adaptation strategy framework. Since the vulnerable people are already coping using their limited resources and indigenous knowledge, the government's adaptation strategies should be built on already existing information about community capacity, knowledge and practices the people are using to cope with climate hazards (Huq, 2008). This is a sure way of ensuring effective adaptation.

6.2.1. Community Level Adaptation Strategies

This section proposes adaptation strategies which can be implemented at the local or community level.

6.2.1.1. Agriculture

The main form of agriculture in the basin is crop farming and it is highly vulnerable to current and projected climate changes. The situation in the Offin basin is aptly described by Watson, *et. al.*, (1997): “in regions where agriculture is unable to cope with existing extremes, where markets and institutions to facilitate redistribution of deficits and surpluses are not in place, and/or where adaptation resources are limited, the vulnerability of the agricultural sector to climate change should be considered high”.

i. Improved crop varieties

The variety of crops being planted by the farmers can be improved or enhanced to ensure that farmers get the best out of their labour. With the help of the Crops Research Institute of the Council for Scientific and Industrial Research, Ghana, and other relevant stakeholders, farmers can be helped to plant seedlings that are well adapted to the current climate. For example, drought resistant varieties which can even grow very well when planted at the end of the rainy season. This is being done by farming communities living along rivers, the lakeshore and the Shire valley in Malawi. They are successfully adapting to changing climatic conditions by growing a second crop of maize that is planted at the end of the rains in March and is harvested in winter (ActionAid, 2008). Early maturing varieties of the crops already being cultivated by the farmers will be a very good entry point in helping the farmers.

ii. Improved Mixed Cropping and Mixed Farming

The farmers traditionally practice mixed cropping especially with food crops. Mixed cropping or crop diversification guarantees the chances that at least one of the crops grown will survive even when the weather becomes unfavourable. This system must be improved for the benefit of the farmers. Some crops like groundnuts, pigeon peas and soybean which are traditionally not grown by farmers in the River Offin basin can be introduced on pilot basis in the basin. These are high value leguminous crops which if incorporated in the mixed cropping systems, have the potential to improve soil quality. Furthermore, these crops also require less water and tolerate drought and short rain incidences better than most of the crops the farmers currently grow and are not yielding much because of lack of rain. These crops have high demand on the market which is not met by their production and their prices are high so the income of the farmers will be improved.

Moreover, it has been realized that mixed crop and livestock farmers are associated with positive and significant adaptation to changes in climatic conditions compared to specialized crop and/or livestock farmers. The results imply that mixed farming systems are better able to cope with changes to climatic conditions through undertaking various changes in management practices (Nhemachena and Hassan, 2007).

A mixed seedling technique is also proposed where seedlings of varieties of the same species are planted on the same farmland or put in the same hole to ensure that germination is guaranteed. This technique is being practiced by some farmers in Pwalugu in the northern part of Ghana (ActionAid, 2008) to prevent total non-germination of seeds and total crop failure.

iii. Soil quality

The farmers expressed concern reduced reduced soil fertility and low yield of crops and advocated the use of chemical fertilizers, the cost of which they could not afford. The soil analysis also indicated low soil carbon content. To improve soil fertility, whilst reducing mineral fertilizer use and on-farm energy costs, the use of soil conservation practices such as minimum tillage, application of animal manure, cover cropping, mulching and composting are proposed for the rural farmers. The farmers should be introduced to methods to improve soil fertility using organic manure instead of chemical fertilizers. Instead of burning vegetative material from the farms during land preparation (mainly through slash and burn), the farmers should be helped to develop composting techniques that will use the vegetative materials produced from their farms.

There are examples of successful applications of community-based composting technique in Salima, Malawi for example, where farmers use the ‘Chimato’ system to compost vegetative material in special mud structures and have used it to improve the quality of their soil (ActionAid, 2008). There

should be more research into simple community-based techniques that will improve management of soil moisture in rain-fed areas with very simple and easily managed approaches.

6.2.1.2. Water availability for farming and domestic activities

This section proposes possible interventions that can be employed at the community stage to help the people to get water all year round for both their domestic activities and agriculture. The major sources of water for the communities are the streams and rivers in the basin.

i. Runoff water harvesting

Simple water harvesting techniques in the Offin river basin should be developed which will enhance infiltration of water and improve the soil moisture content of soils in the Offin basin. Currently, most of the run-off from rainfall just flows over the land surface with very little infiltration and in just a few hours after rainfall, most of the water is gone and the soil remains dry despite the rains. The flow of runoff after rains can be reduced by placing obstacles in the flow path. For example, a simple method of building loose stone dykes in valley bottoms have been used in some rural farming communities in Niger where such dykes slow the flow of run-off water, thus increasing infiltration into the ground (Tearfund, 2008).

