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ORIGINAL ARTICLE

Food security and climate change in drought-sensitive savanna zones of Ghana

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Abstract Desertification, climate variability and food security are closely linked through drought, land cover changes, and climate and biological feedbacks. In Ghana, only few studies have documented these linkages. To establish this link the study provides historical and predicted climatic changes for two drought sensitive agro-ecological zones in Ghana and further determines how these changes have influenced crop production within the two zones. This objective was attained via Markov chain and Fuzzy modelling. Results from the Markov chain model point to the fact that the Guinea savanna agro-ecological zone has experienced delayed rains from 1960 to 2008 while the Sudan savanna agro-ecological zone had slightly earlier rains for the same period. Results of Fuzzy Modelling indicate that

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very suitable and moderately suitable croplands for millet and sorghum production are evenly distributed within the two agro-ecological zones. For Ghana to adapt to climate change and thereby achieve food security, it is important to pursue strategies such as expansion of irrigated agricultural areas, improvement of crop water productivity in rain-fed agriculture, crop improvement and specialisation, and improvement in indigenous technology. It is also important to encourage farmers in the Sudan and Guinea Savanna zones to focus on the production of cereals and legumes (e.g. sorghum, millet and soybeans) as the edaphic and climatic factors favour these crops and will give the farmers a competitive advantage. It may be necessary to consider the development of the study area as the main production and supply source of selected cereals and legumes for the entire country in order to free lands in other regions for the production of crops highly suitable for those regions on the basis of their edaphic and climatic conditions.

Keywords Climate change · Agro-ecological zones · Savanna · Modelling · Desertification · Agriculture · Food security

1 Introduction

According to the Intergovernmental Panel on Climate Change climate change (IPCC), climate change will complicate achieving food security for developing countries (Catford 2008; Ingram et al. 2008). This is due to the generally predicted negative impacts on agriculture, particularly in tropical and sub-tropical countries (Parry et al. 2004; Stern and Treasury 2007) where yields are predicted to decline. In Sub-Saharan Africa, adverse effects are expected, warmer and drier conditions (Hulme et al, 2001). An increase in both frequency and intensity of extreme weather events (droughts and floods) is anticipated (IPCC 2007)

For Ghana, as in most African countries, agriculture is of immense importance for economic development. Agriculture provides employment to about 50.6% of the labor force and accounts for about 75% of the foreign exchange earnings and contributes the largest share to the Gross Domestic Product (GDP), even though the share of the sector in national output declined from 44% in 1990 to 37% in 2005 (MOFA 2007). Other roles are provision of food security, social stabilization, economic shocks buffering, support of environmental sustainability, and maintenance of cultural values associated with farming. Beyond this, the agricultural sector offers opportunities for economic development and poverty reduction in Ghana. As most of the agriculture activities in Ghana hinges upon rain, any adverse changes in the climate would likely have a devastating effect upon agricultural production, and consequently, the economy and food security. This will further complicate the achievement of the Millennium Development Goals (MDGs).

Ghana is vulnerable to several kinds of drought conditions and desertification processes. Soil erosion and bushfires are widespread and poses the greatest threat to the Guinea and Sudan savanna zones in the north of Ghana. Inappropriate mechanization of agriculture and land degradation emanating from deforestation and overgrazing is largely contributing to desertification in northern Ghana. Desertification in Ghana has diverse adverse effects on crop yields resulting in low income and loss of livelihoods, famine and malnutrition and increased migration from the north to the south of Ghana. Desertification, climate change and food security are closely linked through drought, land cover changes, and climate and biological feedbacks. In Ghana, only few studies have documented these linkages. Moreover, these studies are almost wholly captured in separate literature with separate readership, even though there are strong relationships.

