

**UNIVERSITY OF GHANA**



**THE INFLUENCE OF CLIMATE VARIABILITY AND CHANGE ON THE  
ATTAINMENT OF ENERGY SECURITY IN GHANA: A STUDY OF THE  
AKOSOMBO HYDROELECTRIC POWER PROJECT**

**BY**

**SYLVESTER AFRAM BOADI**

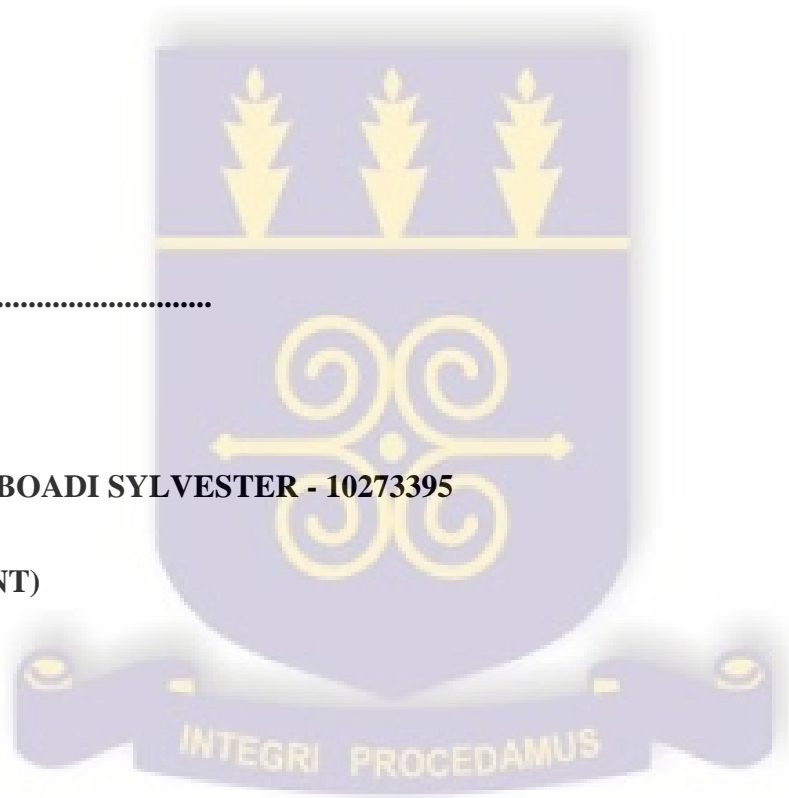
**(10273395)**

**This thesis is submitted to the University of Ghana, Legon in partial fulfillment of  
the requirement for the award of MPhil Climate Change and Sustainable  
Development degree.**

**JULY, 2015**

**DECLARATION**

With the exception of the works of other writers and scholars which are duly acknowledged, I declare that this research is my own work produced under the supervision of Dr. Kwadwo Owusu and Dr. Albert Ahenkan according to the rules of thesis writing for the University of Ghana, Legon. No part or whole of this study can be used or reproduced in any form without acknowledgement.



.....

**DATE:**

**AFRAM BOADI SYLVESTER - 10273395**

**(STUDENT)**

.....

**DATE:**

**DR. KWADWO OWUSU**

**(PRINCIPAL SUPERVISOR)**

.....

**DATE:**

**DR. ALBERT AHENKAN**

**(CO-SUPERVISOR)**

## **DEDICATION**

This research is dedicated to my father Mr. Afferam Boadi and my uncle, ASP Peter Adjei.



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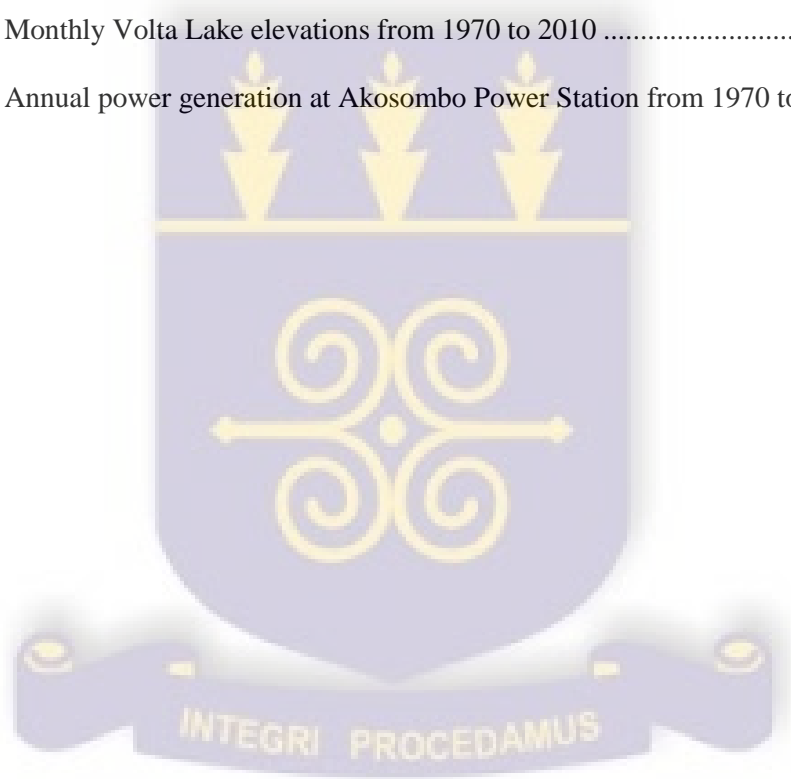
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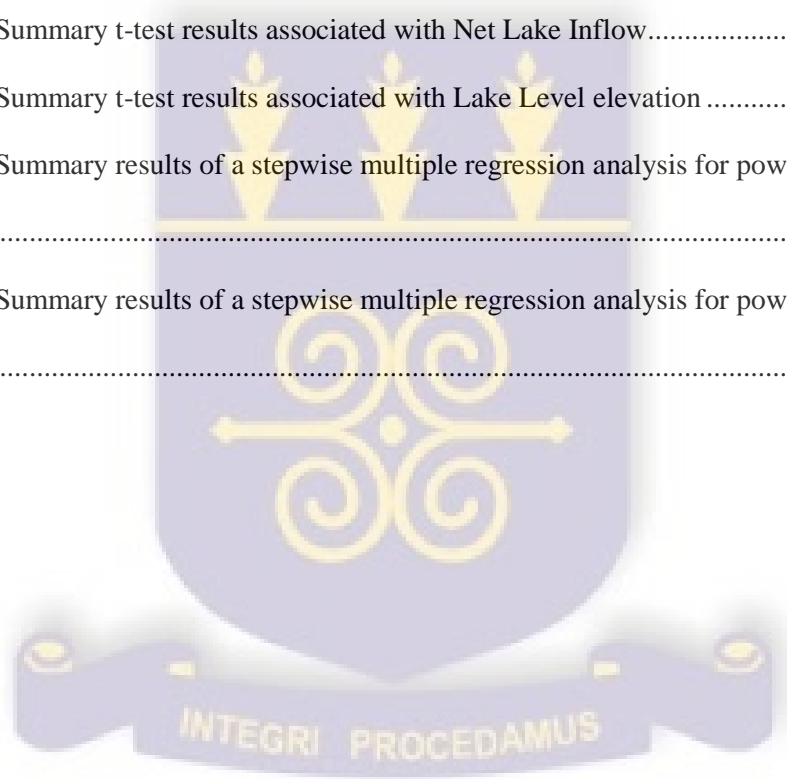
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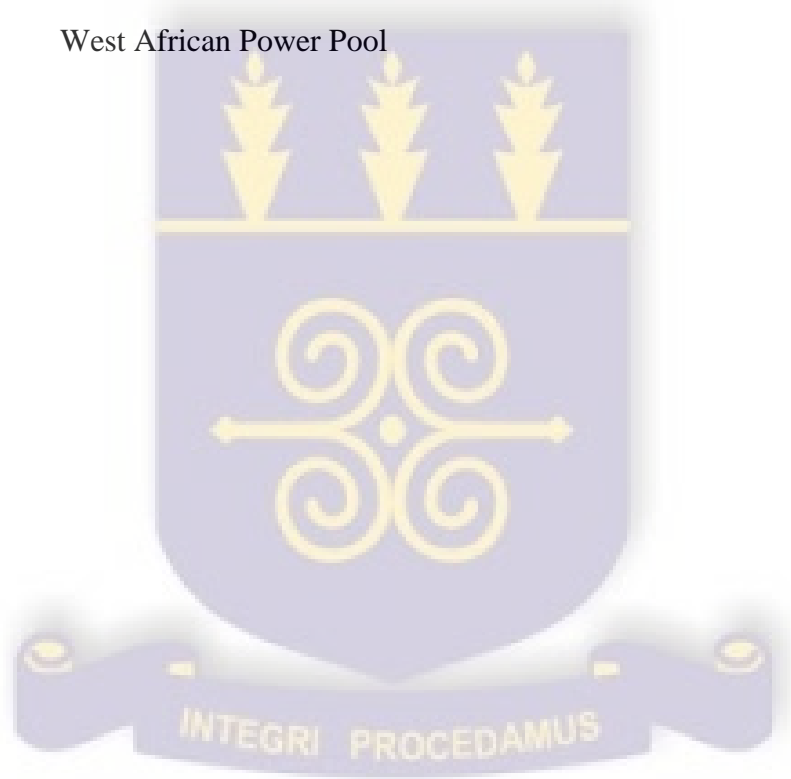
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## LIST OF ABBREVIATIONS

|               |   |
|---------------|---|
| <b>BCM</b>    | Billion cubic meters                            |
| <b>COAPS</b>  | Centre for Ocean-Atmospheric Prediction Studies |
| <b>ECG</b>    | Electricity Company of Ghana                    |
| <b>ENSO</b>   | El Niño-Southern Oscillation                    |
| <b>EPA</b>    | Environmental Protection Agency                 |
| <b>GMet</b>   | Ghana Meteorological Agency                     |
| <b>GoG</b>    | Government of Ghana                             |
| <b>GRIDCo</b> | Ghana Grid Company                              |
| <b>GWh</b>    | Gigawatt-hours                                  |
| <b>IHA</b>    | International Hydropower Agency                 |
| <b>IPCC</b>   | Intergovernmental Panel on Climate Change       |
| <b>IPPs</b>   | Independent Power Producers                     |
| <b>JMA</b>    | Japan Meteorological Agency                     |
| <b>KTTP</b>   | Kpone Thermal Power Plant                       |
| <b>kWh</b>    | kilowatt-hours                                  |
| <b>L.I</b>    | Legislative Instrument                          |
| <b>LNG</b>    | Liquefied Natural Gas                           |
| <b>MEST</b>   | Ministry of Environment, Science and Technology |
| <b>MW</b>     | Megawatts                                       |
| <b>NEDCo</b>  | Northern Electricity Distribution Company       |
| <b>NES</b>    | National Electrification Scheme                 |
| <b>OND</b>    | October – November – December                   |
| <b>PV</b>     | Photovoltaics                                   |
| <b>RETs</b>   | Renewable energy technologies                   |
| <b>SE4ALL</b> | Sustainable Energy for All                      |
| <b>SHEP</b>   | Self-Help Electrification Programme             |
| <b>SNEP</b>   | Strategic National Energy Plan                  |

|               |   |
|---------------|---|
| <b>SPSS</b>   | Statistical Package for Social Sciences               |
| <b>SST</b>    | Sea surface temperature                               |
| <b>SWH</b>    | Solar water heaters                                   |
| <b>UNFCCC</b> | United Nations Framework Convention on Climate Change |
| <b>USD</b>    | US Dollars  |
| <b>VALCO</b>  | Volta Aluminium Company                               |
| <b>VRA</b>    | Volta River Authority                                 |
| <b>WAGP</b>   | West African Gas Pipeline                             |
| <b>WAPP</b>   | West African Power Pool                               |



## ABSTRACT

The impacts of climate variability and change including the influence of ENSO are real and affect several productive economic sectors such as agriculture, water, forest resources and energy. Energy is a very important sector for achieving sustainable development. Ghana has continuously relied heavily on Akosombo and Kpong hydropower stations to supply electricity for household and industrial use. Historical records have shown that variability and change in rainfall including the influence of ENSO has affected lake water levels and consequently the amount of power generated by these hydropower projects. This led to power crises and periodic blackouts in 1984, 1998, 2003, and 2007. The current power crisis has been ongoing for the past three years. This study therefore sought to assess the likely effect climate variability and change will have on Ghana's energy security since many projections for the country point to a warmer dry future. This study used regression analysis, F-test and t-test to analyze the influence of rainfall, ENSO, lake level elevation and net lake inflow on power generation at the Akosombo Hydroelectric power station from 1970 to 2010. The study found that ENSO explained 19.5% of the variability in rainfall inputs into the lower Volta Basin where Ghana's hydropower projects are found. Rainfall variability accounted for 21.2% of the year to year fluctuations in power generation from the Akosombo Hydroelectric power station between 1970 and 1991. Additionally, ENSO and lake water level accounted for 72.4% of the interannual fluctuations in power output between 1991 and 2010. The occurrence of an El Niño episode was found to reduce Akosombo power output by 1169.64GWh per year. The study therefore concludes that the country should diversify its power needs away from hydropower in order to attain energy security for current and future generations.

## **CHAPTER ONE - INTRODUCTION**

### **1.1 BACKGROUND OF THE STUDY**

The impacts of climate variability and change are real and would continue to affect sensitive sectors of the global economy. Productive sectors such as agriculture, water, health, energy, and transport among others bear the brunt of these variability and change in the world's climate. Even though the entire globe will experience the impacts of these changes, the more severe impacts will be felt in low latitude developing countries where several non-climatic stressors are already at play (IPCC, 2007a). Sub-Saharan Africa continues to exhibit vulnerability to variability and change in climatic parameters such as temperature, rainfall and extreme events resulting from both anthropogenic climate change and natural variability. The principal known source of tropical climate variability is the El Niño-Southern Oscillation [ENSO] (Collins et al., 2010; Camberlin et al., 2001). The increasing intensity of drought and floods observed throughout sub-Saharan Africa in recent years points to the fact that the effects of climate variability and change will continue to be negative on the continent (Easterling et al., 2007).

Energy is an important sector for the world and sustainable development is hampered in countries without access to adequate energy supply. However, the energy sector in many developing countries is severely impacted by climate variability and change. It is in response to this that the United Nations sustainable energy for all (SE4ALL - 2030) goals were formulated and implemented. The SE4ALL - 2030 aims at ensuring universal access to modern energy services, doubling the rate of improvements in energy efficiency and doubling the share of renewable energy in the global energy mix by the year 2030.

According to the 2013 Energy Sustainability Index, demand for primary energy is forecasted to rise considerably by the year 2050 (World Energy Council, 2012). Yet, as at 2013, some 1.2 billion people did not have access to electricity and 2.8 billion also lacked access to clean cooking facilities (World Energy Council, 2013).

Hydropower is a major source of electricity supply to the world (IHA, 2012). However, countries that have been able to chart a secure and sustainable pathway to electricity supply have done so by building a well-diversified power generation mix. For instance, Switzerland, the highest rank performer in the 2013 Energy Sustainability Index has the following electricity generation mix: conventional thermal (27%), hydropower (55%), other renewables (4%) and nuclear power (39%). Other peak performing countries such as Sweden, UK and Spain have an equally diversified electricity generation portfolio. In the light of contemporary climate change, diversification of electricity generation away from hydroelectricity is even more important for developing countries striving to build a strong energy system to support their developmental goals (Cole et al., 2014).

Ghana's total installed capacity as at December 2013 stood at 2,814MW while her effective capacity stood at 2,492MW (Acheampong & Ankrah, 2014). At the same time, the energy generation mix showed a 50% generation capacity from hydro-based sources and the remaining 50% from conventional thermal sources (Mathrani et al., 2013). Even with this seemingly balanced share between hydropower and conventional thermal, Ghana still depends heavily on hydropower for its industries and other productive sectors (Badu, 2013). Independent Power Producers (IPPs) who generate the majority of thermal power

in Ghana are not able to meet performance standards. Non-competitive electricity tariffs pose a major problem to thermal power generation and also discourages further investments by Independent Power Producers [IPPs] (Edjekumhene, 2007; Acheampong & Ankrah, 2014). The inability of government to attract further investments to thermal generation coupled with the high cost of extracting power from the other renewable resources like – solar, wind and hydrocarbons (Ministry of Energy, 2010a) explain governments' continued investments in hydropower. A third major hydropower dam at Bui on the Black Volta River has recently been commissioned with an expected generation capacity of 400 MW to help meet the growing energy demand.

## **1.2 STATEMENT OF THE PROBLEM**

Ghana has the potential to grow its economy through industrialization, increased productivity, job creation and equitable wealth distribution (Ministry of Energy, 2010a). However, in order to achieve this economic development, there is the need for adequate generation and supply of energy. According to Badu (2013), Ghana requires 6000MW of power by 2015 to guarantee sustainable growth and development. However, the country's current total installed capacity is just about 2,846.5MW (VRA, 2014). Ghana, thus, has an electricity generation deficit of over 3000MW. According to the 2014 Electricity Supply Plan this huge power deficit still exist (GRIDCo, 2014). Power ration has been frequent in the past three decades and the country has seen an intensification of power cuts that has resulted in the collapse of many manufacturing industries.

The vision for Ghana's energy sector is to make energy available and universally accessible to all sectors of the economy and for export (Ministry of Energy, 2010b). The country's main objective is to increase capacity to 5000MW by 2015 (Ghana National Commission for UNESCO, 2010). Ghana's energy strategy to bridge this power deficit however, weighs heavily on hydropower and included the completion of the 400MW Bui Hydroelectric power project, the development of a 625MW Western Rivers Hydropower project, the development of a 90MW Juale Hydropower project, the implementation of the Aboadze TICO Power plant steam turbine and the operationalization of the 125MW Osagyefo Power Barge (Ministry of Energy, 2010b). Also the government has set a target of generating 10% of power from other renewable sources which include mini hydro plants (Mathrani et al., 2013). This reveals Ghana's continuous dependence on hydroelectricity for the attainment of secure and sustainable electricity supply. Investments in the major hydropower infrastructure in the country were done in the early 1960s when the rainfall pattern was favorable (Owusu, 2009). These investments were made with the assumption that mean rainfall will continue at levels similar to those prior to independence (Owusu et al., 2008). Historic records have however shown that rainfall pattern over West Africa has undergone a period of decline, punctuated by a series of severe droughts accompanied by a shift in the rainfall regime since the 1970s (Opoku-Ankomah, 2000; Kasei, 2009; Amekor, 2007).

The climate of the Volta Basin where Ghana's hydroelectric power projects are found mimics that of West Africa which is associated with high interannual and multi-decadal variability of twenty to thirty year cycle (Ellis & Galvin, 1994). On the whole, annual rainfall amount for Volta Basin is on the decline since the 1970s and only seen a marginal

recovery in post 2000. Owusu et al. (2008) for instance described the declining rainfall total in the Volta Basin since the early 1970s as having a serious negative impact on power production of the Akosombo Dam. Other studies have also demonstrated the strong effect of the El Nino-Southern Oscillation (ENSO) on rainfall distribution and runoff in West Africa (Rowell et al., 1995; Fontaine & Janicot, 1996 cited in Trzaska et al., 2001; Rodríguez-Fonseca et al., 2011; Losada et al., 2012). Ghana's power sector is already showing signs of susceptibility to variability and change in rainfall (The World Bank, 2011), including variability due to ENSO (Waylen & Owusu, 2014; Owusu et al., 2008).