The Central Government, District Assemblyies, NGOS and other stakeholders such as international organisations can also help the people in their adaptation with the development of small-scale community-based irrigation schemes and construction of small dams for dry season farming. These irrigation projects should be smallholder based rather than large scale irrigation projects, and should also be simple and community owned.

Other systems of successful runoff water harvesting based on indigenous knowledge are available which can be adapted to suit the farmers in the Offin basin. These include;

- The *daldal* system of building dams to trap silt and water, developed by the Irob people in northern Tigray in Ethiopia, on the border with Eritrea (Zigta and Waters-Bayer, 2001). It is a way of creating land to produce food and obtain a supply of clean water.
- The *nadi* or dug-out village pond. It is storage structure for rainwater harvesting. The water stored in a nadi is generally used for drinking by livestock and human beings and also acts as a source of groundwater recharge through seepage and deep percolation.
- The *tanka* (underground cistern) is another major source of drinking water in western Rajasthan. It is constructed in a circular or rectangular shape, normally on bare ground where surface runoff can be diverted to the tanka by creating a clean catchment around it.
- The *khadin* (appendix 2), a runoff farming and groundwater recharging system, is popular in the hyper-arid part of Rajasthan. Here, runoff from upland and rocky surfaces is collected in the adjoining valley against an earthen embankment having a masonry waste weir for outflow of runoff excess. Sometimes a sluice gate is provided in an earthen embankment for draining out standing water for crop cultivation. The Khadin has proven to be useful in conserving water for crop production and increasing groundwater availability even in drought periods (Khan 1996; Singh and Khan, 1999).

ii. Rainfall harvesting

All the communities are implementing the old system of rainfall harvesting using barrels placed at strategic points beneath the roof of buildings. This old system which was abandoned by most people with the coming of boreholes and wells is now being revived actively in the communities. Unfortunately, the current system of rooftop rainwater harvesting in the Offin basin is not helping the people very well because the roofing system does not channel all the water which falls on it to one collection point. With an adaptive roofing system, large scale rooftop rainwater harvesting from

a 1,500 m² roof top with an effective rainfall of 250 mm and a 0.8 runoff coefficient is estimated to yield 300 m³ of water, which is enough for a drinking water consumption of 30,000 person days at 10 liters per capita per day (lpcd) (Narain et. al., 2005).

Possible intervention to improve on the efficiency of rainwater harvesting will be to place hollow materials (e.g. PVC pipes or curved corrugated aluminum sheets which they use in roofing) at all the edges of their roof and channeled to a big container (tank) as a collection point where more water can be collected and stored during rains. The roofing material used by the houses in the community is mainly corrugated aluminum sheets and with the right technique, enough rainwater can be harvested for the people. The runoff efficiency of roofs made up of different material has been evaluated (Khan 1995) and corrugated iron sheets are the most efficient with (85%) for corrugated iron sheet roofs followed by stone slab roofs (80%), paved surface (68%) and clay tile roofs (56%). The lowest (39%) is for thatched straw roofs.

iii. Wells and boreholes

One obvious adaptation strategy that readily comes to mind concerning the unavailability of water is the drilling of bore holes and wells. This strategy is already being implemented in the basin both on individual basis and communal basis and it seems to be the strategy that readily comes to the mind of the people. As a result they unanimously call for the construction of more wells and boreholes to provide water. However, the possible environmental consequences of greater groundwater abstraction in the absence of proper planning should be critically considered. Sinking many wells and boreholes within a small area may help solve the immediate problem of providing water to the people whiles it creates another problem such as drastic reduction in groundwater levels in the long term. It is, therefore, necessary that any interventions are planned and implemented within a holistic framework to ensure no backlashes occur.

iv. Groundwater Recharge

Rainwater from rooftops can even be harvested to recharge groundwater to solve the problem of wells drying during the dry season. This approach requires harvesting and channelling roof water to either existing wells, tube wells, bore wells or specially designed wells (Narain *et. al.*, 2005)

