CHANGING RAINFALL CLIMATOLOGY OF WEST AFRICA: IMPLICATIONS FOR RAINFED AGRICULTURE IN GHANA AND WATER SHARING IN THE VOLTA BASIN

By

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To my mother

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I would like to thank my supervisory committee for the invaluable contributions they made to make this project a success. Dr. Peter Waylen as a committee chair has proved a source of encouragement and has been invaluable to me, not only in the preparation of this thesis but also in support of my academic and career development and personal progress. I owe him more than I can ever express in words. I also appreciate Dr. Keith Ingram who showed a lot of interest and provided constructive advice and painstakingly reviewed the manuscript, Dr. Timothy Fik and Dr. Jane Southworth for their constructive suggestion that help to make the research stronger. I thank all of them for their support.

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LIST OF ABBREVIATIONS

BCM	Billion Cubic Meters
CIA	Central Intelligence Agency
COAPS	Center for Ocean-Atmospheric Prediction Studies
ENSO	El Niño-Southern Oscillation
FAO	Food and Agriculture Organization of the United Nations
GHCN	Global Historic Climate Network
GMA	Ghana Meteorological Agency
GPCC	Global Precipitation Climatology Centre
ITCZ	Inter-Tropical Convergence Zone
JMA	Japan Meteorological Agency
MFOA	Ministry of Food and Agriculture, Ghana
P1	Period 1 1951-1970
P2	Period 2 1981-2000
SST	Sea Surface Temperature
VALCO	Volta Aluminum Company
VRA	Volta River Authority
VTU	Variable Temporal Unit
WMO	World Meteorological Organization

Abstract of Dissertation Presented to the Graduate School
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Better understanding of the nature and spatial extent of rainfall variability in humid regions of mid-Ghana and the impact of declining rainfall totals in the Volta basin are the main goals of this study. The data utilized are daily rainfall totals for Ghana and gridded annual rainfall totals covering the Volta basin. The first aspect of variability analyzed is the multi-decadal trend (1951-1970 and 1981-2000) in Ghana, which revealed that the agriculturally important humid regions of southern Ghana have seen reductions in annual rainfall totals similar to those witnessed in the Sahel region. The decreases seem to be most profound along the coast and forest zones, while topography appears to be important as a rainfall divide cutting across the Ghana Meteorological Association's zone A, with significant declines in annual rainfall totals (20%) to the south and west, and smaller (10%) declines to the north and the east. The daily analysis covering 1950 to 2000 concentrating on mid-Ghana also points to significant shifts within the rainfall regime in association with declining mean rainfall totals and number of rainy days. The major and minor rainy seasons have experienced significant reduction in the mean rainfall totals as well as the number of rainy days. The short dry spell in many stations has experienced increases in mean rainfall total in the last two decades of the study. By employing Variable temporal Units (VTUs) in this analysis we were able to identify portions of the rainfall regime

that have undergone changes without the necessity of any *a priori* judgments or definitions of what constitutes the beginning or end of any seasonal sub-division. Finally, evidence is present from the analysis of gridded annual rainfall data that increased variability and declining rainfall totals are the main cause of declining lake levels in the Volta basin above the Akosombo Dam. The trends in spatial and temporal variability of annual rainfall in the riparian nations explain the low impoundment levels frequent in recent decades. Various regional and temporal associations between El Niño-Southern Oscillation (ENSO) phenomena are investigated as a possible cause of variation across the basin. The strengths of these associations and low frequency shifts suggest an unfortunate correspondence between national and climatological boundaries which may serve to heighten regional political tensions resulting from ENSO effects. It is hoped that an understanding of the effect of climate, which transcends political boundaries will help ease tension on water sharing in the Volta basin.

CHAPTER 1
INTRODUCTION

Rainfall variability is an inherent part of African climate and is deeply entrenched in West African society (FAO 2008). Historic rainfall data from the last 50 years have shown a consistent downward trend with sporadic droughts, such as the one in 1983. However, the immediate post-colonial economies of most countries in sub-Sahara Africa were dominantly "planned" and many proposed activities depended on the continued presence of the levels of rainfall prior to independence. Precipitation experienced in the following decades facilitated an increase in national reliance on rain-fed agriculture and the embracing of hydroelectricity as the main source of energy for domestic and industrial consumption. For example, agricultural contribution to employment in Burkina Faso, Ghana and Côte d'Ivoire is 90%, 56% and 68%, respectively (CIA Factbook 2008). Although stakeholders are aware of the negative impacts of rainfall variability and changing climate on agriculture production, and have begun using new strategies to ensure food security, much still needs to be done at the national and local levels to understand the nature of climate variability and any shifts that may have occurred in the rainfall regime. The spatial and temporal components of rainfall variability combined with diminishing monthly and seasonal totals requires an in-depth analysis of rainfall characteristics at a finer resolution (daily level) to yield the maximum benefit in a region that is reliant on rain-fed agriculture and hydro-electricity.

The climatology of the humid Guinea Coast region (below 10°N) of West Africa is studied less extensively than that of the more northerly regions bordering the Sahel. Although knowledge of the West African climate has expanded in the last few decades much is based on findings from the Sahel zone which is quite different from the Guinea Coast region. Moreover, beyond the general downward trending rainfall pattern there are significant differences between the

seasonality of rainfall in the Sahelian and the Guinea Coast regions of West Africa, which reflect differences in the causal mechanisms. Whereas the humid Guinea Coast region has a bi-modal rainfall regime with a major season from March-June and a minor season from August-October, the dry Sahel manifests a uni-modal regime from June-September (Sultan et al. 2004). Both regions also appear to respond differently to major external causes of climate variability, namely El Niño-Southern Oscillation (ENSO) and South Atlantic sea surface temperatures (SST). For instance, a warm South Atlantic induces above average rainfall in the Guinea region and below average rainfall in the Sahel (Lough 1986; Gu and Adler, 2003). It has been argued that the dramatic nature of the impact of rainfall variability on the Sahel explains the attention the region has received (see for example Servat et al. 1997, Nicholson et al. 2000, Owusu and Waylen, 2009).

In spite of the fact that both regions have suffered downward trends in mean annual rainfall since the 1970s there are significant differences that have occurred in the respective rainfall regimes, especially in the more humid southern regions where rain-fed agriculture is the backbone of the economy. However, such differences are not manifest in the annual analysis upon which many studies have been based on. An obvious option to combat the impact of rainfall variability and declining totals would be irrigation, but given that the capital outlay is beyond most of the economies in the region and the lack of donor support based on environmental concerns (Postel 1993), irrigation constitutes less than 5% of agricultural land in many countries. The use of seasonal climate information has been identified and been promoted by both governmental and non-governmental institutions as a possible tool. Moreover, because forecasts are based on historic rainfall observations over the previous 30 to 50 years, they may not apply if there have been significant changes in the climatology of the region over this period.

Similarly, a better understanding of the spatial components of variability will help in the effective utilization of shared water resources in the sub-region and a reduction of tension and the potential for conflict. Thus, it is important to analyze rainfall variability in order to shed light on the changes that have occurred, especially within the bi-modal regime of the Guinea Coast region. Although only a relatively small proportion of the Volta basin lies within humid mid-Ghana, the water that the basin contributes to the region is important economically and provides a potential source of water and local climate change because of its micro-climatic impacts, and therefore is considered simultaneously. The study utilizes annual, monthly and daily rainfall totals over 50 years to identify the spatial and temporal dimensions of rainfall variability in Ghana and the Sahel (Volta basin) by comparing the characteristics of the period from 1951 through 1970 and from 1981 through 2000, hereafter referred to as Period 1 (P1) and Period 2 (P2) respectively.

Statement of the Problem

The research addresses the nature of the spatial and temporal variability of rainfall in the humid areas of Ghana and the Volta basin and demonstrates their impacts on rain-fed agriculture and water sharing. The issue is approached through the investigation of rainfall variability in both the Sahelian and the Guinea Coast regions of West Africa by drawing on examples from Ghana and the entire Volta basin for the period from 1951 through 2000. The three part study first utilizes annual rainfall data from the Ghana Meteorological Service Agency (GMA) to analyze the spatial and temporal extent of the downward rainfall trend reported for the sub-region and the impact that geographic relief has on rainfall distribution and variability in Ghana. The second section, using daily rainfall data, identifies the shifts in the rainfall regime and potential impacts upon the two crops per year rain-fed agriculture practiced in the sub-humid region, which is the bread-basket of Ghana. The final part, utilizing annual and monthly data

from the Historical Climate Data Network and the Gridded data source, demonstrates the differences in rainfall variability in the Sahelian and the Guinea Coast sub-sections of the Volta basin and how variability and climate change affect water resource sharing between Burkina Faso and Ghana.

Objectives

The main objective of the study is to analyze the spatial and temporal variability rainfall in the humid regions of mid-Ghana within the period 1950-2000. An added objective is to verifiy the differences in the spatial variability of rainfall in both the Sahel and Guinea Coast region of the Volta basin and how that impact water resource sharing.

The reliance on climatic knowledge of the Sahel for decision making in the Guinea Coast region is now demonstrated to be inadequate since the two areas have different rainfall regimes and respond differently to rainfall forcing mechanisms. Rainfall variability is analyzed based on these objectives:

(1a) Analysis of temporal variability of annual rainfall in Ghana to determine the nature and spatial extent of the multi-decadal downward trends observed in the Sahel.

(1b) Analysis of spatial variability quantifying differences in the magnitude of reductions in the humid and sub-humid sections of the study area.

(2) Analysis of the agriculturally significant variables of rainfall totals and the number of days with rain in during various periods during the traditional growing season over two twenty-year periods to highlight changes that have occurred in the rainfall regime and the impacts such changes have on rain-fed agriculture.

(3) Analysis of multi-decadal variability in the Sahel and the Guinea Coast regions and their contribution to water input in the Volta basin. The objective is to demonstrate differences in variability in the two regions and how they impact resource utilization across national boundaries.

Study Area

The humid regions of mid-Ghana and the Volta basin are the two distinct areas of interest of this study. Ghana covers a total area of 238 540 $km^2$of which about 42% is suitable for cultivation.

The actual area cultivated is about 11 400 km^2 (4.8% of the total area or 11.4% of the cultivable area). Average rainfall in Ghana is between 1,100 to 2,000 mm/year, but ranges from as little as 890 mm/year in the coastal zone near Accra to 2,030 mm/year in the southwestern rainforests. The seasonal rainfall distribution is bi-modal in the southwestern forest zone, giving rise to a major and a minor growing season; elsewhere, a uni-modal distribution supports a single growing season from May to October.). Rainfall totals can vary substantially from year to year and, in the southern part of the country, rainfall is related to some extent to the sea surface temperature (SST) in the Gulf of Guinea, while the position of the West African monsoon trough is more important for the inter-annual rainfall variation in northern parts of the country.

Agriculture production in Ghana is mainly rain-fed and operated by smallholder farmers with average holdings of 1.5 hectares. Climate sets the stage for different production system in the ecological zones of the country as defined by the Ghana Meteorological Agency (appendix A). In the forest region of zone A (appendix A), cocoa production is the main farming activity. Zone B produces vegetables and some maize. This zone is small and more urbanized. Zone C is dedicated to food production with yams, plantains, cassava and maize as the main produce. The Sudan savanna region of Zone D specializes in legume production and animal husbandry. The sub-humid region of Zone C and portions of Zone A constitute the main focus of the first part of this study (appendix B). Earlier studies suggest that rainfall characteristics in the major growing season (April-July) have not changed significant in recent years, unlike the minor growing season (September-November). The minor growing season however, provides food and household income for the long dry season that normally lasts from December-March. It also provides the seeds for the major rainy season. Improving climate knowledge of the rainfall climatology for this region will improve rain-fed agriculture and food security of Ghana and the sub-region.

The Volta basin occupies 400,000 km^2, shared between six riparian nations (appendix C): Burkina Faso, (43%); Ghana, (40%); Togo, (6%); Benin, (4%); Mali, (4%); and Côte d'Ivoire, (3%). Ghana occupies the lower half of the basin and the point at which the three principle tributaries (the Black Volta, the White Volta and the Oti River) join the main Volta at the Volta Lake behind the Akosombo Dam. The impoundment, created in 1964, is one of the largest man-made lakes in the world with a total surface area of 8,500 km^2 and a storage capacity of roughly 150 billion cubic meters (BCM). The hydropower generation plants have a capacity in excess of 900MW (Sutherland et al. 2004). Annual rainfall varies greatly across the basin, from 1500 mm in the south to 400 mm in the north. Rainfall regime also differs between the humid south and the dry north as manifested in their respective bi- and uni-modal regimes (Sultan et al. 2004)

The basin extends over at least four climatic regions, from Rainforest in the south to the Sahel in the north, with Guinea and Sudan Savanna in between (Rogers et al. 2007). Each climatic zone is strongly influenced by the movement of the Inter-Tropical Convergence Zone (ITCZ), which is responsible for both rainfall regimes (Sultan et al. 2004; Rodgers et al. 2007). Southern zones exhibit one peak in June/July and another in September/October, within an overall moist season stretching from April to mid-November. In the uni-modal north, the rainy season occurs from May to October with a peak in September. The basin experiences high degrees of spatial and temporal variability in rainfall (van de Giesen et al. 2001), making it unreliable for agricultural production resulting in diminishing food security. Irrigation is limited to the more arid northern regions especially in Burkina Faso, still only 0.4% of national agricultural land is irrigated according to Gleick (1993). In Ghana the water is utilized mainly for power generation and domestic consumption (van Edig et al. 2001, van de Giesen et al. 2001). The basin offers the

opportunity to demonstrate the differences in rainfall variability in the Sahel and the Guinea coast regions and the impacts it has on resource sharing.

Research Outline

The three-part study is undertaken as individual publishable papers. After this introductory chapter outlining the problem and objectives of the study, chapter 2 covers the first paper that analyzes the annual rainfall trends in Ghana. Chapter 3 is the second paper which investigates daily rainfall characteristics in the changing rainfall regime of mid-Ghana. Chapter 4 is the final paper and highlights the spatial variability in the Sahel and the Guinea Coast regions of the Volta basin and how declining rainfall inputs to the basin impact water resource sharing between Burkina Faso and Ghana. Chapter 5 is a summary and conclusion that links the three papers together and highlights the contribution of the study to Geography in general and the climatology of West Africa in particular. The final chapter also touches on the limitations of the study as well as areas for future research.

CHAPTER 2
TRENDS IN SPATIO-TEMPORAL VARIABILITY IN ANNUAL RAINFALL IN GHANA, (1951-2000)

Introduction

Rainfall variability in humid West Africa (south of 8°N) is less studied than that of the Sahelian zone, responsible for the general consensus of a downward rainfall trend in West Africa over the last few decades. Such a generalization may not be useful for modeling and planning purposes. Rainfall mechanisms in the drier Sahel and the humid Guinea Coast region differ; the former region has a single rainfall peak (in summer) but the later region has a bi-modal seasonal distribution. It is therefore not necessarily true that a failure in the rainfall regime and its subsequent impact on agriculture and livelihood, in one zone means the same for the other. In fact, it has been observed that a warmer South Atlantic is associated with more rainfall in the Guinea Coast region and less rainfall in the Sahel (Gu and Adler 2003). It is also suggested that the El Niño-Southern Oscillation phenomena (ENSO) may be more strongly associated with Sahelian rainfall than with that of the Guinea Coast region (Ward et al. 2004). Therefore there is a need to investigate rainfall trends and variability in the humid areas to better inform agricultural decision making. Agricultural productivity has decreased in recent decades following declining rainfall since the early 1970s, with the rainfall showing signs of improvement after 2000.

This analysis will contribute to the knowledge of rainfall trends and aid in agricultural and allied industrial decision-making in this important agro-climatic zone. The study utilizes annual rainfall totals over 50 years to identify the spatial and temporal dimensions of rainfall variability in Ghana by comparing the characteristics of the period 1951 to 1970 and 1981 to 2000, hereafter referred to as P1 and P2 respectively. Specific emphasis is placed on the sub-humid

areas of mid-Ghana because of its national and regional significance to agricultural production and food security.

Rainfall Variability in Ghana

Declining rainfalls have been reported throughout West Africa over the past 50 years and may be viewed in the long term (Weldeab et al. 2007) as part of general southward shift in the seasonal migration of the Inter-tropical Convergence Zone (ITCZ). A great deal of research into the nature and causes of rainfall variability in the sub-region has concentrated on the Sahel (Mahe et al. 2001). Nicholson et al. (2000) argue that practical difficulties in obtaining data outside the Sahel may be a contributing reason, while on a more practical note Servat et al. (1997) conclude that, the tragic consequence of drought on the countries in the Sahel is what explains, and justifies, the regional focus. At higher frequencies, Gu and Adler (2003) observe that a high (low) south Atlantic sea surface temperature (SST) is associated with high (low) rainfall in the Guinea coast (south of 8°N) and low (high) rainfall in the Sahel. Limited studies within the humid zone itself point to a similar reduction in annual rainfall totals, for example in Côte d'Ivoire (Servat et al. 1997) and in Ghana (Gyau-Boakye and Tumbulto 2000).

Much of the literature on rainfall in Ghana has concentrated on selected regions or stations (for example, Adiku et al. 1997, Tanu, personal communication and Gyau-Boaakye and Tumbulto 2000). Tanu analyzed rainfall variability in Ho and Tamale, and observed the risk of a dry spell during the rainy season to be higher in the south, (Ho), than the north (Tamale). Similar patterns are present in the intra-seasonal rainfall variability of Accra and Tamale (Adiku et al. 1997). The national study of Opoku-Ankomah and Cordery (1994) suggests that variability in the northern zone is distinct from the remainder of the country, due to the movement of the ITCZ and influence of Atlantic SSTs, as noted by Boateng (1967).

Natural and human induced changes have been investigated as the cause of the anomalous low rainfall in the sub-region (Giannini et al. 2003). Diagnostic studies (Ward 1998; Giannini et al. 2003) provide information concerning the forcing of West Africa rainfall by global sea surface temperature (SST). Continental surface conditions also play a role in determining the persistence of the drought condition (Zheng and Eltahir, 1998). The loss of vegetation, associated increase in soil albedo and declining temperatures, was proposed as a cause of Sahelian drought by Charney (1975). However, this mechanism of self-perpetuating drought (Leroux 2001) was quickly challenged and these arguments have resurfaced recently (Govaerts and Lattanzio 2007). SSTs alone do not explain variability throughout West Africa, although sub-Saharan rainfall is negatively correlated with SSTs in the South Atlantic (Opoku-Ankomah and Cordery 1994), and positively correlated with the Gulf of Guinea (Adler et al. 2000). This echoes the dipolar structure of higher SSTs in the South Atlantic and at the Equator, and lower SSTs in the North Atlantic which has been used to explain reductions in areas affected by the monsoon (Leroux 2001), and is consistent with observations of SSTs in the North Atlantic and the strength and location of the Azores anticyclone (Hastenrath 1991), and similar variations in the South Atlantic anticyclone (Leroux 2001). Other factors investigated include variations in the African Easterly Jet (AEJ) and the Tropical Easterly Jet (TEJ), (Leroux 2001; Price et al. 2007), and ENSO (Ofori-Sarpong and Annor 2001). At best ENSO is only strongly associated with rainfall in the Sahel with a non-stationary or no clear association with the Guinea Coast region (Ward et al. 2004).

Study Area and Methods

The study area encompasses the four agro-ecological regions of Ghana (Figure 2-1), although emphasis is placed on Zones A and C (Ghana Meteorological Agency GMA classification) with two stations falling in Zone D and one in Zone B. Zone B covers the dry

coastal strip of southeastern Ghana, where mean annual rainfalls of between740 and 890 mm supports very little agriculture. The rainfall anomaly in Zone B is part of a larger area from the coast of Cape Three Points in Ghana to Benin and is referred to as the 'Dahomey gap'. The low rainfall is attributed to a complex series of coastal (oceanic) and atmospheric interactions (Acheampong 1982). Zone D in the north of the country experiences similar rainfall totals (1000 mm) but has a single wet season. The agricultural potential in this zone is diminished by high rainfall variability and poor soils. The most productive zones of the country in terms of food and cash crop production are zones A and C, both of which are extremely dependant on traditional rain-fed agriculture (Adiku et al. 2007).