Thus, while not attempting to provide all the details of the relationship, this study first of all synthesizes results from a number of empirical analyses on climate change and crop production in Ghana. Subsequently, this study set out to attain the following objectives:

(1) Analyse historical and predicted climatic changes for Ghana and determine how these changes have influenced crop production
(2) Model the onset of rains for the drought-sensitive Guinea and Sudan savanna zones of Ghana from 1960–2008
(3) Model the current suitable land for millet and sorghum production in the face of changing climate and land degradation. Given the limited number of research in Ghana on climate change and food security, it is anticipated that our findings may yield insights pertinent for policy and decisions at different spatial scales by government and communities.

2 Description of the study area (agro-ecological zones)

Ghana, a country west of Sub-Sahara Africa, lies between latitudes 4° 44′ and 11° 15′ N and longitudes 3° 15′ W and 1° 12′ E with a land area of 238,539 km^2. By the year 2005 the country had a population of 22.1 million people with a population growth rate of 2.6% per annum (EPA 2000a). Ghana mainly relies on rain-fed agriculture and is therefore particularly vulnerable to desertification and climate variability, especially through resulting impacts on water and food security.

Ghana is divided into six agro-ecological zones on the basis of climatic conditions, geology, and soil: Sudan savanna (SS), Guinea savanna (GS), Forest-savanna Transition (FT), Deciduous Forest (DF), Rain Forest (RF), and the Coastal savanna (CS) zones (FAO 2005) (Fig. 1, Table 1). The climate of Ghana is tropical with distinct wet and dry seasons (Frimpong et al. 2003; Donkor et al. 2006). The country experiences temporal and spatial temperature variations based upon seasonal changes and ecological zone, respectively. The mean annual temperature is generally high—above 24°C. Mean annual rainfall is about 736.6 mm and rainfall generally decreases from south to north (EPA 2000a).

The three northern regions (Upper West, Upper East and Northern) constitute the dryland areas and the most seriously affected desertification-prone areas of Ghana. The Upper West and Upper East regions largely form the Sudan savanna and the Northern region, the Guinea savanna zone. The Sudan savanna and Guinea savanna together cover two-thirds of the country with estimated areas of 1,900 km^2 and 147,900 km^2 respectively (EPA 2000a). The northern Ghana is not highly populated; however, the fertility rate is much higher than the national average, reaching 3.6% compared to a national rate of 2.7% (EPA 2000a). Poverty levels in the three northern regions ranges from 69 to 88% with the Upper East Region showing the highest poverty incidence in Ghana (Canagarajah and Pörtner 2003).

The constraints to agricultural development in northern Ghana include erratic rainfall pattern, low soil fertility, inadequate irrigation facilities, and difficulty in accessing credit, post harvest losses, land tenure system, inaccessible roads and annual wildfires. The north of Ghana is also the most threatened region in terms of water scarcity and drought. Land degradation and drought in the arid areas of northern Ghana are causing severe hardship for many people who directly depend upon natural resources, particularly agriculture for continued existence.