Over the years, Ghana's domestic demand for electricity has been increasing between 6% and 10% annually (RCEER, 2005; Sackey, 2007). Norton Rose Fulbright (2013) reports Ghana's anticipation of the West African Gas Pipeline (WAGP) supplying gas to support thermal power generation in order to shore up the increasing demand-supply imbalance. This led to the springing up of gas-fired IPPs. The supply of gas from Nigeria through the WAGP has however been unreliable with actual supply ranging from a low 40mmscf/d (Acheampong & Ankrah, 2014) to the contractually obligated supply of 120mmscf/d (VRA, 2014). The dependence on fuel from external supply sources is mostly putting Ghana at risk in terms of the security of supply (Energy Commission, 2013; Badu, 2013). The insecurity surrounding the supply of fuel for thermal power generation has deepened the overdependence on hydropower in Ghana.

The overdependence on hydropower has exposed the country to the impacts of climate variability and change. One of the potential effects of variability and change in climate,

especially reduction in the amount and variation in the distribution of rainfall, is the possibility of changes to river flow and runoff which will affect energy supply from hydropower sources (Energy Commission & United Nations, 2012; Harrison et al., 1998). Historical records have shown that the Akosombo dam has suffered in the past due to interannual and decadal climate variability, including ENSO's influence on rainfall in the Volta Basin. Droughts in 1982/83, 1997 resulted in low lake levels behind the Akosombo which led to the energy crisis of 1984 and 1998 respectively (Fiagbe & Obeng, 2006; Amekor, 2007). There were other power crisis in 2003 and also 2006/07 (Bekoe & Logah, 2013). The current power crisis which started "as short-term power outages has grown into a monstrous load-shedding routine" (VRA, 2015: pp. 1-2), and has been ongoing for the last three years and continue to worsen. It appears that the country has ignored the visible climatic challenges faced by the existing hydropower infrastructure and continues to pursue a hydro-dependent energy policy and strategy. It is on this premise that this study seeks to use empirical records from the Akosombo Hydroelectric power station in the Volta Basin to demonstrate the influence of climate variability including variability due to ENSO, on the attainment of energy security in Ghana.

### **1.3 OBJECTIVES OF THE STUDY**

The overall objective of this study is to assess the influence of climate variability and change on the Akosombo Hydroelectric Power project's capacity to provide secure and sustainable electricity for Ghana's development.

The study specifically seeks to:

- Examine the variability and change in rainfall in the lower Volta River Basin for the four decades between 1970 and 2010
- Analyze the annual and decadal variability in lake inflow, lake level elevation, and electricity generation from the Akosombo Hydroelectric Power Station for the four decades between 1970 and 2010
- Identify the influence of changes in rainfall including ENSO effect on power production.

#### **1.4 HYPOTHESIS**

H<sub>0</sub>: Changes in rainfall has no effect on energy production from the Akosombo Hydroelectric Power project.

H<sub>1</sub>: Changes in rainfall has significant effect on energy production from the Akosombo Hydroelectric Power project.

#### **1.5 DEFINITION OF TERMINOLOGY**

This research makes use of some terminologies which are explained below in the context of the study.

### **Climate Variability**

Climate variability refers to the climatic parameter of a region varying from its long-term mean (Selvaraju & Baas, 2007). According to the IPCC (2013) climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events.

### **Climate Change**

Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer (IPCC, 2013).

### **El Niño-Southern Oscillation**

The El Niño-Southern Oscillation (ENSO) is a natural phenomenon which involves fluctuating sea surface temperatures in the central and eastern equatorial Pacific Ocean, accompanied by large-scale fluctuations in air pressure. ENSO is characterized by a shift between a neutral phase and two extreme phases: an unusually warmer than normal sea surface temperatures across the east-central equatorial Pacific (El Niño) and an unusually colder than normal sea surface temperatures across the east-central equatorial Pacific (La Niña). ENSO has climatic teleconnections with many places of the world (WMO, 2014).

### **Energy Security**

Energy security refers to the effective management of primary energy supply from domestic and external sources, the reliability of energy infrastructure, and the ability of energy providers to meet current and future demand (World Energy Council, 2013). Energy security also refers to the resilience of the energy system to unique and unforeseeable events that threaten the physical integrity of energy flows or that leads to intermittent energy price increases, independent of economic fundamentals (OECD, 2010).

### **Energy Sustainability**

Energy sustainability is the provision of adequate and reliable energy services at an affordable cost, in a secure and environmentally benign manner and in conformity with social and economic development needs of present and future generations (Vera et al., 2005).

### **Energy Equity**

Energy equity is defined as the accessibility and affordability of energy supply across the population (World Energy Council, 2013).

### **Environmental Impact Mitigation**

Environmental impact mitigation (also environmental sustainability) refers to the achievement of both supply and demand-side efficiencies and the development of energy supply from renewable and other low-carbon sources (World Energy Council, 2013).

## **1.6 SIGNIFICANCE OF STUDY**

The increasing variability and change in climate especially in rainfall, temperature, river flow and runoff has serious implications for electricity production in Ghana. This study provides an informed analysis to the general public, researchers and policy makers on the current state of Ghana's energy infrastructure and how variability and change in climate including variability due to ENSO, influences a hydro-reliant power system's ability to provide sustainable access to adequate, reliable and affordable electricity.

The study also seeks to find answers to some of the inherent challenges in Ghana's electricity supply chain. The study provides useful information for major stakeholders in the energy sector in Ghana. Policy makers especially should find the study very useful in their bid to formulate and implement policies aimed at addressing both the supply and demand-side problems in Ghana's power sector. Access to secure and sustainable energy plays a significant role in improving the living conditions of people. This study therefore makes significant contribution towards improving the livelihoods of people by recommending ways of providing sustainable and affordable energy to Ghanaians regardless of the challenges presented by climate change. The study is therefore a useful research material for all stakeholders in energy, environment and sustainable development sectors, including statisticians, analysts, researchers and policy makers.

## **1.7 THESIS STRUCTURE**

The study is organized into six chapters. Chapter one is an introductory chapter. It outlines the background of the study, the problem under study, objectives, research hypothesis and

significance of the study, Chapter 2 is devoted to a review of the relevant theoretical and empirical literature on climate variability and change impacts on hydropower production. The chapter also presents the conceptual framework used for the study. Chapter 3 details the methodology used for the study. Chapter 4 presents the results of the data analysis. Chapter 5 covers the discussion of the results presented in the previous chapter. Chapter 6 presents the conclusions of the study, makes some recommendations and outlines areas for future research based on the findings of the study.

## **1.8 SUMMARY**

This introductory chapter established the study background and outlined the basis for the research. The chapter discusses the problem of the study, the study objectives as well as the research hypothesis. Also, a section is devoted to the definition of terminologies used throughout the study. The final two sections were used to provide the significance of the study and the structure of the thesis.

## **CHAPTER TWO – LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK**

### **2.1 INTRODUCTION**

This section on literature review discusses the implications of climate variability and change on Ghana's power sector. The first section outlines Ghana's energy endowments and power sector as well their sustainability implications. The second section is devoted to a discussion of Ghana's energy policy and strategy. Section three takes a look at climate variability and hydropower production. A review on the influence of El Niño-Southern Oscillation (ENSO) on rainfall variability is then provided. Section five is used to provide a conceptual framework for the study. The chapter is then concluded with a chapter summary.

### **2.2 ENERGY ENDOWMENT/POWER SECTOR**

#### **2.2.1 Energy Endowment**

Ghana has a vast array of energy resources that include hydropower, biomass, hydrocarbons and solar (Ghana National Commission for UNESCO, 2010). The main energy resources widely relied upon are however woodfuel, electricity and petroleum products (EPA & MEST, 2011). Woodfuel (firewood and charcoal) are responsible for over seventy percent (70%) of total primary energy supply while also accounting for about sixty percent (60%) of final energy demand in Ghana (Energy Commission & United Nations Ghana, 2012). According to the Ghana National Commission for UNESCO (2010), petroleum products make up twenty-three percent (23%) of total energy consumed by Ghanaians while electricity accounts for twelve percent (12%) of the total energy

consumed. Additionally, Ghana is endowed with small scale renewable energy prospects including a limited and hugely underutilized wind potential, mini hydro and solar prospect, which at the moment is mostly used for sun drying of food and cash crops (Agyemang-Bonsu et al., 2009; Norton Rose Fulbright, 2013).

Ghana introduced its first Solar Power Plant at Navrongo in 2013 at an estimated cost of Eight million US Dollars (US \$8m) - (Adra, 2014). One report which analyzed 19 stations out of the 22 synoptic stations in the country found that Wa records the highest solar irradiation (5.524KWh/m<sup>2</sup>-day) compared to the lowest recorded at Akim Oda (4.567KWh/m<sup>2</sup>-day) - (Energy Commission & Meteorological Services Department, 2005). Ghana therefore has abundant solar energy that allows for the installation of solar energy systems. Solar energy however cannot be used everywhere in the country. Tse (2000) argues that rural areas are particularly suited for this type of technology as most consumers of power in these places need it for lighting and low-consumptive uses such as fans, radio sets and television. The solar energy available to Ghana was approximately 400,000Gigawatt-hours annually in 2006 (Energy Commission, 2006). A huge part of this annual total can be harnessed for use in these low-consumptive rural areas. Ghana has been weighing her options for mini hydro exploitation since the 1970s (Koffi, 2012). But up to date none of the identified prospects and opportunities have been developed (Dernedde & Ofosu-Ahenkorah, 2002).

The petroleum resource aspect of Ghana's energy endowments has become increasingly significant since the country started commercial oil production in 2010 (EPA & MEST,

2011; KPMG, 2012). The possibility of using the country's light crude oil for power production exist. The power so generated however will be very expensive compared to generating electricity from Ghana's own gas from Atuabo (Mathrani et al., 2013; VRA, 2014).

### **2.2.2 Power Sector**

The major players in Ghana's power sector are the Volta River Authority (VRA), Bui Power Authority (BPA), Independent Power Producers (IPPs), the Ghana Grid Company (GRIDCo), the Electricity Company of Ghana (ECG) and the Northern Electricity Distribution Company (NEDCo), institutions engaged in the generation, distribution and transmission of power (Clark et al., 2005; Ministry of Energy, 2010b). The country derives its power from mainly hydro and conventional thermal power sources (Brew-hammond & Kemausuor, 2007). It is evident from various energy scholars that hydropower has been the mainstay of Ghana's power sector until the 1990s when thermal power started to gain prominence (Bekoe & Logah, 2013; ENERGYWORLD/Africa, 2010/11.). Of recent importance also are the advances made into the generation of electricity from small scale Renewable Energy Technologies (RETs) like – wind, solar PV, mini hydro, biofuels, among others (Ahiataku-Togobo, 2012).

Hydropower is the dominant source of renewable energy globally contributing more than sixteen percent (16%) of energy produced in 2011 (IEA, 2013). Africa as a whole has a vast array of hydro resources with less than ten percent (10%) of this potential exploited as at 2004 (Wamukonya, 2004). Ghana's dependence on hydropower for its electricity supply and power needs cannot be downplayed (Stanturf et al., 2011). Rodgers et al. (2007)

reiterate this point by stating that the production of hydropower was and still is an important factor for economic growth in Ghana. Since the establishment of VRA in 1961 to start the exploitation of the hydropower resource of the Volta River (ENERGYWORLD/Africa, 2010/11), Ghana has concentrated and relied on the hydropower potential of the Volta River Basin for its industrial and residential power needs (Energy Commission & United Nations Ghana, 2012).

The construction of the Akosombo Dam and the Volta River Department project began “with the installation of four (4) generating units with total capacity of 588MW” (RCEER, 2005: p. 18). With the completion of this phase in 1965, two additional generating units were added in 1972 to increase the total installed capacity to 912MW (Fiagbe & Obeng, 2006; VRA, 2004). The dam at Kpong was added in 1982 to generate an additional 160MW - comprising four turbine-generator units of 40MW capacity each (Fiagbe & Obeng, 2006). Koffi (2012) points out an effort in 1984 to develop a 10-150Kw mini hydro at Likpe Kukurantumi on the Dayi River. With the retrofitting of the Akosombo plant from 912MW to 1020MW (VRA, 2004) and the construction of the Bui dam to supply about 400MW of power, it appears both past and present governments have a high regard for the hydropower technology regardless of the climatic or environmental and livelihood constraints.

The introduction of energy policy reforms in Ghana coincided with the increase in the thermal proportion of the country’s energy mix with the help of IPPs (Clark et al., 2005), who generate the greater share of Ghana’s thermal power component (Acheampong & Ankrah, 2014). Thermal power generation began with the commencement of the operations

of the Takoradi Thermal Power Station in 1998. The thermal contribution to total electricity generated in the country had risen to thirty-four percent (34%) by 2003 (EPA and MEST, 2011). Currently, the thermal power component stands at about forty eight percent (48%), generated mainly from; Takoradi Power Company (TAPCO) – T1 (330MW), Takoradi International Company (TICO) – T2 (220MW), Takoradi Thermal Plant – T3 (132MW), Tema Thermal 1 Power Plant (TT1PP) [110MW], Tema Thermal 2 Power Plant (TT2PP) [50MW], Mines Reserve Plant (MRP) [80MW], Sunon Asogli Power Plant (200MW), and CENIT (110MW) - (Acheampong & Ankrah, 2014). Ghana has a 125MW Osagyefo Power Barge which was refurbished by a partnership between Government of Ghana and Balkan Energy Company LLC, with the expectation that the latter would convert it into a combined cycle with a total installed capacity of 185MW (KPMG, 2012). Whether this upgrade in capacity will be honored remains to be seen. However, thermal plants in the country are mostly unreliable due to the high unavailability rate, a factor mostly attributed to erratic fuel supply (Energy Commission, 2013).

Renewable Energy Technologies which include solar photovoltaics (PV), solar water heaters (SWH), wind /electric turbines, biogas generators, biomass fuel sources, among others are mostly sustainable and environmentally friendly than the fossil fuel-based technologies (Tse, 2000). According to Norton Rose Fulbright (2013), the Government of Ghana (GoG) has a target of raising the contribution of wind and solar power to ten percent (10%) of the country's total wind and solar capacity by the year 2020. Currently, VRA's two megawatts (2MW) solar photovoltaic (PV) grid-connected plant at Navrongo is the

only significant solar generated power technology in Ghana (Adra, 2014; Acheampong & Ankrah, 2014).

### **2.2.3 Sustainability issues**

Sustainable energy is essential for the eradication of poverty and also for the sustainable development of economies (OFID, 2010). According to Iwayemi (2010), it is a widely accepted fact that when the use of modern energy services per capita increases, higher and sustainable economic growth is achieved in addition to significant improvements in living standards. Energy poverty among African nations will thus lead to a diminished productive capacity. It is therefore on point that Iwayemi (2010: p. 17) concluded that “expanded access to adequate, reliable efficient, secure, environmentally responsive and affordable energy is a key element in Africa’s quest to achieve sustained economic growth.” The trend of rainfall Ghana recorded immediately after independence led the country to rely heavily on rain-fed agriculture and on hydro sources for power (Owusu, 2009). However, Barrios et al. (2010) in a study found that decline in rainfall since the 1960s has had a negative impact on real GDP per capita growth rates in Africa. In their study, this negative influence of rainfall on GDP per capita growth rate is explained by citing the impacts of a declining rainfall on agricultural productivity and on energy supply, especially on hydropower supply. Efforts to reduce the impacts of rainfall decline on the agricultural sector are widespread. Similarly, there is the need for efforts to tackle the influence of rainfall decline on sustainable energy development on the African continent.

After independence, Ghana wanted to expand its economy through industrial development. Dr. Kwame Nkrumah thus elated to implement the Akosombo hydropower project to kick

start a new and growing economy (Amfo-Otu, 2010). Ghana is highly reliant on hydropower for electricity with the majority of this hydropower coming from the Akosombo and the Kpong generating stations (Stanturf et al., 2011). The Akosombo power plant when operating at full capacity contributes 1020MW of the total installed capacity of 2,846.5MW. The contribution of the Akosombo power station to total power generation was 82.9% in 2005. This however dropped to 66.7% in 2006 (Hagan, 2007). Currently, the hydropower component of energy supply in the country stands at fifty-two percent (52%) – VRA Hydro - 47% and Bui Hydro – 5% ([www.vra.com](http://www.vra.com)). The Akosombo plant together with the downstream Kpong plant accounted for about sixty-five percent (65%) of electricity generated in 2012 (Ahiataku-Togobo, 2012). The Akosombo plant supplies the bulk of the share contributed by these two (2) large scale hydropower projects. It is also worth mentioning that the availability of headwater for power generation at the Kpong Power Station is dependent on the spillage of water from the Akosombo dam (Fiagbe & Obeng, 2006). Thus, the generation of power at Kpong (with an installed capacity of 160MW) depends on conditions at the Akosombo generation station. This makes the Akosombo Hydroelectric Power Plant all the more central to hydroelectric power generation in Ghana.

The problem with this over-reliance on hydro sources is that, the energy sector is exposed to a host of challenges, paramount among which is susceptibility to variability and change in climate (The World Bank, 2011). Hydropower infrastructure have historically been fraught with evaporation, discharge, temporal variability and glacial melt vulnerabilities which manifest in the form of flooding, seasonal offset, and drought challenges

(Blackshear et al., 2011). The hydropower sector will thus continue to exhibit these vulnerabilities going into a future where climate change continues to alter hydrological processes to varying degrees across the globe (Hamududu, 2012).

## **2.3 ENERGY POLICY AND STRATEGY**

Ghana has been working on getting the appropriate policies and strategies to help provide accessible and reliable energy services. These efforts are seen in energy strategies such the electricity for all by 2020 and the National Electrification Scheme [NES] (Bukari, 2012; Adra, 2014; Gordon, 2006). The Ministry of Energy started rolling out the National Electrification Scheme in 1989 as the major government policy to supply electricity to various parts of the country within a 30- year period, 1990 – 2020 (Energy Commission, 2013). Under the National Electrification Scheme, the government modelled a Self-Help Electrification Programme (SHEP) meant to connect communities located within twenty kilometers (20km) of the existing power network (Clark et al., 2005). Communities must however meet a set criteria comprising a specified number of interested households, in addition to the communities providing their own wooden voltage poles, erecting the poles themselves and wiring their houses (Bukari, 2012). Despite the existence of national strategies, and laws such as the Energy Regulations 2008 (L.I 1937) and Renewable Energy Act 2011 (Act 832), the World Energy Council (2013) outlines the absence of credible, sustained and focused energy policy as a major challenge to Ghana’s energy sector. The country therefore needs strong and target-specific energy policies and strategy to help lift itself out of the perennial power crises it experiences.