Monthly rainfall totals, provided by the GMA, covering the period 1951 to 2000, are divided into two 20-year periods 1951-1970 and 1981-2000 (P1 and P2). This division is based on observations of a period of mostly above normal rainfall in P1 and mostly below normal rainfall in P2, while the 1970s shows a more transitional pattern (Figure 2-2), corresponding to a shift in climate experienced in many regions around the world during the mid 1970s which has been widely reported (for example, Waylen et al. 2000; Chavez et al. 2003). This delineation is also consistent with the identification of (multi-decadal) trends or oscillations in West African rainfall (Lare and Nicholson 1994 and Ward et al. 2004). Three classes (or terciles) of above normal, normal and below normal rainfall are defined by the 33rd and 66th percentiles of annual totals estimated over 1951-2000. This typology corresponds with the GMA forecast (www.meteo.gov.gh/forecast_farmers.html) and is appropriate for agricultural applications. In addition to using long term records at 15 stations from GMA which form the core of the analysis, we also utilize less complete, but spatially more numerous, data from the Global Historic

Climate Network (GHCN) covering Ghana, Benin, Burkina Faso, Côte d'Ivoire and Togo to demonstrate the spatial extent of the declining rainfall pattern.

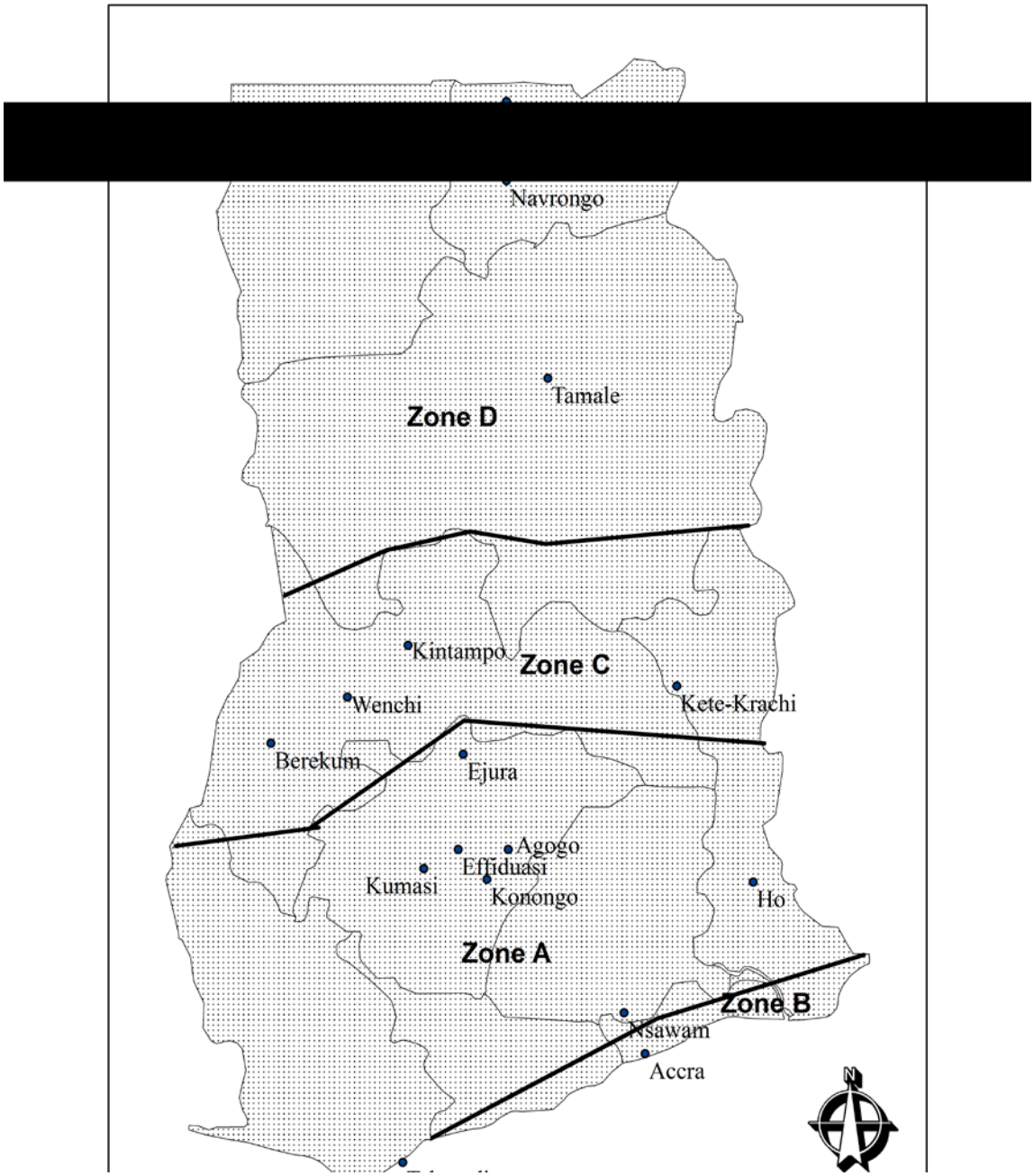


Figure 2-1. Agro-ecological zones of Ghana with selected rainfall stations based on Ghana Meteorological Agency classification

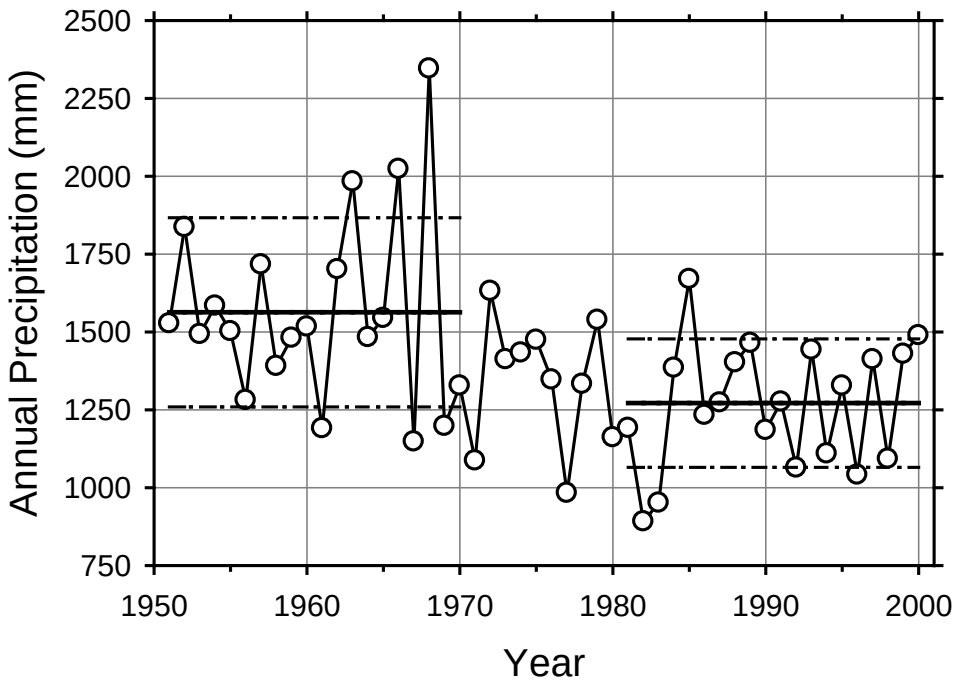


Figure 2-2. Annual rainfall fluctuations in Kumasi, 1951-2000. The solid lines represent the 20-year means and the dotted lines show the +/- 1 standard deviations

The hypergeometric distribution and standard F- and t-tests are employed to identify changes in rainfall occurrences in each tercile, and means and variances of annual totals, under the null hypothesis of no significant changes between P1 and P2. The hypergeometric distribution arises when a random selection is made (without replacement) among objects of two distinct types. In its general form the hypergeometric distribution is describe by three parameters: *N*, the population; *k*, the number of success in the population; and *n*, the sample size.

$$p(x) = \frac{\binom{k}{x}\binom{N-k}{n-x}}{\binom{N}{n}}$$

In this application N corresponds to the total number of complete annual records at a station between 1951 and 2000. The total number years falling in above normal or below normal

terciles in this record – roughly a third, constitutes k, and the number of years of record available in P1 (P2) determines n. Significance levels, α of 0.05 and 0.01 are used throughout.

Results and Discussion

Mean annual rainfall totals within all four agro-ecological zones experienced a decline from P1 to P2, except Kete-Krachi, in zone C (Table 2-1). The reductions at six of the 15 stations were significant at the 0.01 level and an additional four at the 0.05 level. Stations experiencing significant declines are located towards the southwestern forest and the coastal zones A and D (Figure 2-1). No consistent pattern of changes in the standard deviation (SD) emerges, which might be expected given the sample sizes. Although none of the changes in the SD of the 14 declining stations is significant, 11 stations experienced a decline while four saw an increase in the SD in P2. Figure 2-3 plots the combined changes in the mean and SD from P1 to P2. As expected, most of the stations display declining SD when means decrease in P2. A few stations like Konongo, Agogo and Effiduasi have declining means with little change in the SD. Both combinations (declining mean and possibly declining standard deviation) suggest that P2 will display a higher frequency of rainfall in the lower tercile.

A notable deviation from the two patterns observed are Kete-Krachi, which has both higher mean and SD, and Navrongo with a declining mean and increased SD in P2. The Kete-Krachi anomaly may be partially explained by its proximity to the Volta, which was created by the filling of the Akosombo dam in the early 1960s. The case of Navrongo highlights the dual rainfall mechanism in West Africa. Its proximity to the Sahel gives rise to the single rainfall distribution, a reduced mean and increased SD. The greater frequency of rainfall totals in the lower tercile (droughts) in P2 is consistent with the declining rainfall pattern reported for the Sahel.

Table 2-1. Differences in the mean, standard deviation and coefficient of variation of annual rainfall between 1951-70 (P1) and 1981-2000 (P2)

Station	Zone	Mean (mm) (P1-P2)	SD (mm) (P1-P2)	CV (%) (P1-P2)
Agogo	A	174.5*	-8.8	-3.1
Effiduase	A	307.8**	-11.1	-4.3
Ejura	A	175.9*	81.6	3.7
Ho	A	188.1**	20.2	-0.8
Konongo	A	317.1**	14.0	-2.0
Kumasi	A	291.6**	97.4	3.2
Nsawam	A	136.9*	106.9	6.4
Takoradi	A	335.3**	72.9	-0.6
Accra	B	260.5**	40.7	-3.6
Berekum	C	169.8*	105.1	6.1
Kete-Krachi	C	-39.7	-147.2*	-10.3
Kintampo	C	150.9	52.0	1.7
Wenchi	C	115.1	25.5	0.4
Navrongo	D	93.3	-33.4	-4.7
Tamale	D	77.3	51.3	3.1

*Significant at 0.05
**Significant at 0.01

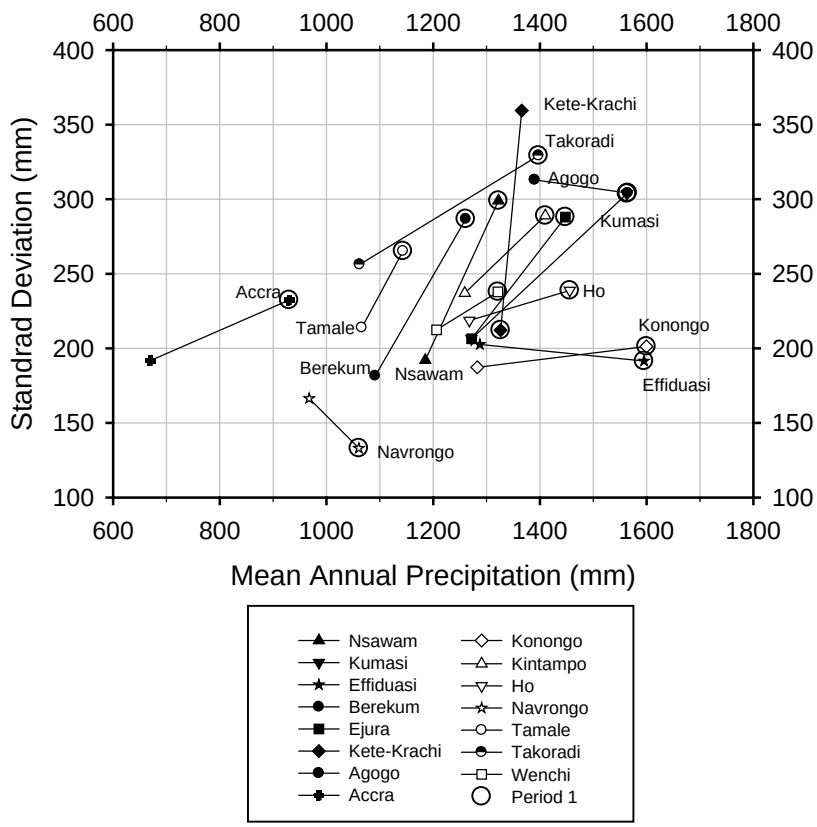


Figure 2-3. Mean and standard deviation of annual rainfall totals between P1 and P2

The general observation is of declining mean annual rainfall being concentrated towards the south-west forest and coastal regions. The annual rainfall totals between P1 and P2 in zone A dropped from around 1800mm to about 1600mm, zones B and D saw a reduction from around 1200mm to about 1000mm while zone C also experienced reductions from 1400mm to 1200mm. These reductions are similar to those reported for the Sahel within the same periods. Figure 2-4 also indicates similar reductions in neighbouring West African countries.

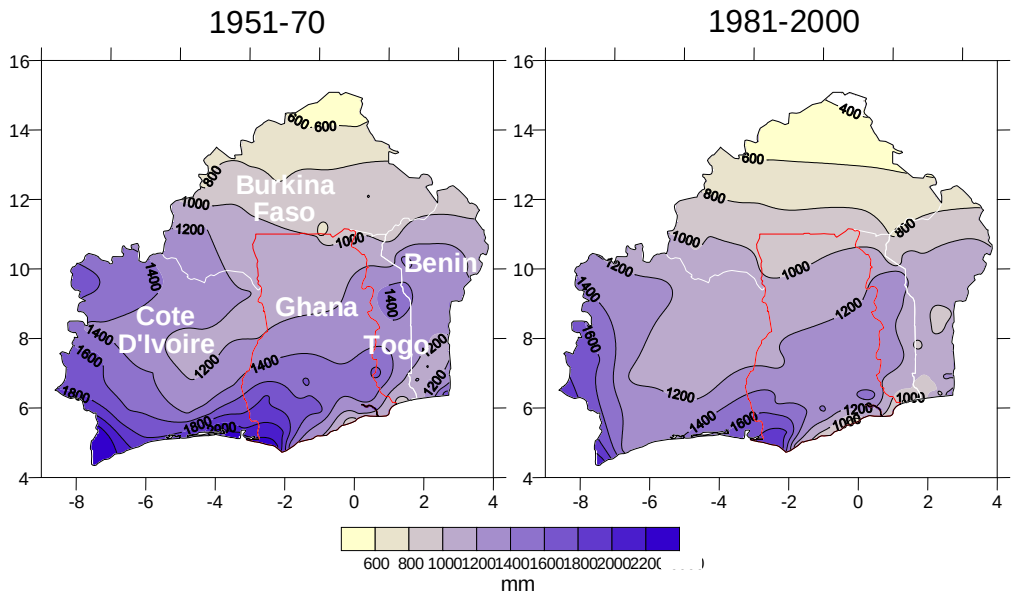


Figure 2-4. Regional mean annual rainfall in 1951-1970 (P1) and 1981-2000 (P2) Central West Africa

The differences in the absolute and percentage mean annual rainfall totals are shown in Figure 2-5a and 2-5b respectively. P2 has seen a reduction as high as 300mm (20%) in the forest regions of zone A to as low as 100mm (10%) for zones B and D. The results of F and t-tests shown in Table 2-1 and Figure 2-4 indicates that stations in zones A and B, as well as one in zone C, have seen a significant reduction in the mean annual rainfall totals from P1 to P2. In general the reductions seen in zones C and D, that occupy the northern half of Ghana are minimal, ranging from 150.9mm in Kintampo to an increase of 39.7mm in Kete-Krachi.

Results of the application of the hypergeometric tests to tercile occurrences shown in Table 2-2, are similar to those of (the parametric test in) Table 2-1. Almost all the stations in Zones A and B showed signs of being significantly wetter (more years reporting totals in the upper tercile than expected, and fewer years in the lower tercile) in P1 than in P2. Indications of drier conditions (significantly fewer upper tercile and more lower tercile occurrences) are exhibited in P2. Some stations like Wenchi and Tamale (zones C and D) towards the north and east of the study area indicate wetter conditions in P1 but no significant drying in P2

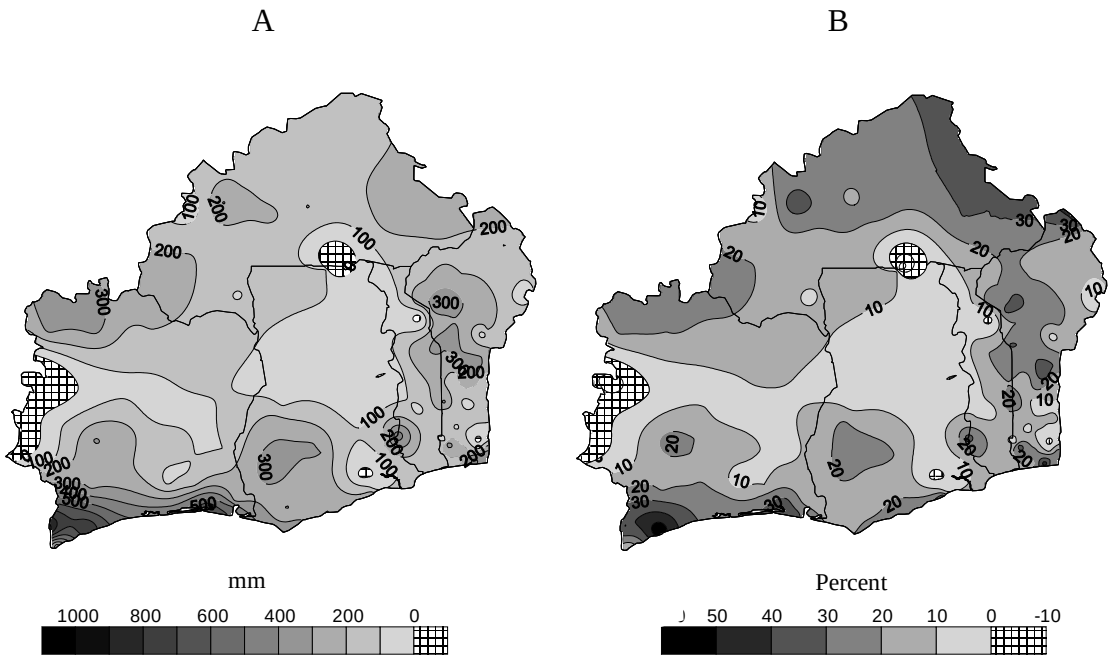


Figure 2-5. Differences in absolute and percentage rainfall. A) Absolute differences (mm) in mean annual rainfall (P1-P2) and B) expressed as percentage of mean rainfall in P1. Greater reductions in both absolute and percentages are apparent in the south-west region of Ghana.

The distribution of significant decreases in rainfall appears to bisect GMA zone A. A physical basis for such a sub-division may be offered by a consideration of topography and proximity to the ocean. Figure 2-6 shows that the stations that have experienced significant reductions in mean annual rainfall totals lie on the windward side of the Kwahu Plateau with regard to the rain-bearing south-westerly monsoon winds, while the north-eastern stations, on the

leeward, display much smaller changes. The plateau (identified in Figure 2-6) has an average elevation of 460m, and stretches from Koforidua in the south-east to Wenchi in the west. Gorshkov and Makarieva (2006) note that in West Africa (north of 10°N) mean annual precipitation declines in an exponential manner with distance inland. Drawing a line between Axim and Adieko (Côte D'Ivoire), parallel to the coast of south-western Ghana and approximately orthogonal to the south-west monsoons (Figure 2-6), perpendicular distances are measured to 22 stations falling in the rectangle defined (Figure 2-7). A similar analysis of the relationship between distance between the Axim-Akiedo line and the combined GMA and GHCN data reveals a very strong relationship ($r^2 = 0.885$) to the south-west of the Plateau and a very marked break with stations further inland. In the area of Sunyani and Wenchi (8°N, 2°W in (Figure 2- 6) the divide is bisected by the Tano river valley and is less easily defined, however Figure 2-7 seems to indicate that these stations are part of the progression noted on the windward side of the plateau.