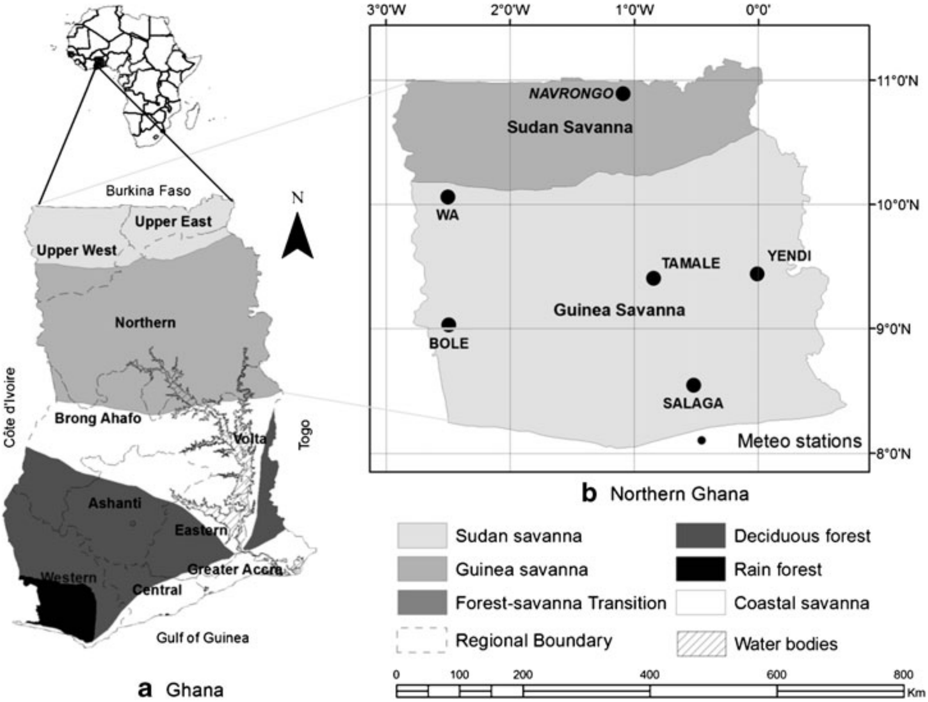


Fig. 1 Location map with **a** Ghana, West Africa **b** Guinea and Sudan savanna agro-ecological zones

2.1 Crop production in Ghana

The main crops cultivated in Ghana include cocoa (*Theobroma cacao*), *Citrus spp*, oil palm (*Elaeis guineensis*), avocado (*Persea Americana*), rubber plant (*Ficus elastic*), *Coffea spp*, mango (*Mangifera indica*), roots or tubers: cassava (*Manihot esculenta*), yam (*Dioscorea spp*), cocoyam (*Xanthosoma spp*)cereals: maize (Zea mays), millet (*Pennisetum glaucum*), *sorghum spp*, rice (*Oryza sativa*), legumes: groundnut (*Apios americana*), cowpea (*Vigna unguiculata*), vegetables: tomatoes (*Lycopersicon esculentum*), pepper (*Capsicum annuum*), onion (*Allium cepa*) and okra (*Abelmoschus esculentus*) . Cereals, roots, and tubers constitute an important portion of most Ghanaian staple diets and are widely cultivated by farmers,

Table 1 Climate of the agro-ecological zones of Ghana, adopted from Food and Agriculture Organization of the United Nations (2005)

Agro-ecological zone	Area (km^2)	Daily mean temperature (°C)	Total annual rainfall (mm)	Daily solar radiation MJ/m^2	Major rainy season	Minor rainy season
Rain Forest	9,500	26.2	1,985	16.33	March–July	Sept.–Nov.
Deciduous Forest	66,000	26.1	1,402	15.68	March–July	Sept.–Nov.
Forest-savanna Transitional	8,400	26.0	1,252	16.23	March–July	Sept.–Oct.
Coastal savanna	4,500	27.1	800	18.60	March–July	Sept.–Oct.
Guinea savanna	147,900	28.1	1100	19.24	May–Sept.	
Sudan savanna	2,200	28.6	957.6	21.84	May–Sept.	

while providing a reliable source of income for farmers. Table 2a and b below outline the production levels of the main cereal and root crops respectively cultivated in Ghana. The annual production levels of these crops are far below the estimated achievable yields, resulting in food deficit (MOFA 2007). Hence higher productivity in these crops is necessary to ensure food security in Ghana. In 2002, crop production increased significantly and a study by FAO (2005) attributed the increase to improved fertilizers and use of organic manure.