The vision of Ghana's energy sector is to guarantee the supply of available and accessible energy services to the entire citizenry (Ministry of Energy, 2010b). This vision is more important now as the country tries to grow its industrial sector in order to achieve sustainable economic and human development (Acheampong & Ankrah, 2014). In order to achieve this vision, the government aims to realize the target of generating 5000MW of power by the year 2015 (Ghana National Commission for UNESCO, 2010). In fulfillment of the same vision, Badu (2013) postulates that Ghana will need about 6000MW of installed capacity by 2015 in order to sustain national economic growth. Considering the fact that the current total installed capacity is 2,846.5MW (VRA, 2014), it is fair to argue that Ghana's energy strategy meant to achieve this target and bridge the over 3000MW generation deficit has not been effective.

Governments' programmes and projects to help increase the generation capacity to the required level include getting the 125MW Osagyefo Power Barge operational, the development of the 625MW Western Rivers Hydropower project, the development of the 90MW Juale Hydropower project and the implementation of the Aboadze TICO power plant steam turbine project (Ministry of Energy, 2010b). Also inclusive in the range of projects to be completed and/or implemented are the 400MW Bui Hydropower project (Ministry of Energy, 2010a), the development of a Nuclear Power station by 2018 (Badu, 2013), the building of a 700MW coal-fired electric power plant and the completion of a 220MW Kpone Thermal Power Plant (KTPP) by the first quarter of 2015 (VRA, 2014). In 2005, the government laid out the nation's energy strategy contained in the Strategic National Energy Plan (SNEP) for the period 2006 to 2025 (KPMG, 2015). This strategy

had four (4) hydro schemes planned for completion by 2020: the Bui project was to be completed in 2012, Hemang and Juale by 2015 and Pwalugu by 2020 (Gordon, 2006). The Government of Ghana has already signed a Memorandum of Understanding (MOU) with the Brazilian Government for the development of Juale and Pwalugu hydro plants at the cost of US \$155 million (KPMG, 2015). These projects were meant to boost power supply and cater for the increasing demand of electricity in the country.

The problem with pursuing a hydro-dependent policy and strategy is that it makes the energy sector more vulnerable to variability in climate, especially, variability in rainfall, including variability due to ENSO (Davey et al., 2011). The climate variability challenge is particularly evident during low operating water level periods of the Akosombo dam. Electricity generated by the plant reduces at such times. This reduction in power generation from the Akosombo plant results in severe power shortages culminating in frequent power outages throughout the country (Niassé, 2005). For instance, Amekor (2007) reports the incidences of low rainfall and dwindling inflows into the Akosombo dam in 1981-1983, 1997 and 2006 resulting in the energy crises of 1984, 1998 and 2007 respectively. Such periods are typically associated with the rationing of power in the country (Bekoe & Logah, 2013) which translates into severe negative impacts on the sustainable socio-economic development of several economic sectors (Malley, 2011).

Lake inflows, river runoff, rainfall inputs among other factors dictate lake level elevation and consequently the amount of power produced (Amekor, 2007; Lacombe et al., 2012; Rodgers et al., 2007). “Akosombo dam and power plant were planned in a wet period when

inflows were greater than 40km<sup>3</sup>/yr” (Stanturf et al., 2011: p. 166). Presently, low and irregular inflows (36.5km<sup>3</sup>/yr between 1985 and 2000) coupled with past droughts have lowered lake water levels in the Volta Lake (Stanturf et al., 2011). Riverflow in the Volta Basin varies greatly from year to year. A study by Van de Giesen et al. (2001) of the Volta Basin indicated that riverflow has a coefficient of variation of fifty-seven percent (57%) from one year to the other. This points to a high level of variability in the interannual riverflow. Comparatively, Gyau-Boakye (2001) studied the run-off from two important tributaries of the Volta Lake (the White Volta and the River Oti) for two distinct periods (1951- 1970 and 1971 – 1990). In his study, he records a mean streamflow reduction of 23.1% for the White Volta and 32.5% for the Oti River. One study also showed through the analysis of a forty-year (40yr) rainfall and run-off data from Ghana that there was a significant reduction in rainfall and run-off over the past three (3) decades (Opoku-Ankomah & Amisigo, 1998). Significant changes in hydropower generation may result from these variations in the annual run-off pattern (Guegan et al., 2012).

Aside these climatic challenges, there are several non-climatic challenges which affect the operation of the hydropower infrastructure in the country. These challenges include; land degradation effects, dry season upstream water abstractions at Burkina Faso, uncalculated spillage of water from the dam, and inefficient and poor reservoir management by VRA (Leemhuis et al., 2009; Rodgers et al., 2007; Brew-Hammond & Kemausor, 2007; Graham (1995) cited in Saadia (2008); Van de Giesen et al., 2001).

In Ghana currently, the growth rate of manufacturing sector slowed down in the first half of 2013 as a result of power rationing which started in September 2012 (Okudzeto et al., 2014). This clearly suggest that Ghana has been struggling to provide sufficient electricity for its economic sectors (Clark et al., 2005) under the current energy policy and strategy. A continuation of such a hydro-dependent energy policy and strategy will have negative effects on the country's energy supply going into a future where climate variability and change is predicted with a high probability to continue and even become more severe (IPCC, 2007b, 2013).

## **2.4 CLIMATE VARIABILITY AND HYDROPOWER PRODUCTION**

The Intergovernmental Panel on Climate Change (IPCC) has stated that the warming of the climate system is unequivocal with unprecedented observed changes over decades to millennia (IPCC, 2007b). The Fifth Assessment Report states that the earth's surface has been successively warmer in each of the last three decades than any preceding decade since 1850. Also, land and ocean temperatures have increased by 0.85°C over the period 1880 to 2012. In addition to multi decadal warming, temperatures exhibit substantial decadal and interannual variability. The report also states that many of the impacts associated with the changes in climate will continue for centuries even if the anthropogenic emissions are stopped. In many mid-latitude and subtropical dry regions, mean precipitation will decrease by the end of this century. Drought frequency is therefore likely to increase in presently dry regions by the end of the 21<sup>st</sup> century which will have significant impacts on water resources. Additionally, the report states that the impacts from climate-related extreme events such as heat waves, droughts, floods, etc. have altered and affected economic sectors

and human systems through damage to infrastructure, disruption of water supply and livelihood options. In many regions changing precipitation and temperature patterns are altering hydrological systems. Most energy production sectors require huge amounts of water, either directly (hydropower systems) or indirectly (cooling for thermal energy systems). Climate change is likely to increase the frequency of meteorological droughts (less rainfall) and agricultural droughts (less soil moisture) in presently dry regions by the end of the 21<sup>st</sup> century and as such future water availability for energy generation will change (IPCC, 2013).

Energy systems are increasingly being affected by changing climatic trends as for example, increasing variability, frequent extremes, and large interannual variation in climate parameters in some regions (Ebinger & Vergara, 2011). Hydropower is one of such energy systems as it relies on water resources such as runoff, river flow (Hamududu, 2012), and precipitation.

Phinney et al. (2005) studied the implications of temperature rise, reduced runoff and precipitation decreases on hydropower production in California and the Western United States. Based on warming of 1°C, 1.7°C and 2.4°C and precipitation decreases of 3%, 6% and 3%, future climate scenarios estimate hydropower production from the Colorado River Basin to reduce by 56, 43, and 53 percent for the periods 2010-2039, 2040-2069 and 2070-2098 respectively. Decreases in hydropower generation are also recorded for the California (Lake Shasta) and the Columbia River Basins as well, albeit on a smaller scale.

Blackshear et al. (2011) studied climate variability and change impact on the Mekong River Basin in South Asia. The Basin has numerous hydropower resources with about 130 hydropower projects operating or planned along the river. Climate scientists predict that South Asia will record increase in precipitation and a likely increase in droughts and floods in the Mekong River Basin. The study also recorded that temperature increases in the Himalayas will increase glacial melt that will increase the Mekong River discharge for at least several decades. Discharge will however start to decline once the glacial have melted. The beginning of the monsoon is predicted to arrive later in the year, and thus making the dry season longer and increasing the occurrence of droughts. They therefore concluded that, all of these climate change interactions will make it more difficult to predict river discharge and the generation of a stable supply of power from hydropower infrastructure along the Mekong River.

The IPCC (2001a) described Africa's water resource sector as a key area of vulnerability likely to impact the supply of water for household use, agriculture, industry and power generation, especially, hydroelectric power generation. Climate change is known to exert a multitude of immediate and long-term impacts on water resources in African countries (Urama & Ozor, 2010), especially as African countries have invested significantly in hydroelectricity infrastructure (Yamba et al., 2011). McKinney (2003) and IHA (2012) attribute the near-zero emissions and the very low cost of generating power from hydro sources as some of the reasons for hydroelectricity's great popularity.

Beilfuss (2012) evaluated the hydrological risk of hydro-dependent power systems in the face of climate change using the Zambezi Basin as a case study. He found that droughts have significant impacts on river flow and hydropower production in the basin. For example, the severe 1991/92 drought reduced hydropower generation which resulted in an estimated US \$102 million reduction in GDP, \$36 million reduction in export earnings, and the loss of 3,000 jobs (ibid). The IPCC (2007a, 2013) has categorized the Zambezi Basin as the river basin exhibiting the worst potential effects of climate change and variability because of the impacts of temperature increases and reductions in rainfall. There are two large hydropower dams operating on the mainstream Zambezi River namely, Kariba Dam and Cahora Bassa Dam. Climate variability due to droughts has had significant impacts on the potential of these dams to meet the firm power requirements and also the total power generation goals (Beilfuss, 2012). The World Bank (2010) quantified the potential climate change impacts in the Zambezi River Basin to be a firm energy fall of 32% per year and an average annual energy generation fall of 21% per year under moderate climate change scenarios. Under the less optimistic scenarios, firm power reduces by 43% per year while average annual energy falls by 25%.

Hamududu (2012) in another study on hydropower and water resources in Central and Southern Africa found decreases in the hydropower potential of the Zambezi Basin by 9-34%, 8-34% decreases for the Kafue Basin while the potential of the Shire Basin decreases by 7-14% as the southern African region experiences reductions in precipitation, runoff, and more drier and shorter rainy seasons. This according to the study has made power cuts common and widespread in the region as most countries depend heavily on hydropower.

Yamba et al. (2011) also provided evidence of recent drought occurrences in the South Africa Development Community region which resulted in a deficiency of water supply and subsequently affected hydropower generation in most of the drought affected countries.

Grijsen (2014) in a study presented a Climate Risk Assessment (CRA) for the five main river basins in Cameroon, focusing on climate change impacts on water resource availability for power generation mostly in the Sanaga, Benue, Nyong, and Ntem River Basins. The study recorded a 16% reduction in runoff from the Sanaga basin due to decrease in precipitation around 1970. Munang & Ayongue (2010) cited in the study recorded an increase in temperature of 0.8°C, a decline in rainfall by 112mm/yr (6.5%) and reduction in runoff by 142m<sup>3</sup>/s (7.5%) for the Sanaga Basin. According to Grijsen (2014), the cumulative effect of these variability in climate will either reduce power production of the Lagdo dam in the Niger Basin by 35% or increase it by 15% by year 2050. The study also found a possible 15% reduction or 5% increase in the power generated by the Edea, Song Loulou, Lom Pangar and Nachtigal power plants in the Sanaga Basin by 2050. Minor to moderate impacts were also recorded for power generation from the other basins.

Droogers (2009) studied the impacts of climate change on hydropower generation in Tana basin in Kenya using the Water Evaluation and Planning tool (WEAP) approach. According to this study a 10% reduction in rainfall can easily result in a loss of hydropower generation by 25 to 50%. The study reports an increase in water demand of between 15% and 28% in Kenya for low and high projections respectively. Average hydropower production will as a result reduce substantially from 2,253GWhr/yr to between

1763GWhr/yr and 2144GWhr/yr. Under low and high projections, the study found average revenue from electricity to fall by 5% and 22% per year. Hamududu (2012) reported a rationing of power in Kenya following a persistent drought in the year 2000 which affected most hydroelectric plants. Hydropower capacity dropped by 25% during the 2000 drought resulting in an estimated 1.5% reduction in GDP valued at \$442 million (Stiftung, 2010). Droogers (2009) therefore concluded that increases in annual climate variability will lead to a lower energy security for Kenya.

Seitz & Nyangena (2009) in a study documented an increase in major droughts in the East African region. These droughts according to the study have become frequent in the past, occurring in 1970, 1975, 1979-80, 1989-90, 1999/2000 and 2005. Riebeek (2006) in a different study found interannual lake level fluctuations in Lake Tanganyika, Lake Victoria and Lake Turkana since the 1960s due probably to these periods of intense droughts, which are followed by increases in rainfall and extreme rainfall events. Seitz & Nyangena (2009) therefore concluded in their study that, hydropower generation in East African countries might continue to be under threat due to the strong link between climate variability and hydropower generation in these countries.

Malley (2011) analyzed the relationship between water shortages due to climate variability and hydropower generation in the Mtera Reservoir in Tanzania which supplies 50% of hydropower to the national power grid. The study found that rainfall variability was responsible for 64% of the declining water levels in the Mtera dam. Analysis revealed a high interannual rainfall variability. The study also found higher frequencies of below

average annual rainfall from the late 1980s to 2003 indicating an increasing frequency of drier-years in the region. In 1997 for example, drought conditions caused a 17% drop in hydropower generation from the Mtera dam (Karekezi et al., 2009). WWF (2002) cited in Malley (2009), documented power shortages from 1990-2008 due to water supply problems from the Mtera reservoir. Malley (2009) thus attributed the resultant nation-wide power ration which affected several economic sectors to the failure of the Mtera dam due to climatic variability impacts. Tanzania's hydroelectric power plants were operating at half capacity after a severe drought in 2004 (EIA, 2005). Casmiri (2009) reported that out of the total installed capacity of 561 MW, only 140 MW was available as at February 2006 and just 50 MW was available by March 2006.

Ecological conditions in West Africa have changed over the last decade and is certain to continue to change, making climate change very evident (Wittig et al., 2007). It is therefore very risky for Ghana to continue the current hydro-dependent energy policy and strategy. Given the current line of climate variability and change and the impacts of climate variability reviewed in this section, there is a possibility that the country maybe investing in a power technology that might not be sustainable going into the future.

## **2.5 EL NINO-SOUTHERN OSCILLATION**

One of the principal ways through which climate variability and change occurs and will continue to occur is through the exacerbation of the impacts of the natural variability happening on top of the anthropogenic changes (Collins et al., 2010). One of the most important sources of the natural variability in the tropics is the El Niño-Southern

Oscillation (ENSO) which is accompanied by global teleconnections that drive changes in rainfall and weather patterns in many parts of the world (Davey et al., 2011; Collins et al., 2010). ENSO is the most dominant interannual signal of climate variability in the tropics and is known to influence many extreme events such as hurricanes, floods, and droughts as well as the hydrology of many regions of the world (Ward et al., 2014).

According to the IPCC (2001b), the frequency and intensity of El Niño-Southern Oscillation (ENSO) has intensify from the mid-1970s when analyzed in relation to the previous 100yrs. El Niño which is the warm phase has been more common, persistent and more intense as opposed to La Niña, the cold phase. Allan (1994) identified decadal to multi-decadal global scale fluctuations in the ENSO phenomenon and the climate system at large. He also found regions under the influence of ENSO over the entire globe to be changing on decadal to multi-decadal time scales. Africa in particular exhibits a vulnerability to the effects of interannual climate variations especially to the ENSO phenomena (Hulme et al., 2001; Conway et al., 2007).

The effects of ENSO vary with location. For instance, Davey et al. (2011) in a study documented that El Niño events are known to cause rainfall deficits in the Philippines, Indonesia, and Australia while the Central Pacific islands experience excess rainfall. One study used a 47-year (1951- 1997) record of gridded data of sub-Saharan Africa to document the correlation between precipitation and sea-surface temperature (SST) in key tropical areas. The study showed that ENSO has significant impacts over the Sahel and the Gulf of Guinea during the northern summer periods. The study also revealed a negative correlation between NIÑO3 SST and rainfall in March to June and August to November in

Western equatorial Africa. These findings mean that, in El Niño years, the dry period separating the two rainy seasons gets longer through a reduced occurrence of the rainy seasons (Camberlin et al., 2001). Funk et al. (2005) cited in Seitz & Nyangena (2009) attributed reductions in the levels of East African lakes to ENSO-events. Due to climate variability influence on hydropower generation, Seitz & Nyangena (2009) concluded that, such reductions in East African lake levels are likely to disrupt power generation.

Joly & Voldoire (2009) report that a significant part of the West African Monsoon's interannual variability can be explained by El Niño-Southern Oscillation (ENSO) teleconnections. This finding is also consistent with a study by Otto-Bliesner (1999), who states that ocean-atmosphere response to ENSO explains a substantial portion of the interannual variability in the world's current climate system. On a decadal scale, observational studies as recorded by Rodríguez-Fonseca et al. (2011) indicate that variability of West African Monsoon is related to a global SST interhemispheric pattern, which was partly responsible for the transition between the wet 1950s and 1960s and the dry 1970s and 1980s. The dry periods of the 1980s was caused by severe drought conditions over West Africa corresponding to a decrease in precipitation in the whole monsoon system (Mohino et al., 2011).

Waylen & Owusu (2014) state that ENSO, with a periodicity of 3-7 years, influence the climate of West Africa. Drought over West Africa is characterized by the growth of positive SST anomalies in the Eastern Pacific complimented by a negative SST anomaly in the Northern Atlantic (Fontaine & Janicot, 1996). This is also accompanied by

substantial reductions in rainfall input over the Gulf of Guinea. Trzaska et al. (1996), Janicot et al. (1996) and Janicot et al. (2001) found the influence of ENSO on West African rainfall to have grown stronger after the 1970s. Several studies on ENSO-influence on rainfall in West Africa show minimal influence while others suggest lower/higher rainfall in El Niño and La Niña years respectively (Ward et al., 2010).

In a study published by The World Bank (2011), it is reported that the climate of Ghana is strongly influenced by the ENSO phenomena. Since rainfall variability, including variability due to ENSO will likely continue to influence hydropower generation, building the country's power system around hydropower is a great risk and perhaps there is the need for the country to diversify away from hydropower into other power supply sources.

## **2.6 CONCEPTUAL FRAMEWORK**

The conceptual framework gives the interrelationships between climate variability and change and Ghana's ability to achieve energy security through a reliance on hydropower. The framework, which was adopted from Blackshear et al. (2011) shows how changes in precipitation and temperature influence the hydropower potential of countries. The framework also establishes the grounds for the study objectives and mostly the research hypothesis.

Energy security refers to the effective management of primary energy supply from domestic and external sources, the reliability of energy infrastructure, and the ability of energy providers to meet current and future demand (World Energy Council, 2013). For

Ghana to attain energy security, there is therefore the need for reliability in the power supply sources and also a commitment on the part of power suppliers to meet current and future demand as well as the introduction of some equity in the supply of power to the citizens.