Table 2-2. The number of years in different rainfall terciles for 1951-70 (P1) and 1981-2000 (P2) and the statistical significance of these changes

Station	Zone	Period 1 (1951-1970)				Period 2 (1981-2000)				(1951-2000)
		Above	Normal	Below	Total	Above	Normal	Below	Total	Total
Agogo	A	8*	3	4	15	5	6	9	20	41
Effiduasi	A	11**	6	1**	17	3*	6	10*	19	47
Ejura	A	6	4	4	14	5	6	7	18	41
Ho	A	12**	4*	4	20	5	7	8	20	46
Konongo	A	14**	5	1**	20	1**	8	11**	20	50
Kumasi	A	12**	5	3*	20	3*	6	11**	20	50
Nsawam	A	9	7	4	20	4	8	7	19	49
Takoradi	A	11**	5	3*	19	2**	9	9*	20	48
Accra	B	8	9	2**	19	3	4	10**	17	46
Berekum	C	8	5	4	17	4	6	8	18	44
Kete-Krachi	C	6	8	6	20	5	6	9	20	48
Kintampo	C	10*	5	4*	19	3	4	7	14	42
Wenchi	C	9	5	6	20	6	7	7	20	50
Navrongo	D	8	8	4	20	5	6	9	20	50
Tamale	D	9	3*	8	20	5	7	8	20	50

* Significant at 0.05
** Significant at 0.01

The southern slopes of the Plateau are forested and shielded by the topography from the impact of the harmattan winds, while the northeastern side is mainly occupied Guinea and Sudan Savanna. With rainfall distribution in Ghana, and West Africa in general, influenced by the moist Southwest Monsoon and the dry Northeast Trade Winds, it is no coincidence that a plateau with

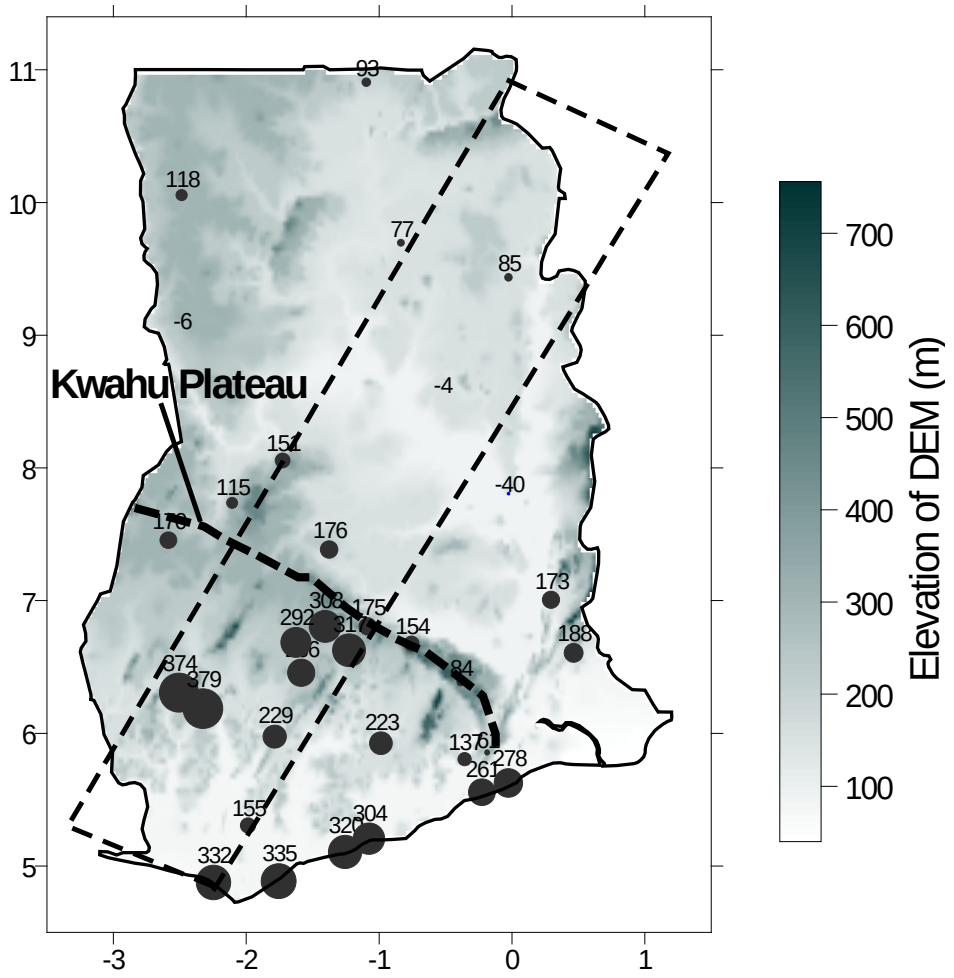


Figure 2- 6. Changes in mean annual rainfall (mm) P1-P2 based on data from GHCN. The dotted rectangle indicates the area in which mean annual rainfalls are portrayed in Figure 2-7 with respect to the increased change south-west of the Kwahu Plateau.

a southeast to northwest orientation can have such a significant impact on mean annual rainfall totals. In long-run, the general regional decline in precipitation may potentially be attributed to global precession of the perihelion from the boreal summer, 10,000 yrs BP to its present position

in the boreal winter (Weldeab et al. 2007). This will have reduced summer heating over the continent, thereby influencing the northernmost extension of the ITCZ and associated monsoonal flows.

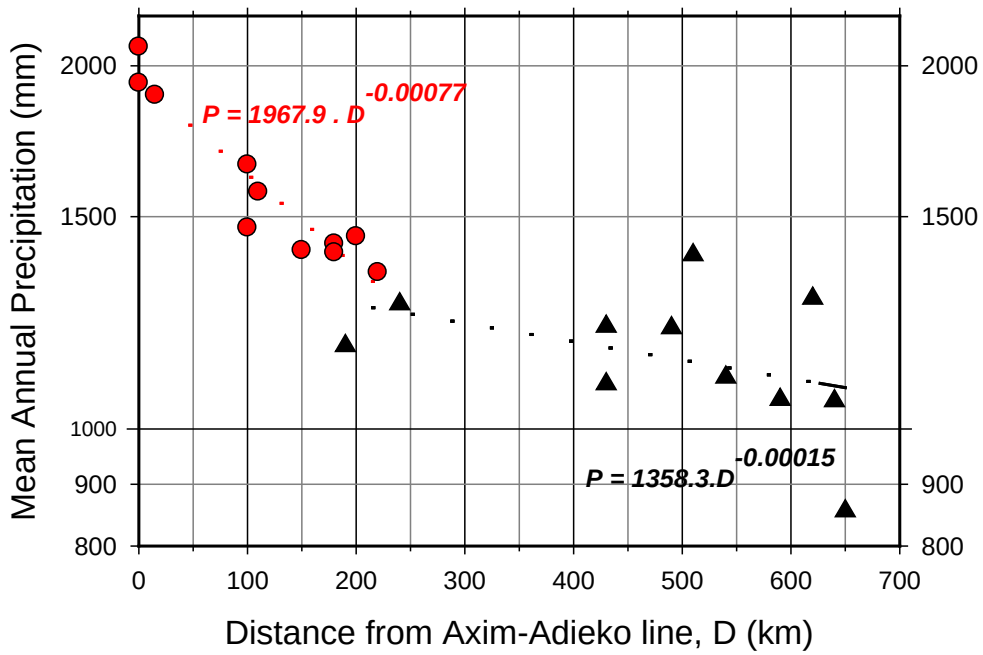


Figure 2-7. Changes in mean annual rainfall with distance from the southwest coast. Stations are identified relative to the Kwahu plateau.

Conclusion

The observations in this paper support the notion of downward trends in annual precipitation that have been highlighted in the Sahel and parts of the humid regions of the Guinea Coast. Moreover, while displaying declining rainfalls, they provide further confirmation that such trends may well vary considerably between regions. Such changes are more frequently larger and statistically significant in the southwest than those of either mid- or northern Ghana.

The Kwahu plateau appears to constitute an important divide in the extent of these changes. Mean annual precipitation has dropped by 20% in the forest region to the south-west, twice as much as experienced in the savanna zones. Such changes are likely to have significant

impacts in the areas of rainfed agriculture which is widely practiced in Ghana. Large scale rainfall deficits like the one observed here have the potential to destroy plant cover, reduce evapo-transpiration, increase surface albedo and other aspects of water and energy balance (Lare and Nicholson 1994) and set in motion a long period of below normal rainfall. The decline in precipitation with elevation is unusual in the presence of onshore winds (Barros and Lettenmaier 1994), but given the relatively low topography, it is consistent with Gorshkov and Makarieva's (2006) hypothesis of the absence of forest, and thus a "biotic pump", in the interior of West Africa.

The revelation of the Kwahu plateau as an important divide in the changing rainfall pattern in Ghana may pose a problem for planning and modeling based on the GMA agro-ecological classification. Although the higher annual rainfall totals in the south-west supports the differentiation of zones A and C, the influence of the plateau on rainfall in the southern parts of the country makes extending zone A to the interior less realistic.

CHAPTER 3
THE CHANGING RAINFALL CLIMATOLOGY OF MID-GHANA

Introduction

Rainfall variability has serious implication for food production and livelihood in developing regions such as West Africa where irrigation is limited and inter-annual and multi-decadal variability occurs in association with declining total rainfall. The situation is exacerbated by the fact that more than half the population in the sub-region is directly engaged in exclusively rain-fed agriculture. Ghana, like the other parts of the sub-continent, has undergone a period of declining annual rainfall total as well as a shifting regime since the early 1970s and is only showing signs of recovery since 2000 (Paeth and Hense 2004; Owusu and Waylen 2008). About 42% of Ghana's 238,540 km^2 is suitable for cultivation, and only about 27% of this total is actually cultivated (FAO 2005). In a pilot study of Wenchi located on the northern fringe of mid-Ghana, Owusu and Waylen (in press) identified, in addition to an overall drying, greater reductions in the mean rainfall totals and the mean numbers of rainy days during the minor rainy season and a slight increase of rains in the short dry spell. This reduction in rainfall and potential diminution of the minor rainy season, if present throughout humid mid-Ghana, is likely to prevent cultivation of crops and crop varieties that have longer growing seasons, as well as the adoption of a single crop per year, instead of the current two crops, under rain-fed agriculture. Government agencies and international organizations are currently encouraging the application of seasonal forecast information. However, in order to develop models to predict changing rainfall patterns or to utilize available forecast information it is important to understand both the spatial and temporal extent of the declining and shifting rainfall pattern in the agriculturally important regions of mid-Ghana.

In this study we employ the methodology used in a pilot study to examine the rainfall regime of stations throughout mid-Ghana (5.5° to 7°N and 2°W to 1°E) to determine the spatial extent of the changes observed at Wenchi. Daily rainfall data are examined through the temporal analysis of various definitions of "variable temporal units" (VTUs) of various starting dates and durations. These VTUs are independent of, yet encompass, the starting dates and durations of the major and minor growing seasons as defined by farmers and the Ghana Meteorological Agency (GMA). They allow the identification, examination and comparison of changes in rainfall regime at time periods relevant to farmers. Within each VTU, two variables are calculated to describe the rainfall characteristics of the unit: total rainfall and number of rainy days. Means and variances of each variable are calculated for each unit over two 20-year periods, 1951-1970 (P1) and 1981-2000 (P2) under the null hypothesis of no significant differences in means and variances between the two periods. A buffer decade of the 1970s accounts for peculiar trends observed in West Africa and a generally accepted shift in global climate patterns over that decade (Trenberth 1990; Navarra 1999; Waylen et al. 2000; Chavez et al. 2003; Shi et al. 2007; Owusu and Waylen 2008). Exclusion of the buffer decade reduces noise that would be created given the multi-decadal oscillatory nature of rainfall in West Africa (Ellis and Galvin 1994: Lare and Nicholson 1994: Ward et al. 2004: Peel et al. 2005). In this way, temporal and spatial variability in the rainfall regime of mid-Ghana may threaten the current two crop per year rain-fed agriculture system may be detected. The main objectives of this research, therefore, are to reveal those portions of the rainfall regime most changed, to detect spatial differences in the nature of the variability across the region, and to provide information about sections of the regime, and in which geographic areas, traditional agricultural practices would still be sustainable.

Study Area

The humid region of mid-Ghana runs from west to east between 5°N to 8°N roughly in accordance with the regional rainfall pattern and is bounded to the south-west by the tropical forest, to the south-east by the Coastal (Accra) plains, and the semi-arid areas to the north (Figure 3-1). For the purpose of this study it comprises the administrative regions of Ashanti, Brong-Ahafo, Eastern and Volta (Figure 3-1) and includes 11 meteorological stations with records of sufficient length for the study. According to the GMA classification (Figure 3-2), the Brong-Ahafo region falls within agro-climatological Zone C and the others form part of Zone A. Mean annual rainfall totals increase from 1000 mm in the south to a peak of 1500 mm in Ashanti and then diminish towards the north. The migrating ITCZ and monsoons produce peak rains in May/June and September/October, with a long dry season (harmattan) lasting from November through March (Figure 3-3). The major rainy seasons begins in late March/early April and runs until mid July. This is followed by a short dry spell in July-August and the minor rainy season of September-October. The regime displays variability in the time of the onset of each rainy season and the beginning of the short dry spell. Adiku and Stone (1995) identified declining annual rainfall totals at some stations in association with a higher incidence of extremes, particularly drought.

Agricultural production in the humid region of Ghana is highly diversified, including food crops such as yams, maize, and cassava in the drier regions of Brong-Ahafo, Volta and northern Ashanti and cash crops, such as cocoa, in the wetter portions of Ashanti and Eastern region. The region is the nation's breadbasket, making it crucial to the food security of Ghana despite the fact that production is almost completely rain-fed. According to Ministry of Food and Agriculture (MOFA 2003), only 0.08% of Ghana's arable land is under irrigation. Rainfall variability therefore has a significant impact on crop yields and food security in Ghana.

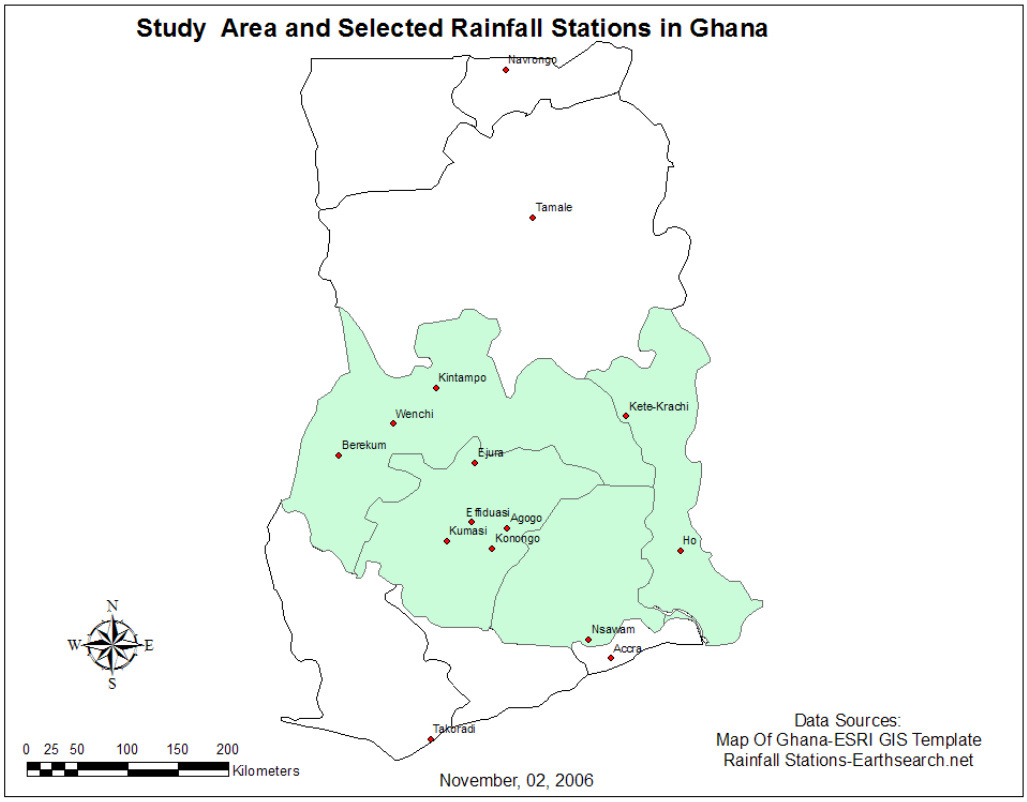


Figure 3-1. Map of Ghana showing the study area.

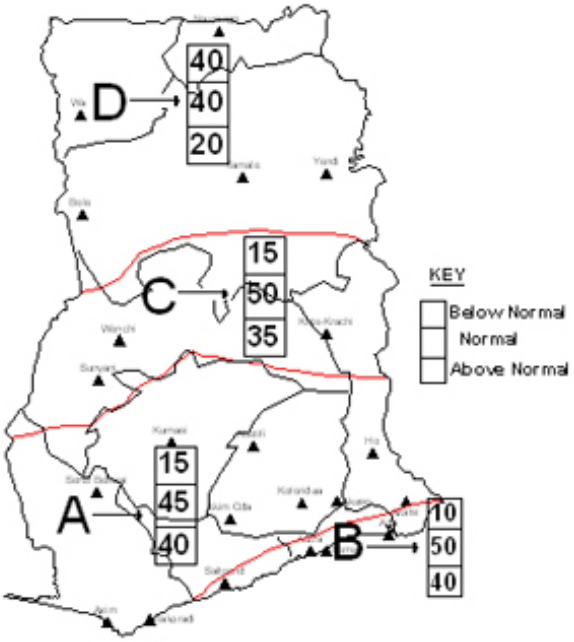


Figure 3-2. Agro-Ecological zones of Ghana according to the Ghana Meteorological Agency

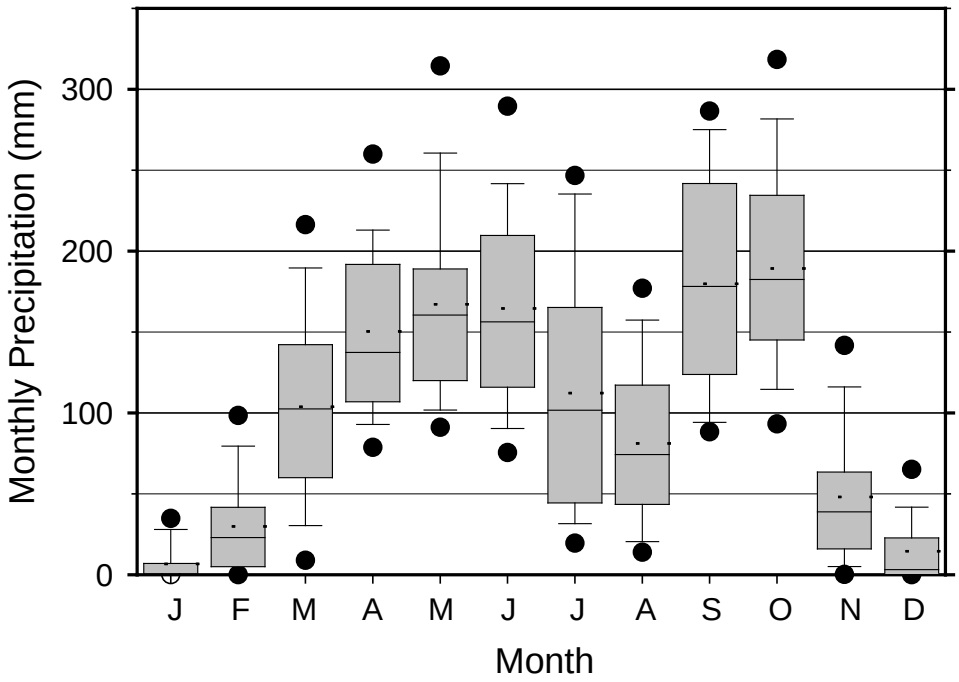


Figure 3-3. Rainfall regime in mid-Ghana showing a bi-modal distribution.

