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## Impact of climate change and variability on hydropower in Ghana

Sylvester Afram Boadi\* and Kwadwo Owusu

*Climate Change & Sustainable Development Programme, University of Ghana, P.O. Box LG 59, Legon, Accra, Ghana*

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Ghana continues to rely heavily on hydropower for her electricity needs. This hydropower reliance cannot ensure sustainable development since there is a strong association between hydropower production and climate variability and change including ENSO-related lake water levels reduction. Using regression analysis this study found that rainfall variability accounted for 21% of the inter-annual fluctuations in power generation from the Akosombo Hydroelectric power station between 1970 and 1990 while ENSO and lake water level accounted for 72.4% of the inter-annual fluctuations between 1991 and 2010. There is therefore the need to diversify power production to attain energy security in Ghana.

**Keywords:** climate change and variability; El Niño-Southern Oscillation; hydropower; energy security; Ghana

### Background

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 (IPCC, 2007). The reliance on climate sensitive sectors such as hydropower has become a challenge to sustainable development as a result of climate variability and change impacts on power generation (Okudzeto, Mariki, Paepe, & Sedegah, 2014). There is evidence showing that African countries have not been able to meet their development targets due to climate variability and change impacts on hydro-power production (Beilfuss, 2012), resulting from both anthropogenic climate change and natural variability such as the El Niño-Southern Oscillation (ENSO) which is the largest known source of climate variability in the tropics (Camberlin, Janicot, & Pocard, 2001; Collins et al., 2010). Ghana has the potential to grow its economy through industrialization, increased productivity, job creation, and equitable wealth distribution (Ministry of Energy [MoE], 2010a). However, in order to achieve this economic development, there is the need for adequate generation and supply of energy.

In addition to an annually increasing power demand locally, the Volta River Authority (VRA) exports power to the Communauté Electrique du Benin [CEB] – comprising Togo and Benin, SONABEL (Burkina Faso), while also interchanging power with Compagnie Ivoirienne d'Electricité [CIE] of La Cote d'Ivoire, as part of efforts to achieve a West African Power Pool (VRA, 2015). According to Badu (2013), Ghana requires 6000 MW of power by 2015 to guarantee sustainable growth and development.

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\*Corresponding author. Email: [safam\\_boadi@st.ug.edu.gh](mailto:safam_boadi@st.ug.edu.gh)

However, the country's current total installed capacity is just about 2846.5 MW (VRA, [VRA], 2014). Ghana, thus, has an electricity generation deficit of over 3000 MW. 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 in the last three years.

Ghana's energy strategy to bridge this power deficit however weighs heavily on hydropower and included the recently completed 400 MW Bui Hydroelectric power project, the development of a planned 625 MW Western Rivers Hydropower project and 90 MW Juale Hydropower project, the implementation of the Aboadze TICO Power plant steam turbine and the operationalization of the 125 MW Osagyefo Power Barge (MoE 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, Waylen, & Qiu, 2008). Historic records have however shown that rainfall pattern over West Africa has undergone a period of decline, accompanied by a series of severe droughts and a shift in the rainfall regime since the 1970s (Kasei, 2009; Owusu, 2009). 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 from the Akosombo Hydropower Dam. Other studies have also demonstrated the strong effect of ENSO on rainfall distribution and runoff in West Africa (Losada et al., 2012; Rodríguez-Fonseca et al., 2011). Ghana's power sector is already showing signs of susceptibility to variability and change in rainfall (Bekoe & Logah, 2013), including variability due to ENSO (Owusu et al., 2008; Waylen & Owusu, 2014).

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 Ghana, 2012; Harrison, Whittington, & Gundry, 1998). 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. This poses a developmental challenge as even in a stable climate, the year to year variability mostly associated with ENSO continues to affect power production from hydro sources. Meanwhile Ghana's climate has been projected to be warmer and drier due to climate change (Environmental Protection Agency & Ministry of Environment, Science, Technology and Innovation [EPA & MESTI], 2015; McSweeney, New, & Lizcano, 2010; Minia, 2008). 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 that climate variability including variability due to ENSO, will make a hydropower-dependent energy strategy unsustainable for current and future power needs. The objective of this study is therefore to identify the influence of variability and change in rainfall including ENSO effect on the Akosombo Hydroelectric Power project's (the largest dam in Ghana) capacity to provide secure and sustainable electricity for Ghana's development.