Narain *et. al.*, (2005) describes the Percolation Tanks, which are recharge structures constructed on small streams with adequate catchment for impounding surface runoff. These tanks are used solely for quick recharging of groundwater. Percolation tanks are more efficient than ponds for recharging and conserving water due to low evaporation losses but the selection of suitable sites for the construction of percolation tanks and subsequent maintenance are crucial for their effective functioning (Narain *et. al.*, 2005)

6.2.1.3. High Temperatures

This section proposes strategies that can be explored to help the people adapt to the effects of heat or high temperature.

i. Community Reforestation Projects:

The communities should embark on reforestation projects. The planted trees will provide shade for the communities and also help in creating a cool atmosphere and reduce heat. The reforestation can be done with or without external assistance. Tree seedlings can be harvested from the wild and planted as has been successfully done by some farmers within the basin who are planting trees on their farms. Also, fast growing trees seedlings can be purchased from the forestry commission of Ghana and planted in the community. The trees will also serve additional purposes as windbreaks during storms and generally contribute to carbon sequestration. There should be diversity in the trees grown to ensure that the people benefit from every single tree that is planted. Fruit trees such as

mango, oranges, and pear which already do well in the basin can be cultivated for the additional benefits of providing food during its fruit-bearing season and the fruits can even be harvested and sold to augment the income from agriculture.

Fast growing commercial trees should also be promoted so that in the near future they can be harvested and sold for profit. For example teak plantations can be cultivated in the community as has been done at Nnerebehi, one of the communities in the basin. The teak plantation planted in Nnerebehi some years ago have helped the community in so many ways: some were harvested to help in the town's electrification project since teak trees are commonly used as electric poles in Ghana; the teak plantation also now serves as a meeting point for the community due to the shade it provides and most community meetings are held under the shade of the trees. This story can also be replicated in diverse ways in different communities.

Also in Ethiopia's Tigray Region, community woodlots have been planted since 1991 primarily for ecological regeneration rather than for economic benefits. A study in 50 *tabias* (the lowest administrative unit in Tigray, comprising usually four or five villages) in the 1998-99 cropping season showed that nine out of ten *tabias* have woodlots and on average, there were nine woodlots per *tabia* with an average size of about 8 ha (Reig and Steeds, 2003). Most of the woodlots were managed at the village level by the village council, and were used only by members of that village, usually to cut and collect grass for animal feed and other purposes, to collect fruits or seeds, and to practise beekeeping

ii. On Farm Tree cultivation

As farmers also complain of the effect of intense sunshine on their crops, strategies proposed here include the incorporation of tree crops on farmlands. There can be both ecological and economic advantages for incorporating trees into farmlands. The trees can provide shade for their crops, as is

being done by some farmers with the support of IITA's STCP. Apart from providing shade, the trees can also help in improving the fertility of the soil, depending on the type of tree grown. Tree planting practices such as the intercropping of *Sesbania sesban* with maize are undertaken as part of soil improvement and management strategies (Deweese, 1995). Economically, the trees when harvested can also add to the income of the farmer. The trees incorporated into farm, as one farmer puts it, will serve as insurance for them in their old age when the trees are felled and sold for higher income. Trees produced on farm can be an important asset to complement the seasonal crop household benefits.

6.2.1.4. Income Generation

The main source of income to most inhabitants of the River Offin basin is agriculture. This puts their income sources in very high vulnerability to the projected climate changes. Possible strategies that can prevent a complete dependence on high vulnerability livelihoods and also to prevent a complete loss of income in the event of very bad climate are proposed in this section.

i. Diversifying sources of income

The communities will have to reduce their total dependence on agriculture as the only source of income and diversify their sources of income. This is a good adaptation strategy for communities whose major source of income is from agriculture and is expected to be negatively affected by climate change. More communities in similar danger like those in the Offin basin are already diversifying their sources of income. Even in the Offin basin there are some people who have started diversifying their sources of income. However, there is not much diversity in what most of them are choosing to do in addition to crop farming. Almost every person is moving into petty trading in daily household necessities. The people can be helped in raising the level of food security and

increasing the income of the community by establishing profitable, innovative and sustainable agricultural activities like snail and mushroom breeding, thus increasing their economic power.