Hydroelectric power is mostly an indigenous resource, generated internally, which gives a guarantee on the source of supply (Ölz et al., 2007). The fact that the cost of generation for hydroelectricity is comparatively lower puts the prices of electricity tariffs within the purchasing range of a majority of the citizens. This improves the energy equity status of the country. However, the impacts of climate variability and change on hydropower potential across the world makes investments in the technology risky, most especially for developing countries striving to achieve sustainable development and improve the lives of their citizenry. The introduction of climate variability and change into a hydro-dependent power sector presents huge problems, more so for sub-Saharan African countries. Figure 2.1 gives a conceptualization of the problems inherent in a hydro-dependent power sector.

Changes in precipitation, caused by both anthropogenic climate change and/or natural variability such as ENSO (IPCC, 2007b), sets in motion a series of processes which leads to a decrease in evaporation, an increase in the frequency of droughts and floods, or a host of seasonal offsets such as a delay or early start of the dry or rainy seasons (Figure 2.1). Decreased evaporation is recorded when there is an increase in precipitation. Increased frequency of droughts and floods, and seasonal offsets are on the other hand the result of a decrease in precipitation (Figure 2.1).

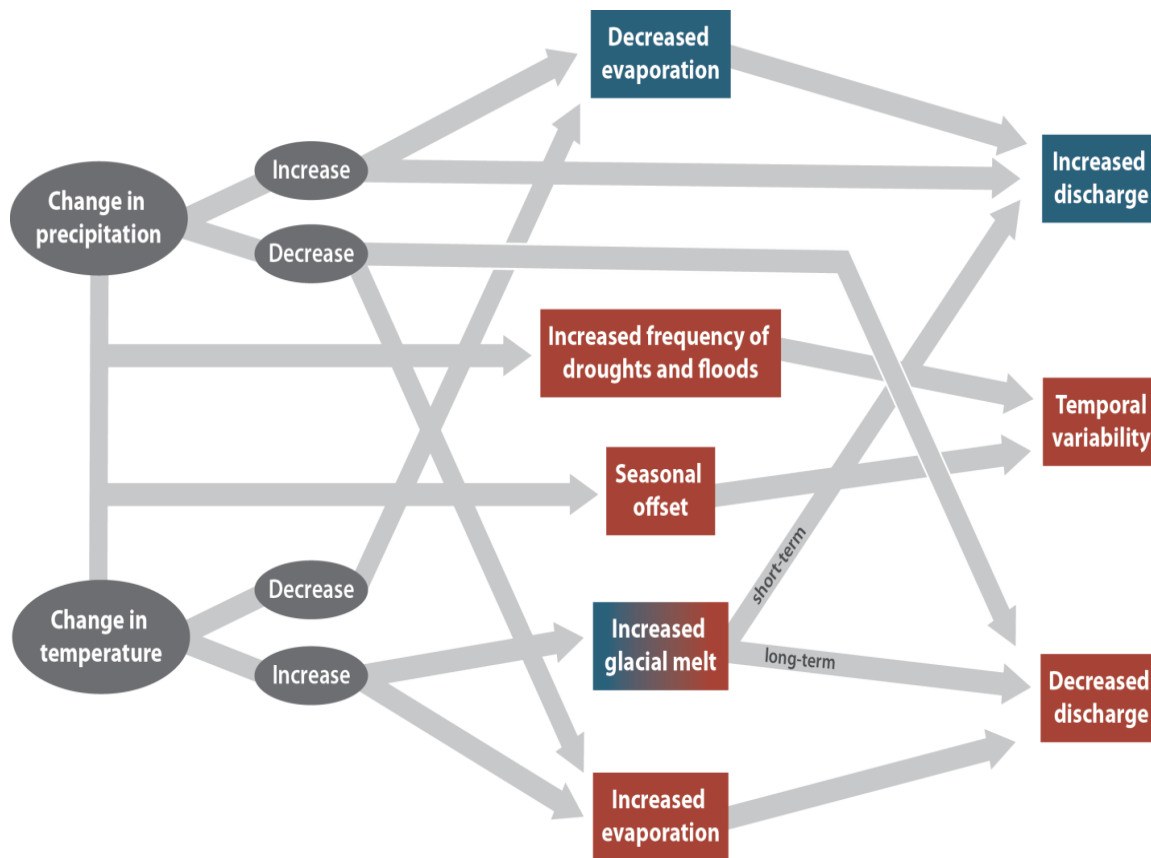


Figure 2.1: Conceptual Framework showing the impacts of climate variability and change on hydropower generation. Red indicates effects that are typically detrimental to hydroelectric production, and blue indicates effects that typically improve hydroelectric production potential.

*Source: Blackshear et al. (2011)*

As can be seen from Figure 2.1, changes in temperature can manifest as either an increase or a decrease (Figure 2.1). Changes in temperature are mostly caused by the enhancement of the greenhouse effect through anthropogenic forcing of the climate system (IPCC, 2013). From Figure 2.1, an increase in temperature leads to either glacial melt or an increase in evaporation while a decrease in temperature usually results in a decrease in evaporation. Some unique interactions of changes in temperature and precipitation can also lead to increase frequency of droughts and seasonal offsets. It can again be seen from Figure 2.1 that the effect of increase in temperature on glacial melt is initially positive as

the melted glacial increases river flow, runoff and consequently increases discharge. In the long-term however, the impacts on hydropower become mainly negative (after the glacial has melted).

Seasonal offsets, which refers to variation in the onset and end of the rainy and dry seasons, will change. With the delivery of water supply at varied and unpredictable times, availability of water for use at homes, industries and economic sectors (including the energy sector) will be affected. An increase in the frequency of drought and floods leads to temporal variability of precipitation events which in turn reinforces the frequency and severity of droughts and floods. Increased evaporation reduces the amount of water available in water bodies.

The final three boxes on the framework show the changes in river discharge, which is what broadly determines how much electricity a given hydropower scheme can generate (Figure 2.1). Increased discharge will enhance the hydropower potential of a region or a country by making water available for power generation. Decreased discharge, on the other hand, reduces the availability of water for hydropower generation. Also, the cumulative effect of temporal variability and decreased discharge on river systems is low power generation potential. This will reduce power supply and create either a deficit in power supply or widen the existing supply-demand imbalance.

An increase in demand for power with supply remaining stationary, can also create a supply-demand imbalance. According to the 2010 Ghana Wholesale and Power Reliability Assessment, an increase in power demand has the capacity to return a power system

providing adequate and sufficient power back to a state of inadequate and insufficient power supply unless there are persistent and continued investments in energy infrastructure (PSEC, 2010). It is evident that Ghana continued to rely on the Akosombo power station until the late 1990's when the country began investing in alternative power sources (ENERGYWORLD/Africa, 2010/2011) especially thermal power to cater for the accumulated increased demand. The insecurity surrounding fuel supply for thermal power generation has led to a low thermal plant availability (Energy Commission, 2013). Fuel shortages which results from low and erratic gas supply from the West African Gas Pipeline (WAGP) among others, deepens the country's dependence on hydropower.

Climate variability and change influence on Ghana's hydro-dependent power sector will affect the availability of water for power generation. Several studies have indicated that the overall impact of variability and change in climate on the Volta River has been negative (Opoku-Ankomah & Amisigo, 1998; Barry et al., 2004; van Edig et al., 2001; Lacombe et al., 2012; Lautze et al., 2006). This has resulted in a low generation capacity leading to high energy insecurity and high energy inequity. The frequent failure of hydropower systems should have pushed the country to diversify away from hydropower to alternative power sources. It is difficult to understand why the government continues to cut a pathway to energy security through hydropower generation when the climate of the country keeps changing and becoming more variable.

## **2.7 SUMMARY**

This chapter provided a discussion of the implications of climate variability and change on hydropower generation. First, the chapter discussed Ghana's energy resources and power sector. The chapter also discussed Ghana's energy policy and strategy. A review of the impacts of climate variability and change on hydropower was then provided. A section was devoted for a review of the influence of ENSO on hydropower. Finally, the chapter was used to provide a conceptual framework for the study.

## **CHAPTER THREE – RESEARCH METHODOLOGY**

### **3.1 INTRODUCTION**

This chapter discusses the research methodology used for the study. First, a profile of the study area is provided. The data used for the study were mainly from the Akosombo Hydroelectric Power Station and six (6) Synoptic station located within the Volta Basin. The methods of data collection as well as the methods of data analysis are also discussed. The final section outlines some limitations of the study.

### **3.2 STUDY AREA**

The Volta River Basin is the area of study. The Volta River Basin is located between Latitudes 5°N and 14°N and Longitude 2°E and 5°W (Figure 3.1). It has a total surface area of about 414,000km<sup>2</sup> across six West African countries namely, Benin, Burkina Faso, Cote d'Ivoire, Mali, Togo and Ghana (Kasei, 2009). The Basin can be divided into a north portion and a south portion. Ghana has about 40% of the total area of the Volta Basin which covers about 70% of the country's land area. The Basin in Ghana is dotted by rivers such as the Oti and Daka, the White and Black Volta, and the Pru, Sene and Afram rivers (Aquastat Survey, 2005; Jung, 2006).

The vegetation in the south Volta Basin in Ghana ranges from tropical humid forest and dry forest in the interior to savannah in the northern part of the country. The climate is mainly semi-arid to arid. The rainfall regime is divided into two: a dry season and a rainy season. In the south Basin, rainfall amounts exceed potential evaporation in 6 to 9 months.

Temperature in the Basin ranges between 27°C in the south and 36°C in the north (Jung, 2006; Kasei, 2009).



Figure 3.1: A Map of the Volta Basin showing the Synoptic stations used for the study  
Source: GIS Lab, Department of Geography and Resource Development, University of Ghana, Legon

On the whole, the mean annual temperature for the Volta Basin indicates an increasing trend. According to Jung (2006), the increase in temperature in the south Volta Basin is about 1°C between 1991 and 2000.

The Akosombo hydroelectric power project is located in the south Volta Basin in Ghana. The project is part of the Volta River Authority (VRA) established in 1961. The VRA was tasked to manage the development of the Volta River Basin, which included the construction and supervision of the dam, the power station and the power transmission work. The VRA is also responsible for the reservoir impounded by the lake. The dam was built between 1961 and 1965. The primary purpose of the dam was to provide electricity for the Aluminium industry – Volta Aluminium Company (VALCO). The Akosombo hydroelectric power project was called the largest single investment in the economic development plans of Ghana. Its original electrical output was 588MW, which was later upgraded to 912MW. A fairly recent upgrade increased the electrical output to 1020MW in a retrofit project completed in 2006. The construction of the dam flooded parts of the Volta River Basin, and the subsequent creation of the Volta Lake. Lake Volta is the world's largest man-made lake, covering 8,502 square kilometers (<http://www.listnbest.com/10-largest-man-made-lakes-world>), which is about 3.6% of Ghana's total land area. The dam's power plant contains six 170MW Francis turbines. Each turbine is supplied with water via a 112 -116m long and 7.2m diameter penstock with a maximum of 68.8m of hydraulic head afforded. The minimum operating water level is 73.15m (240ft) and the maximum level is 84.73m [278ft] ([www.vra.com](http://www.vra.com)).

### 3.3 METHODS OF DATA COLLECTION

The research was carried out using a quantitative approach. In order to determine the rainfall variability in the Volta Basin part located in Ghana, rainfall data for six (6) Synoptic stations were collected from the Ghana Meteorological Agency (GMet). The Synoptic stations used were: Bole, Kete-Krachi, Navrongo, Wa, Tamale and Yendi (Figure 3.1). All these stations are located upstream of the Akosombo dam as lake water levels are only influenced by rainfall recorded upstream (Khan & Short, 2001). These six (6) stations were used by Bekoe & Logah (2013) and were also part of the twenty-eight (28) stations employed by Kasei (2009) in his study of the water resources in the Volta Basin. The rainfall data collected for the study consist of monthly rainfall totals for these six (6) Synoptic stations for the period 1970 to 2010.

Data on the Volta Lake water levels, monthly lake inflows, and monthly power generation at Akosombo Power Station for the years 1970 to 2010 were obtained from the VRA. Finally, the El Niño-Southern Oscillation (ENSO) indices (1970 to 2010) were downloaded from the Centre for Ocean-Atmospheric Prediction Studies (COAPS) hosted by the Florida State University. The index used for the ENSO signal is the Japan Meteorological Agency (JMA) Index. This index uses a 5-month running mean of spatially averaged sea surface temperature anomalies (SSTA) over the tropical Pacific ( $4^{\circ}\text{S} - 4^{\circ}\text{N}$ ,  $150^{\circ}\text{W} - 90^{\circ}\text{W}$ ). Events are classified as either El Niño (Warm Phase), Neutral Phase, or La Niña (Cold Phase). Years are defined as 6 consecutive month periods including October-November-December (OND) at or above the +0.5 anomaly for warm (El Niño) events and at or below the -0.5 anomaly for cold (La Niña) events. All other years between +0.5 and -0.5 are classified as

the Neutral Phase of ENSO. The JMA Index ENSO year runs from October through to September (<http://coaps.fsu.edu/jma>).

### **3.4 METHODS OF DATA ANALYSIS**

The monthly and annual data of rainfall, lake level elevation, net lake inflow, and power generation were statistically analyzed to detect trends in each data set from 1970 to 2010. Microsoft Excel and SPSS were used for the data analysis. Preliminary test revealed that most of the assumptions for parametric test; homogeneity of variances, normality of distribution, no significant outliers, independence of observations, heteroscedasticity and colinearity were not violated. As such parametric tests, F-test, t-test and regression analysis, were used for analyzing the rainfall, lake level elevation, net lake inflow and power generation data. Significance levels of 0.05 were used throughout.

All rainfall, lake level elevation, net lake inflows and power generation were divided into two periods: P1 (1970 -1990) and P2 (1991 -2010) to correspond to widely reported failure of the West African Monsoon in the 1970s and 1980s, and its recovery afterwards (Giannini et al., 2003; Trenberth et al., 2007; Rodríguez-Fonseca et al., 2011; Turner et al., 2011).

#### **3.4.1 Analysis of Rainfall data**

The monthly rainfall inputs from 1970 – 2010 were summed to derive the annual rainfall totals for each of the six (6) Synoptic stations, namely Bole, Kete-Krachi, Navrongo, Wa, Tamale and Yendi. In order to test for significant differences in annual rainfall between P1 and P2 for each station, an independent samples t-test was used to analyze the annual

rainfall totals. The t-test, a parametric statistical test comparing the means of two datasets was used to examine the variability in each annual rainfall total between P1 and P2 for significant differences. A test statistic,  $t$ , is defined by five (5) parameters:  $\bar{X}$ , corresponds to the mean of the first dataset;  $\bar{Y}$ , is the mean of the second dataset;  $n$  is the number of observations in the first dataset;  $m$  is the number of observations in the second dataset; and  $S$  is the standard deviation of all the collected observations.

$$t = \frac{(\bar{X} - \bar{Y})}{S \sqrt{\frac{1}{n} + \frac{1}{m}}}$$

In this application,  $\bar{X}$  is the mean of P1,  $\bar{Y}$  is the mean of P2,  $n$  is the number of years in P1,  $m$  is the number of years in P2 and  $S$  is the standard deviation of the annual rainfall total for each Synoptic station. Using this function, the means of P1 and P2 were compared for significant differences.

The annual rainfall totals for all the six (6) stations were then summed and averaged to derive the mean annual basin rainfall for the lower Volta Basin. This was used to generate a line graph showing the rainfall pattern for the lower Volta Basin. Additionally, interannual changes in mean annual basin rainfall were calculated by subtracting each year's mean annual rainfall amount from the long-term Basin average rainfall of 1100mm. This was used to calculate the percent change in rainfall for the lower Volta Basin.

El Niño-Southern Oscillation (ENSO) is known to be the largest determinant of variability in tropical rainfall (Mude et al., 2007). As a result, the relationship between the ENSO

phenomenon and rainfall variability in the Volta Basin section of Ghana was analyzed. As indicated earlier, the Japan Meteorological Agency Index (JMA Index) used in this study puts ENSO into three (3) phases: warm (El Niño), neutral and cold (La Niña) phases. Using this as a grouping variable, a one-way ANOVA is used to test for differences in rainfall to assess if variability in rainfall has a statistically significant relationship with ENSO. An F-statistic,  $F$ , is defined as:

$$F = \frac{MS_{\text{between}}}{MS_{\text{within}}}$$

Where  $MS_{\text{between}} = \frac{SS_{\text{between}}}{df_{\text{between}}}$ , and  $MS_{\text{within}} = \frac{SS_{\text{within}}}{df_{\text{within}}}$

$$SS_{\text{total}} = \sum [\sum(x^2)] - \frac{[\sum(\sum X)]^2}{N}$$

$$SS_{\text{between}} = \sum \frac{(\sum X)^2}{n} - \frac{[\sum(\sum X)]^2}{N}$$

$$SS_{\text{within}} = SS_{\text{total}} - SS_{\text{between}}$$

Where;  $x$  is the individual observation,  $n$  is number of observations in group,  $N$  is total number of observations in all groups (total sample size),  $df_{\text{between}} = (k-1)$ ,  $df_{\text{within}} = (N-k)$ , and  $k$  is the number of groups.

In this application,  $x$  is the mean annual basin rainfall inputs from 1970 – 2010, the total number of years falling under the El Niño (11), Neutral Phase (21) and La Niña (9) phases determines  $n$ . The total number of observations in all groups (41) determines,  $N$ , and the number of groups (3) constitutes  $k$ . Partial Eta Square is used to measure the percentage of the variability in rainfall attributable to the ENSO phenomena.

### 3.4.2 Analysis of Net Lake Inflow data

The monthly Net Lake Inflows were aggregated to derive annual Net Lake Inflows in Million Acre-Feet (MAF). This was then used to generate a line graph showing the annual Net Lake Inflow from 1970 - 2010. In order to test for significant differences in annual Net Lake Inflow between P1 and P2, an independent samples t-test was used to analyze the annual Net Lake Inflow. The t-test, a parametric statistical test, was used to compare the means of the two Net Lake Inflow datasets (P1 and P2) for significant differences.

### 3.4.3 Analysis of Lake Level Elevation data

Lake level elevation measurements are made daily by the VRA. These daily Lake level elevations at Akosombo were summed then averaged to derive the monthly Lake level elevation  $\left(\frac{\text{Sum of Daily Lake Level Elevation for the month}}{\text{Total number of days in the month}}\right)$ . This monthly data is then aggregated and averaged  $\left(\frac{\text{Sum of monthly Lake level elevation}}{\text{Total number of months in a year}}\right)$  to derive the mean annual Lake level elevation for the period under study (1970 – 2010). The monthly averages were used to generate a line graph showing the Lake level elevation from 1970 – 2010.

In order to test for significant differences in Volta Lake level elevation between P1 and P2, an independent samples t-test was used to analyze the annual averages of the lake level elevations. The t-test, a parametric statistical test, was used to compare the means of the two Lake level elevation datasets (P1 and P2) for significant differences.

### 3.4.4 Analysis of Power Generation data

The Monthly power generation data from the Akosombo Power Station were aggregated to derive the annual power generation for the period under study (1970 – 2010). These annual power generation data were used to generate a line graph showing the power generation pattern for the Akosombo Power Station from 1970 – 2010. Additionally, the annual variations in power generation were found by subtracting the total power generation of a current year from that of the previous year (*Total power generation of present year – Total power generation of past year*).