### Climate variability and change impacts on hydropower generation

Energy systems are increasingly being affected by changing climatic trends. For example, increasing variability, frequent extremes, and large inter-annual variation in climate parameters are severely affecting hydropower production in some regions (Ebinger & Vergara, 2011). Hydropower is especially vulnerable as it relies on water resources such as runoff, river flow (Hamududu, 2012), and precipitation. Beilfuss (2012) evaluated the hydrological risk of hydro-dependent power systems in Southern Africa 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. The IPCC (2001, 2013) has categorized the Zambezi Basin as the river basin exhibiting the most severe effects of climate change because of the impacts of temperature increases and reductions in rainfall. There are two large hydropower dams operating on the main-stream Zambezi River namely, Kariba Dam and Cahora Bassa Dam. Climate variability and associated droughts have 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%. 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.

Grijnsen (2014) in a study presented a Climate Risk Assessment (CRA) for the five main basins in Cameroon, focusing on climate change impacts on water resources 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 and Ayongue (2010) in their study recorded an increase in temperature of 0.8 °C, a decline in rainfall by 112 mm/yr (6.5%) and reduction in runoff by 142 m<sup>3</sup>/s (7.5%) for the Sanaga Basin. According to Grijnsen (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 based on a different projection. Minor to moderate impacts were also recorded for power generation from the other basins.

These impacts from climatic changes on hydropower is magnified by the year-to-year variability in rainfall, such as that introduced by ENSO, which 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). Joly and Voltaire (2009) report that a significant part of the West African Monsoon's inter-annual variability can be explained by ENSO teleconnections.

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 inter-hemispheric 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 were caused by severe drought conditions over West Africa corresponding to a decrease in precipitation in the whole monsoon system (Mohino et al., 2011). 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) attributed reductions in the levels of East African lakes to ENSO-events. Hydro-power generation depends on lake water levels which led Seitz and Nyangena (2009) to conclude that, these reductions in East African lake levels are likely to disrupt power generation.

In Ghana, climate variability and change including ENSO has been recorded to reduce the hydropower generation capacity of the Akosombo Generating Station (Owusu et al., 2008; Bekoe & Logah, 2013; Waylen & Owusu, 2014). The growth rate of manufacturing sector in the country has currently slowed down since 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, Davis, Eberhard, Gratwick, & Wamukonya, 2005) under the current energy policy and strategy which is 52% hydropower driven ([www.vra.com](http://www.vra.com)). It is therefore very risky for Ghana to continue the current hydro-dependent energy policy and strategy. Given the current trend of climate variability and change impacts on hydropower and the projected increase in temperature and reduction in rainfall (EPA & MESTI, 2015), there is a strong possibility that the country is investing in a power technology that may not be sustainable going into the future.

## **Data and methodology**

### ***Study area***

The Volta River Basin which is the area of study is located between Latitudes 5°N and 14°N and Longitude 2°E and 5°W (Figure 1). It has a total surface area of about 414,000 km<sup>2</sup> shared between six riparian nations: Benin, Burkina Faso, Cote d'Ivoire, Ghana, Mali and Togo (Owusu et al., 2008; 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, Senne and Afram rivers (Aquastat Survey, 2005).

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 (Kasei, 2009). On the whole, the mean annual temperature for the Volta Basin indicates an increasing trend. The increase in temperature in the south Volta Basin was 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 VRA which was 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 Aluminum industry operated by the Volta Aluminum 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 912 MW,