Data and Methods

Daily rainfall data are provided by the Ghana Metrological Agency (GMA) for stations with extensive, reliable data from 1951 to 2000. A total of 11 stations all reporting at least 13 complete years of record in each of P1 and P2 are utilized in this study. Final numbers of complete years of record in both period ranges from 33 at Agogo to 40 at Kumasi and Konongo. A VTU is a time period with a fixed starting date and prescribed duration calculated for the purpose of identifying patterns in rainfall characteristics which otherwise would evade annual, seasonal or monthly analyses. Forty-six starting dates are employed extending from day 30 (March 1) to day 275 (October 1) at five-day increments, thus starting well before and ending well after the traditional growing season. Each possible starting date is associated with following durations ranging from 30 to 90 days, at 10-day increments. This arrangement yields 172 VTUs per year of record, that is, 46 starting dates each associated with seven durations. VTUs

extending beyond December 31 are excluded. This definition obviates the necessity of defining the conditions that mark the beginning and end of each season in a year, which will vary for different crops. However, it provides information at an appropriately fine temporal scale to be able to capture specific times during which agriculturally relevant characteristics of the rainfall regime might have experienced significant change between P1 and P2.

The random variables of total rainfall and number of rainy days are calculated in each VTU from 1951 to 2000. Evidence of inter-decadal, inter- and intra- seasonal variability is sought by examining the means and variances of the two variables in the 172 VTUs during P1 and P2. Total rainfall is derived as the sum of all daily rainfall totals within a VTU and the number of rainy days is the number of non-zero observations. Each of the 344 time series (172 cycles x 2 variables) is sub-divided into P1 and P2, and the mean and standard deviation in each are calculated. Numerical comparisons of the variances and means are carried out using F and t-tests, at the 0.05 and 0.10 levels. Distributions are assumed to be normal. Seven standard tests for normality are performed using the NCSS statistical package (Hintze 2004) on each time series and the number of tests which reject normality at the 0.05 level recorded in order to test the validity of this assumption for different starting dates and durations. The Mann-Whitney test (Lewis 1977) is also performed to compare each appropriate P1 and P2 as a non-parametric alternative to the F- and t- tests as suggested by Owusu and Waylen (in press).

Results and Discussion

The assumption of normality holds true for most of the temporal Variable Units (VTUs) employed in the analysis. However, the assumption becomes less well founded during periods of lower rainfall in the very earliest and latest VTUs. In accordance with the central limit theorem, the assumption becomes more valid as the length of VTUs increase and in the portions of the

season with larger amounts of rain. Differences in the means and standard deviations of the two derived variables are used to describe the changing rainfall regime between P1 and P2.

Total Rainfall

Over the last two decades of the past century mid-Ghana experienced diminishing rainfall totals and higher inter-annual variability as illustrated by Kumasi (Figure 3-4). Ten out of the eleven stations studied (Table 3-1) manifest significant reductions in the mean total rainfall in P2 especially during the minor rainy season. In addition to the reductions in rainfall amounts, results also indicate significant intra-annual shifts in rainfall regime. The major rainy season (late March

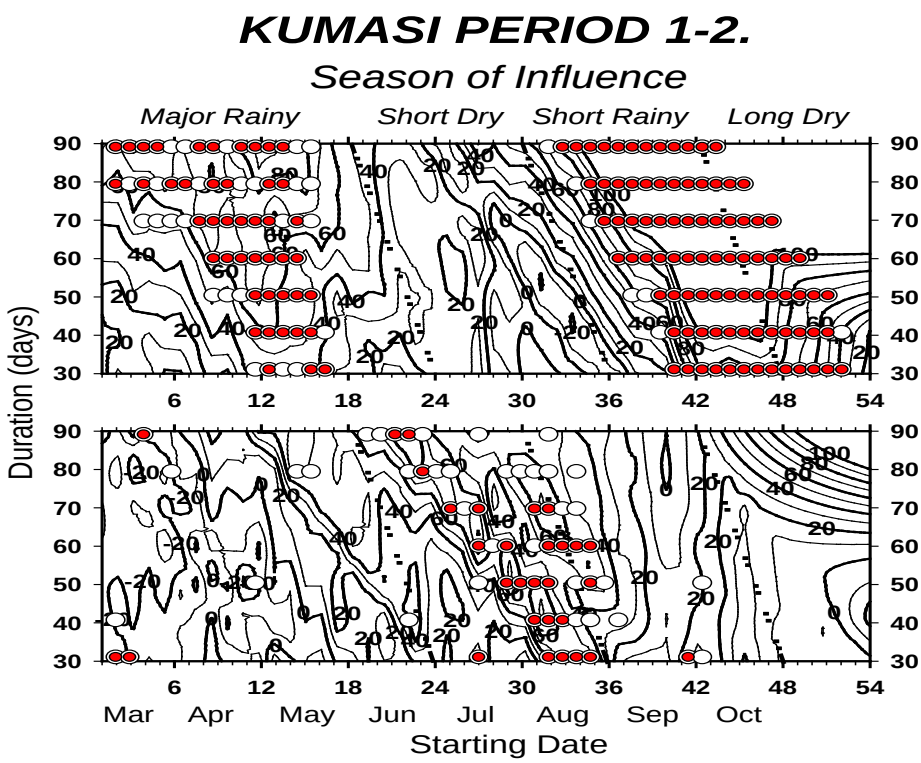


Figure 3-4. Diminishing rainfall total and high inter-annual variability in mid-Ghana as shown in Kumasi.

to mid July), and the minor rainy season (mid August to November) experienced declines in mean total rainfall in most VTUs in 10 stations. However, the short dry spell shows an increase in the mean rainfall totals in P2 at 7 stations with one station remaining unchanged. At many

stations, the rainy season was shorter in P2 than P1 with significant reductions in the mean rainfall total early in the major rainy season and towards the end of the minor rainy season. There has been a concomitant increase in the standard deviation at the beginning of the major rainy season, suggesting a delay and irregular start to the season. Similar increases in the standard deviation of rainfall totals at the end of the minor rainy season indicate a possible shortening of the season and an earlier start and extension of the long dry season (harmattan). Any rainfall reduction during the minor rainy season has serious implications for rain-fed agriculture as it is a very short season of about 2.5 months. The second crop obtained during this time is stored against the long dry season and provide seeds for the following year.

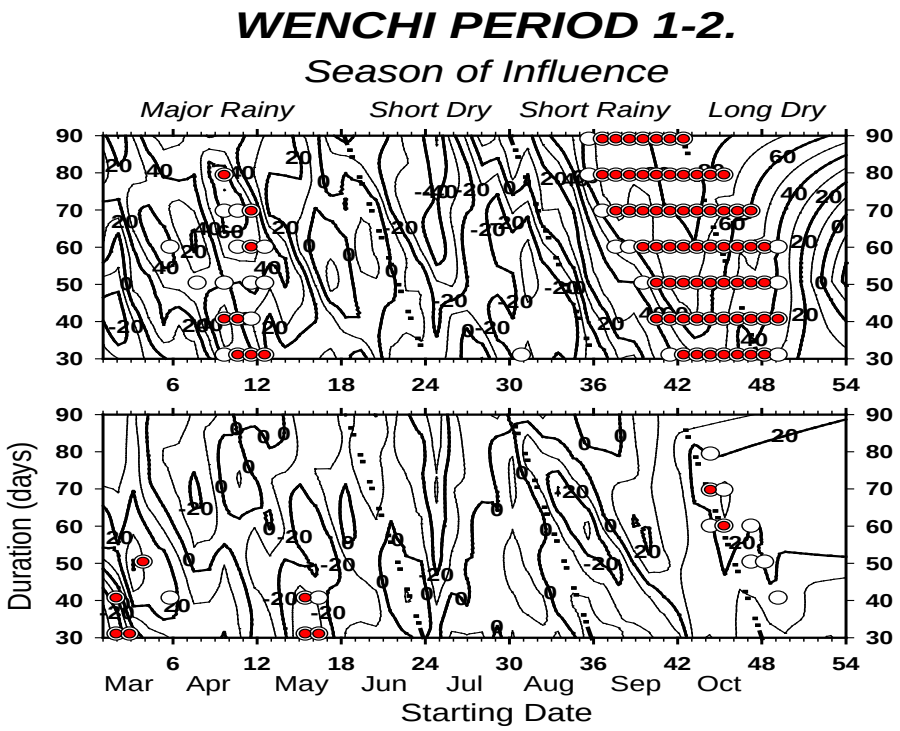


Figure 3-5. Increased mean rainfall total and reduced inter-annual variability during the short dry spell at Wenchi in mid-Ghana.

The short dry spell, however, seems to have experienced a steady (but not significant) increase in the mean rainfall total while at the same time experiencing a reduction in the standard deviation in 7 stations in a fashion similar to that shown at Wenchi (Figure 3-5). This

widespread increase in rainfall totals does not benefit agricultural production in the regions as it hinders the slash and burn land preparation and increases the threat of post-harvest losses from fungal diseases for the major season crops.

Number of Rainy Days

Not surprisingly, mean number of rainy days per VTU follows similar trends to those of mean rainfall totals. Number of rainy days has decreased during both major and minor rainy seasons at all stations except Nsawam, which is located near to Accra and the coast where the number has remained unchanged (Table 3-2). In one important regard number of rainy days differs from the pattern of rainfall totals. During the short dry spell most stations experience fewer rainy days despite the totals remaining constant or increasing (Figure 3-6). Decreases are mostly not significant and may be as few as 2 to 3 days for VTUs of 60-day duration. Mean number of rainy days however shows the most significant reduction in both major and minor rainy seasons in mid-Ghana. During the major rainy season, VTUs of 90 days duration for instance, show reductions in number of rainy days from 5 to 10 days in P2 as compared with P1. The reduction seems to be more significant during the minor rainy season with as many as 16 fewer days in VTUs of 90 days. Considering that the minor rainy season is about about half the length of the major rainy season, there is an increased potential of crop failure. Another important observation is that most changes in the minor rainy season are statistically significant even when reductions are as few as 4 days (Figure 3-6), again reflecting the generally short duration of the minor rainy season. In both rainy seasons, standard deviations generally increase slightly and not uniformly throughout the season. Standard deviations for number of rainy days in the short dry spell remain unchanged or diminish slightly, consistent with mean rainfall total that slightly increased in P2. This signal also displays only slight regional differences among

stations with only Wenchi and Berekum, in Zone C, and Ho and Ejura in Zone A, exhibiting a significant reduction in standard deviation.

Spatial Variability

The most striking exception to these regional generalizations is Kete-Krachi, which reports increased rainfall totals in P2 as compared with P1 for both major and minor rainy seasons, and the short dry spell (Figure 3-7). Although the characteristics of the short dry spell may have changed slightly at the other stations, Kete-Krachi is the only station to show a significant increase from P1 to P2. For example, VTUs of 40 to 80 days duration experienced increases in mean rainfall total from 80 to 120 mm during the short dry spell (Figure 3-7) and most VTUs in the minor rainy season display increases in excess of 100 mm. Simultaneously, inter-annual variability has increased throughout the rainfall regime (Figure 3-7). Number of rainy days decline significantly (0.10 level) by 3 to 6 days in the major rainy season and by 4 to 10 days in the minor rainy season from P1 to P2 (Figure 3-8), while mean number of rainy days increases from 2 to 4 days during the short dry spell. Inter-annual variability in number of rainy days declines significantly towards the end of the rainy seasons.

Two possible climatological explanations for the anomalous behavior of this station may be: (a) changes in instrumentation and data collection, and (b) the possible impact of the Volta Lake, which was created by the Akosombo dam in 1964, on the local climate. Further studies must be conducted to fully explain the anomaly, but at this point we are inclined to support the later hypotheses given the location of the station and the general south-west direction of monsoon flow in the study area.

The changes observed at the 10 remaining stations, fall into three distinct spatial groupings.

(a) The two stations in Zone C (Wenchi and Berekum) experienced less reduction in total rainfall during the major rainy season (around 40 mm in many VTUs) (Figure 3-9) than stations in zone A. The minor rainy season experienced early termination with significant reduction of around (60 mm) in VTUs of above 60 days duration. The short dry spell experienced an increase of about 20 mm in P2. Variability increased during both major and minor rainy season and declined or remained the same in the short dry spell. Mean number of rainy days (Figure 3-10) mimics mean rainfall totals with distinct and significant reductions in the two rainy seasons for P2 compared with P1. The standard deviation of number of rainy days did not change much between the two periods. Berekum only shows a significant reduction (0.10 level) in the standard deviation in P2 during the short dry spell.

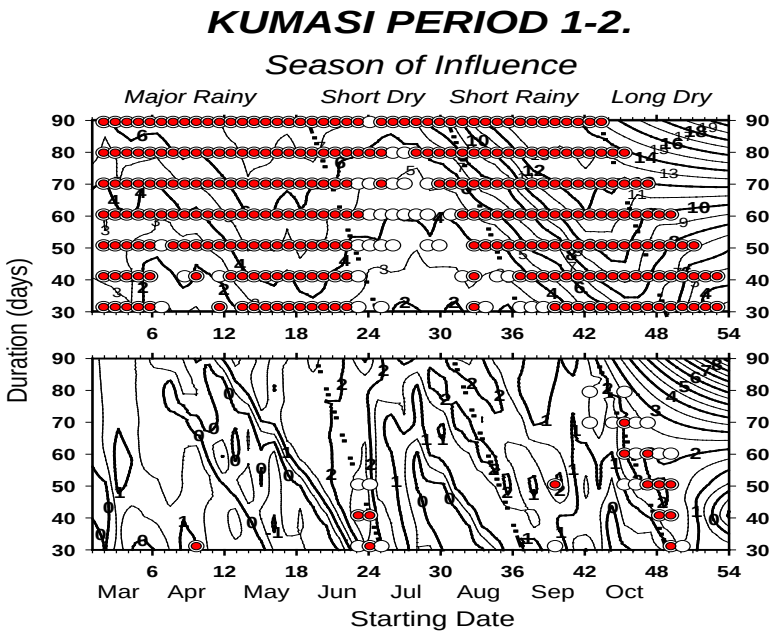


Figure 3-6. Reduction in the number of rainy days recorded in the rainy seasons at Kumasi. The standard deviation of the number of rainy days at the bottom showing less significant variability.

(b) Three stations, Kumasi, Konongo and Kpeve, unlike the former grouping exhibit declining trends, including the short dry spell (Figure 3-11). Both rainy seasons had significant reductions in mean rainfall totals with declines up to 80 mm in some VTUs (Figure 3-4), particularly towards the end of the minor rainy season. The standard deviation of number of rainy days increased in the major rainy season and declined in the short dry spell. The clearest distinction of these three stations from Zone C is provided by the mean number of rainy days, which declined throughout the year (Figure 3-12), with reductions upwards of 6 days in VTUs of more than 60 day duration in the major rainy season and from 12 to 16 days in the minor rainy season. The standard deviation for number of rainy days were not significantly different between the two periods.

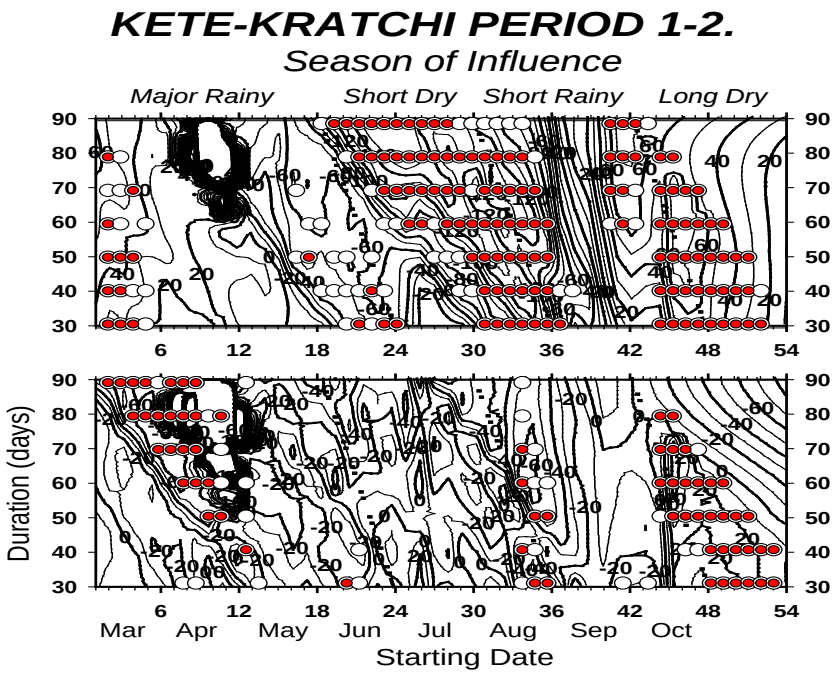


Figure 3-7. Increases in mean rainfall totals recorded at Kete-Krachi. Inter-annual variability has also increased in P2 as shown by the bottom figure.

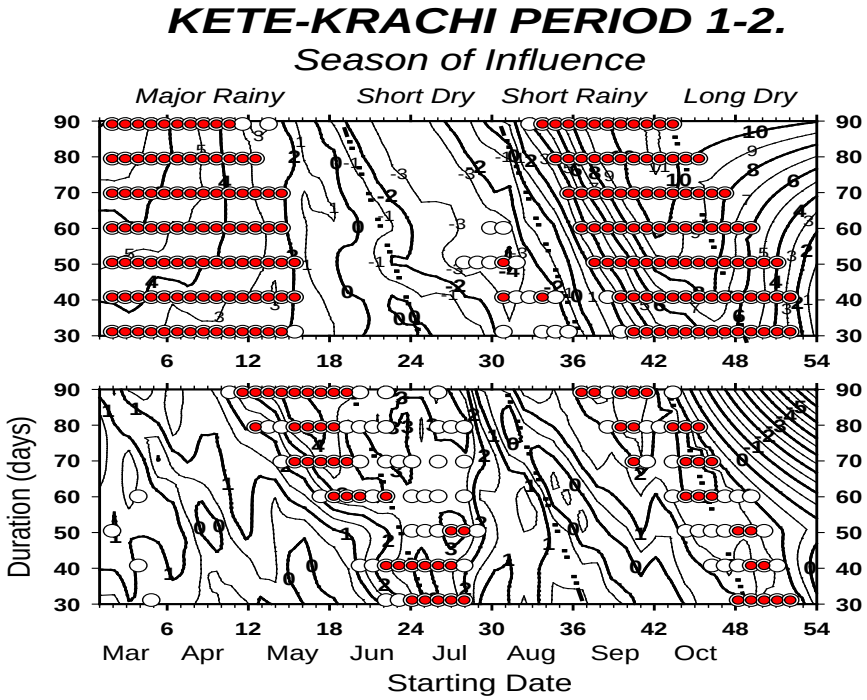


Figure 3-8. Significant reduction in the number of rainy days in both the major and the minor rainy seasons and increases during the shot dry spell. Bottom figure shows significant reduction in variability at the end of the rainy seasons.