A regression analysis was conducted to establish the influence of rainfall, ENSO, lake level elevation and net lake inflow on annual fluctuations in power generation for the two periods, that is, P1 and P2. Annual fluctuations in power generation from Akosombo Power Station for the two periods were regressed against rainfall, ENSO, lake level elevation and lake net inflow data using a stepwise multiple regression to determine if a change in these variables has significant change on annual variation in power generation. A multiple regression equation is described by four (4) parameters:  $Y$ , the predicted variable (dependent variable);  $a$ , is the model constant;  $B$ , is the slope; and  $X$ , represents the different predictive variables (independent variables).

$$Y = a + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + \mathcal{E}$$

In this application,  $Y$  is power generation,  $a$  is the constant (y-intercept),  $B$  is the slope,  $X_1$  is the rainfall inputs,  $X_2$  is ENSO,  $X_3$  is the lake level elevation,  $X_4$  is net lake inflow, and  $\mathcal{E}$  is the error.

Land-use/cover changes, upstream water abstractions especially at Burkina Faso, and siltation are known to affect the Net Lake Inflow at Akosombo which also influences the level of water behind the Akosombo Dam (Lautze et al., 2006; Rodgers et al., 2007; Leemhuis et al., 2009). Net Lake Inflow and Volta Lake water levels were therefore included in the model. The objective of this study was to isolate and assess the influence of variability and change in climate, especially rainfall, on the ability of Ghana's hydropower infrastructure to provide energy security. Land-use/cover changes, upstream water abstractions and siltation, which are mostly categorized as traditionally inherent constraints to hydropower generation, were therefore not included in the regression model used in the study. They are however discussed in the study as factors which have traditionally influenced hydropower generation.

### **3.5 LIMITATIONS OF THE STUDY**

The main limitation for this study had to do with the limited number of Synoptic stations used in the analysis of the rainfall for the lower Volta Basin. As can be seen from the map of the study area (Figure 3.1), the Basin extends beyond the six stations used in the study. Due to the problem of data availability, which is a major problem for most climatological studies in Africa, and also the fact that only rainfall received in the upper catchment of rivers (in this case, upstream of the Akosombo dam) influence the water available in storage reservoirs downstream (Khan & Short, 2001), data for the study was limited to rainfall inputs from Bole, Kete-Krachi, Navrongo, Wa, Tamale and Yendi. Even though the Basin extends beyond these six (6) Synoptic stations, the rainfall drivers are the same for the entire basin and the data quality was very high in the 6 stations. Thus, the stations

although few, still give a good representation of the rainfall for the entire lower Volta Basin.

### **3.6 SUMMARY**

This chapter presented the methodology used for the study. The study area was first presented. The characteristics of the data used were described. Also, the data collection and data analysis techniques used for the achievement of the research objectives were discussed. Finally, the limitations of the study were also presented.

## **CHAPTER FOUR – RESULTS**

### **4.1 INTRODUCTION**

This chapter presents the results of the analysis of rainfall, lake level elevation, net lake inflows, power generation outputs, and ENSO data collected for the purpose of this research. The first section presents the results for rainfall variability in the lower Volta Basin. The second section presents the results for the variability and change in lake inflow and lake level elevation. The final section presents the results for fluctuations in electricity production from the Akosombo Hydroelectric Power Station.

### **4.2 RAINFALL VARIABILITY IN THE LOWER VOLTA BASIN**

The first objective of the study was to examine the variability and change in rainfall in the lower Volta Basin for the four decades between 1970 and 2010. In order to test for significant differences in the total annual rainfall for Bole, Kete-Krachi, Navrongo, Wa, Tamale, and Yendi, the total annual rainfall inputs were grouped on the two year periods, P1 (1970 – 1990) and P2 (1991 -2010). Table 4.1 and 4.2 present the descriptive statistics and t-test results respectively, for these six synoptic stations. These synoptic stations were carefully selected for their location upstream of the Akosombo Dam and low levels of missing data.

As can be seen from Table 4.1, P1 and P2 distributions were sufficiently normal for all six stations for the purpose of conducting a t-test (i.e. skew  $< |2.0|$  and kurtosis  $< |9.0|$ ; Schmider, Ziegler, Danay, Beyer, & Buhner, 2010).

Table 4.1 Descriptive statistics associated with annual rainfall totals for the six synoptic stations

| Stations    | P1 (1970 – 1990) |         |        |       |       | P2 (1991 – 2010) |         |        |       |       |
|-------------|------------------|---------|--------|-------|-------|------------------|---------|--------|-------|-------|
|             | N                | M       | SD     | S     | K     | N                | M       | SD     | S     | K     |
| Bole        | 21               | 1051.68 | 150.79 | -.225 | -.506 | 20               | 1123.20 | 172.04 | .693  | 1.132 |
| Kete-Krachi | 21               | 1329.84 | 222.07 | .311  | -.355 | 20               | 1385.52 | 365.90 | 1.096 | 2.142 |
| Navrongo    | 21               | 983.73  | 165.86 | .066  | -.626 | 20               | 982.42  | 163.78 | .375  | .320  |
| Wa          | 21               | 943.92  | 179.62 | -.250 | .951  | 20               | 1068.03 | 142.85 | -.198 | -.347 |
| Tamale      | 21               | 1070.70 | 137.34 | .421  | 1.310 | 20               | 1097.26 | 199.63 | .296  | .990  |
| Yendi       | 21               | 1209.09 | 215.65 | .421  | -.015 | 20               | 1245.22 | 199.99 | .153  | -.892 |

Note: S is Skewness; K is Kurtosis

Std Error for Skewness: P1 (.501), P2 (.512); Std Error for Kurtosis: P1 (.972), P2 (.992)

Source: *Fieldwork (2015)*

Table 4.2 Summary t-test results for the six synoptic stations

| Stations    | Levene's test for equality of variances |    |      | T-test |    |       |
|-------------|---|----|------|--------|----|-------|
|             | F                                       | df | Sig  | t      | df | Sig   |
| Bole        | .112                                    | 39 | .740 | -1.417 | 39 | .164  |
| Kete-Krachi | 2.976                                   | 39 | .092 | -.592  | 39 | .557  |
| Navrongo    | .040                                    | 39 | .843 | .025   | 39 | .980  |
| Wa          | .150                                    | 39 | .701 | -2.441 | 39 | .019* |
| Tamale      | 2.207                                   | 39 | .145 | -.498  | 39 | .621  |
| Yendi       | .063                                    | 39 | .803 | -.555  | 39 | .582  |

\*Significant at 0.05

Source: *Fieldwork (2015)*

A Shapiro-Wilk's test ( $p > .05$ ) and a visual inspection of their histograms, normal Q-Q plots and box plots showed that the total annual rainfall amounts were approximately normally distributed for both P1 and P2 at all six stations.

At Bole, the first period, P1 (N=21) was associated with a mean annual rainfall total of  $M = 1051.68$  and  $SD = 150.79$ . By comparison, the second period, P2 (N=20) was associated with a numerically higher rainfall of  $M = 1123.20$  and  $SD = 172.04$  as shown in Table 4.1. As is shown in Table 4.2, the assumption of homogeneity of variances was tested and satisfied via Levene's F-test,  $F(39) = .112$ ,  $p = .740$ . To test the null hypothesis that P1 and P2 were associated with no statistically significant difference in total annual rainfall amounts, an independent t-test was performed. The independent samples t-test was associated with statistically non-significant effect,  $t(39) = -1.417$ ,  $p = .164$ . The null hypothesis can therefore not be rejected. There is therefore no statistically significant difference in rainfall amounts between P1 and P2.

At Kete-Krachi, the first period, P1 (N=21) was associated with a rainfall of  $M = 1329.84$  and  $SD = 222.07$ . By comparison, the second period, P2 (N=20) was associated with a numerically slightly high rainfall of  $M = 1385.52$  and  $SD = 365.90$ . To test the null hypothesis that P1 and P2 were associated with no statistically significant difference in total annual rainfall amounts, an independent t-test was performed. As shown in Table 4.2, the assumption of homogeneity of variances was tested and satisfied via Levene's F-test,  $F(39) = 2.976$ ,  $p = .092$ . The independent samples t-test was associated with statistically non-significant effect,  $t(39) = -.592$ ,  $p = .557$ . The null hypothesis can therefore not be

rejected. Thus, there is no statistically significant difference in rainfall inputs between the first period (P1) and the second period (P2).

At Navrongo, the first period, P1 (N=21) was associated with a rainfall of M=983.73 and SD=165.86. By comparison, the second period, P2 (N=20) was associated with a rainfall of M=982.42 and SD=163.78. As shown in Table 4.2, the assumption of homogeneity of variances was tested and satisfied via Levene's F-test,  $F(39) = 0.040$ ,  $p = .843$ . To test the null hypothesis that P1 and P2 were associated with no statistically significant difference in total annual rainfall amounts, an independent t-test was performed. The independent samples t-test was associated with statistically non-significant effect,  $t(39) = .022$ ,  $p = .980$ . The null hypothesis can therefore not be rejected. This means there is no statistically significant difference in rainfall between the first period (P1) and the second period (P2).

At Wa, the first period, P1 (N=21) was associated with a rainfall of M=943.92 and SD=179.62. By comparison, the second period, P2 (N=20) was associated with a numerically higher rainfall of M=1068.03 and SD=142.85. Additionally, the assumption of homogeneity of variances was tested and satisfied via Levene's F-test,  $F(39) = .150$ ,  $p = .701$  (Table 4.2). To test the null hypothesis that P1 and P2 were associated with no statistically significant difference in total annual rainfall amounts, an independent t-test was performed. The independent samples t-test was associated with statistically significant effect  $t(39) = -2.441$ ,  $p = .019$ . The null hypothesis is therefore rejected. Thus, the second period (P2) was associated with a statistically significantly larger rainfall inputs than the first period (P1).

At Tamale, the first period, P1 (N=21) was associated with a rainfall of  $M=1070.70$  and  $SD=137.34$ . By comparison, the second period, P2 (N=20) was associated with a numerically slightly high rainfall of  $M=1097.26$  and  $SD=199.63$ . Additionally, the assumption of homogeneity of variances was tested and satisfied via Levene's F-test,  $F(39) = 2.207$ ,  $p = .145$  (Table 4.2). To test the null hypothesis that P1 and P2 were associated with no statistically significant difference in total annual rainfall amounts, an independent t-test was performed. The independent samples t-test was associated with statistically non-significant effect,  $t(39) = -.498$ ,  $p = .621$ . The null hypothesis can therefore not be rejected. This means there is no statistically significant difference in rainfall between the first period (P1) and the second period (P2).

At Yendi, the first period, P1 (N=21) was associated with a rainfall of  $M=1209.09$  and  $SD=215.65$ . By comparison, the second period, P2 (N=20) was associated with a numerically slightly high rainfall of  $M=1245.22$  and  $SD=199.99$ . As can be seen from Table 4.2, the assumption of homogeneity of variances was tested and satisfied via Levene's F-test,  $F(39) = 0.063$ ,  $p = .803$ . To test the null hypothesis that P1 and P2 were associated with no statistically significant difference in total annual rainfall amounts, an independent t-test was performed. The independent samples t-test was associated with statistically non-significant effect,  $t(39) = -.555$ ,  $p = .582$ . The null hypothesis can therefore not be rejected. This means there is no statistically significant difference in rainfall received between the first period (P1) and the second period (P2).

### Mean Annual Basin Rainfall

The monthly rainfall inputs from 1970 – 2010 for the six (6) Synoptic stations, namely Bole, Kete-Krachi, Navrongo, Wa, Tamale and Yendi were used to derive the annual rainfall totals for each station. The mean annual basin rainfall for the study area which is derived from the annual rainfall totals is then employed in this section on the analysis of rainfall. Figure 4.1 shows the mean annual rainfall pattern for the lower Volta Basin.

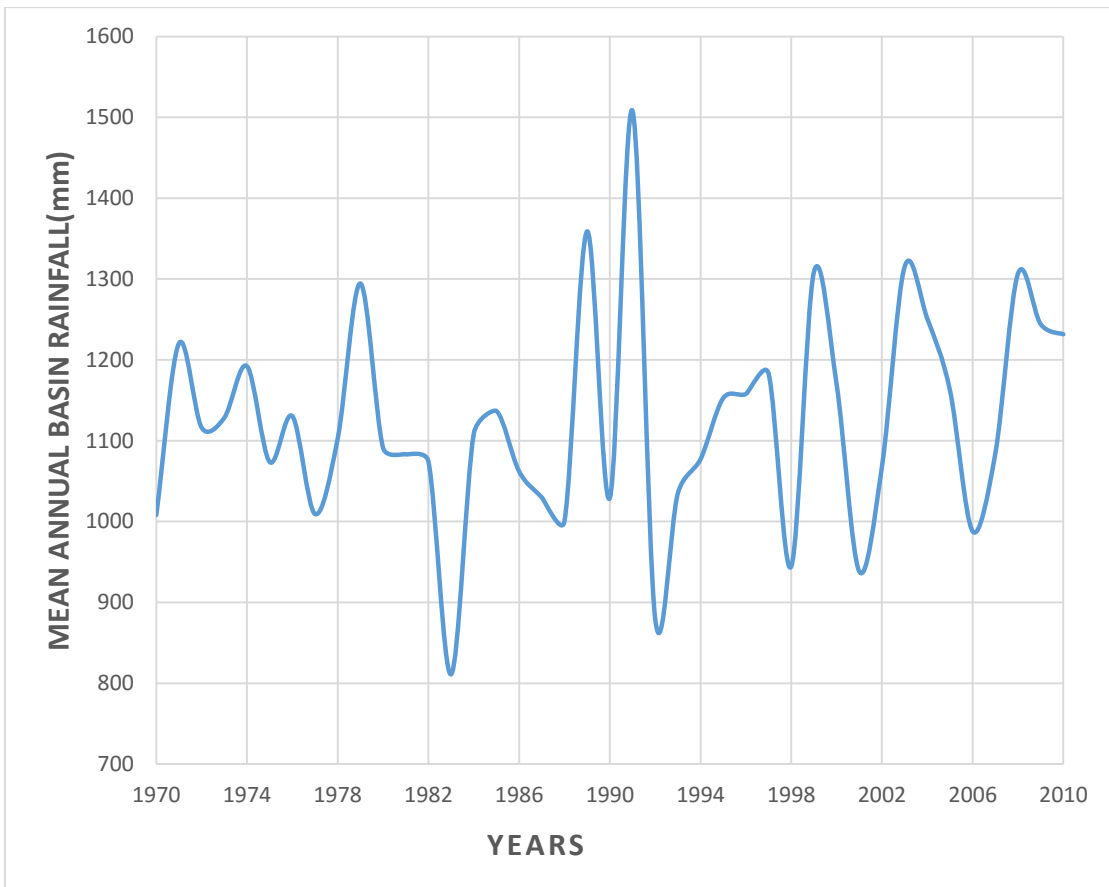


Figure 4. 1: Rainfall trends in the Lower Volta Basin from 1970 to 2010  
 Source: Based on data from GMet (2015)

As shown in Figure 4.1, the rainfall received for the entire basin has been erratic, showing high year to year variability over the study period. Table 4.3 presents the interannual

rainfall changes from the long-term average rainfall for the lower Volta Basin. The mean annual basin rainfall for the 1970s was quite high, reaching about 1295mm in 1979 before plummeting to its lowest ever recorded amount of 811mm in 1983, a 26.27% reduction from the Basin average.

Table 4.3: Changes in Mean Annual Basin Rainfall

| P1 (1970 – 1990) |                       |                      | P2 (1991 – 2010) |                       |                      |
|------------------|-----------------------|----------------------|------------------|-----------------------|----------------------|
| YEAR             | CHANGE FROM MEAN (mm) | CHANGE FROM MEAN (%) | YEAR             | CHANGE FROM MEAN (mm) | CHANGE FROM MEAN (%) |
| 1970             | -91.90                | -8.35                | 1991             | 408.07                | 37.10                |
| 1971             | 120.40                | 10.95                | 1992             | -220.07               | -20.01               |
| 1972             | 16.18                 | 1.47                 | 1993             | -65.00                | -5.91                |
| 1973             | 28.38                 | 2.58                 | 1994             | -22.92                | -2.08                |
| 1974             | 92.12                 | 8.37                 | 1995             | 52.68                 | 4.79                 |
| 1975             | -26.32                | -2.39                | 1996             | 57.82                 | 5.26                 |
| 1976             | 30.38                 | 2.76                 | 1997             | 83.07                 | 7.55                 |
| 1977             | -90.70                | -8.25                | 1998             | -155.63               | -14.15               |
| 1978             | 2.72                  | 0.25                 | 1999             | 208.50                | 18.95                |
| 1979             | 194.48                | 17.68                | 2000             | 70.20                 | 6.38                 |
| 1980             | -8.73                 | -0.79                | 2001             | -161.77               | -14.71               |
| 1981             | -16.82                | -1.53                | 2002             | -32.25                | -2.93                |
| 1982             | -25.68                | -2.33                | 2003             | 215.12                | 19.56                |
| 1983             | -288.95               | -26.27               | 2004             | 150.95                | 13.72                |
| 1984             | 8.58                  | 0.78                 | 2005             | 62.37                 | 5.67                 |
| 1985             | 36.82                 | 3.35                 | 2006             | -112.13               | -10.19               |
| 1986             | -37.97                | -3.45                | 2007             | -16.00                | -1.45                |
| 1987             | -70.03                | -6.37                | 2008             | 206.58                | 18.78                |
| 1988             | -99.70                | -9.06                | 2009             | 144.25                | 13.11                |
| 1989             | 258.97                | 23.54                | 2010             | 131.67                | 11.97                |
| 1990             | -70.88                | -6.44                |                  |                       |                      |

Note: + (Increase), - (Reduction)

Source: Based on data from GMet (2015)

The rainfall amount seem to have recovered between 1984 and 1991, recording 1508mm of rain in 1991 (a 37.1% increase over the Basin average) before hitting another low of

about 880mm in 1992, a 20% reduction from the Basin average. Other low rainfall years within the period include 1998, 2001 and 2006 (when there was a 14.15%, 14.71% and 10.19% reduction respectively in rainfall over the Basin average). Also Figure 4.1 shows that 1999 received 1308.5mm of rainfall, an 18.95% increment over the Basin average. Rainfall amounts were generally low after 1999 until the year 2003, which recorded a 19.56% increase over the Basin average rainfall input. Additionally, the rainfall trend shown in Figure 4.1 points to a declining mean basin rainfall after 2008.