In some regions in Africa where previously agriculture (particularly animal rearing) was the only source of income, women now engage in a wider range of income-generating activities than previously (handicrafts, wood selling, working for others) and often run small shops selling basic goods, such as sugar, salt, or macaroni. Men have also diversified their activities, with many involved in commerce, such as buying and selling animals or commodities such as grain or wheat flour, and transporting goods, people or livestock to market.

6.2.1.5. Farmer co-operative groups

It is suggested that farmers and other identifiable groups in the communities should get themselves organized into cooperative groups. This will help very much in concentrating efforts at fighting climate change. It will be easier for the communities to implement projects that will help them to adapt to climate change, in groups than as individuals. When the people are organized in groups, it will also be easier for their voices to be heard as one unit than they trying to put their message across as individuals. They can set up committees that will help manage specific aspects of their adaptation such as flood and storm prevention committees. Financial institutions will also be willing to give the farmers the assistance they ask for, for example micro-credit facilities, when they are organized into co-operative societies.

Experienced farmers are usually leaders and progressive farmers in rural communities and these can be targeted in promoting adaptation management to other farmers who do not have such experience and are not yet adapting to changing climatic conditions. Making use of local successful lead farmers as entry points in promoting adaptation among smallholder farmers can have significant positive impacts in increasing use of various adaptation options (Nhemachena and Hassan, 2007).

Between 1997 and 2001, two regional projects were implemented in eight African countries, which tried to build on farmer innovation in agriculture (Critchley et al. 1999; Reij and Waters-Bayer, 2001). It was realized from the study that innovations were often adopted and adapted by resource-poor farmers, in particular women farmers. Although total financial costs were very modest, varying from \$ 20,000-60,000/country/year excluding external technical support, tangible results were generated with wide policy relevance (Reij and Steed, 2003).

A good case study of the benefits of farmer group organization is the “The farmers’ clubs of Salima, Malawi”. They offer an example of truly transformative adaptation and exemplify how adaptation can and must be a process by which people are empowered to act collectively, organise and take control of their own development (Actionaid, 2008). The action of the Salima women started two years ago, in response to ever worsening harvests and increased food insecurity in their communities. They came together to form a local women’s rights organisation called the Salima Women’s Network on Gender (SAWEG) began to organise women into farmers’ clubs and today communities in Salima are more food secure than they were two years ago.

6.2.2. National Level Adaptation Strategies

The government has a major role to play in the adaptation efforts of local populations by creating the right atmosphere in terms of policy and institutional frameworks to guide and support effective adaptation by individuals and communities by ensuring that all adaptation efforts are part of a holistic national programme and would be sustainable.

6.2.2.1 Policy Interventions:

This section reviews and proposes policy interventions that may be needed to ensure effective adaptation to climate change and also ensure that any adaptation strategies embarked upon at the

local level will be part of a holistic national adaptation framework. Government policies are expected to support research and development on appropriate technologies to help farmers adapt to changes in climatic conditions. Examples of such policy measures include crop development, improving climate information forecasting, and promoting appropriate farm-level adaptation measures such as use of irrigation technologies. Results confirm that access to credit and extension and awareness of climate change are some of the important determinants of farm-level adaptation. An important policy message from these results is that enhanced access to credit, information (climatic and agronomic) as well as to markets (input and output) can significantly increase farm-level adaptation.

i. The Ghana Poverty Reduction Strategy

The current Ghana Poverty Reduction Strategy (Part II) document spells out the direction of the country from 2005 to 2009. Climate Change adaptation is recognised as a priority area and focuses on the effect of climate change especially drought and desertification; lack of awareness on climate change and its impacts and poor dissemination of meteorological data and forecast to support economic development as major issues. The strategies suggested by the GPRS II to address these issues include:

- Facilitate the provision of quality meteorological data and forecast in support of weather sensitive sectors of the economy (GPRS II);
- Initiate measures to stem land degradation; and
- Initiate measures toward minimizing the impact of climate change/variability

Implementation of these suggestions have not been very clear as of the inception of 2009 and very likely that a new policy direction on poverty reduction may be drawn with the coming of a new government.

ii. Ghana's National Adaptation Programme of Action (NAPA)