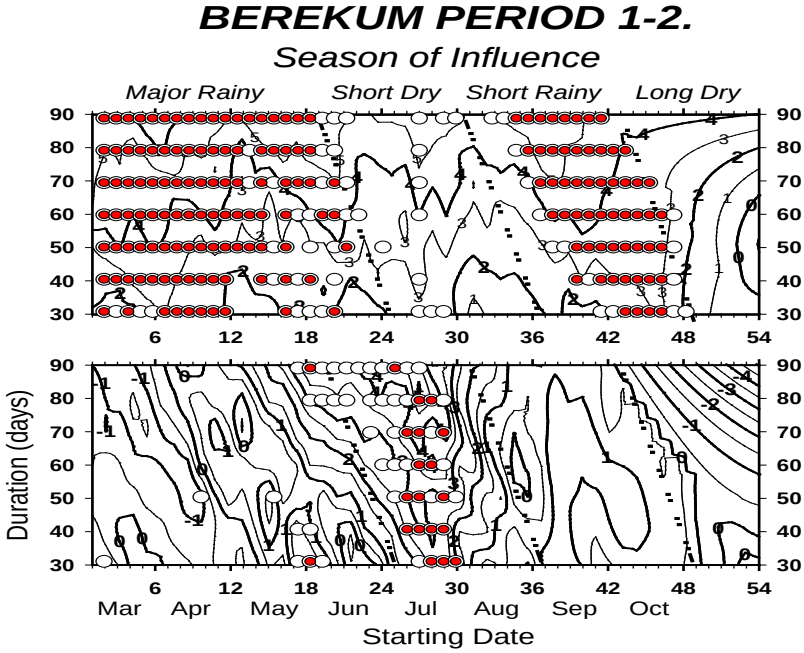


Figure 3-9. Significant reduction in mean number of rainy days during the rainy seasons in zone C. The bottom figure shows reduction inter-annual variability during the short dry spell.

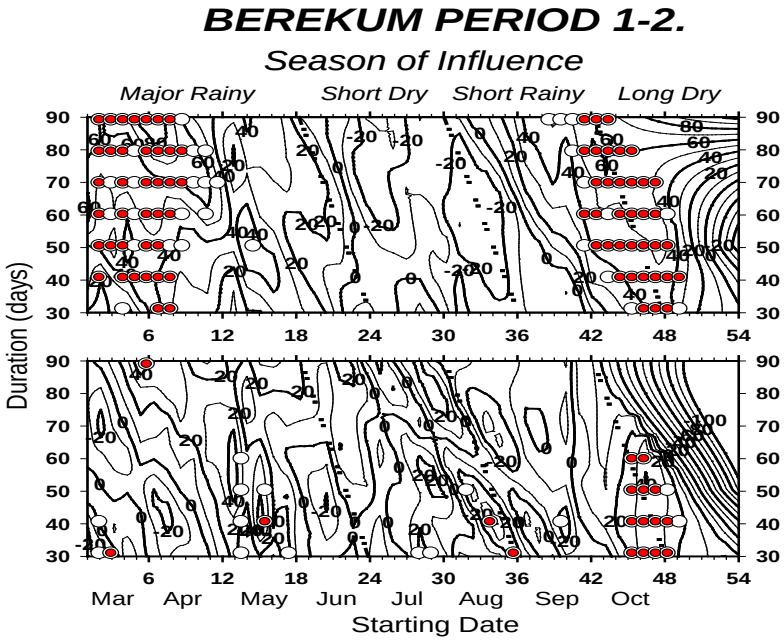


Figure 3-10. Significant reduction at the beginning of the major rainy season and the end of minor rainy season and increased in mean rainfall totals during the short dry spell. Inter-annual variability has show only a minimal change.

(c) The third group consists of the stations to the south and the east of the Zone A that show minimal and less consistent reductions. Total rainfall in the major and minor rainy seasons declined from 20 to 40 mm, but differences are significant only at the end of the minor rainy season. Changes in the short dry spell are small and generally not significant. Their standard deviations show no significant change at Ho where a significant reduction was recorded in the minor rainy season. Number of rainy days declines significantly in both major and minor rainy seasons with reductions of 8 days in VTUs of above 70 days duration, while their standard deviations only significant increased during the minor rainy season.

Changes in rainfall regime are apparent throughout mid-Ghana and raise two climatological issues: (a) there is considerable regional agreement with the GMA classification of Agro-Ecological zoning of the country. Stations in Zone C seem to behave consistently with rainfall reductions in the rainy seasons and increases in the short dry spell. Stations in zone A, however, seem to divide into two major groups. One group on the windward side of the Kwahu plateau, which has mainly experienced significant reductions in mean rainfall totals and number of rainy days throughout the rainy season. The second group inland of the Plateau exhibits inconsistent behavior with some reductions rainfall amounts for the two rainy seasons and increases in mean rainfall total during the short dry spell. (b) The influence of the Kwahu Plateau appears to be detectable at this temporal resolution, finer than the analyses of annual totals completed by Owusu and Waylen (2009), which showed that reductions in annual rainfall were significantly greater in the forest region on the windward side of the Kwahu plateau and only minimal on the leeward side. In this daily analysis, stations in the forest region near Kumasi experience reductions throughout the year, at least for mean number of rainy days, while inland of the plateau reductions are mainly restricted to the two rainy seasons and, in most cases, the short dry spell has experienced slight increases in rainfall totals.

This multiple station analysis of the changing characteristics of the rainfall regime in agricultural mid-Ghana confirms earlier suggestions by Adiku and Stone (1995) and Owusu and Waylen (in press) that changes detected at individual stations may be widespread and have national and regional significance. The humid regions of mid-Ghana especially the interior forest regions had a greater reduction in both rainfall totals and number of rainy days in VTUs corresponding to the major and minor rainy seasons, as distinct from the drier regions where changes are restricted mainly to the minor rainy season.

Changes in SSTs, especially those of the Equatorial Atlantic (Opoku-Ankomah and Cordery, 1994), and positive land surface feedbacks (Shanahan et al. 2009) are linked to the north-south migration of the ITCZ and associated monsoonal system to explain changes in the rainfall climatology of the sub-region. The trends identified are consistent with other studies at the annual scale that have concluded that West African and Ghana have undergone a period of reduced rains since the 1970s. The relative stability of the major rainy season, and the infilling of the short dry spell that have accompanied the early termination of the minor season also suggest a shift in regime from bi-modal towards uni-modal regime, especially in the northern stations closest to the uni-modal zone D of northern Ghana (Figure 3-2). Increases in both mean rainfall totals and number of rainy days during the short dry spell are not necessarily beneficial to the rain-fed agriculture of Mid-Ghana as the break has traditionally been used for slash and burn to prepare the land for the minor rainy season. The short dry spell is also used to harvest and dry the major rainy season produce. Perhaps, the most devastating aspect of the changing rainfall climatology is reduction in rainfall amounts and early termination of the minor rainy season. Traditionally this season provided a second crop that is stored against the lean long dry season (harmattan) from November to April and also provided seeds for the following major

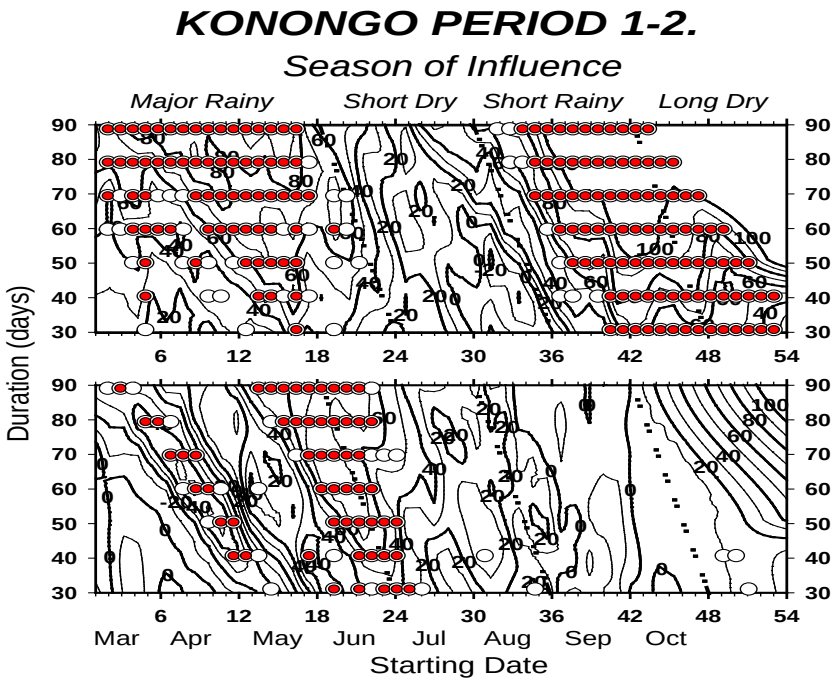


Figure 3-11. Significant reduction in the mean rainfall totals in the interior forest areas of zone A.

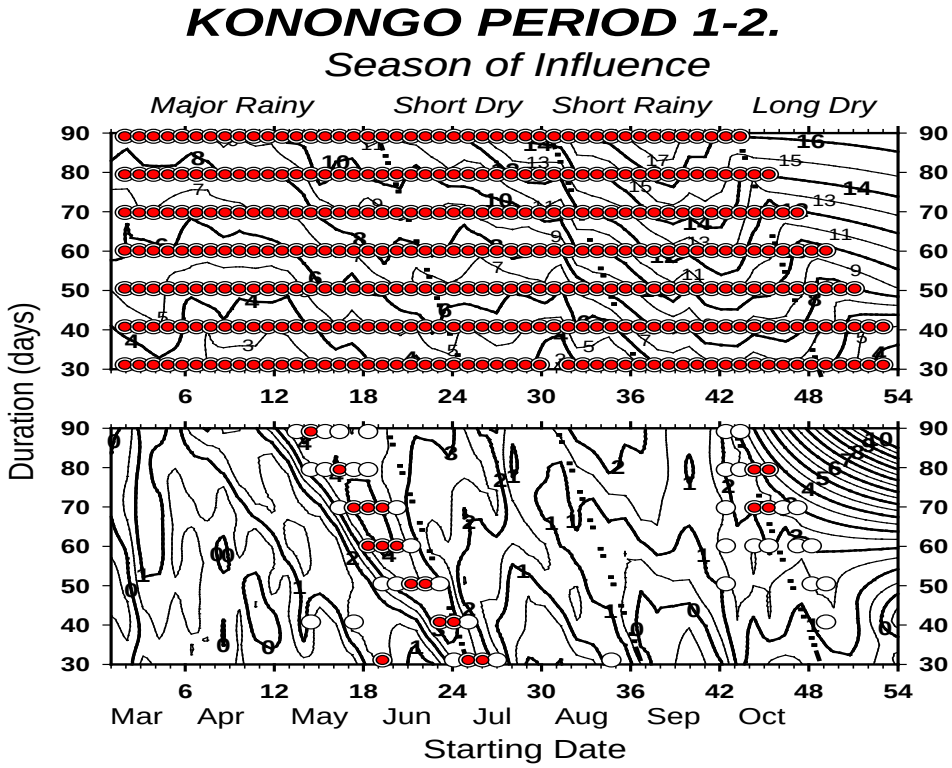


Figure 3-12. Significant reduction in the mean number of days in the interior forest areas of zone A.

rainy season. Erosion of the minor rainy season therefore will seriously diminish food security of the West African region.

Conclusions

Analysis of VTUs applied to daily rainfall in mid-Ghana indicated that the declining rainfall and changing regime reported earlier for Wenchi is widespread and detectable at times and over durations crucial to the traditional rain-fed agriculture of the region. Over the last two decades of the 20th century, the major and minor rainy seasons have undergone varying degrees of drying. This reduction in rainfall is not uniform, either temporally through the rainy seasons or spatially across the study area. Most locations had significant reductions in rainfall during the minor rainy season and at the beginning of major rainy season, and often an increase in rain during the short dry spell. The universal decline of mean rainfalls totals and number of rainy days during the minor rainy season, often associated with greater inter-annual variability, is particularly threatening to the production of a second crop during this time of the year. Meanwhile, increases in means of both variables and reduction in their standard deviations during the short dry spell, only exacerbates these problems. as this season has traditionally been used to store the first crop and to perform slash and burn in preparation for the second crop. Humid conditions during the short dry spell increase the likelihood of losses from fungi and hinders the successful burning of cleared vegetation.

The exact nature of these changes varies spatially. Drier portions of the study area, which coincide with zone C of the GMA classification and the eastern side of Zone A manifest an increase in rainfall totals during the short dry spell and smaller reduction in mean number of rainy days. However, the forested regions windward of the Kwahu plateau exhibit reductions in both variables during the major and minor rainy seasons, consistent with earlier findings that

there have been greater reductions in annual rainfall totals within the forest region than the sub-humid areas of Ghana (Owusu and Waylen 2009).

The study highlights the local significance of the Kwahu Plateau in determining the type and extent of low frequency changes in rainfall characteristics. The plateau bisects the GMA Zone A, northwest to southeast, and the degree of spatial variability encountered at daily and annual scales suggests that further sub-division of this zone may be appropriate. The creation of Volta Lake may also have had important local impacts on the rainfall at Kete-Krachi, which is the only station in this study to report increases in means of both variables throughout rainy seasons in P2.

Finally, application of VTU to the analysis of daily rainfall permits the objective examination and comparison of rainfall regimes that experience different changes in time and space of two agriculturally pertinent variables, without the necessity of any *a priori* judgments or definitions of what constitutes the beginning or end of any seasonal sub-division. Based on these findings, stakeholders can be provided with information that may facilitate the evaluation of various seasonal solutions (agricultural alternatives) across mid-Ghana to mitigate the probable impacts of rainfall variability on rain-fed agriculture and other rain dependant activities. For instance, while the main concern of the changing rainfall climatology in zone C could be the infilling of the short dry spell, the major concern in the forest regions of zone A could be the significant reductions that have occurred in the mean total rainfall and mean number of rainy days in the major rainy season, which suggests that a generalized climate forecast may not be useful in mitigating the impact of rainfall variability in the study area.

Table 3-1. Characteristics of mean rainfall totals in Mid-Ghana 1951-1970 (P1) and 1981-2000 (P2)

Station	Zone	Latitude (^{o})	Longitude (^{o})	Major Season	Short Dry Spell	Minor Season
Agogo	A	6.97 N	0.98 W	Reduction	Increase	Reduction**
Effiduasi	A	7.21 N	1.22 W	Reduction**	Increase	Reduction**
Ejura	A	7.37 N	1.37 W	Reduction	Increase	Reduction**
Ho	A	6.59 N	0.47 E	Reduction*	Increase	Reduction**
Kete-Krachi	A	7.83 N	0.05 W	Increase*	Increase**	Increase**
Konongo	A	6.62 N	1.2 W	Reduction**	Reduction	Reduction**
Kpeve	A	6.68 N	0.32 E	Reduction	Reduction	Reduction
Kumasi	A	6.69 N	1.62 W	Reduction**	Reduction	Reduction**
Nsawam	A	5.80 N	0.35 W	Reduction*	Unchanged	Reduction
Berekum	C	7.45 N	2.58 W	Reduction**	Increase	Reduction**
Wenchi	C	7.73 N	2.10 W	Reduction*	Increase	Reduction**

**significant at 0.05 level *significant at 0.10 level

Table 3-2. Characteristics of mean number of rainy days in Mid-Ghana 1951-1970 (P1) and 1981-2000 (P2)

Station	Zone	Latitude (^{o})	Longitude (^{o})	Major Season	Short Dry Spell	Minor Season
Agogo	A	6.97 N	0.98 W	Reduction**	Reduction*	Reduction**
Effiduasi	A	7.21 N	1.22W	Reduction**	Reduction	Reduction**
Ejura	A	7.37 N	1.37 W	Reduction**	Reduction	Reduction**
Ho	A	6.59 N	0.47 E	Reduction**	Reduction	Reduction**
Kete-Krachi	A	7.83 N	0.05 W	Reduction**	Increase	Reduction**
Konongo	A	6.62 N	1.2 W	Reduction**	Reduction**	Reduction**
Kpeve	A	6.68 N	0.32 E	Reduction**	Reduction*	Reduction**
Kumasi	A	6.69 N	1.62 W	Reduction**	Reduction**	Reduction**
Nsawam	A	5.80 N	0.35 W	Unchanged	Unchanged	Unchanged
Berekum	C	7.45 N	2.58 W	Reduction**	Reduction*	Reduction**
Wenchi	C	7.73 N	2.10 W	Reduction**	Reduction*	Reduction**

**significant at 0.05 level *significant at 0.10 level

CHAPTER 4
CHANGING RAINFALL INPUTS IN THE VOLTA BASIN: IMPLICATIONS FOR WATER SHARING IN GHANA

Introduction

The immediate post-colonial economies of most countries in sub-Sahara African were dominantly "planned" and many proposed activities assumed stationarity of mean rainfall at levels similar to those prior to independence. Precipitation experienced in the following decades facilitated an increase in national reliance on rainfed agriculture and the embracing of hydroelectricity as the main source of energy for domestic and industrial consumption. For instance, Ghana constructed two hydroelectricity generating plants on the Volta River at Akosombo and Akuse in the early 1960s with a combined electricity generating capacity of 1160 MW which supplied around 90% of the nation's energy needs until the late 1980s. Gleick (1993) reported that rain-fed agriculture constitutes at least 97% of agriculture in all West African countries. Since the 1970s, West Africa has undergone a period of declining rainfall, punctuated by a series of severe droughts and marked by a shift in rainfall regime. As a result lake levels have fluctuated so widely that at times, power has had to be rationed (van Edig et al. 2001). The most extensive shortages occurred in Ghana during 1983 and 1998, and the 2007 crisis has been ongoing for about a year. Consequently Ghana has neither been able to meet industrial demand nor fulfill its international commitments to supply power. Accusations of water withdrawals upstream, beyond Ghana's borders, causing reductions of flow in the lower basin have increased regional tensions and the potential for conflict (van Edig et al. 2001).

However, despite the political rhetoric, studies have shown that water withdrawals upstream in Burkina Faso have very little impact on reservoir levels downstream in Ghana (Andreini et al. 2000). Rainfall variability and the incidence of meteorological drought have been identified as the main causes of reduction in reservoir levels and their subsequent impact on

power generation (van Edig et al. 2001, Rodgers et al. 2007). This study analyzes the trends in the spatial and temporal variability of rainfall in the six riparian nations above the Akosombo Dam to explain the low impoundment levels that have become frequent in recent decades. El Niño-Southern Oscillation phenomena (ENSO) are investigated as a possible cause of the spatial and temporal variation in rainfall across the basin. Regional data from beyond the basin are also analyzed to show that the decline is widespread and that there has been a shift in the rainfall regime in association with the reduction of water impoundment. It is hoped that a better understanding of the causes of variability will help reduce the potential for conflict in the basin and help foster new agreements for water resource sharing, which at present are non-existent in any meaningful way.

The Study Area

The Volta basin occupies 400,000 km^2, shared between six riparian nations (Figure 4-1): Burkina Faso, (43%); Ghana, (40%); Togo, (6%); Benin, (4%); Mali, (4%); and Côte d'Ivoire, (3%). Ghana occupies the lower half of the basin and the point at which the three principle tributaries (the Black Volta, the White Volta and the Oti River) join the main Volta at the Volta Lake behind the Akosombo Dam. The lake, one of the largest man-made lakes in the world with a total surface area of 8,500 km^2, was created in 1964 and stores roughly 150 billion cubic meters (BCM) and has an installed hydropower generation capacity in excess of 900 MW (Sutherland *et a.*, 2004). The Black Volta basin (147,000 km^2) drains western Burkina Faso and small areas within Mali and Côte d'Ivoire; the White Volta basin (106,000 km^2) draws water from much of northern and central Ghana and Burkina Faso, and to the east, the Oti basin (72,000 km^2) occupies the northwestern regions of Benin and Togo. Annual rainfall varies greatly across the basin, from 1500 mm in the south to 400 mm in the north (Figure 4-2).