In order to test for significant differences in the mean annual basin rainfall, the two year categories, P1 (1970 – 1990) and P2 (1991 -2010) were used as a grouping variable. The first period, P1 (N=21) was associated with a mean annual basin rainfall  $M=1098.17$  ( $SD=112.78$ ). By comparison, the second period, P2 (N=20) was associated with a numerically slightly high rainfall  $M=1150.29$  ( $SD=153.66$ ). To test the null hypothesis that P1 and P2 were associated with no statistically significant difference in mean annual rainfall amounts, an independent t-test was performed. As can be seen in Table 4.4, P1 and P2 distributions were sufficiently normal for the purpose of conducting a t-test (ie. skew  $< |2.0|$  and kurtosis  $< |9.0|$ ; Schmider, Ziegler, Danay, Beyer, & Buhner, 2010). A Shapiro-Wilk's test ( $p>.05$ ) and a visual inspection of their histogram, normal Q-Q plots and box plots showed that the rainfall amounts were approximately normally distributed for both P1 and P2, with a skewness of 0.052 ( $SE=0.501$ ) and a kurtosis of 2.117 ( $SE=0.972$ ) for P1 and a skewness of 0.248 ( $SE=0.512$ ) and a kurtosis of 0.181 ( $SE=0.992$ ) for P2. Table 4.4 presents a summary of the results of the independent samples t-test.

Table 4.4: Summary t-test results associated with Mean Annual Basin Rainfall

| Parameters         | P1 (1970-1990)           | P2 (1991-2010) |
|--------------------|--------------------------|----------------|
| N                  | 21                       | 20             |
| Mean               | 1098.17                  | 1150.29        |
| Standard Deviation | 112.78                   | 153.66         |
| Skewness           | .052                     | .248           |
| Kurtosis           | 2.117                    | .181           |
| Levene's Test      | F (39) = 2.365, p= .132  |                |
| T-test             | t (39) = -1.243, p= .221 |                |

Note: Standard Error for Skewness: P1 (.501), P2 (.512)  
Standard Error for Kurtosis: P1 (.972), P2 (.992)

**Source: Based on data from GMet (2015)**

As shown in Table 4.4, the assumption of homogeneity of variances was tested and satisfied via Levene's F-test,  $F(39) = 2.365$ ,  $p = .132$ . The independent samples t-test was associated with statistically non-significant effect,  $t(39) = -1.243$ ,  $p = .221$  (Table 4.4). The null hypothesis can therefore not be rejected. This means there is no statistically significant difference in mean annual basin rainfall between the first period (P1) and the second period (P2).

### **El Niño-Southern Oscillation**

El Niño-Southern Oscillation (ENSO) as pointed out earlier is the largest determinant of rainfall variability in the tropics as a whole (Mude et al., 2007). An analysis of ENSO is therefore conducted to examine the influence of the phenomenon on rainfall variability in the Volta Basin. Figure 4.2 illustrates the trend of the ENSO phenomenon for the period 1970 -2010 using the JMA Index. In Figure 4.2, El Niño years have positive sea surface

temperature (SST) anomaly of  $0.5^{\circ}\text{C}$  and above. La Niña years have negative SST anomaly of  $-0.5^{\circ}\text{C}$  or below. The Neutral Phase also known as normal years have SST anomaly of between  $-0.5^{\circ}\text{C}$  and  $0.5^{\circ}\text{C}$ .

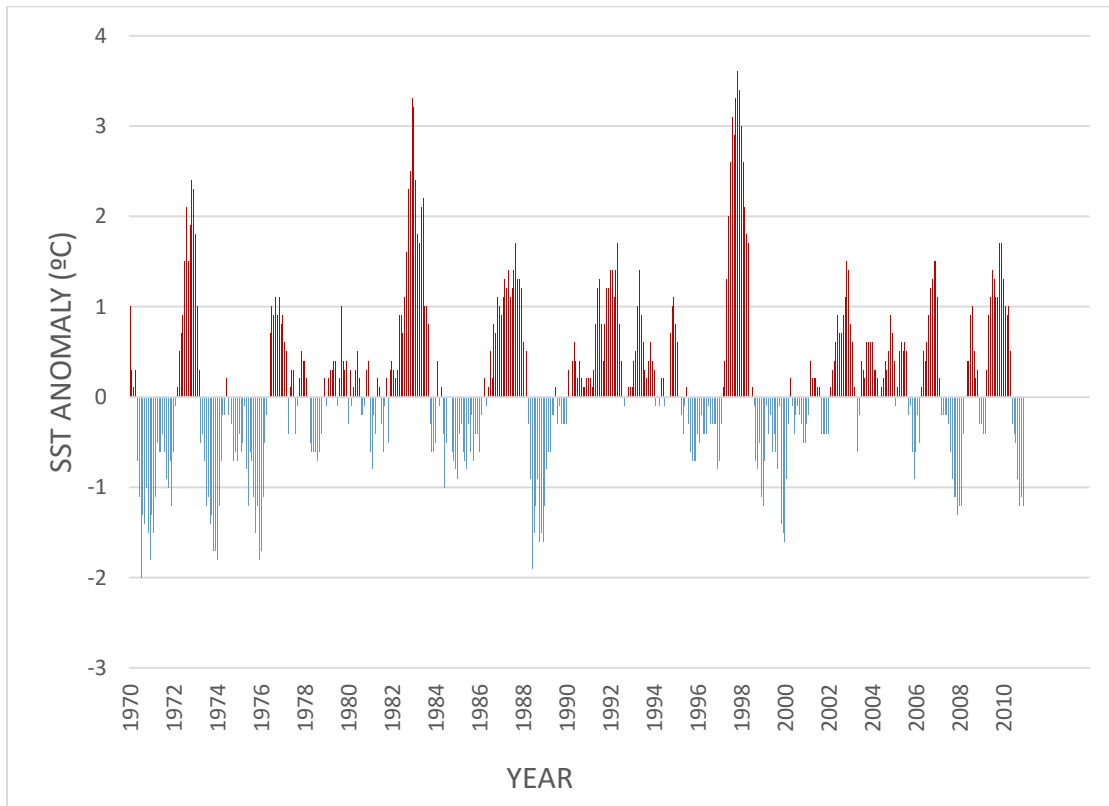


Figure 4. 2: ENSO occurrence from 1970 to 2010

*Source: Based on data from JMA (2015)*

As shown in Figure 4.2, major El Niño years include 1972/1973, 1982/1983, 1987/1988 and 1997/1998. On the other hand, major La Niña years include 1973/1974, 1975/1976, 1988/1989, 1999/2000, 2008 and 2010.

A one-way analysis of variance was conducted to evaluate the null hypothesis that there are no differences in mean annual basin rainfall received based on the three phases of

ENSO: El Niño years (M=1040.21, SD= 145.94, N=11), Neutral Phase (M=1130.85, SD= 122.14, N=21) and La Niña years (M= 1208.57, SD=98.07, N=9). The assumption of normality was evaluated using histograms (see Appendix B) and found tenable for all groups. As shown in Table 4.5, the assumption of homogeneity of variances was tested and found tenable using Levene's Test,  $F(2, 38) = 0.385$ ,  $p = .683$ . The ANOVA was statistically significant,  $F(2, 38) = 4.605$ ,  $p = .016$ . Thus, there is enough evidence to reject the null hypothesis and conclude that there is a statistically significant difference in mean annual basin rainfall for the different phases of ENSO.

Table 4.5 Summary ANOVA results for ENSO influence on Mean Annual Basin Rainfall

| Parameters                 | El Niño                         | Neutral Phase | La Niña |
|----------------------------|---------------------------------|---------------|---------|
| N                          | 11                              | 21            | 9       |
| Mean                       | 1040.21                         | 1130.85       | 1208.57 |
| Standard Deviation         | 145.94                          | 122.14        | 98.07   |
| Levene's Test              | $F(2, 38) = .385$ , $p = .683$  |               |         |
| ANOVA                      | $F(2, 38) = 4.605$ , $p = .016$ |               |         |
| <b>Partial Eta Squared</b> | <b>.195</b>                     |               |         |

*Source: Fieldwork (2015)*

A Scheffe Post-Hoc test is used to evaluate pairwise differences among group means for the three (3) ENSO phases. At 95% Confidence Interval, there appears to be no statistically significant difference in mean annual rainfall between El Niño and Neutral Phase years. There also appears to be no statistically significant difference in mean annual rainfall between La Niña and Neutral Phase years. There is however a statistically significant difference in mean annual rainfall between the El Niño and La Niña phases (Mean Difference = -168.36,  $p = .017$ ). The Effect size as estimated by Partial Eta Squared is large,

0.195 (19.5%). This means that 19.5% of the variability in mean annual basin rainfall is attributable to the ENSO phenomenon.

### **4.3 VARIABILITY AND CHANGE IN LAKE INFLOW AND LAKE LEVEL ELEVATION**

The second objective of the study was to analyze the variability and change in lake inflow, lake level elevation and power generations at the Akosombo Hydroelectric power station for the four decades between 1970 and 2010.

#### **Net Lake Inflow**

The annual Net Lake Inflows in Million Acre-Feet (MAF) derived from the monthly Net Lake Inflows was used for the analysis presented in this section. The calculated annual data was used to generate a line graph of the annual Net Lake Inflow from 1970 -2010 illustrated in Figure 4.3.

The trend of Lake Net Inflows have been quite irregular. As shown in Figure 4.3, the Net Lake Inflow increased to about 31.07MAF in 1974 from about 14.55MAF in 1970. Another decline set in until it reached a lowly 10.93MAF in 1977. There was again an increasing trend, reaching 40.54MAF in 1979 before net inflows starting falling again culminating in the lowest net inflow ever recorded in the period under study, 3.03MAF in 1983. Other low net inflow years include 1990 and 1992. From Figure 4.3, the highest ever recorded net inflow into the Volta Lake was in 1989. Other high net inflow years in the period are 1991, 1999 and 2010. After recording a low inflow in 2006, net inflows started rising up to 2010.

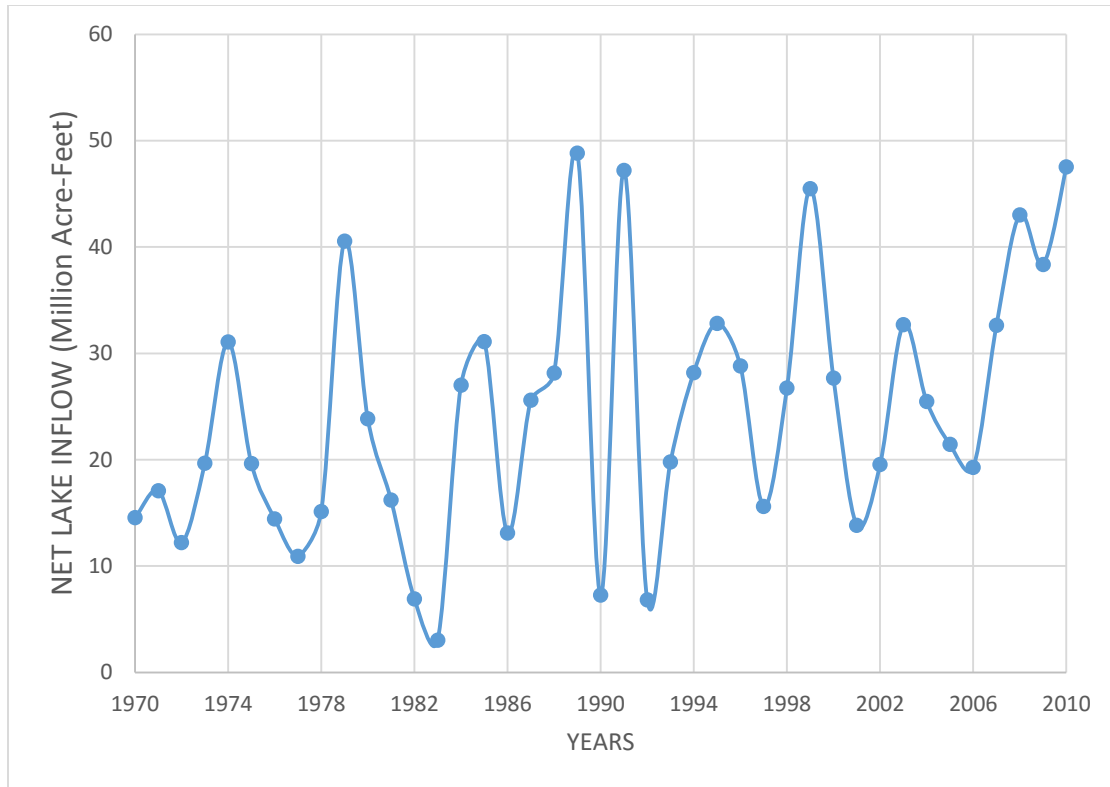


Figure 4. 3: Net Inflow into the Volta Lake Reservoir from 1970 to 2010  
**Source: Based on data from the VRA (2015)**

In order to test for significant differences in Net Lake Inflow, the two year categories, P1 (1970 – 1990) and P2 (1991 -2010) were used as a grouping variable. The first period, P1 (N=21) was associated with a Net Lake Inflow of  $M=20.30$  ( $SD=11.35$ ). By comparison, the second period, P2 (N=20) was associated with a numerically higher Net Lake Inflow of  $M=28.65$  ( $SD=11.51$ ). To test the null hypothesis that P1 and P2 were associated with no statistically significant difference in net lake inflow, an independent t-test was performed.

Table 4.6: Summary t-test results associated with Net Lake Inflow

| Parameters         | P1 (1970-1990)         | P2 (1991-2010) |
|--------------------|------------------------|----------------|
| N                  | 21                     | 20             |
| Mean               | 20.30                  | 28.65          |
| Standard Deviation | 11.35                  | 11.51          |
| Skewness           | .864                   | .131           |
| Kurtosis           | .688                   | -.632          |
| Levene's Test      | F (39) = .005, p= .944 |                |
| T-test             | t (39)= -2.337 p= .025 |                |

Note: Standard Error for Skewness: P1 (.501), P2 (.512)  
Standard Error for Kurtosis: P1 (.972), P2 (.992)

**Source: Fieldwork (2015)**

As can be seen in Table 4.6, P1 and P2 distributions were sufficiently normal for the purpose of conducting a t-test (i.e. skew  $< |2.0|$  and kurtosis  $< |9.0|$ ; Schmider, Ziegler, Danay, Beyer, & Buhner, 2010). A Shapiro-Wilk's test ( $p > .05$ ) and a visual inspection of their histogram, normal Q-Q plots and box plots showed that the net lake inflows were approximately normally distributed for both P1 and P2, with a skewness of 0.864 (SE=0.501) and a kurtosis of 0.688 (SE=0.972) for P1 and a skewness of 0.131 (SE=0.512) and a kurtosis of -0.632 (SE=0.992) for P2. Additionally, the assumption of homogeneity of variances was tested and satisfied via Levene's F-test,  $F(39) = 0.005$ ,  $p = .944$ . The independent samples t-test was associated with statistically significant effect,  $t(39) = -2.337$ ,  $p = .025$  (Table 4.6). The null hypothesis is therefore rejected. This means there is a statistically significant difference in net lake inflow between the first period (P1) and the second period (P2). Thus, the second period was associated with statistically significantly higher net lake inflows than the first period.

### **Lake Level Elevations**

The analysis of Lake Level elevation was conducted using the monthly and annual Volta Lake elevations at Akosombo. Figure 4.4 illustrates the pattern of the monthly Volta Lake level elevation for the period 1970 – 2010.

The Volta Lake levels for the study period have been characterized by a series of monthly upsurges and declines. As shown in Figure 4.4, the water level in the Volta Lake was generally high in the 1970s before starting to decrease in the early 1980s. This culminated in the low monthly averages of 239.65ft in July 1983 and 239.16ft in January 1984. The highest monthly average Lake level recorded throughout the study period is 277.17ft in November 2010. Other high lake level elevation months include October 1970, November 1974, December 1974, November 1975, November 1991 and December 2010. The lowest level recorded in the period is 235.16ft in July 2007. Also low lake levels were recorded in July 1985, August 1994, July 1998, July 2002, June 2003 and August 2006. It can also be seen from Figure 4.4 that lake levels have generally been on the rise since hitting the lowest level of 235.16ft in 2007, culminating in the highest level ever recorded in November 2010 (277.17ft).

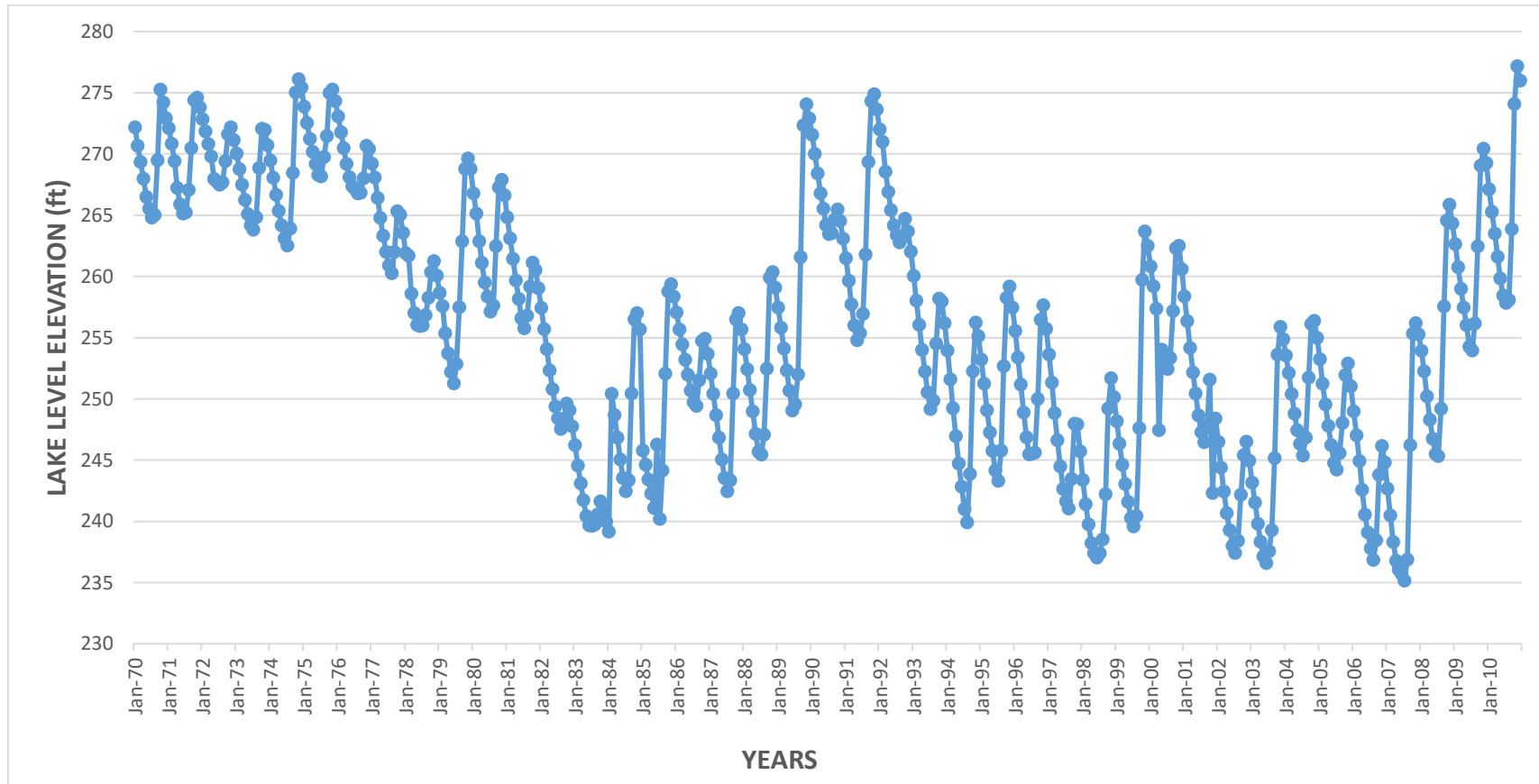


Figure 4. 4: Monthly Volta Lake elevations from 1970 to 2010  
*Source: Based on data from the VRA (2015)*

In order to test for significant differences in the lake level elevation, the mean annual lake level elevations were used. The two year categories, P1 (1970 – 1990) and P2 (1991 -2010) were again used as a grouping variable. The first period, P1 (N=21) was associated with a Lake Level Elevation of M=259.89 (SD=9.03). By comparison, the second period, P2 (N=20) was associated with a numerically low Lake Level Elevation of M=251.37 (SD=7.61). To test the null hypothesis that P1 and P2 were associated with no statistically significant difference in lake level elevation, an independent t-test was performed. As can be seen in Table 4.7, P1 and P2 distributions were sufficiently normal for the purpose of conducting a t-test (i.e. skew  $< |2.0|$  and kurtosis  $< |9.0|$ ; Schmider, Ziegler, Danay, Beyer, & Buhner, 2010).