There is the need for urgent completion and implementation of Ghana's National Adaptation Programme of Action (NAPA) which would spell out clearly how the country intends to address issues of climate change adaptation. The strategies that will come out of the NAPA should not be implemented independently but must be incorporated into all national policies on agriculture or food security, poverty reduction, forestry, water and all other human development sectors. A lot cannot be said at the moment about the consultations with most vulnerable groups at the developmental stages of the NAPA because indications are that it is at a very advanced stage of formulation but the implementation, monitoring and evaluation of the NAPA should have the active and recognised involvement of the most vulnerable sectors of the community.

iii. Agricultural Policy

Although agriculture remains the largest contributor to Ghana's GDP the crops sub-sector has not done well recently. This has been attributed to climate variability and land/soil degradation associated with traditional farming practices (Ghana Poverty Reduction Strategy (GPRS) II, 2005) and the government needs to formulate policies to reduce or stop land degradation and enhance the ability of farmers to adapt to the impacts of climate variability/change. Ghana's current agricultural policy, the reviewed Food and Agriculture Sector Development Policy (FASDEP II) rightly seeks to enhance the environment for all categories of farmers, while targeting poor and risk prone and risk-averse producers. A proper implementation of this policy will help address some of the issues of farmers have with the impact of climate change.

To ensure sustainable agricultural production and for farmers to produce food all year round, the government should actively promote the development of small scale irrigation dams and dug-outs to store and provide water for agriculture in the dry season and lengthen the growing period. It is hoped that the Ghana Irrigation Policy being formulated will help address some of these challenges. In ensuring efficient adaptation, these government interventions should come in at the right time to complement the farmers' efforts and that of the researchers and extension services. For instance the use of irrigation technologies needs to be accompanied by other good crop management practices such as use of crops with better use of water; use of efficient irrigation systems, growing crops that require less water and using improved irrigation water use practices.

iv. Water policy

'Institutional capacity and cooperation are essential for effective implementation of water laws and policies, some of which could help adaptation to climate change if enforced.' (Levina, 2006). The Ghana National Water Policy, under water resources management (Focus Area 6) identifies climate variability and change as a major challenge. The policy recognises water as a finite and vulnerable resource and has an objective to minimize the effects of climate variability and change through several means. However, to date, little is seen on how the policy is being implemented to protect the most vulnerable although a policy objective is to ensure adequate support to vulnerable people for implementing their own coping strategies. Interventions in the management of water resources in Ghana should move from the usual reactionary approach to a more proactive approach where the sector will develop programmes to ensure the protection of water basins by introducing adaptive strategies to people living in the basin that will give them incentives to help in protecting the river basins. The water sector should also lead in the development of legal and regulatory structures that support adaptive change.

The government should also ensure a pro-poor approach to water resources management. The peculiar needs of the poor and vulnerable in rural areas does not seem to be adequately considered in the government's water sector development. More small town and community water supply systems should be developed. Communities in the Offin River basin and similar communities that are particularly vulnerable to climate change and variability should be targeted, and appropriate sustainable solutions that reflect their needs and interests should be prioritised when the government is planning developments in the water sector. It is ironic that the River Offin provides the water needs of the Kumasi metropolis while communities that live very close to the river have no access to pipe-borne water.

v. Forest policy

The Ghana government must lead in the reforestation of degraded forests and off-reserve areas and also put in place comprehensive policies and packages to attract and encourage the private sector to get involved in reforestation and afforestation projects. The Presidential Special Initiative on afforestation should be strengthened and expanded so that more areas will benefit from the initiative. The Modified Taungya system already in place in some communities should also be well evaluated, improved and expanded to other communities where there are degraded forests.

The government must also promote the development and use of alternative wood products. Currently, emphasis on wood products has been on the few popular and commercial trees such as Odum, Wawa and Onyina. However, other products such as bamboo and rattan as well as other lesser known wood species can be researched into and explored.

To protect the existing natural forests from exploitation for fuelwood, the various district assemblies should engage the communities and assist them in setting up forest plantations and woodlots that would readily provide the people with wood-fuel as well as improving the environment.