Rainfall regimes also differ between the humid south and the dry north as manifested in their respective bi- and uni-modal patterns (Sultan et al. 2004)

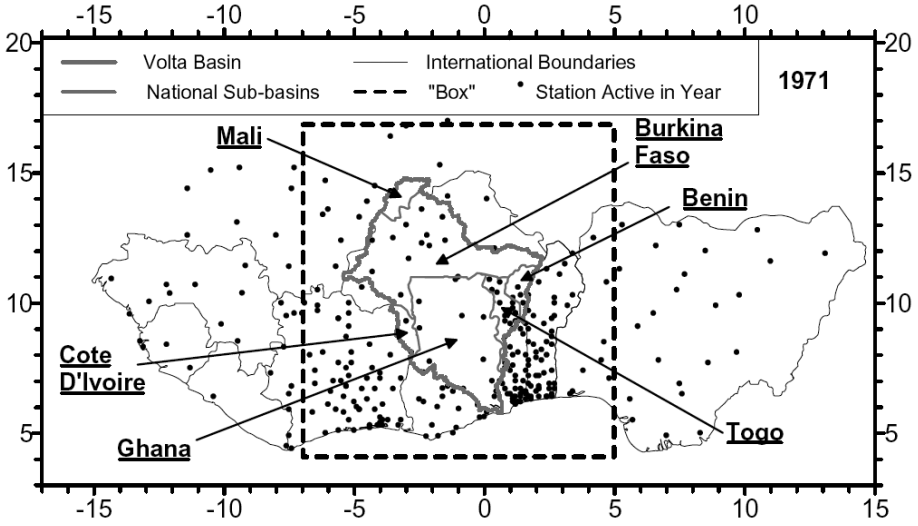


Figure 4-1. Central West African nations showing the Volta basin limits and stations with available historic monthly rainfall records

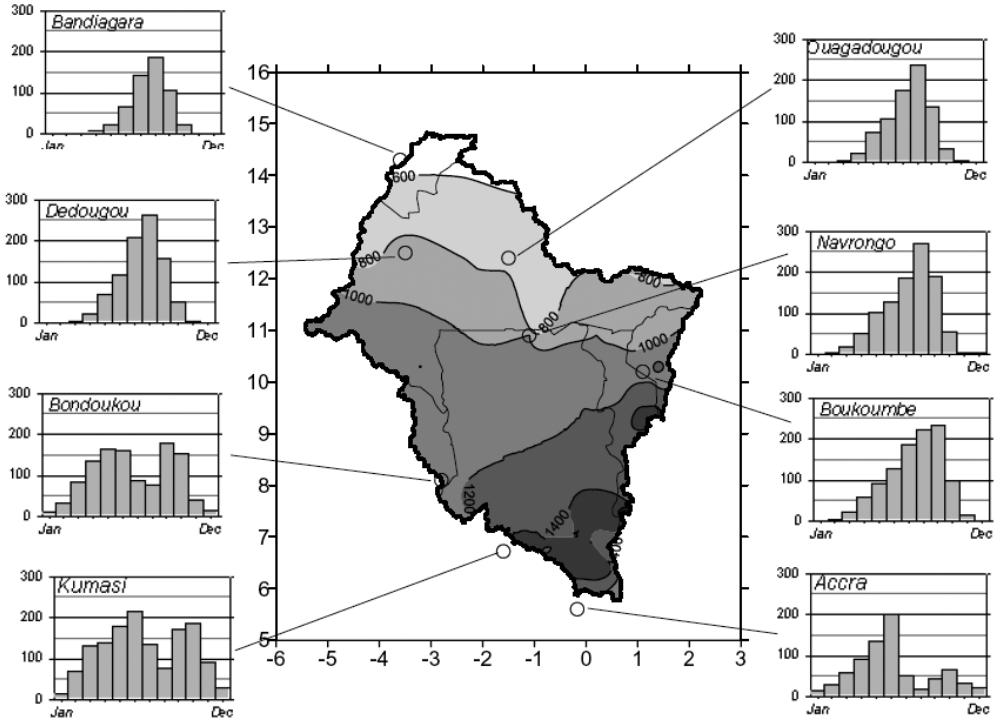


Figure 4-2. Mean annual rainfall across the Volta basin with bi-modal and uni-modal distribution

The basin extends over at least four climatic regions, from rainforest in the south to the Sahel in the north, with Guinea and Sudan Savanna in between (Rogers et al. 2007). Each climatic zone is strongly influenced by the movement of the Inter-Tropical Convergence Zone (ITCZ), which is responsible for both rainfall regimes (Sultan et al. 2004; Rodgers et al. 2007). Southern zones exhibit one peak in June/July and another in September/October, within an overall rainy season stretching from April to mid-November. In the uni-modal north, the rainy season occurs from May to October with a peak in September. The basin experiences high degrees of spatial and temporal variability in rainfall (van de Giesen et al. 2001), making it unreliable for agricultural production resulting in diminishing food security. Irrigation is limited to the more arid northern regions especially in Burkina Faso, still only 0.4% of national agricultural land is irrigated according to Gleick 1993. In Ghana the water is utilized mainly for power generation and domestic consumption (van Edig et al. 2001, van de Giesen et al. 2001).

Transboundary Issues in the Basin

The Volta basin unlike many transboundary rivers in Africa, has no agreements on water sharing among the countries involved. Despite the Akosombo Dam's reliance on water from upstream countries, Ghana did not arrive at any agreements to ensure continued flow of the Volta at the time of construction (Lautze et al. 2005). After over forty years of operation, attempts are still underway to form strategic partnerships and water-sharing agreements between the riparian nations. A series of memoranda of understanding has been established among the countries through the initiative of the World Bank. The most profound memorandum requires that a country "proposing to execute any project which will regulate, abstract or otherwise change river flow must notify co-riparian states of its intentions so that each state may consider whether it wishes to lodge an objection." (World Bank 1995). In the building of the Ziga dam, Burkina

Faso actually followed this protocol and invited a Ghanaian delegation to sign a non-binding agreement in order to satisfy the World Bank (Lautze et al. 2005).

Intense negotiations have failed to yield a firm agreement; a failure which reemerges when reservoir levels sink so low that energy crises and power rationing arise as they did in 1983, 1998, and 2007. For instance, in 1998, exacerbated by drought in the basin, Ghana accused Burkina Faso of causing low water levels by increased withdrawals and obstruction of flow. Andreini et al. (2000) showed that withdrawals in Burkina Faso have very little impact on lake levels in Ghana. At the same time, Burkina Faso has opted to produce its own power because it considers Ghana's power production capacity to be highly uncertain. Historic and institutional factors have made it impossible for Ghana to generate enough money from the power generation to re-invest in the sector. A major financial problem at the time of the dam's construction required the Ghanaian government to secure a loan from a private aluminum company, Henry J Kaiser of the United States, which later operated in Ghana as Volta Aluminum Company (VALCO) (van Edig et al. 2001). Through tax and export exemption granted for 50 years VALCO consumed 45% of the power generated and paid less than competitive prices. Also, as part of the government's "Vision 2020" plan to electrify every household in the country, many rural communities were added to the national grid in the late 1980s and early 1990s. Increased consumption was heavily subsidized and generated returns less than production costs.

Rainfall variability and its negative impacts on water resource sharing have huge potential for conflict which should be properly addressed. Ghana has expanded provision of electricity to many households in recent years in line with the nation's "Vision 2020" program. Burkina Faso on the other hand has constructed a series of small dams for irrigation and domestic water supply. The conflict potential is more imminent with increased population

growth and associated increases in demand for water for agriculture in Burkina Faso, power generation in Ghana, and domestic consumption in urban centers throughout the entire basin.

Data and Methods

Gridded monthly precipitation data are available at 0.5º intervals over the period 1951-2000 from the Global Precipitation Climatology Centre's (GPCC) new "50-year Climatology Product" (http://gpcc.dwd.de) from data collected under the auspices of the WMO (Beck et al. 2005). Data from each riparian nation and neighboring nations permit the spatial interpolation of data over each national sub-basin, which in turn allows the identification of changes that have occurred in each country over the period of analysis. Interpolated annual surfaces are fitted to the gridded data using simple Kriging without drift (Golden Software 1995) as elevation is fairly subdued throughout the basin and topography seems to have little regional effect. Volumes beneath the surfaces corresponding to the "footprint" of each national sub-basin are extracted, and mean annual sub-basin input computed by dividing by sub-basin area. This calculation yields annual time series information for the entire basin and for each of the national sub-basins.

Data are divided into two periods (P1; 1951-1970, and P2; 1981-2000) with an intervening ten year buffer. This division is based on observations of mostly above median rainfall in P1, and below median rainfall in P2, while the buffer period shows a transitional pattern (Figure 4-3), corresponding to a widely reported shift in climate around the globe in the mid 1970s (for example, Trenberth 1990; Navarra 1999; Waylen et al. 2000; Chavez et al. 2003; Shi et al. 2007). This trend is also consistent with observed multi-decadal trends or oscillations in West African rainfall (Ellis and Galvin 1994; Lare and Nicholson 1994: Ward et al. 2004).

Two classes of "above", and "below median" rainfall are defined based on annual totals estimated over the available record 1951-2000 and are used to compare rainfall characteristics. The hypergeometric distribution and standard F- and t-tests identify changes in the numbers of

above and below median years, and variances and means of annual rainfall in each period, under the null hypothesis of no significant differences in these characteristics between P1 and P2. The hypergeometric distribution arises when a random selection is made without replacement among objects of two distinct types. It has been used in several similar climatological analyses (for example, Ropelewski and Halpert 1987; Grimm et al. 2000) and has the advantage that it does not assume distribution in annual rainfall amounts.

In its general form the hypergeometric distribution is describe by three parameters: *N*, population size; *k*, number of success in the population; and *n*, sample size.

$$p(x) = \frac{\binom{k}{x}\binom{N-k}{n-x}}{\binom{N}{n}}$$

In this application, N = 50 the total number of estimated mean annual precipitation inputs in sub-basins 1951 and 2000, (50). Success refers to the number of years above or below the median, thus k = 25. The sample size is the number of years in P1 or P2, thus n = 20. Significance levels for α of 0.05 and 0.01 are used throughout.

Years are classified, *a priori*, as warm, cold or neutral phase of ENSO (Table 4-1) employing the scheme detailed by the Center for Ocean-Atmosphere Prediction Studies (COAPS) at Florida State University (http://coaps.fsu.edu/jma.shtml), based on the procedures outlined by the Japan Meteorological Agency. The derived annual surfaces for years falling within each category are averaged to produce composite surfaces according to ENSO phase. These surfaces can then be manipulated to demonstrate spatial differences in the nature and strength of rainfall signal in response to ENSO over the basin in this time period.

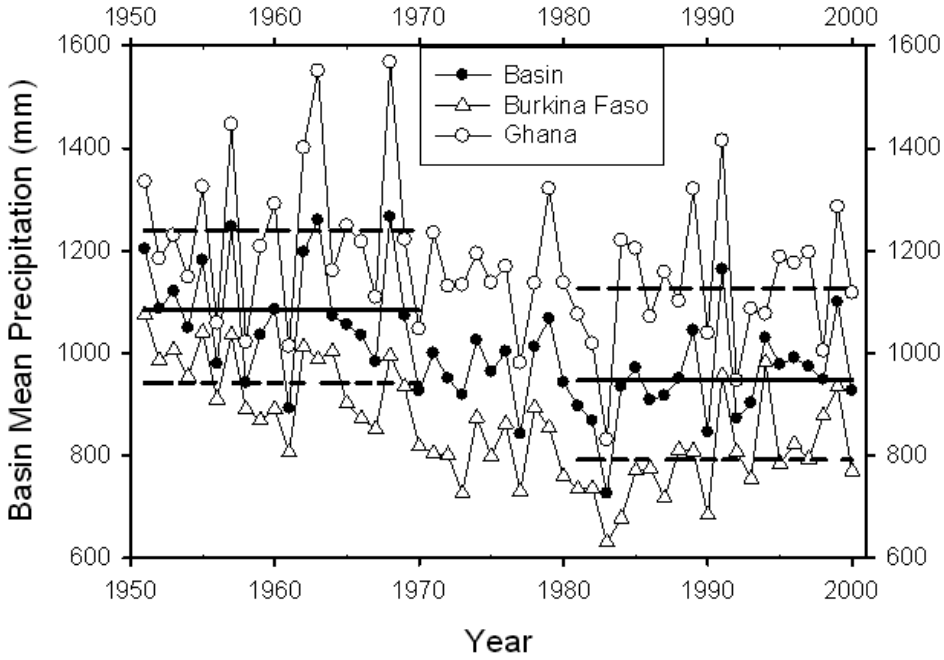


Figure 4-3. Time series of estimated mean annual precipitation inputs to the entire Volta basin and larger sub-basins in Ghana and Burkina Faso. Solid lines represent 20 year means and dotted lines represent + or – 1 standard deviation of the entire Volta basin.

Table 4-1. Different phases of ENSO over the study period based on JMA classification

ENSO Phase	Year
Cold	1954 1955 1956 1964 1967 1970 1971 1973 1974 1975 1988 1998 1999
Neutral	1950 1952 1953 1958 1959 1960 1961 1962 1966 1968 1977 1978 1979 1980 1981 1983 1984 1985 1989 1990 1992 1994 1995 1996 2000
Warm	1951 1957 1963 1965 1969 1972 1976 1982 1986 1987 1991 1997

Results and Discussion

Figure 4 shows the general downward pattern in rainfall experienced throughout the Volta basin, since 1951. Mean annual rainfall totals have diminished from 1400 mm to 1200 mm in the south and from 700 mm to 600 mm in the north. Results of the F- and t-tests, as well as the hypergeometric distribution, shown in Tables 4-2 and 4-3 respectively, indicate that the reductions observed in the basin are significant at least at 0.05 level. Results also indicate that the

national sub-basins most affected by the declining rainfall are those in the Sahel. Burkina Faso, constituting about 43% of the basin, has had the largest decline. This spatial heterogeneity in the declining rainfall pattern is consistent with earlier research in West Africa (Servat et al. 1997; Gyau-Boakye and Tumbulto 2000; Jenkins et al. 2002; Owusu and Waylen in press). Table 3 shows that in Burkina Faso, 17 of the 20 years in P1 recorded above median rainfall and only 2 of the 20 in P2 fall into this category. There has also been a reduction of 150 mm (Table 4-2) in the estimated mean annual rainfall input. Changes in Ghana, the other major contributing national sub-basin, have been similar but less marked. Numbers of years with above median rainfall were 13 in P1 and 8 in P2 (Table 4- 3), and the reduction in mean annual basin input of 112 mm (Table 4-2) was significant at only the 0.05 level. The reductions are consistent with earlier findings attributing declining impoundment levels in Ghana to significant changes in rainfall outside Ghana (Gyau-Boakye and Tumbulto 2000; Rogers et al. 2007). Over all, the entire basin recorded 15 years of above median in P1 an only 5 such years in P2 (Table 4-3) with a total shortfall of 136mm (Table 4-2) in precipitation between the two periods.

Visual inspection of mean monthly precipitation regional surfaces during the two periods, (for example see Figures 4-5a and 4-5b) reveals that the reduction in annual rainfall has been associated with a shift in the rainfall regime, especially in the southern portions of the basin.

The months most affected are September and October, coincident with the peak of the minor rainy season of the humid south and peak rainfall in the uni-modal north of the basin, as well as the July/August short dry spell. The short dry spell has become wetter in the second period (Figure 4-6) whereas the wet September/October months are becoming drier in P2 (Figures 4-5a and 4-5b). Diminished rainfall towards the end of the rainy season leads to prolonged dry season with increased evaporation, which exacerbates the reduction in the lake

Table 4-2. Differences in mean annual rainfall and standard deviation in the Volta Basin

Country	Mean Annual Rainfall P2-P1 (mm)	Standard Deviation P2-P1 (mm)
Benin	-215.3**	-55.3
Burkina Faso	-150.6**	13
Ghana	-112.6*	-28.6
Côte d'Ivoire	-112.3*	-45.3
Mali	-127.9**	12.4
Togo	-161.1**	-62.4
Entire Basin	-136.6**	-18.3

*Significant at 0.05 level
**Significant at 0.01 level

Mean annual basin rainfall
P1 = 1093.2mm P2 = 956.6

Table 4-3. Above median rainfall in the Volta Basin 1951-1970 (P1) and 1981-2000 (P2)

Country	Years Above Median (P1)	Total (P1) 1950-1969	Years Above Median (P2)	Total (P2) 1980-1992	Total 1950-1992
Benin	15**	20	6*	20	50
Burkina Faso	17**	20	4**	20	50
Ghana	13*	20	8	20	50
Côte d'Ivoire	12	20	8	20	50
Mali	19**	20	1**	20	50
Togo	14*	20	7*	20	50
Entire Basin	15**	20	5**	20	50

*Significant at 0.05 level
**Significant at 0.01 level

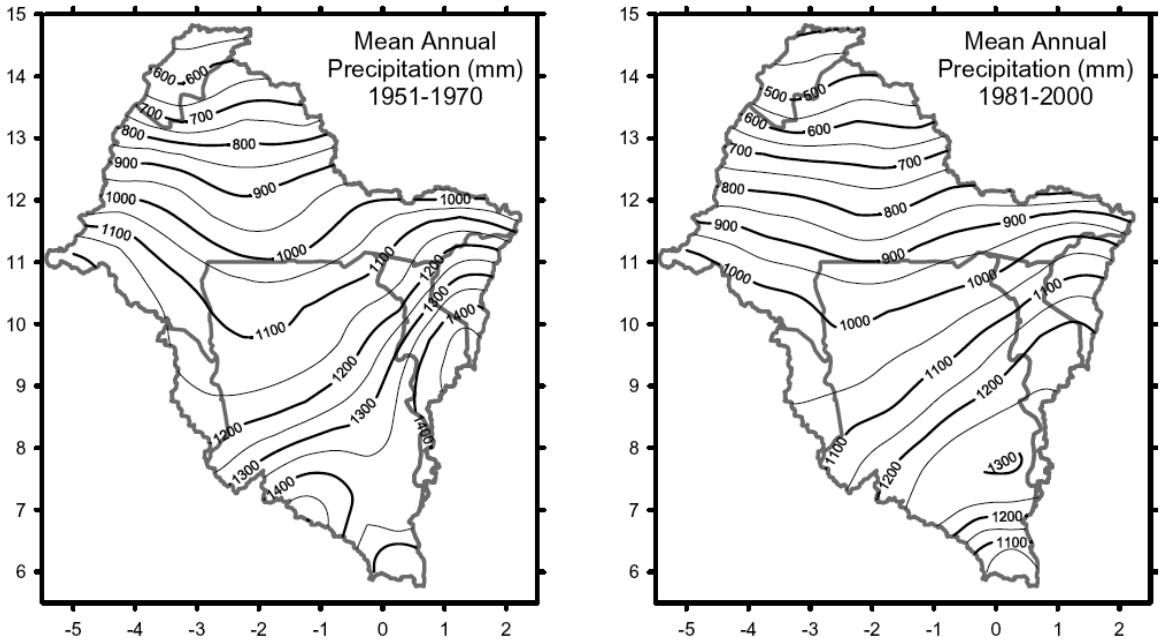


Figure 4-4. Mean annual rainfall in P1 and P2 in the Volta basin

levels. An early to the rainy season also has the potential to increase demand for more withdrawals for irrigation thereby causing further reducing in the lake levels.

Other higher frequency causes of variability have been proposed for such changes. One that often emerges in the context of Sahelian rainfall is ENSO. Figures 4-7 to 4-9 show that the warm phase of ENSO in the observation period (Figure 4-7) is associated with reduced rainfall in the basin, particularly in the Sahel region.

On the other hand, the increased rainfall associated with cold phase years is more noticeable in the south. The composite mean 1000 mm isohyet tends to migrate north of Ghana during cold phase years (Figure 4-8), with many regions of the southern half of the basin experiencing mean rainfall totals around 1200 mm. During warm phases regions within the Ghanaian sub-basin experience mean annual rainfall of below 1000 mm (Figure 4-9). The neutral phase does not seem to have a strong effect on spatial distribution of rainfall in the basin but

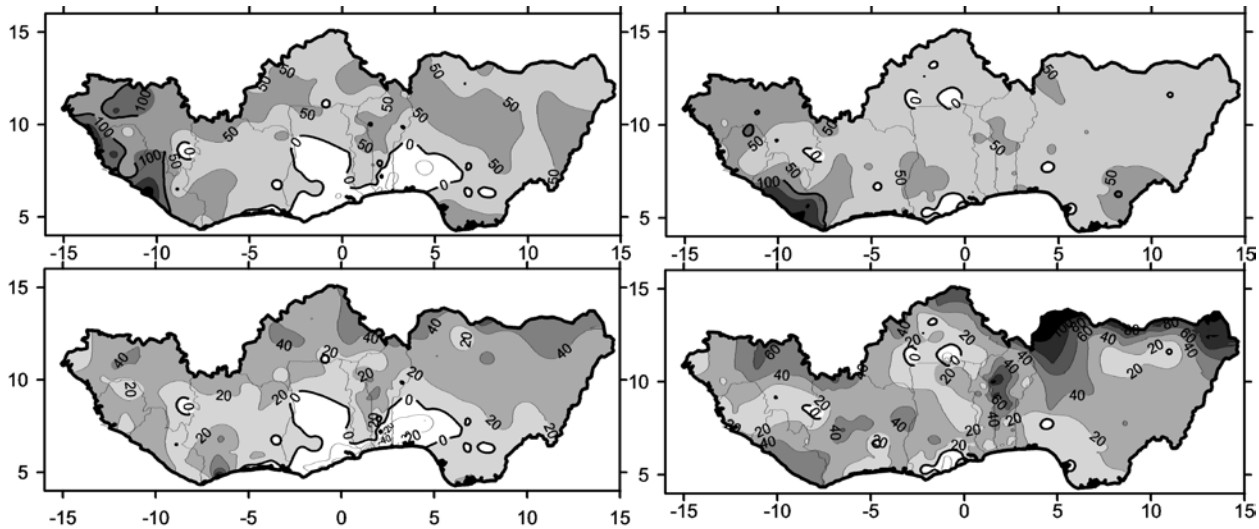


Figure 4-5. Changes in mean monthly rainfall (P1 minus P2) for September (left) and October (right), showing drying trends (shaded areas) in the minor season. Upper maps illustrate the absolute difference (mm), and lower express the differences as a percentage of the long-run mean.