Table 4.7: Summary t-test results associated with Lake Level elevation

| Parameters         | P1 (1970-1990)          | P2 (1991-2010) |
|--------------------|-------------------------|----------------|
| N                  | 21                      | 20             |
| Mean               | 259.89                  | 251.37         |
| Standard Deviation | 9.03                    | 7.61           |
| Skewness           | -.418                   | .623           |
| Kurtosis           | -1.040                  | -.612          |
| Levene's Test      | F (39) = 1.276, p= .226 |                |
| T-test             | t (39) = 3.259, p= .002 |                |

Note: Standard Error for Skewness: P1 (.501), P2 (.512)

Standard Error for Kurtosis: P1 (.972), P2 (.992)

*Source: Fieldwork (2015)*

A Shapiro-Wilk's test ( $p > .05$ ) and a visual inspection of their histogram, normal Q-Q plots and box plots showed that the rainfall amounts were approximately normally distributed for both P1 and P2, with a skewness of -0.418 (SE=0.501) and a kurtosis of -1.040

(SE=0.972) for P1 and a skewness of 0.623 (SE=0.512) and a kurtosis of -0.612 (SE=0.992) for P2. As shown in Table 4.7, the assumption of homogeneity of variances was tested and satisfied via Levene's F-test,  $F(39) = 1.276$ ,  $p = .226$ . The test was associated with a statistically significant effect,  $t(39) = 3.259$ ,  $p = .002$ . The null hypothesis is therefore rejected. This means there is a statistically significant difference in Lake Level Elevation between the first period (P1) and the second period (P2). The second period (P2) was associated with a statistically significantly lower Lake Level elevation than the first period (P1).

#### **4.4 FLUCTUATIONS IN ELECTRICITY PRODUCTION FROM THE AKOSOMBO HYDROELECTRIC POWER STATION**

The annual power generation derived from the monthly power generation totals at the Akosombo Hydroelectric Power Station are used for the analysis presented in this section. Figure 4.5 shows the trend of the annual power generation at the Akosombo Power Station. It can be seen from the line graph that annual power generation was on the increase from 1970 until it reached 5277GWh in 1980. After 1980, a decreasing trend was experienced, with output plummeting to its lowest of 1468GWh in 1984. Other low power output years include: 1998, 2003 and 2007. Power generation in 2007 was very low, recording an output of 3104GWh. However, it can be seen that total annual power output had been on the increase over the study period.

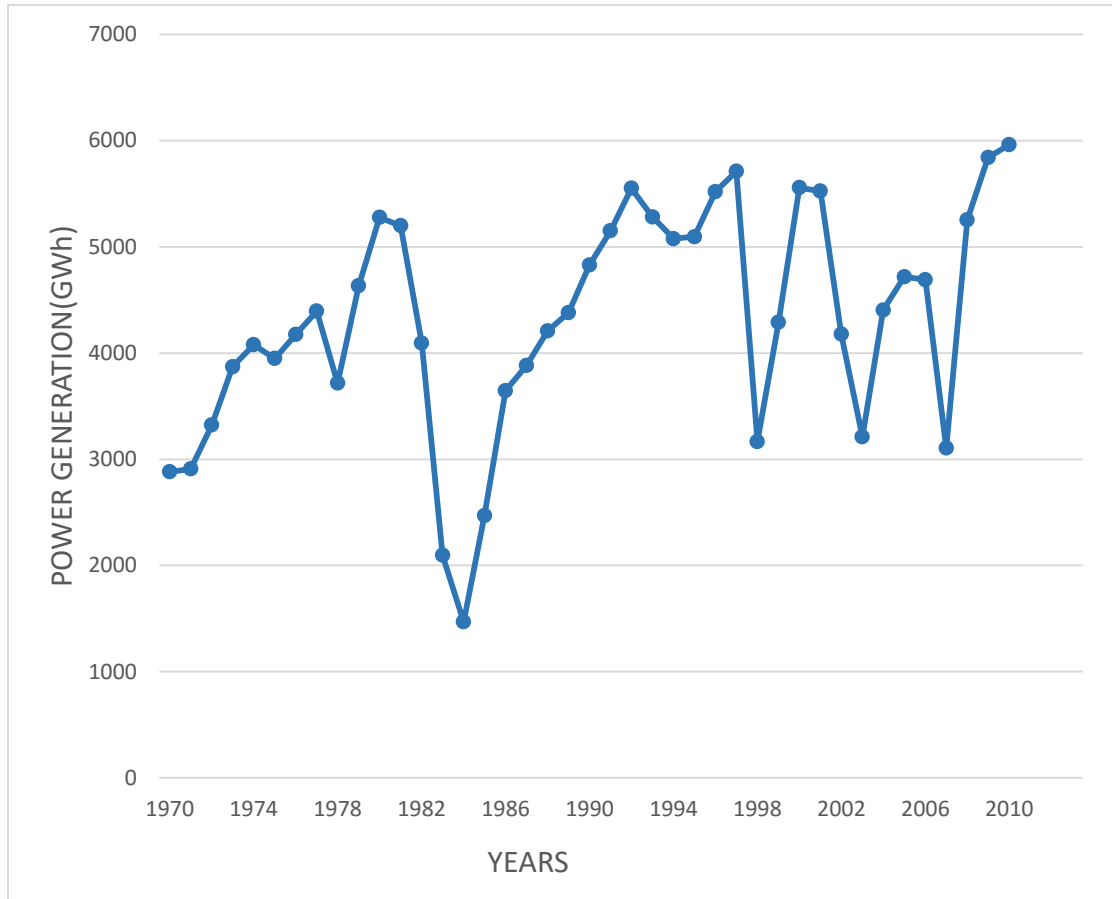


Figure 4. 5: Annual power generation at Akosombo Power Station from 1970 to 2010  
**Source: Based on data from the VRA (2015)**

In order to test for how much of the annual fluctuations in power production is explained by rainfall, ENSO, lake level elevation and net lake inflow, a stepwise multiple regression was ran using mean total basin rainfall, ENSO indices, lake level elevation and net lake inflow as predictor variables. The regression was ran using the two year categories, P1 and P2. The results of the stepwise multiple regression analysis for P1 and P2 are shown in Table 4.8 and 4.9 respectively. Homoscedasticity was checked via a scatter plot of standardized residuals and standardized predicted values with no violations found (see Appendix C). Normality and colinearity were also checked with no violations found.

Table 4.8: Summary results of a stepwise multiple regression analysis for power generation (P1)

| Variables           | Regression Coefficient | Standard Error of Regression Coefficient | Standardized Coefficient (Beta) | t     | Sig  |
|---------------------|------------------------|--|---------------------------------|-------|------|
| Mean Basin Rainfall | 2.964                  | 1.312                                    | .460                            | 2.260 | .036 |

Note:  $R^2 = .212$ , Adjusted  $R^2 = .170$ ;  $F(1, 19) = 5.106$ ,  $p = .036$

*Source: Fieldwork (2015)*

Table 4.9: Summary results of a stepwise multiple regression analysis for power generation (P2)

| Variables            | Regression Coefficient | Standard Error of Regression Coefficient | Standardized Coefficient (Beta) | t      | Sig  |
|----------------------|------------------------|--|---------------------------------|--------|------|
| ENSO                 | -1169.642              | 200.733                                  | -.702                           | -5.827 | .000 |
| Lake Level elevation | 69.930                 | 16.902                                   | .499                            | 4.137  | .001 |

Note:  $R^2 = .753$ , Adjusted  $R^2 = .724$ ;  $F(2, 17) = 25.947$ ,  $p = .000$

*Source: Fieldwork (2015)*

The overall model for P1 was statistically significant,  $p = .036$ ,  $R^2 = .212$ , Adjusted  $R^2 = .170$ , under the null hypothesis is that the model has no explanatory power. The null hypothesis is thus rejected indicating that the model has explanatory power. As can be seen from Table 4.8, the correlation associated with the  $t$  distribution of mean basin rainfall is statistically significant ( $t = 2.260$ ,  $p = .036$ ) under the null hypothesis that the coefficient for mean basin rainfall is zero (i.e. Mean basin rainfall does not help predict power generation). The null hypothesis is therefore rejected meaning mean basin rainfall helps predict power generation. The regression coefficients associated with monthly total basin rainfall is 2.964. This means that if mean basin rainfall increases by a unit (1mm), one will expect power generation to increase by 2.964GWh. The other variables (ENSO, lake level

elevation and net lake inflow) were omitted from the P1 model because their contribution to the annual fluctuations in power generation for the period between 1970 and 1990 were not statistically significant.

The overall model for P2 was statistically significant,  $p=.000$ ,  $R^2=.753$ , Adjusted  $R^2=.724$ , under the null hypothesis is that the model has no explanatory power. The null hypothesis is thus rejected indicating that the model has explanatory power. Based on interpretations of beta weights, ENSO ( $\beta = -.702$ ) was by far the best predictor of annual fluctuations in power generation compared to Lake level elevation ( $\beta=.499$ ). As can be seen from Table 4.9, the correlation associated with the t distribution of ENSO is statistically significant ( $t=-5.827$ ,  $p=.000$ ) under the null hypothesis that the coefficient for ENSO is zero (i.e. ENSO does not help predict annual variation in power generation). The null hypothesis is therefore rejected meaning ENSO helps predict annual variation in power generation. Also, Table 4.9 shows that the correlation associated with the t distribution of Lake level elevation is statistically significant ( $t= 4.137$ ,  $p=.001$ ) under the null hypothesis that the coefficient for Lake level elevation is zero (i.e. Lake level elevation does not help predict annual variation in power generation). The null hypothesis is therefore rejected meaning Lake level elevation helps predict annual variation in power generation. The regression coefficients associated with ENSO, and Lake level elevation are -1169.642 and 69.930 respectively. This means that if ENSO indices increases by a unit, holding Lake level elevation constant, one will expect power generation to decrease by 1169.642GWh. Also if Lake level elevation increases by one unit (1ft) holding ENSO constant, one will expect power generation to increase by 69.930GWh. It can be seen that mean basin rainfall and

net lake inflow were omitted from the regression model because their contribution to the annual fluctuations in power generation for the period between 1991 and 2010 were not statistically significant.

#### **4.4 SUMMARY**

This chapter presented the results of the study. The results were organized based on the study objectives. The results from the analysis of the rainfall data was first presented. The variability and change in lake inflow and lake level elevation was then presented. Finally, the results from the analysis of power generation from the Akosombo Hydroelectric Power Station was presented.

## **CHAPTER FIVE – DISCUSSION**

### **5.1 INTRODUCTION**

This chapter discusses the results of data analysis presented in Chapter 4. The discussion follows the objectives of the study. First, results on the variability and change in rainfall are discussed. This is followed by the discussion of the results on the influence of ENSO on rainfall. Results on fluctuation in power generation from the Akosombo Hydroelectric power station and the energy security implications for Ghana is then provided. The chapter concludes with a summary of the major points discussed.

### **5.2 VARIABILITY AND CHANGE IN RAINFALL**

A visual inspection of the graph showing the mean annual basin rainfall trend (Figure 4.1) suggests that year to year rainfall inputs have been very erratic, ranging from approximately 1500mm in 1991 to about 810mm in 1983. Results of a t-test run to examine the significance of the interannual variability and change in mean annual rainfall between P1 (1970 -1990) and P2 (1991 – 2010) does not show statistically significant difference over the study period even though there are slight changes in the means. However, as shown in Table 4.4, comparisons of the standard deviations of mean annual rainfall for P1 and P2 reveal that rainfall inputs received in P2 were associated with greater variability than rainfall inputs received in P1. The higher standard deviation for P2 means that dry years were drier and wet years were very wet compared to P1. This demonstrates that mean rainfall exhibited year to year variability even though the observed interannual variability did not create significant differences in the mean annual rainfall received for the two

periods. This is somewhat not surprising because aside major El Niño years (1982/1983 and 1997/1998) when rainfall have been abnormally low in Ghana, interannual variability in the form of a shift or delay in the rainfall onset, and a reduction in the length of rainfall period constitutes the best measure of variability and change in rainfall over the years (Lacombe et al., 2012).

Over the 41- year period, 1983 recorded the lowest rainfall inputs, a 26.27% reduction over the long-term Basin average, corresponding to the well documented severe drought conditions experienced in 1982/1983 which was associated with the strong El-Niño occurrence (Figure 4.2). Additionally, the evaluation of variability and change in rainfall in the 6-Synoptic stations based on t-test analysis showed that annual rainfall totals for Bole, Kete-Krachi, Navrongo, Tamale and Yendi exhibited no significant differences for P1 and P2 (Tables 4.1, and 4.2). However, annual rainfall totals for Wa showed that 1992 -2013 recorded significantly higher rainfall amounts compared to 1970 – 1991 (Table 4.2). The annual rainfall inputs increased from 943mm for P1 to 1068mm for P2. This shows clearly that rainfall received at Wa for the second period (1991- 2010) increased significantly over the amounts recorded in the first period (1970-1990) giving an indication that there is spatial variability of rainfall within the lower Volta Basin.

### **5.3 INFLUENCE OF EL NIÑO-SOUTHERN OSCILLATION (ENSO) ON RAINFALL**

The El Niño Southern-Oscillation has been blamed for rainfall anomalies in many parts of the world (Mason & Goddard, 2001). Also, several studies project ENSO as the largest determinant of rainfall variability in Africa and the tropics at large (Nicholson & Kim,

1997; Lyon & Barnston, 2005; Mude et al., 2007). This study therefore evaluates the relationship between rainfall and the ENSO phenomenon in order to study how the phenomenon modulates rainfall in the lower Volta Basin.

An ANOVA test run to establish the influence of the ENSO phenomenon on mean annual basin rainfall revealed a statistically significant result (Table 4.5). This means the ENSO phenomenon has a significant influence on the variability observed in the rainfall inputs in the lower Volta Basin. A Post-Hoc analysis further indicates that the actual differences in rainfall amounts lie between the El Niño and La Niña years. During El Niño years, the average rainfall received in the basin is about 1040mm compared to 1208mm of rainfall received in La Niña years. The average rainfall input for the lower Volta Basin section in Ghana is 1100mm. This means that the occurrence of El Niño and La Niña in the Eastern Pacific are associated with below-normal (low) and above-normal (high) rainfall inputs respectively for the lower Volta Basin which is consistent with the findings of Owusu et al. (2008) and Joly & Voltaire (2009). Also, a look at the standard deviations in Table 4.5, indicate that rainfall received in El Niño years showed much variability than the rainfall received in La Niña years.

The strength of the relationship between ENSO and rainfall in the basin, as assessed using partial eta squared was strong, with 19.5% of the mean annual rainfall inputs in the Basin accounted for by the ENSO phenomenon. This is quite a significant effect as Cabrera et al. (2010) found ENSO to be just one of the many weather phenomena affecting rainfall in any given locality. Considering the fact that the IPCC (2001b) found the ENSO

phenomenon to be occurring more frequently since the mid-1970s with the El Niño event becoming more common, persistent and intense, low rainfall episodes recorded in the Basin over the period under study (1970 - 2013) could fairly be attributed to the El Niño event.

#### **5.4 RAINFALL, LAKE ELEVATION AND NET LAKE INFLOW INFLUENCE ON POWER GENERATION AND ENERGY SECURITY IN GHANA**

A visual inspection of the line graph showing the trend of power generation from the Akosombo Power Station (Figure 4.5) indicates lower power generations in 1984, 1998, 2003 and 2007 which is consistent with the findings of Amekor (2007) and Bekoe & Logah (2013). It can be seen from the mean annual rainfall graph in Figure 4.1 that all these low power generation years are either low rainfall years or preceded by a low rainfall year. Additionally, by comparing Figure 4.4, it is clear that each of these low power generation years is preceded by a low lake elevation year and is also a low lake level year. For instance, the 26.27% reduction in Basin average rainfall recorded in 1983 had severe implications for lake water levels as well as power generation in 1984. It is clearly seen from Figure 4.5 that the total annual power output of 1468GWh recorded in 1984 is the lowest generated over the 41-year study period. This supports the findings of Leemhuis et al. (2009) who stated that the 1984 power shortages in the country were as a result of low lake level in the previous years.

T-test results studying the significance of the variability and change in Lake level elevation indicate that lake water levels for P2 were significantly lower compared to lake levels recorded in P1. This result was not expected as P2 is known to be characterized by the

recovery of the West African Monsoon (Trenberth et al. 2007; Rodríguez-Fonseca et al., 2011; Turner et al., 2011). It was therefore expected that low lake elevations will be associated with P1 and not P2. The study results however suggest otherwise. This is probably due to the inability of Lake level elevations to recover completely from the abnormally low levels recorded in the early 1980s, an explanation consistent with the findings of Leemhuis et al. (2009). It is clear from Figure 4.4 that P2 was associated with frequent and consistent lower lake levels. For instance, for P1, low lake level elevations were recorded in 1983 and 1984 while for P2, low level elevations were recorded in 1994, 1998, 2002, 2003, 2006 and 2007. The mean lake level elevation for P1 was 259.89ft compared to the significantly lower 251.37ft recorded in P2. This suggests that the lake water level behind the Akosombo dam has suffered consistently lower levels over the entire P2 period. It is therefore not surprising that the lowest lake level over the entire study period was recorded in July 2007 (235.16ft).

Additionally, t-test results for net lake inflow show significant differences in net lake inflows between P1 and P2 (Table 4.6). The results illustrate that there were significant increases in net lake inflows for P2 over the levels recorded in P1. Also, a visual inspection of Figure 4.3 indicates pronounced year to year variability. A comparison of the standard deviations in Table 4.6 however does not reveal any significant difference in the interannual variation between the two periods. Figure 4.3 shows that 1982, 1983 and 1997 were associated with low net inflows. These years were consequently followed by low power output years as can be seen from Figure 4.5. This suggest that lower net inflows in one year are more likely to be followed by lower power outputs in the following year.