3 Climate change and its impacts on agriculture

3.1 Historical changes

In Ghana, recorded temperatures have risen about 1°C over the last 40 years of the twentieth century, while rainfall and runoff decreased by approximately 20% and 30%, respectively (Asante 2004). The country also experienced severe weather extremes, including a major drought from 1981–1983 (Ofori-Sarpong 1980; 1986). These climatic variations, among other factors, affected crop production, particularly cereal production which declined from 518,000 tonnes in 1982 to 450,000 tonnes in 1983 (Asante 2004). A study by Sagoe (2006) indicated that root crops production in Ghana was significantly influenced by variability in rainfall from 1970 to 2003 as shown in Fig. 2. Sagoe (2006) further argued that the highest amount of rainfall between the periods was recorded in the Rain forest zone and the lowest in the Coastal savanna zone. Increases in total rainfall within a year increased production. Increases were however highest in cassava, followed by cocoyam and then yam. This can be explained by the fact that increases in acreages under production are higher under cassava production and lower under yam production when compared to cassava and cocoyam.

3.2 Forecasted changes

Projected climate change scenarios suggest that Ghana is likely to experience higher temperatures and greater rainfall variability in the future (IPCC 2007). Temperature is expected to increase for all agro-ecological zones on the average by 0.25°C from 2010 to 2020 (EPA 2000b). For rainfall, the situation is more complex, with projected decreases in

Table 2 Production levels of cereal crops and root crops in Ghana ('000 tonnes), adopted from Food and Agriculture Organization of the United Nations (2005)

Crop	Major cultivated zones	Average 1997/99	2000	2001	2002
Cereal crop					
Maize	RF, DF, FT, GS,CS, SS	1,008	1,013	938	1,400
Millet	GS,SS	155	169	134	159
Sorghum	FT, GS,SS	330	80	280	316
Rice	GS,SS	136	129	152	168
Total		1,629	1,391	1,504	2,043
Root crop					
Cassava	RF, DF, FT	7,339	8,107	8,966	9,731
Yam	FT, GS	2,787	3,363	3,547	3,900
Cocoyam	RF, DF, FT, GS,CS	1,605	1,625	1,688	1,860
Total		11,731	13,095	14,201	15,491