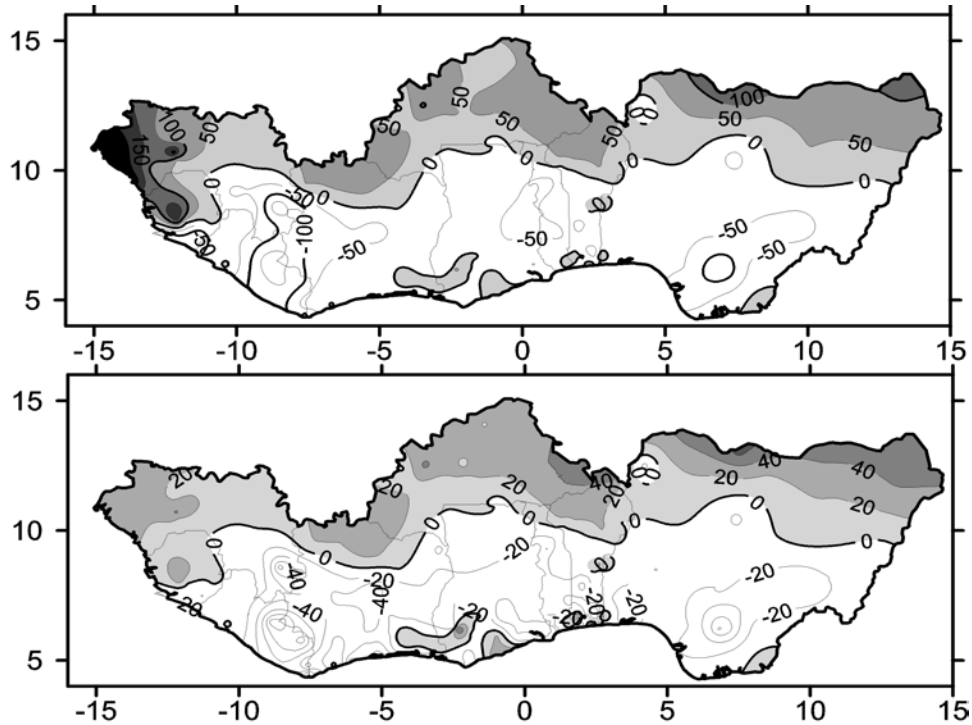


Figure 4-6. As in figure 4-5 except for August.

rather shows a general increase over warm phase and a general reduction compared to cold phase (Figure 4-10).

A variety of opinions have been expressed as to the nature and extent of the impact of ENSO in the region (Ropelewski and Halpert 1987; Ward et al. 2004). As knowledge

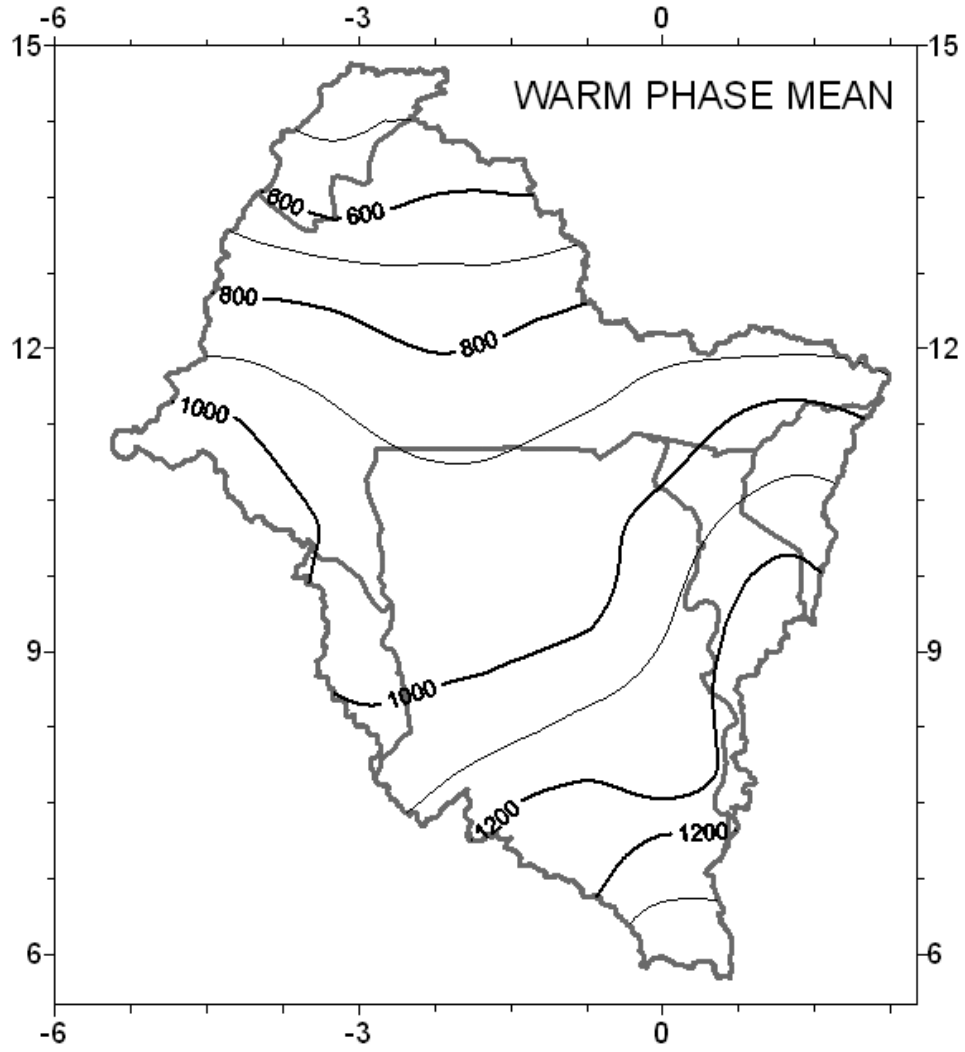


Figure 4-7. Composite map of mean annual rainfall during warm phase ENSO years, based on COAPS classification

concerning the complex global oceanic and atmospheric teleconnections increases, there is a growing consensus that the strength of the ENSO signal in West Africa may be conditioned upon the Atlantic and, Indian Oceans as well as the Pacific (Nicholson 1997). Although ENSO

events in the Pacific have a typical frequency of 5-7 years, lower frequency changes may occur in both the nature of the events within the Pacific basin and their connection with the Indian Ocean. A recent paper (Shi et al. 2007) indicates that there may be multi-decadal scales of oscillation in the nature of the ENSO phenomena in the Pacific and the degree to which these

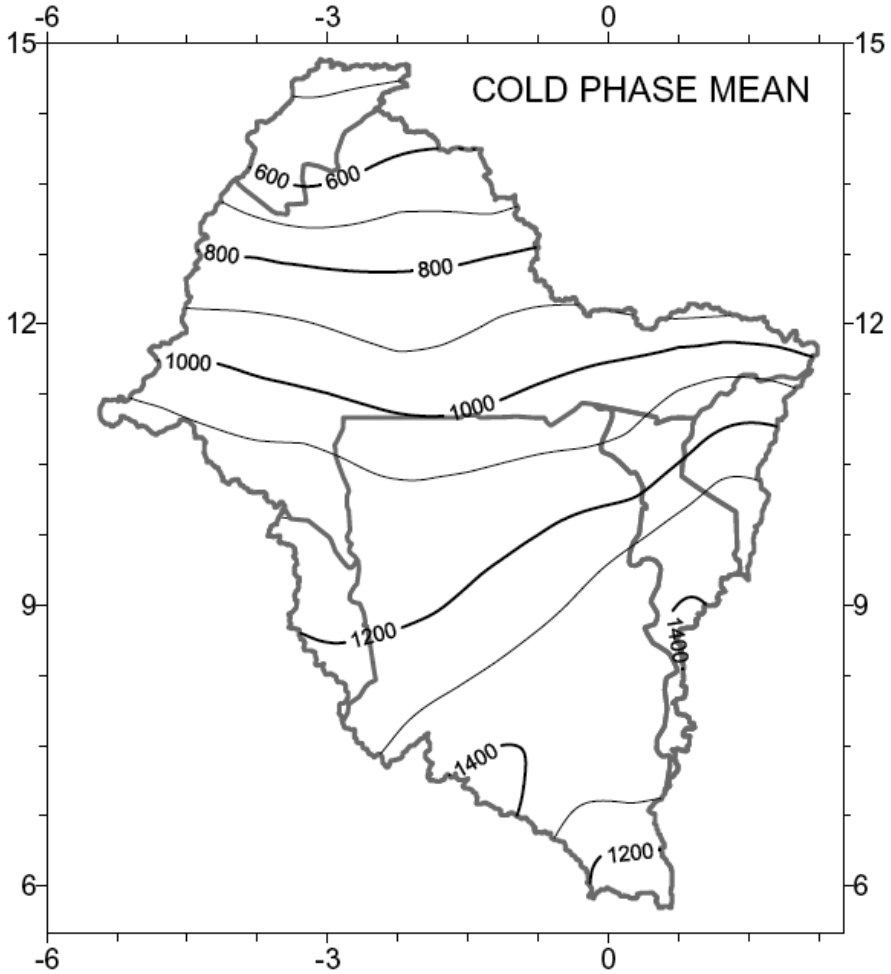


Figure 4-8. Composite map of mean annual rainfall during cold phase ENSO years, based on COAPS classification

effects are transmitted to the Indian Ocean. The authors chose a cut-off date of 1980 to define the most recent change from non-connectivity to connectivity, which corresponds well with the division used in this paper.

Given the limited number of years falling into each ENSO category, a second subdivision pre/post 1980 or 1970 would leave very few samples in each of the 6 resultant sub-categories (particularly the less frequent cold and warm phases). Figure 4-11 compares the variability caused by the low frequency shifts in the entire basin and each national sub-basin to the

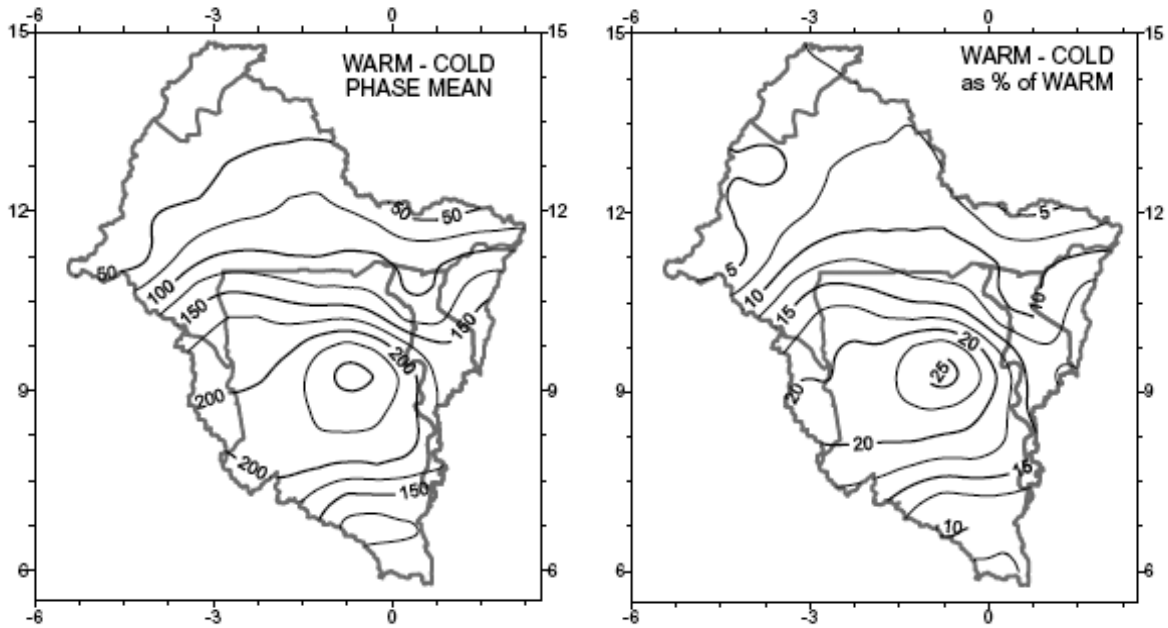


Figure 4-9. Differences in composite surfaces of mean annual rainfall during cold and warm ENSO phases

variability about the long run mean resulting from the effects of ENSO. These two major sources of variability clearly differ between the Sahelian sub-basins, in which the change from P1 to P2 is most pronounced, and the southern sub-basins in which ENSO phase appears to be a more dominant factor.

Conclusion

The findings of this study support the notion of downward trending annual rainfall totals reported for the West African sub-region, pointing to the fact that total rainfall input to the Volta

basin has declined since the early 1970s. Consistent with other studies in the region, this low frequency reduction in annual input has been more intense in the drier Sahelian, uni-modal

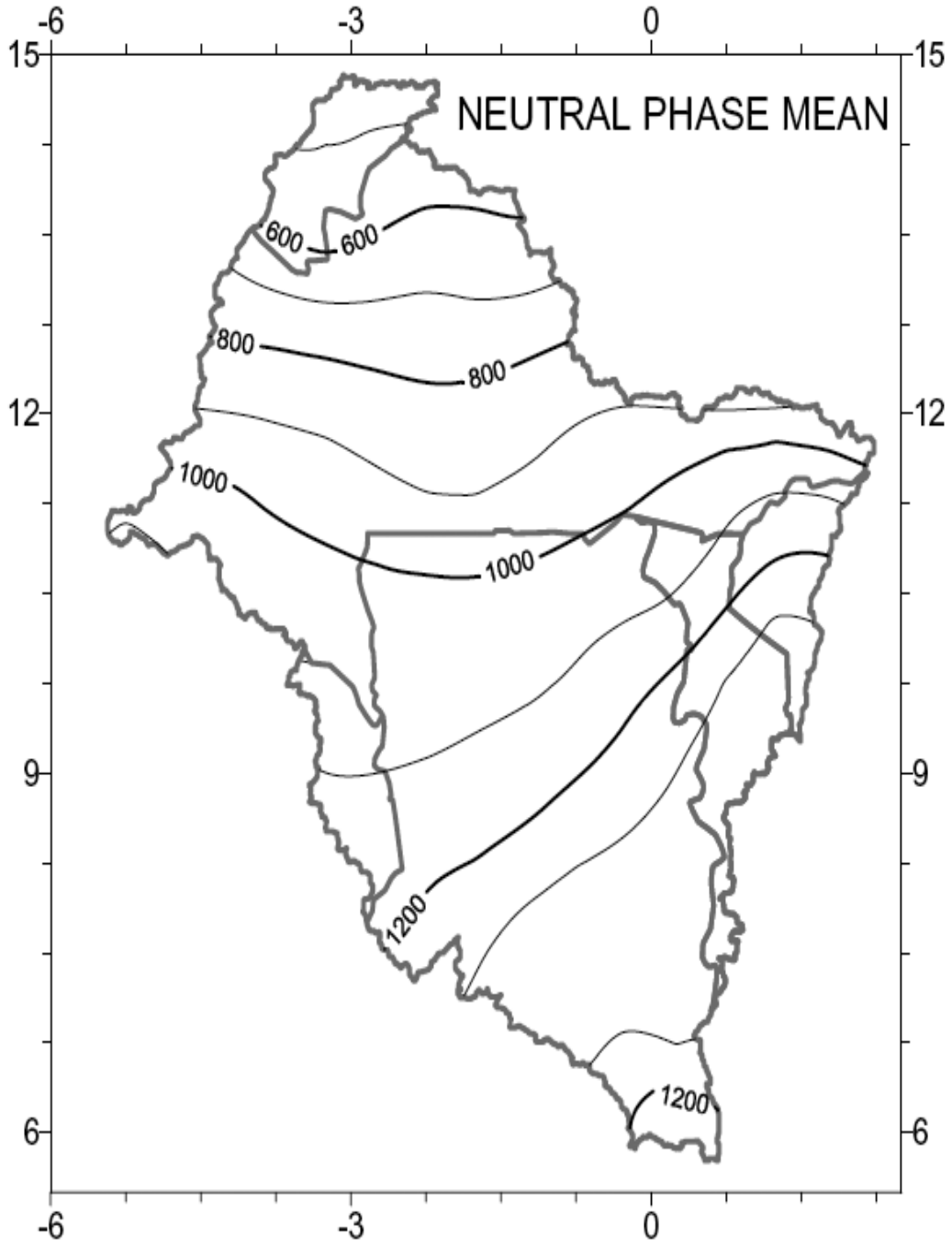


Figure 4-10. Composite map of mean annual rainfall during neutral phase ENSO years, based on COAPS classification

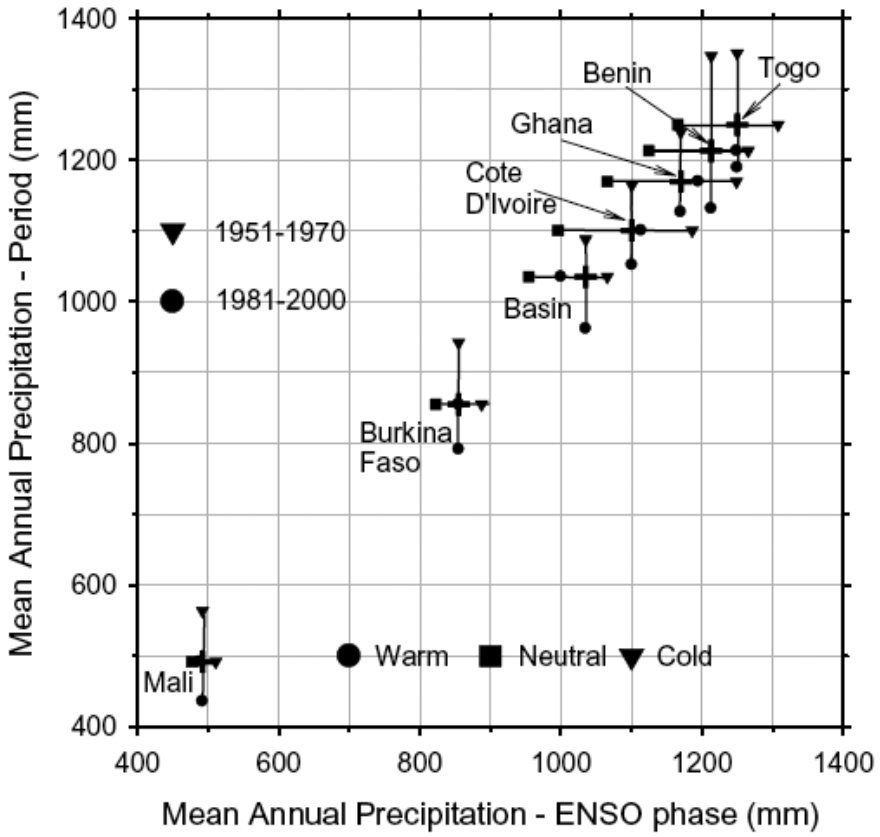


Figure 4-11. Comparisons of the variability in annual rainfall inputs to the entire basin and each national sub-basin about long run mean conditions in association with ENSO phases (horizontal) and the two periods under consideration (vertical)

northern basin than the more humid, bimodal, forest and Guinea savanna south. Of the two national territories contributing the most water to the, Burkina Faso has experienced greater reductions in rainfall than Ghana both in absolute and relative terms than Ghana. However, the humid zones are not impervious to changes themselves. The drying of the north is synchronous with shifts in rainfall regime in the south, with the dry season becoming longer. From the perspective of water resource management in the basin, the problems of reduced rainfall inputs from the uni-modal regions are exacerbated by teleconnectivity with ENSO. Reductions in rainfall associated with warm phases of ENSO (El Niño) are most pronounced in the southern portion of the region, especially below 10°N.