There are however some exceptions to this finding. For instance, it can be seen that 1990 and 1992 experienced very low net inflows, the two lowest inflows to be recorded aside 1983, yet did not induce low power generations in 1991 and 1993. It is possible that the high amounts of rainfall received in 1989 and 1991 compensated for these low net inflows, thus preventing them from translating into low lake elevations and consequently low power generations.

The total power generation from the Akosombo Hydroelectric Power Station has generally been on the increase after 1991 mainly due to the host of retrofitting exercises carried out during that period (VRA, 2004). However, Figure 4.5 shows that interannual variation in power output has become a more common feature during this period. A regression analysis examining the effect of mean annual rainfall, ENSO, lake level elevation and net lake inflow on fluctuations in power generations for P1 suggest that, rainfall contributed significantly in creating differences in power generation. It can be observed from Table 4.8 that the regression model explains 21.2% of the variability and change in interannual fluctuations in power generation. The model shows that, for every 1mm increase in rainfall there is a 2.964GWh increase in power generation. It therefore stands to reason that if rainfall reduces, power output will fall as a result. This finding confirms what studies by Gyau-Boakye (2001), Van de Giesen et al. (2001), and Lautze et al. (2006) similarly found that mean annual rainfall influences power generation from the Akosombo Power Station.

A regression analysis for the second period, P2, indicate that ENSO and lake level elevation are the significant predictors of the interannual fluctuations in power generated from the

Akosombo Power Station. The model as shown in Table 4.9, explains 72.4% of the variability in the interannual fluctuations in power generation across the second period (1991 – 2010). A study of the beta weights shows that ENSO ( $\beta = -.702$ ) makes the highest contribution to the fluctuations in annual power generation compared to lake level elevation ( $\beta = .449$ ) for the P2 period.

An increase in the ENSO index by 1 unit is associated with a reduction of 1169.64GWh in the annual power output, holding Lake level elevation constant. Since increases in the ENSO index means warming of the Eastern Pacific (i.e. El Niño), the study concludes that, the occurrence of the El Niño phase is associated with 1169.64GWh reduction in power generation. This was expected as the study had earlier established that the El Niño event is associated with low rainfall inputs in the lower Volta Basin.

Again, it can be seen from Table 4.9 that, an increase of 1ft in lake level elevation across the P2 period, corresponds to 69.93GWh increase in annual power generation, holding ENSO constant. This was also expected because the amount of power generated at a hydropower station is dependent on the flow rate, water level and the overall energy conversion efficiency of the generating plant (Kaunda et al., 2012). This shows how significant ENSO and lake water levels are to hydroelectric power generation from the Akosombo Hydroelectric Power Station. It also suggest a strong relationship between ENSO, lake level elevation and power generation over the 20-year period (P2).

The regression analysis for the two periods suggest that power generation was significantly influenced by rainfall when the rainfall inputs for the whole Volta Basin were in a low phase. However, when the rainfall pattern shifted during the second period (P2), fluctuations in power generation were significantly dictated by the ENSO phenomena and lake level elevation. It is also possible that the low frequency of El Niño and La Niña episodes in P1 in contrast to the high frequency of these events in P2 accounts for why power fluctuation is significantly influenced by the ENSO phenomena over just the P2 period. It is therefore understandable that the lowest lake level for the study period was in July 2007, corresponding to the 2006/07 El Niño year (Figure 4.2), in addition to the fact that 2006 and 2007 years recorded successive reductions in mean basin rainfall (Table 4.3). The results from the regression analysis for both periods, thus, reveal the influence of climate variability and change on fluctuations in power generation through their influence on mean basin rainfall, and lake level elevation which supports the findings of Saadia (2008), Amekor (2007) and Kasei (2009), and as this study has demonstrated, through its effects on the ENSO phenomena. The IPCC (2001b) found the El Niño event to be occurring more frequently and severely since the mid-1970s. Since El Niño is associated with a reduction of 1169.64GWh in annual power generation, the study concludes that fluctuations in power generation at the Akosombo Hydroelectric power station will continue, especially in a future where El Niño is predicted to be more frequent and severe as a result of anthropogenic climate change. This shows that low power generation from the Akosombo Hydroelectric power station and other hydroelectric power sources like the Bui will more likely become worse as future El Niño episodes become more severe.

These climate variability challenges when added to traditionally inherent hydropower challenges such as risk from siltation and flooding (Harrison et al., 1998), upstream water abstraction especially at Burkina Faso, transboundary water problems (Lautze et al., 2006), and technical challenges (Sackey, 2007), will seriously affect the ability of Ghana's hydropower infrastructure to supply adequate and sufficient electricity for present and future generations. This means Ghana's power output will continue to fluctuate and more likely worsen unless there is a change in the direction of the country's power policy. Power shortages and frequent blackouts will continue to plague the country as the major electricity supply sector, i.e. hydropower sector, continues to suffer due to variability in rainfall, ENSO and lake level elevation. The continuous reliance on hydropower for the provision of adequate and secure power for Ghana is therefore risky and probably unsustainable considering the average demand of electricity keeps rising between 10 and 15% per year (Acheampong & Ankrah, 2014). According to a report by the Ghana National Commission for UNESCO (2010), a situation of reducing power supply amidst significant annual increases in electricity demand introduces a tight demand-supply balance with no reserve margin which leads to the persistence of periodic blackouts.

Previous research (OFID, 2010; Bukari, 2012; Okudzeto et al., 2014) had shown that the supply of sufficient power generally boosts productivity and growth. Alternatively, inadequate power supply stifles sustainable development. For example, the 2010 Wholesale Power Reliability Assessment Report showed that Ghana's GDP growth reduces between 2 and 6% annually as a result of erratic power supply (PSEC, 2010). This means that persistent power shortages will hinder the ability of the country to achieve

sustainable development. There is therefore an urgent need for an effective and efficient energy policy with a clear direction on diversifying away from hydropower if the government wants to attract and sustain industries as a way of achieving development for the country.

## **5.5 SUMMARY**

This chapter was used to discuss the study results. A discussion of the variability and change in rainfall in the lower Volta Basin was first presented. This showed that rainfall exhibited greater interannual variability throughout the study period. The chapter then presented a discussion of the influence of ENSO on rainfall in the lower Volta Basin. Finally, rainfall variability, lake elevation and net lake inflow influence on power generation and energy security in Ghana were discussed.

## **CHAPTER SIX – SUMMARY, CONCLUSIONS AND RECOMMENDATIONS**

### **6.1 INTRODUCTION**

This chapter presents the conclusions from this study. The first section presents the findings of the study. The second section covers recommendations based on the findings of the study. The final section presents the conclusions of the study.

### **6.2 SUMMARY OF FINDINGS**

The major finding of the study is that year to year fluctuations in power output from the Akosombo Hydroelectric power station were significantly influenced by rainfall between 1970 and 1990, and thereafter, by ENSO and lake level elevations. Additionally, there were pronounced year to year variations in rainfall, lake levels and net lake inflows for the entire study period. Rainfall explained 21.2% of the interannual fluctuations in power output between 1970 and 1990 while ENSO and lake water level explained 72.4% of the interannual fluctuations in power output between 1991 and 2010. ENSO events were also found to be occurring frequently in the P2 period (1991 – 2010) than in the P1 period (1970 – 1990). Lake water levels were also found to be significantly lower for the P2 period than for P1. The combination of these factors and their effect on power generation means hydropower output from the Akosombo Hydroelectric power station will continue to be more variable and unreliable going into the future.

ENSO with a periodicity of 3 to 7 years has a significant influence on the amounts, distribution and variability of rainfall in the lower Volta Basin of Ghana. The study found that ENSO accounts for 19.5% of the mean rainfall received in the Basin. There were however, no significant differences in rainfall amounts between P1 (1970 – 1990) and P2 (1991 – 2010) even though there were slight differences in the mean annual total for the two periods.

Climate variability and change was therefore found to influence power generation through its influence on rainfall, the ENSO phenomena and Lake water level at the Akosombo Power Station. The overall effect of these findings is that while ENSO (especially, the El Niño phase), becomes more frequent and severe, and rainfall and lake water levels continue to be more variable from one year to the other, hydropower generation in the country will continue to suffer. Since electricity generated at Akosombo power station and hydropower in general represents a hugely significant proportion of Ghana's power generation mix, a significant reduction in power generated from this sector will worsen the already recurring power shortages and its attendant blackouts in the country.

### **6.3 RECOMMENDATIONS**

Based on the above findings, the study makes the following recommendations.

Ghana should consider the possible diversification of its electricity generation away from hydropower to non-hydro based options, preferably cleaner technology, in order to guarantee the supply of adequate and sufficient power for its citizens and meet the desired

target of exporting power to the West African sub-region. It is clear from the findings that climate variability and change will continue to affect power output from Ghana's hydropower sector and as such a continued reliance on this power source is not advisable. The expansion of the thermal sector looks more feasible especially with the commencement of commercial gas production from the country's oil fields following the discovery of large gas reserves.

#### **6.4 CONCLUSION**

This study sought to demonstrate empirically that variability and change in rainfall as well as through its effects on ENSO will present severe climatic risks to Ghana's power sector unless the country makes an effort to change the hydro-dependent energy policy it is currently implementing. The findings of the study support the study hypothesis that changes in rainfall inputs in the lower Volta Basin influences power generation from the Akosombo Hydroelectric power station. The generation of power from the Akosombo Power Station is quite complex considering the array of factors which influence power generation in Ghana (Stanturf et al., 2011). Aside climate variability and change, there are complex challenges such as transboundary water issues, dam siltation, threats of structural damage to the hydro-infrastructure as a result of flooding, among others challenges, dictating the amount of power generated within any specific year.

The study found that mean basin rainfall, lake level elevations and the ENSO phenomena accounted for a greater part of the interannual variability in power output from the Akosombo Hydroelectric power station. The study revealed that climate variability and

change influenced hydropower generation through its effect on rainfall between 1970 and 1990. However, between 1991 and 2010, climate variability and change influenced power outputs through its effects on ENSO and also through lake water levels behind the Akosombo dam.

This means that Ghana needs to diversify away from hydropower in order to achieve energy security and sustainable development. With rainfall predicted to become more variable and El Niño increasing in both frequency and magnitude, the country must act swiftly to alter the current energy policy pathway if the frequently recurring power shortages and subsequent blackouts are to be resolved.

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**APPENDIX A: T-TEST OUTPUT**

| Tests of Normality       |               |                                 |    |       |              |    |      |
|--------------------------|---------------|---------------------------------|----|-------|--------------|----|------|
|                          | YearB         | Kolmogorov-Smirnov <sup>a</sup> |    |       | Shapiro-Wilk |    |      |
|                          |               | Statistic                       | Df | Sig.  | Statistic    | df | Sig. |
| Rainfall For Bole        | P1(1970-1990) | .121                            | 21 | .200* | .976         | 21 | .859 |
|                          | P1(1991-2010) | .128                            | 20 | .200* | .965         | 20 | .653 |
| Rainfall For Tamale      | P1(1970-1990) | .110                            | 21 | .200* | .962         | 21 | .554 |
|                          | P1(1991-2010) | .094                            | 20 | .200* | .981         | 20 | .942 |
| Rainfall For Navrongo    | P1(1970-1990) | .125                            | 21 | .200* | .968         | 21 | .686 |
|                          | P1(1991-2010) | .103                            | 20 | .200* | .986         | 20 | .988 |
| Rainfall For Kete-Krachi | P1(1970-1990) | .142                            | 21 | .200* | .968         | 21 | .677 |
|                          | P1(1991-2010) | .113                            | 20 | .200* | .908         | 20 | .059 |
| Rainfall For Wa          | P1(1970-1990) | .179                            | 21 | .078  | .963         | 21 | .580 |
|                          | P1(1991-2010) | .109                            | 20 | .200* | .962         | 20 | .594 |
| Rainfall For Yendi       | P1(1970-1990) | .107                            | 21 | .200* | .977         | 21 | .880 |
|                          | P1(1991-2010) | .140                            | 20 | .200* | .964         | 20 | .629 |

\*. This is a lower bound of the true significance.

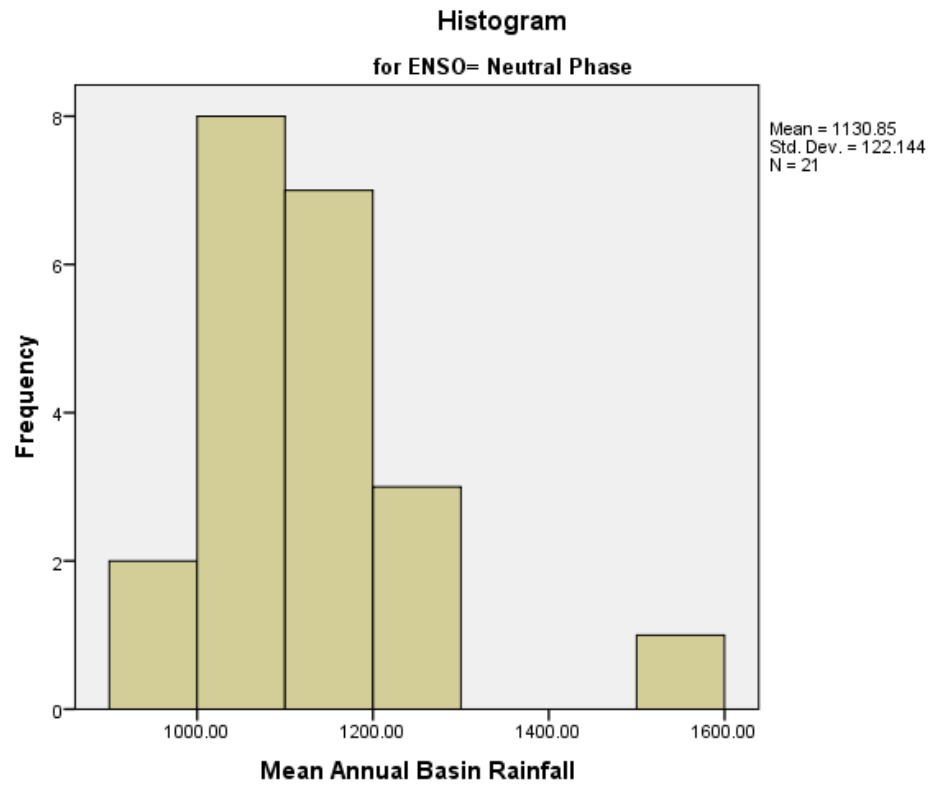
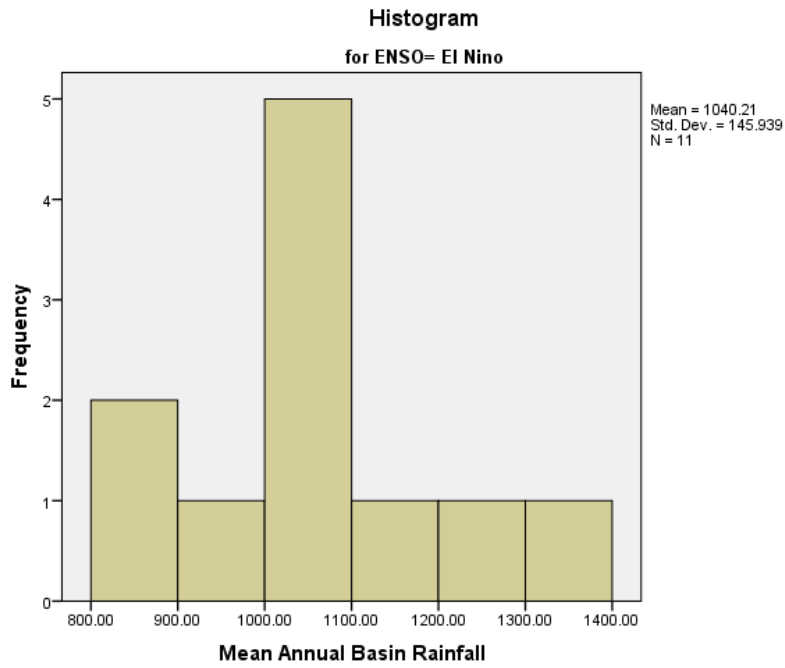
a. Lilliefors Significance Correction

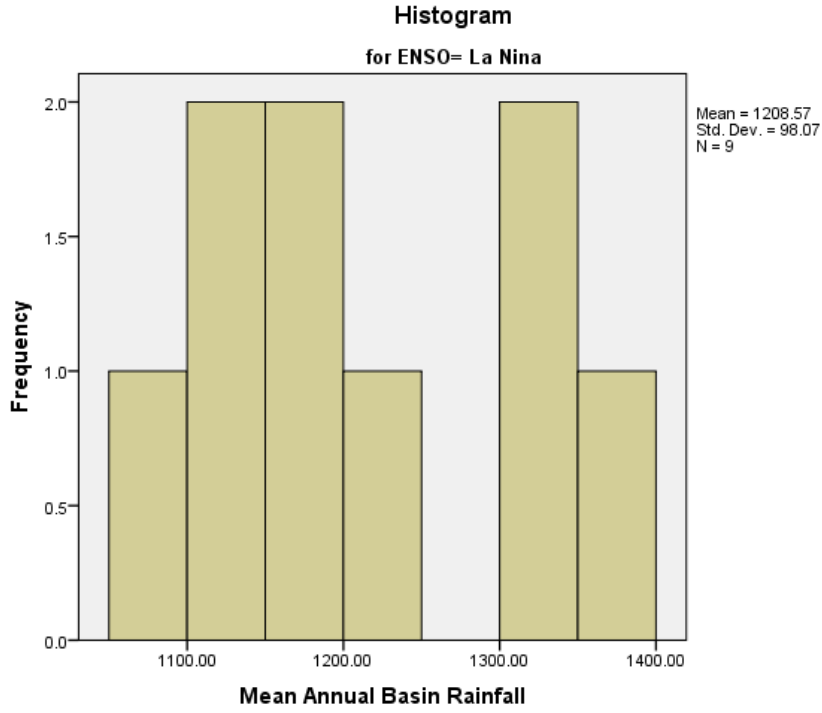
| Tests of Normality         |               |                                 |    |       |              |    |      |
|----------------------------|---------------|---------------------------------|----|-------|--------------|----|------|
|                            | YearB         | Kolmogorov-Smirnov <sup>a</sup> |    |       | Shapiro-Wilk |    |      |
|                            |               | Statistic                       | df | Sig.  | Statistic    | df | Sig. |
| Mean Annual Basin Rainfall | P1(1970-1990) | .175                            | 21 | .091  | .935         | 21 | .175 |
|                            | P1(1991-2010) | .106                            | 20 | .200* | .976         | 20 | .870 |
| Volta Lake Elevations      | P1(1970-1990) | .144                            | 21 | .200* | .923         | 21 | .099 |
|                            | P1(1991-2010) | .169                            | 20 | .139  | .912         | 20 | .070 |
| Volta Lake NetInflow       | P1(1970-1990) | .141                            | 21 | .200* | .947         | 21 | .296 |
|                            | P1(1991-2010) | .108                            | 20 | .200* | .964         | 20 | .623 |

\*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

## APPENDIX B: ONE-WAY ANOVA OUTPUT





### APPENDIX C: REGRESSION OUTPUT