vi. Housing Policy

As a matter of urgency, the government must make policy and legislation for all new buildings to have rainwater harvesting structures incorporated into their design. This should not only be limited to rural areas but should be a national policy. It will go a long way to solve the perennial water shortages problems encountered in the country each year, especially also in the urban areas. Much of the rain that falls on the roofs go waste while they could be harvested for future use. Based on Central Arid Zone Research Institute (CAZRI) recommendations, the Government of Rajasthan in India has made harvesting of roof water mandatory in all new buildings with a covered area of more than 1,500 m² (Narain *et. al.*, 2005)

vii. Poverty Reduction

A financial safety net may be required for the poorest people who are often most vulnerable to the impacts of climate change and least able to afford protection. It is suggested that the government develops a policy on alternative livelihood opportunities with special attention on rural and more vulnerable communities to climate change and variability. People living in the Offin basin for example, depend almost completely on crop farming and are heavily affected when there is bad weather which makes them highly vulnerable to climate change. Also during the dry season when the weather is not very favourable to farming, there is virtually nothing for the people to do. This makes them idle and impoverished as they use all their savings made during the cropping season to cater for themselves, and usually there is very little money left for the next cropping season. Providing alternative livelihoods will reduce the over-dependence on agriculture and reduce their vulnerability to climate change and also enhance their standard of living.

The rural farmers should also be assisted to get access to financial assistance. Most of the farmers consulted on this study mention the lack of access to financial assistance from the banks as a major

challenge to improving their farming activities. The people can be supported to access micro-credit or revolving credit programmes that they can use to improve their livelihoods. The current economic environment does not favour them when they want to access loans from the banks. They do not usually have the collateral that the banks require, the process of acquiring the loans is too cumbersome for the farmers or the interest rates are too high. The government can intervene with financial assistance on more flexible terms with simple procedures.

Another means by which the government can assist the farmers is through subsidies for agricultural inputs and tractor services. Most of the financial assistance the farmers request go into their farming so the government can come in with subsidies on agricultural inputs and also help the people with equipment to mechanise their agriculture, such as tractor services.

6.2.2.2. Institutional collaboration

There should be cross-sectoral approaches to climate change adaptation in the Offin basin and other vulnerable areas. Agencies working on areas such as water resources management, land management, forestry and agriculture should work together on climate change adaptation so that all efforts will be coordinated at one point to avoid duplication and eventually non-performance. The government institutions tackling climate change, for example, are separate from those managing water and there is no collaboration between them. There should be good communication between ministerial departments working on environment or climate change.

The Ghana Poverty Reduction Strategy lists several institutions that are expected to be involved in the implementation of strategies aimed at climate change adaptation. Some of the listed institutions are Ministry of Lands Forestry and Mines (MLFM), Ministry of Environment and Science (MES), Ministry of Local Government and Rural Development (MLGRD), District Assemblies, Council for Scientific and Industrial Research, District Assemblies, Forestry Commission, National Disaster

Management Organisation (NADMO), Fire Service, Ghana Meteorological Agency (GMA), Environmental Protection Agency (EPA) and Environmental NGOs. Most of the institutions mentioned above come under different ministries with different visions and direction and there is very little or no co-ordination and collaboration between them although they are expected to address the same issue. Most departments all working on climate related issues in different institutions do not know of the existence of other departments and what the other is doing. In reality, the institutional frameworks necessary for good inter-sectoral collaboration and ensuring synergy between sectors as far as possible in policy planning and implementation are not in place.

There must be collaboration between and within universities on climate change studies, training and research. There are several instances where departments within the same university all working on aspects of climate change do not know what each other is doing. Synergy between and within the universities, which form the focus of science and technology education, will be very effective in addressing issues of climate change.

6.2.2.3. Capacity building

The government must lead in finding means of building the capacity of relevant agencies like the Ghana Meteorological Agency (GMA) and the National Disaster Management Organisation (NADMO) as well as the universities and research centres to come out with high-quality climate information and tools for risk management that will help to improve climate predictions, particularly for rainfall and storm patterns. Information systems on seasonal forecasting should be developed and made readily available to farmers so that they can plan their farming activities and take advantage of the rainfall pattern. The universities and research centres should also be strengthened and resourced to train students, conduct researches and find solutions to the many problems associated with climate change

The Ghana Meteorological Agency (GMA) in particular is expected to play a leading role in the climate change adaptation efforts of the country by providing good weather forecasts and climate information for the necessary agencies to respond accordingly. This requires the development of the capacity of the GMA to at least the minimum global requirement for monitoring the climate and the environment by resourcing the agency with the needed equipment and training the human resource in the correct use of modern equipment and practices. The existing institutional framework in the Ghana Meteorological Agency should be restructured for effective meteorological service delivery and forecasting and bring meteorological services closer to the poor rural farmer who needs it most. Dissemination of weather information should be enhanced and brought to the level of the ordinary farmer who is not educated, does not have a television to watch the weather forecast or may not even understand what it means when he watches it.