Many factors ranging from political populism, mismanagement, over-reliance on the Akosombo Dam, and contractual issues, have conspired to make these hydro-climatological changes more devastating. The less than competitive prices paid by VALCO and domestic energy usage meant less money for re-investment thereby adding to the inefficiencies at the Volta River Authority (VRA) and restricting the nation's ability to diversify which would have provided options to mitigate the consequences of the declining rainfall and subsequent fluctuations in lake level. As competition for water in the Volta basin increases mainly for irrigation upstream in Burkina Faso and for electricity generation in Ghana, the potential for conflict will increase unless the nations diversify their energy needs away from hydro-electricity and embrace greater cooperation in water sharing issues.

CHAPTER 5
CONCLUSIONS

Spatio-temporal variability of rainfall and its impact on the water resources of mid-Ghana are analyzed in this dissertation using parametric and non-parametric tools that indicate both similarities and differences in rainfall distribution and variability in the Sahel and Guinea Coast sub-regions of West Africa. The results have direct application to traditional rain-fed agriculture and water sharing in the Volta basin and have broader implications in terms of methodology and the current and emerging climatological understanding of West African rainfall distribution and variability.

Rainfall Variability

Similar to the Sahel, Mid-Ghana and the Volta basin have experienced significant downward trending rainfall since the 1970s. Despite this similarity, this study illuminates striking differences in the rainfall regimes and the regional strengths of the causal mechanisms of variability in the Sahel and the Guinea coast regions. The uni-modal regime of the Sahel seems to have suffered declines throughout the short rainy season (June-September), while the more southerly areas have experienced shifts in their bi-modal regimes. The short dry spell (July-August) that separated the two rainy peaks has experienced increases in both the average total rainfall and the number of rainy days. The implications of the declining rainfall in both the Sahel and the Guinea coast regions are significant for the nations in West Africa as their economies are highly rain dependant. In the area of agriculture, which provides a high percentage of employment, declining rainfall totals and higher risks for rain-fed agriculture during the minor rainy season could threaten food security and erode household incomes. On the other hand, increases in rainfall during the short dry spell are not conducive to rain-fed agriculture. Traditionally the dry period has been used to store the first crop and to perform slash and burn in

preparation for the second crop. The presence of humid conditions during this time increases the likelihood of post-harvest losses in the first crop through fungus and mold, and hinders the successful burning of cleared vegetation, which threatens the second crop.

Differences in rainfall patterns observed between the Sahel and the Guinea Coast regions call for the identification of rainfall drivers and their relation to the general atmospheric circulation to produce the multi-decadal oscillatory nature of West African rainfall. This knowledge will also help to explain why inter-decadal variability accounts for a greater percentage of variability in the Sahel than the Guinea Coast region, where ENSO impacts seem to dominate. Identification of these rainfall drivers will facilitate the development of a model to predict seasonal rainfall variability

Within Ghana, the findings are consistent with literature suggesting differences between the northern and the southern sections of the country. The forest regions of the south and mainly western sections of the Kwahu plateau have experienced reduction of rainfall around 20% whereas the Savanna zone has only seen reduction around 10% in mean annual rainfall. Apart from proximity to the ocean, the Kwahu plateau seems to be the most important control (in terms of its orientation in relation to the Southwest Monsoon) on rainfall generation and variability in Ghana. This revelation is not consistent with the current agro-ecological zoning of Ghana in which Zone C is bisected by the plateau, and may pose a problem for modeling an application of climate information aimed at improving rain-fed agriculture in mid-Ghana because of variability within the same climatic zones.

Water Sharing in the Volta Basin

The Volta basin has suffered declining annual rainfall inputs since the 1970s, consistent with findings elsewhere in West Africa. However, the economies of the region are highly rain dependant in terms of agriculture and hydroelectricity. During the second period of the study,

variability has increased in the basin as a whole and especially in the Sahelian part of the basin in comparison to sub-humid portions. This multi-decadal change appears to be a major driver of the differences in the Sahelian areas while interannual variability in association with ENSO is more important in Guinea Coast sub-basin. In terms of both absolute and percentage changes, the portions of the Volta basin in Burkina Faso have seen greater decadal declines in annual rainfall totals than those of Ghana, although the bi-modal sections of the latter display a synchronous shift in the rainfall regime. Warm ENSO phases are associated with less rainfall in the Sahelian section of the basin whereas cold phases are associated with more rainfall in the Guinea coast regions. The division between areas experiencing these observed differences in the nature and causes of climatic variability have an unfortunate correspondence with international boundaries, which in the past may have contributed to a lack of mutual understanding of the problems faced by the two major nations and contributed to the accusations of over withdrawal that generated tensions between Ghana and Burkina Faso. It is hoped that, the findings of this study, which support literature suggesting that declining lake levels are mainly caused by declining rainfall totals and increased variability, will help defuse tension and foster agreement of water sharing in the Volta basin which is currently non-existing in any meaningful way.

Methodology

The study analyzed the spatial and temporal nature of rainfall variability using a combination of parametric and non-parametric methodology in addition to a new approach to representing information likely to be of use to farmers in a previously less studied region of enormous importance to rain-fed agriculture.

The consistent application of various combinations of starting dates and durations termed Variable Temporal Units (VTUs) was very robust and allowed for the identification of shifts in the rainfall regime. The unbiased nature of the VTUs allowed specific portions of the rainfall

regime to manifest themselves at the different locations, and conclusions to be drawn, without the necessity of any *a priori* judgments or definitions of what constitutes the beginning or end of any seasonal sub-division. The methodology is not specific to any rainfall regime and can be applied in any region. It has the advantage of employing all available data even when portions of a year may be missing, since it only averages daily rainfall total and count a specific VTU instead of relying on seasonal or annual data.

Results and methods of analysis are also compatible with and complimentary to the tercile format of analysis used by the Ghana Meteorological Agency in its existing seasonal forecasts and information dissemination to rain-fed agriculturists in mid-Ghana. By identifying the specific portions of the rainfall regime that have suffered the most significant reduction (the minor rainy season) in the past two decades, the study serves as a starting point for researchers and for stakeholders interested in rain dependent industries in mid-Ghana.

Geographical Findings

A great deal of research in West Africa has concentrated on the Sahel region from which conclusions and generalizations have been made for the entire sub-region and the Volta basin. This study has contributed to an understanding of the geographic differences in the nature of the declining rainfalls that have occurred since the 1970s, by actually demonstrating that the reductions are equally or more intense in the forest areas of the Guinea coast region. The study further highlights the notion that in the agriculturally important regions of sub-humid Ghana, with their bimodal rainfall regime and dependence upon two distinct cropping seasons, an analysis of annual rainfall totals alone may underestimate the potential agricultural cost in a broad swath of Ghana south of 10 °N. Finally, although geographic relief has not generally been considered a major determinant of rainfall climatology in Ghana, this work indicates that the Kwahu Plateau may represent a important divide between the southwest forest region and the

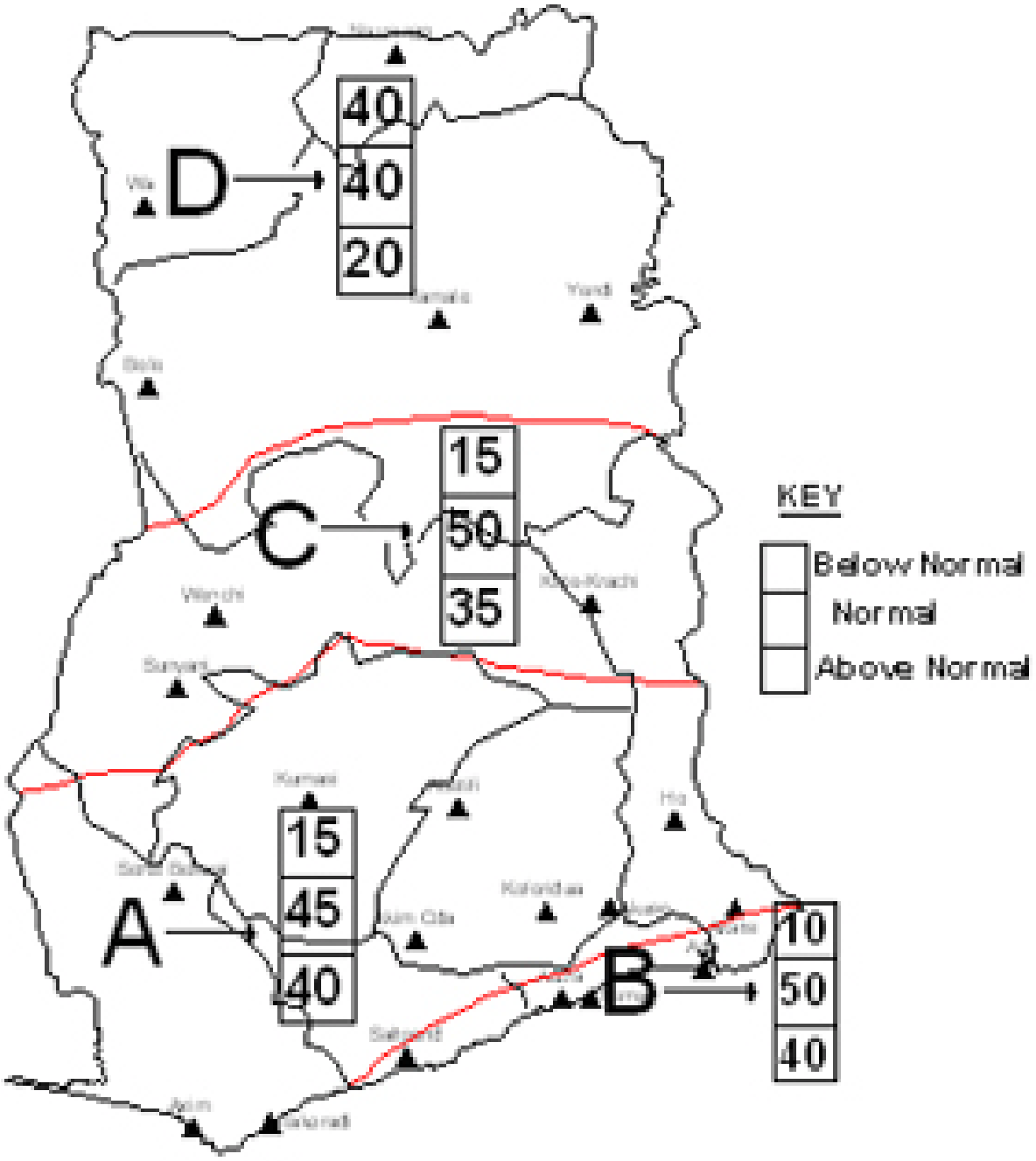
rest of sub-humid Ghana. Such recognition does not appear in the climatic sub-regions of the country employed by the Ghana Meteorological agency as the basis for regional analyses and forecasting.

As is the case with climatological research in many developing regions of the world, lack of data of sufficient duration limits the confidence with which statements about the spatial extent of the findings can be made. Many stations possess data covering P2 (1980-2000), but their use is restricted by the limited availability of data for P1. The second limitation has to do with the extent to which the findings can be generalized beyond the study period, especially the multi-decadal nature of West African rainfall. Data were not available to support the assertion of the study suggesting that mean annual rainfall totals have increased or are beginning to increase post 2000 (Paeth and Hense 2004; Owusu and Waylen 2008). However the findings do conform to an emerging consensus that rainfall in West Africa has a strong multi-decadal component ranging between 20 to 25 years. Further data collection and analysis are needed to support these findings.

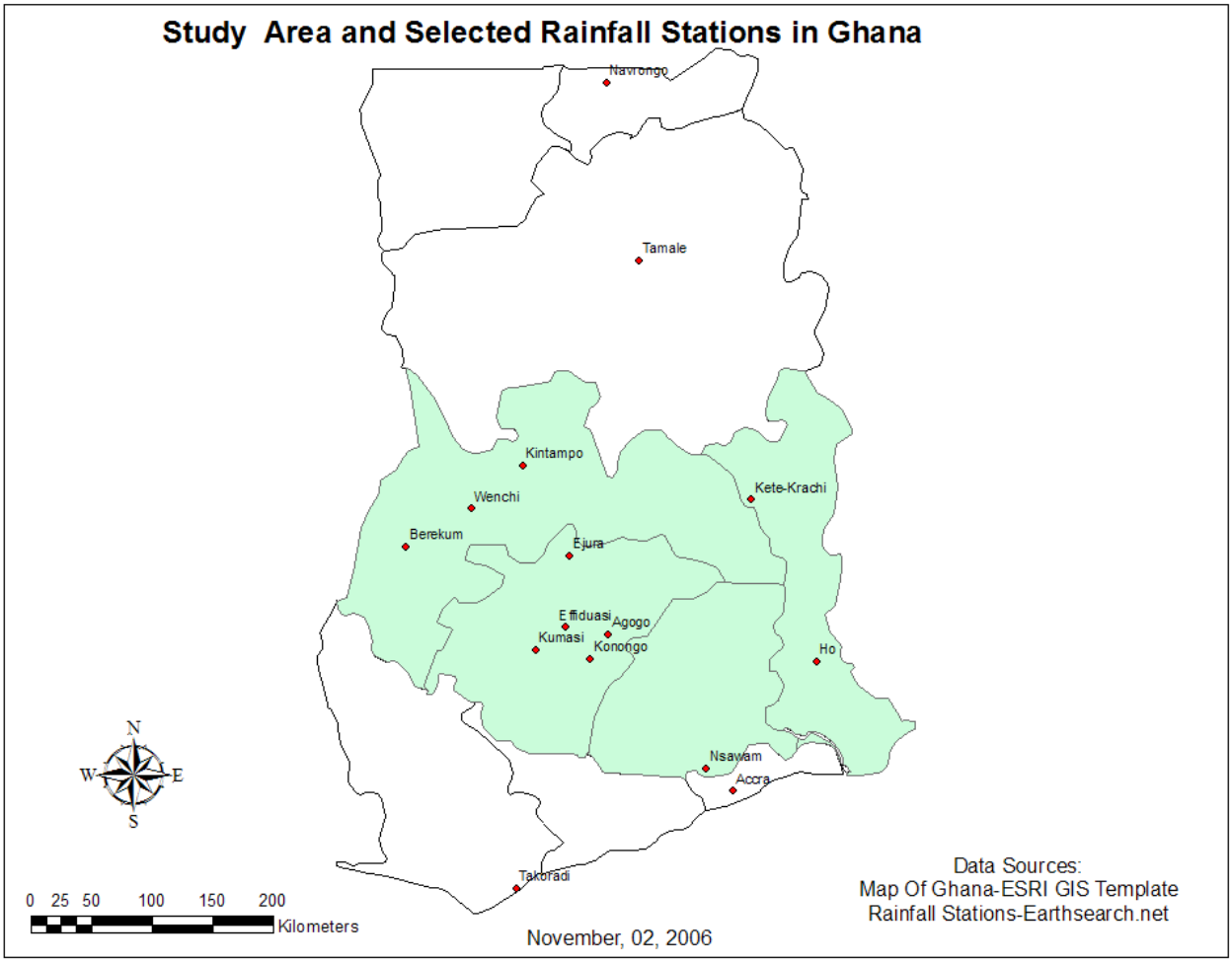
The study provides a comprehensive analysis of rainfall variability in Ghana and the Volta basin thereby contributing to the limited knowledge available in an agriculturally important region. It elucidates similarities and difference in the variability of the rainfall climatology of two broad regions, the northern Sahel north and the Guinea Coast regions, which not only characterize Ghana but also much of West Africa. The techniques employed are sufficiently detailed in their scale to provide information pertinent to the widespread and nationally important, traditional, rain-fed agricultural practices. Moreover the same methodology permits the identification of changes in intra-seasonal regime and inter-annual changes between the two sub-basins of the Volta resulting from ENSO, which could help reduce tension that arise from water sharing. Such an approach can be utilized in any geographic region to provide greater

insights into the scales of variability in the rainfall regime at a variety of temporal scales while providing important information about rainfall totals and frequency of practical value.

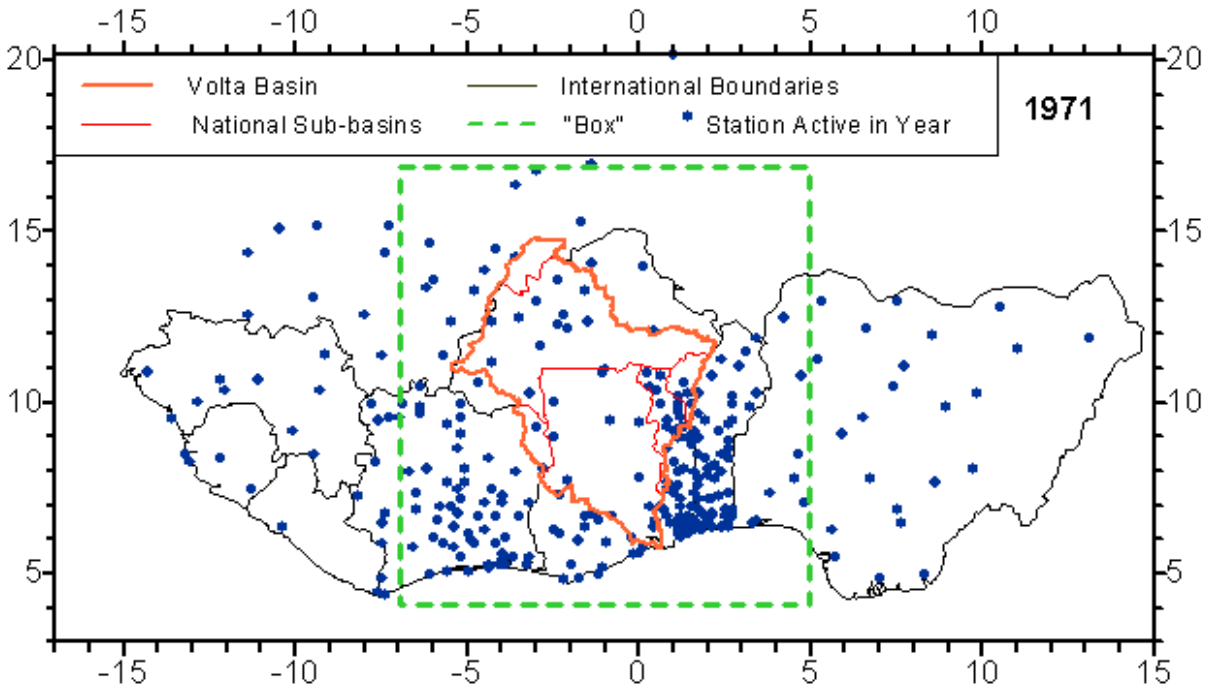
APPENDIX A
AGRO-ECOLOGICAL ZONES OF GHANA. SOURCE: GHANA METEOROLOGICAL AGENCY CLASSIFICATION.



APPENDIX B
STUDY AREA



APPENDIX C
CENTRAL WEST AFRICA SHOWING THE VOLTA BASIN



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BIOGRAPHICAL SKETCH

Kwadwo Owusu was born in Ghana in 1972. He received his secondary education in Techiman and Kumasi, Ghana. In 1998, he received a Bachelor of Arts degree in Geography and Resource Development from the University of Ghana, Legon and served as a Teaching Assistant at the same department until September 1999. He earned a Master of Science in geography degree in 2004 from the University of Florida. He continued at the same institution to pursue a doctorate degree in geography with multi-disciplinary minor. Kwadwo is married with two children.