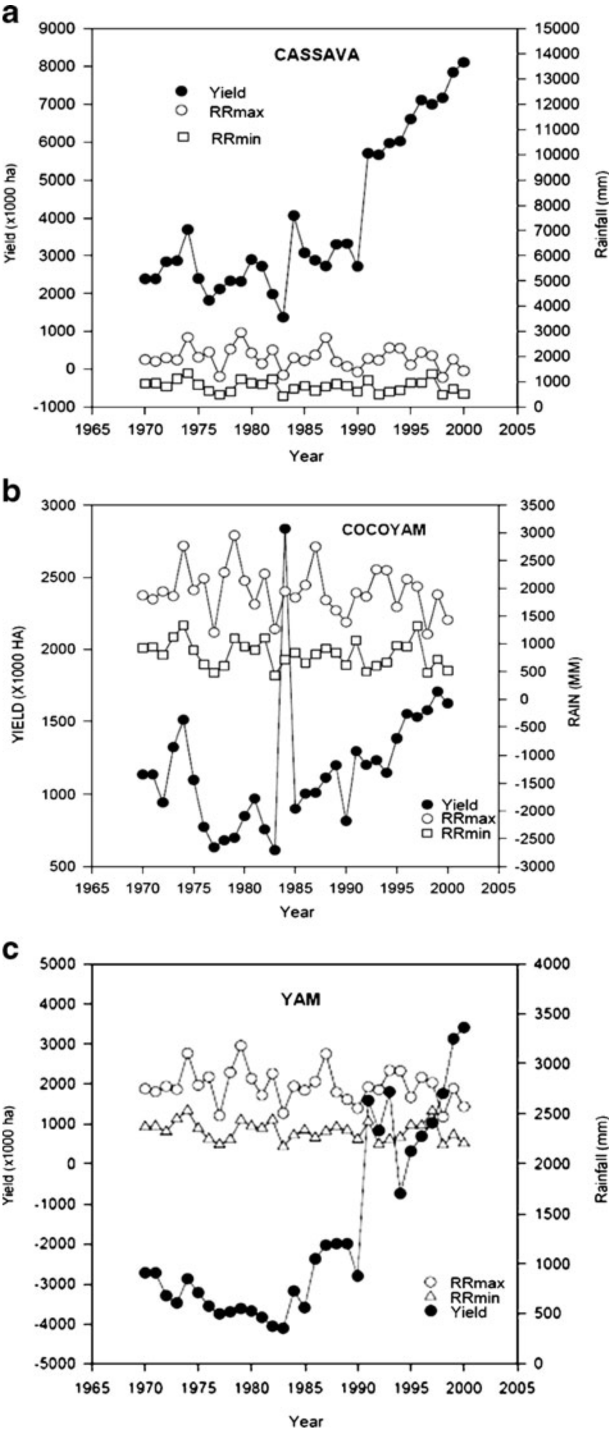


Fig. 2 Production of tuber crops and rainfall patterns in Ghana (1970–2003). A significant correlation exists between rainfall values and tuber crop yield. (Where RR max and RR min refer to the highest and lowest total rainfall recorded in the year respectively)

the SS, GS, FT, and SF zones, and a consistent increase in the RF zone. Solar radiation is projected to increase in all agro-ecological zones. The SS zone is predicted to be the region that will be most affected by drier and warmer conditions. On the other hand, the RF zone is the region least expected to be affected by estimated wetter conditions. The changes in temperature, rainfall and solar radiation for all agro-ecological zones are illustrated in Fig. 3. A reduction between 15–20% in runoffs is also predicted for river basins in Ghana by the year 2020 (EPA 2000b).

Based on projected climate scenarios, Sagoe (2006) predicted future cassava and cocoyam yields for the deciduous forest zone (Fig. 4). The crop model CROPSIM-cassava and CROPGRO (ARGRO980) Tanier were used for cassava and cocoyam respectively. These models are based on the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) crop simulation models, specifically; the Decision Support System for Agrotechnology Transfer Version (DSSAT V) 4.0 (ICASA 2009) that simulate crop growth and yield.

Using 1990/1991 cropping season as the base year, cultivated cassava yields are expected to reduce by 3%, 13.5% and 53% in 2020, 2050 and 2080 respectively. Percent reductions in cocoyam yields are 11.8%, 29.6% and 68% in 2020, 2050 and 2050 respectively. A study by the Ghana Environmental Protection Agency indicates a significant decrease in maize yields from 3,436 Kg/ha in 2010 to 3,432 Kg/ha by 2020 (EPA 2000b).

4 Onset of Rains Model

We modelled the onset of rains based on the Markov chain stochastic process using available and consistent time-series rainfall data from two stations (Wa and Navrongo) within the Sudan savanna and from four stations (Yendi, Bole, Salaga, and Tamale) within the Guinea savanna zone. When processes are viewed as a string of stages in sequence, then each stage may be described by a Markov process (Dietz et al. 2004). The Markov property specifies that the conditional probability of a state depends only on the probability of the