6.2.2.4. Empowering communities

Communities need to be empowered to engage with local and central governments so they can actively use political systems to help meet their climate change adaptation needs. There should be a constant flow of information or interaction between the communities and their local government. The communities should be assisted to proactively engage their political leaders and not only wait for the leaders to come and tell them what they wish to do for them. The people should tell their leaders what they need. The people should be educated on which national agencies and departments are responsible for managing which resources and how they can get their message across to them and hold them responsible for their actions. The role of NGOs in this aspect will be very crucial.

6.2.2.5. Alternative sources of Energy

Alternative sources of energy should be explored in order to reduce total dependence on fuelwood. The effect of fuelwood collection on the forest in terms of deforestation has not been assessed in this

study but it is suggested that other sources of energy are explored to protect the forests and also reduce the emission of carbon gas into the atmosphere. Promotion of the use of Liquefied Petroleum Gas (LPG) has been proposed in the Ghana Poverty Reduction Strategy.

Other sources of energy for domestic use such as very simple solar cookers can also be promoted in the communities. It can very useful on days there are no rains and it saves a lot of fuelwood. There are success stories of the use of simple solar cookers by Solar Cookers International (SCI) working in Kenya and elsewhere in East Africa. The solar cookers are easy to make with locally available materials; it is safe, easy to use and climate friendly.

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Appendices

Appendix 1.

Baseline and projected rainfall values for the deciduous forest zone of Ghana (NCSSAP2).

Baseline Means			Mean change in rainfall.			Scenarios: Mean Rainfall Amount.				Scenarios (Mean DailyRainfall)		
Mean	No. of Raindays	Daily mean		(per cent)				(mm)			(mm per day)	
Month	(mm)	(days)	(mm/day)	2020	2050	2080	2020	2050	2080	2020	2050	2080
Jan	17.1	2	10.1	-3.9	-	-25.3	16.4	14.9	12.7	8.2	7.4	6.4
Feb	54.8	5	11.5	-9.1	-	-58.9	49.8	38.5	22.5	10.0	7.7	4.5
Mar	114.9	9	12.8	-6.0	-	-39.4	108.0	92.0	69.6	12.0	10.2	7.7
Apr	134.4	11	12.5	-4.4	-	-28.7	128.5	114.9	95.9	11.7	10.4	8.7
May	169.4	13	13.2	-4.4	-	-28.4	161.9	125.7	121.3	12.5	9.7	9.3
Jun	215.2	16	13.5	-3.8	-	-24.8	207.0	188.1	161.8	12.9	11.8	10.1
Jul	121.9	13	9.5	-0.8	-	-5.4	120.9	118.5	115.3	9.3	9.1	8.9
Aug	80.9	11	7.4	-0.1	-	-1.0	80.9	80.5	80.1	7.4	7.3	7.3
Sep	142.0	14	10.2	-0.5	-	-3.5	141.3	139.5	137.1	10.1	10.0	9.8
Oct	153.8	15	10.4	0.0	-	-0.7	153.8	153.4	152.8	10.3	10.2	10.2
Nov	67.0	8	8.6	-1.4	-	-9.4	66.0	63.7	60.7	8.3	8.0	7.6
Dec	31.9	3	11.1	0.5	-	-3.6	32.1	31.4	30.8	10.7	10.5	10.3
Ann.	1303.4	120	10.9	-2.8	-	-18.6	1266.8	1161.2	1060.6	10.6	9.7	8.8

Appendix 2.

Baseline and projected temperature values for the deciduous forest zone of Ghana (NCSSAP2).