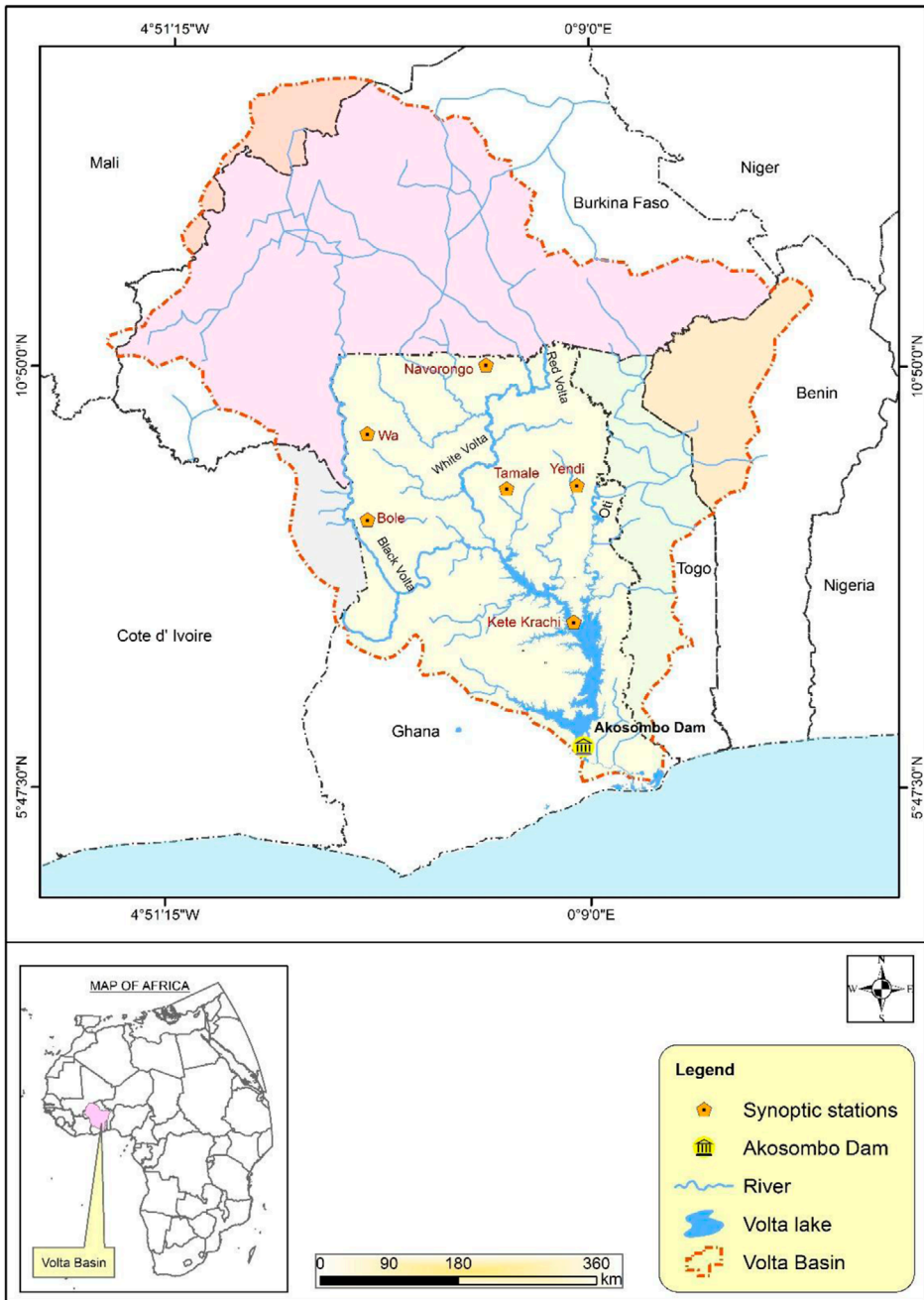


Figure 1. A Map of the Volta Basin showing the Synoptic stations used for the study. *Source: GIS Lab, Department of Geography and Resource Development, University of Ghana, Legon.*

which was upgraded to 1020 MW in a retrofit project completed in 2006. The construction of the dam flooded parts of the Volta River Basin, and subsequently creating the Volta Lake. The lake covers 8502 square kilometers which is about 3.6% of Ghana's total land area. The dam's power plant contains six 170 MW Francis turbines. Each turbine is supplied with water via a 112–116 m long and 7.2 m diameter penstock with a maximum of 68.8 m of hydraulic head afforded. The minimum operating water level is 73.15 m (240 ft) and the maximum level is 84.73 m [278 ft] ([www.vra.com](http://www.vra.com)).

### **Data**

The research was carried out using a quantitative approach. Rainfall data for six Synoptic stations in the South Volta Basin were collected from the Ghana Meteorological Agency (GMet). The Synoptic stations are: Bole, Kete-Krachi, Navrongo, Wa, Tamale and Yendi (Figure 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 stations were used by Bekoe and Logah (2013) and were also part of the 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 Synoptic stations for the period 1970–2010.

Data on the Volta Lake water levels behind the Akosombo dam, monthly lake inflows, and monthly power generation at the Akosombo Power Station for the years 1970–2010 were obtained from the VRA. Finally, ENSO indices (1970–2010) were downloaded from the Center for Ocean-Atmosphere 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°S–4°N, 150°W–90°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>).