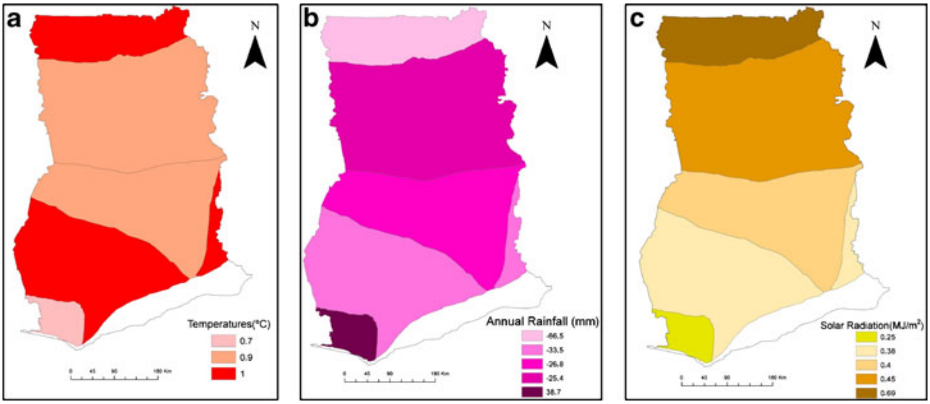
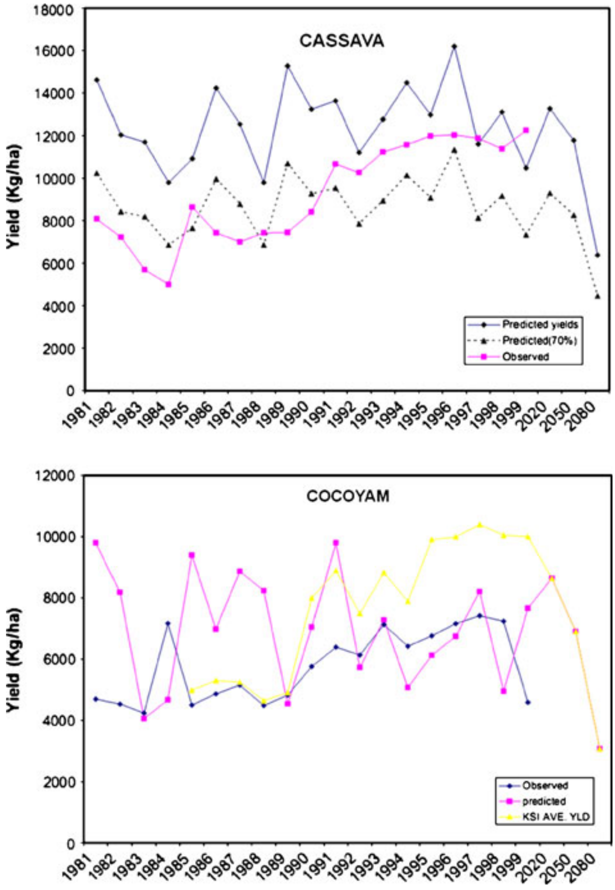


Fig. 3 Changes in climatic variability by the year 2020 for the agro-ecological zones with reference to the baseline (1961–2008), **a** Predicted increases in daily mean temperatures; **b** Predicted changes in annual rainfall; decreases in rainfall are expected in all agroecological zones, except for the RF; **c** Predicted increase in solar radiation

Fig. 4 Predicted changes in tuber crops for the deciduous forest zone based on projected climatic changes



previous state (El-Seed 1987; Dietz et al. 2004). This property is mathematically presented in equations 1 and 2.

$$P(X_{n+1}|X_1, X_2, ..., X_n) = P(X_{n+1}|X_n). \tag{1}$$

Since the system changes randomly, it is generally impracticable to predict the exact state of the system in the future. However, the statistical properties of the system's future can be predicted. A Markov chain is thus considered as a sequence of random variables X_1, X_2, X_3... with the Markov property, namely that, given the present state, the future and past states are independent. Formally,

$$\Pr(X_{n+1} = x|X_1 = x_1, X_2 = x_2..., X_n = x_n) = \Pr(X_{n+1} = x|X_n = x_n). \tag{2}$$

The possible values of X_i form a countable set S called the state space of the chain. The set of all states and transition probabilities completely characterizes a Markov chain. By convention, it is presupposed that all possible states and transitions have been included in the definition of the processes, so there is always a next-state and the process goes on perpetually. The INSTAT™ software developed by the Statistical Services Center, University of Reading, United Kingdom, was used for the Markov modeling process.