Baseline Mean Temp.			Mean Temp. Change				Mean Temp. Scenarios		
Month	T-Max.	T-Min.	T-Mean	2020	2050	2080	2020	2050	2080
Jan	32.2	20.7	26.5	0.8	2.5	5.6	27.3	29.0	32.1
Feb	33.6	22.3	27.9	0.9	2.9	5.9	28.8	30.8	33.8
Mar	33.1	22.7	27.9	0.9	2.8	5.9	28.8	30.7	33.8
Apr	32.4	22.8	27.6	1.0	3.1	6.4	28.6	30.7	34.0
May	31.5	22.4	27.0	1.0	2.9	6.0	28.0	29.9	33.0
Jun	29.7	21.9	25.8	0.8	2.4	5.1	26.6	28.2	30.9
Jul	28.4	21.5	24.9	0.7	2.2	4.8	25.6	27.1	29.7
Aug	28.2	21.3	24.8	0.7	2.1	4.7	25.5	26.9	29.5
Sep	29.1	21.5	25.3	0.7	2.0	4.4	26.0	27.3	29.7
Oct	30.3	21.6	26.0	0.7	1.9	4.6	26.7	27.9	30.6
Nov	31.3	21.8	26.6	0.8	2.4	5.5	27.4	29.0	32.1
Dec	31.0	21.2	26.1	0.9	2.4	5.6	27.0	28.5	31.7
Ann.	30.9	21.8	26.4	0.8	2.5	5.4	27.2	28.8	31.7
Jun	28.4	23.3	25.8	0.8	2.4	5.1	26.6	28.2	30.9
Jul	27.4	23.2	25.3	0.7	2.2	4.8	26.0	27.5	30.1
Aug	26.9	22.8	24.8	0.7	2.1	4.7	25.5	26.9	29.5
Sep	27.4	22.9	25.1	0.7	2.0	4.4	25.8	27.1	29.5
Oct	28.5	23.4	25.9	0.7	1.9	4.6	26.6	27.8	30.5
Nov	29.9	23.1	26.5	0.8	2.4	5.5	27.3	28.9	32.0
Dec	30.0	23.2	26.6	0.9	2.4	5.6	27.5	29.0	32.2
Ann.	29.3	23.5	26.4	0.8	2.5	5.4	27.2	28.8	31.7

Appendix 3.

VULNERABILITY OF WATERSHED TO CLIMATE CHANGE AND VARIABILITY

QUESTIONNAIRE:

1. DEMOGRAPHICS

1.1 Respondent
Code.....

1.2 Age.....

1.3 Sex Male [] Female []

1.4 Community.....

1.4.1 Residential Status..... Period of stay.....

1.5 Occupation: Main.....
Secondary.....

1.6 Literacy Level (Tick)

Basic	Middle Sch.	SSS	Tertiary	Not educated

2. WATER RESOURCES

2.1 Source of water for domestic activities (Tick)

River	Stream	Well	Pipe-borne	Other(name)

2.2 Known water bodies in the community:

2.2.1 Type (stream, river, etc).....

2.2.2 Number.....

2.2.3 Names.....

2.2.4 Annual [] Perennial []

2.2.5 Any change in the form of water body; previously and currently? Describe.

2.2.6 Any water bodies that have dried up?

.....

2.2.7 What might have caused their drying up?

.....

.....

2.3 Proximity of community to water body

2.4 Tributary of Offin river Yes [] No []

2.5 Current usage of water body (Tick)

Drinking/cooking	Washing	Irrigation	Industrial	Fishing	Other (Name)

2.6 Previous usage of water body (Tick)

Drinking/cooking	Washing	Irrigation	Industrial	Fishing	Other (Name)

2.7 Level of importance of water body to the community

Very important [] Not important [] Not known []

2.7.1 Why?

.....

2.8 Activities along the banks of the water body:

Farming	Washing	Logging	Construction	Industrial	Other

2.9 Known sources of pollution into water body

.....

3. INDUSTRIAL ACTIVITY

3.1 Industrial Activity:

Personally involved Yes [] No [] Others []

3.1.1 Type of industry:

3.1.2 Large Scale [] Small Scale []

3.2 Proximity to water body.....

3.3 Does the industry depend on the river for water? Yes [] No []

3.3.1 Water needs of the industry met Yes [] No []

3.3.2 If No, how is the deficit compensated for?

.....

4. FORESTS

4.1 Forest found around water body Yes [] No []

4.1.1 Type of forest Primary [] Secondary []

4.2. State of forests found around water body

Diminishing [] Increasing [] No change []

4.2.1 Why?

.....

4.3 Awareness of importance of forests for stream/river protection

.....

4.4 Uses of forest

Fuelwood	Hunting	Logging	NTFPs	Other

4.5 Knowledge of type of trees currently found in forest

.....

4.6 Knowledge of type of trees previously found in forest

.....

4.7 Level of importance of the forests to the community

Very important [] Not important [] Not known []

4.7.1 Why?

.....