The main limitation of this study was the limited number of Synoptic stations used in the rainfall analysis. As can be seen from the map of the study area (Figure 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 used. Thus, the stations although few, still give a good representation of the rainfall for the entire lower Volta Basin.

### **Methodology**

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 to 2010. Additionally, the annual variations in power generation were determined 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).

The ENSO phases were used to group the mean total rainfall for the lower Volta Basin which had been computed from the monthly rainfall data collected from GMet. The average rainfall for the long-term period, El Niño years and La Niña years were calculated. These averages were used to generate a bar plot to compare the mean rainfall received for the different phases of ENSO.

A regression analysis was conducted in analyzing the power outputs (Saadia, 2008), to establish the influence of rainfall, ENSO, lake level elevation, and net lake inflow on annual fluctuations in power generation. Preliminary test was performed which revealed that most of the assumptions for a regression test; normality of distribution, no significant outliers, heteroscedasticity and colinearity were not violated. The rainfall, ENSO, lake level elevation, net lake inflows and power generation data were divided into two periods: P1 (1970–1990) and P2 (1991–2010) to correspond to the widely reported failure of the West African Monsoon in the 1970s and 1980s, and its recovery afterwards (Giannini, Saravanan, & Chang, 2003; Rodríguez-Fonseca et al., 2011). Significance levels of 0.05 were used throughout.

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 effect 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).

$$Y = a + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + \varepsilon$$

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  $\varepsilon$  is the error.

## Results and discussion

The annual power generation derived from the monthly power generation totals at the Akosombo Hydroelectric Power Station is used for the analysis presented in this section. Figure 2 shows the trend of the annual power generation at the Akosombo Power Station. Annual power generation was generally on the increase from 1970 until it reached an annual total of 5277 GWh in 1980. After 1980, a decreasing trend was experienced, with output plummeting to the lowest annual total of 1468 GWh in 1984. Other low power output years include: 1998, 2003 and 2007. It can be seen from Figure 4 which shows the lake level elevations behind the Akosombo dam that all these low power output years correspond to very low lake water levels. Figure 2 however shows that total annual power output has been on the increase over the study period. This could be attributed to a series of retrofitting exercises which were commissioned in 1989 and ended in 2006 ([www.vra.com](http://www.vra.com)). The years in which retrofits were completed are shown in Figure 2.

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

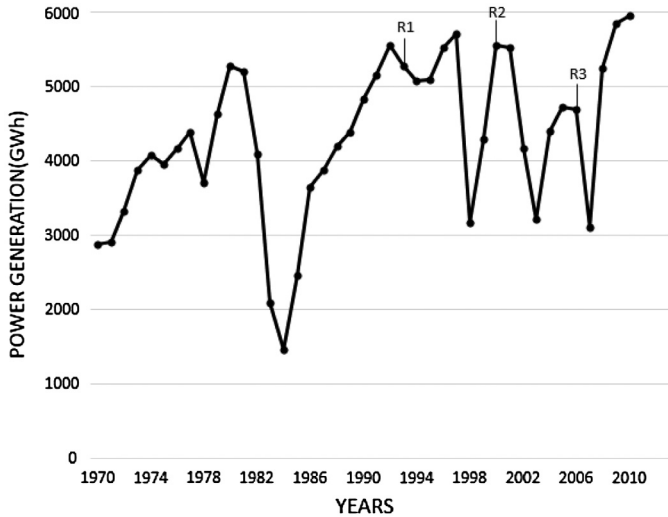


Figure 2. Annual power generation at Akosombo Power Station from 1970 to 2010. *Source: Based on data from the VRA (2015).*

Table 1. Summary results of a stepwise multiple regression analysis for power generation (Period 1).

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

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 Tables 1 and 2.

The overall model for P1 was statistically significant,  $p = .036$ ,  $R^2 = .212$ , Adjusted  $R^2 = .170$ . This means that the model has explanatory power. As can be seen from Table 1, the correlation associated with the  $t$  distribution of mean basin rainfall is statistically significant ( $t = 2.260$ ,  $p = .036$ ). This means that basin rainfall helps predict annual variation in power generation. The regression coefficients associated with monthly total basin rainfall is 2.964 which implies that if mean basin rainfall increases by a unit (1 mm), one will expect power generation to increase by 2.964 GWh. 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  $R^2 = .724$ . 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 2, the correlation associated with the

Table 2. Summary results of a stepwise multiple regression analysis for power generation (Period 2).

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  $R^2 = .742$ ;  $F(2, 17) = 25.947$ ,  $p = .000$ .

$t$  distribution of ENSO is statistically significant ( $t = -5.827$ ,  $p = .000$ ). This means that ENSO helps predict annual variation in power generation in P2. Table 2 also shows that the correlation associated with the  $t$  distribution of Lake level elevation is statistically significant ( $t = 4.137$ ,  $p = .001$ ), which also means that 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 the ENSO indices increase by a unit, holding Lake level elevation constant, one will expect power generation to decrease by 1169.642 GWh. Also, if Lake level elevation increases by one unit (1 ft) holding ENSO constant, one will expect power generation to increase by 69.930 GWh. 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.

A visual inspection of the line graph showing the trend of power generation from the Akosombo Power Station (Figure 2) indicates lower power generations in 1984, 1998, 2003 and 2007 which is consistent with the findings of Amekor (2007) and Bekoe and Logah (2013). It is clearly seen from Figure 2 that the total annual power output of 1468 GWh recorded in 1984 is the lowest generated over the 41-year study period. This happened immediately after the strong El Niño conditions in 1982/83 and its resultant severe droughts in 1983 which lowered the Volta Lake water levels in 1984 (Figure 4). This supports the findings of Leemhuis, Jung, Kasei, and Liebe (2009) who stated that the 1984 power shortages in the country were as a result of low lake level in the previous years.

The 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 1 that the regression model explains 21.2% of the variability and change in inter-annual fluctuations in power generation. The model shows that, for every 1 mm increase in rainfall there is a 2.964 GWh increase in power generation implies that if rainfall reduces, power output will also reduce. This finding confirms the findings of Gyau-Boakye (2001), and Lautze, Barry, and Youkhana (2006) that mean annual rainfall influences power generation from the Akosombo Power Station. Figure 3 which illustrates the distribution of mean rainfall for the different phases of ENSO from 1970–2010 was used to show the relationship between rainfall and ENSO. ENSO as pointed out earlier is the largest determinant of rainfall variability in the tropics as a whole (Mude et al., 2007). During El Niño years, the average rainfall received in the basin is about 1040 mm compared to 1209 mm of rainfall received in La Niña years. The long-term rainfall mean for the lower Volta Basin section in Ghana is 1124 mm.

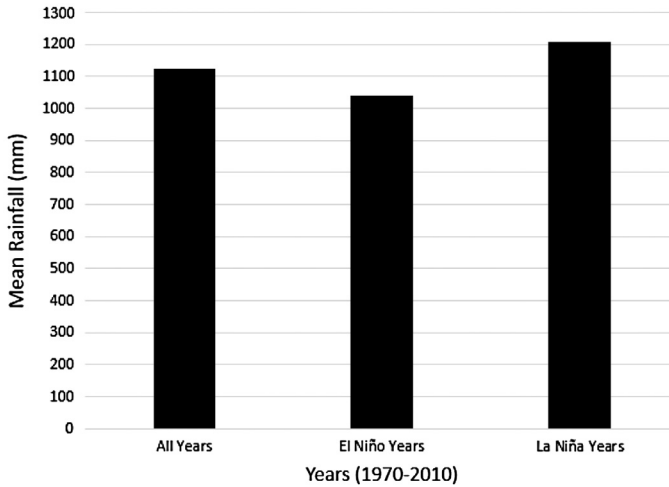


Figure 3. Distribution of mean rainfall for the different ENSO phases from 1970 to 2010. Source: Based on data from GMet.

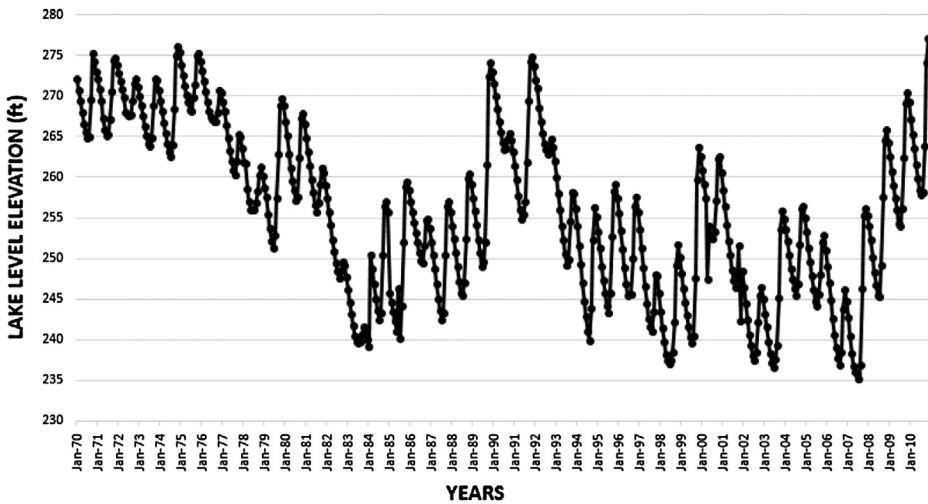


Figure 4. Monthly Volta Lake elevations from 1970 to 2010. Source: Based on data from the VRA (2015).

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 and Voldoire (2009). The IPCC (2001) 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 in the lower Volta Basin with its attendant influence on hydropower generation in Ghana could therefore be projected to continue.

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 2 shows that inter-annual variation in power output has become a more common feature during this period. The regression analysis for the second period, P2, indicate that ENSO and lake level elevation are the significant predictors of the inter-annual fluctuations in power generated from the Akosombo Power Station. The model as shown in Table 2, explains 72.4% of the variability in the inter-annual 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 fluctuations in annual power generation compared to lake level elevation ( $\beta = .449$ ) for the P2 period. The influence of ENSO on the fluctuation of power generation was not surprising 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 2 that, an increase of 1 ft in lake level elevation across the P2 period, corresponds to 69.93 GWh 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, Kimambo, & Nielsen, 2012). This shows how significant ENSO and lake water levels are to hydroelectric power generation from the Akosombo Hydroelectric Power Station. It also suggests a strong relationship between ENSO, lake level elevation and power generation over the 20-year period (P2).

The regression analysis for the two periods suggests 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 ENSO and lake water levels. It is also possible that the low frequency of El Niño and La Niña episodes in P1 as opposed to the high frequency and magnitude of El Niño events in P2 accounts for the significant influence. The results from the regression analysis for both periods, thus, reveal the influence of climate variability and change on fluctuations in power generation through its influence on mean basin rainfall, and lake level elevation, which supports the findings of Saadia (2008), Amekor (2007) and Kasei (2009). The IPCC (2013) found El Niño events to be occurring more frequently and with increased magnitude since the mid-1970s. Since El Niño is associated with a reduction of 1169.64 GWh in annual power generation, the study argues that fluctuations in power generation at the Akosombo Hydroelectric power station and other hydroelectric station in the country will persist especially in a future where El Niño is predicted to be more frequent and severe as a result of anthropogenic climate change and resultant warming of the oceans.

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 and 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 the country changes its power policy direction. The continuous reliance on hydropower for the provision of adequate and secure power for Ghana is therefore problematic and probably unsustainable considering the fact that 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) such 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 load shedding and blackouts.

Previous research (Bukari, 2013; 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, a report by Power Systems Energy Consulting (2010) showed that Ghana's GDP growth reduces between 2 and 6% annually as a result of erratic power supply. 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.

### **Conclusion and recommendation**

This study sought to demonstrate empirically that variability and change in rainfall as well as the effects of ENSO will create huge problems for 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 hypothesis that changes in rainfall inputs in the lower Volta Basin influence 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 inter-annual variability in power output from the Akosombo Hydroelectric power station. It was also 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. The implication of these findings is 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 policy pathway which weighs heavily on hydropower to other sources if the frequently recurring power shortages and subsequent blackouts are to be resolved.

Based on the above findings, the study makes the following recommendations. The Ministry of Energy and Petroleum, Ministry of Power and the VRA should consider the possible diversification of Ghana's electricity generation away from hydropower in order to guarantee the supply of adequate and sufficient power for its citizens and meet the desired target to export 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 encouraged. The expansion of the thermal sector looks more feasible especially with the commencement of gas production from the country's oil fields following the discovery of large gas reserves.

## Disclosure statement

No potential conflict of interest was reported by the authors.

## Notes on contributors

Sylvester Afram Boadi has just completed a Master of Philosophy in Climate Change and Sustainable Development at the University of Ghana, Legon. His area of research concentration is climate variability and change impact on agriculture and energy systems.

Kwadwo Owusu is a senior lecturer and Coordinator of the Climate Change and Sustainable Development Programme, University of Ghana. His areas of research interest are climatology, climate variability, and change impacts on agriculture and smallholder adaptation to climate change.

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