The Markov modeling process entailed preparing daily data by counting and totaling rainy and dry days for the entire dataset (48 years). The discrete nature of the start of the rain event and the data it produces calls for a distribution-free approach when modeling them (Gabriel and Neumann 2006). For the purposes of this study, the start of rains is defined as the first occasion after the 1st of April in which rainfall summed over seven days is equal to or greater than 20 mm. Within this period, there must be at least two days of rain with no period of dry spell that exceeds six days in the next 20 days. Based upon the above criteria, the start of rains for each year was derived. This start of rains is expressed as the number of that day in the year *i.e.,* January 1 is day number one and December 31 is day number 365. Hence, as an example, the 1st of April is day number 61, etc.

The model results indicate that 6th May (day 127) was the average start of rains for both the Sudan savanna and Guinea savanna agro-ecological zones. The results clearly showed early rains (negative) and delayed rain (positive) for the stations studied during the rainy seasons (Fig. 5). The trend analysis shows that generally, the Guinea savanna (Salaga,

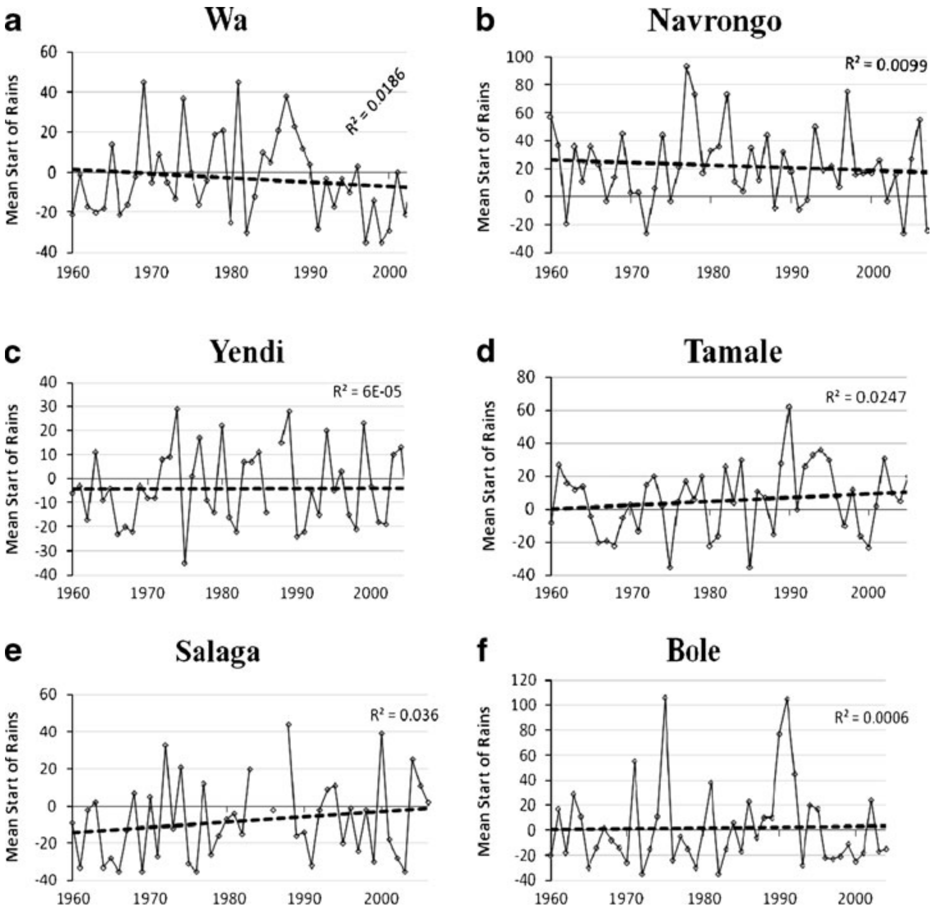


Fig. 5 Start of rains for Wa and Navrongo stations (Sudan savanna zone) and Yendi, Tamale, Bole, and Salaga stations (Guinea savanna zone). The onset of the rainy season is defined as any day after April 1 in which rainfall totalled over 7 days is equal or more than 20 mm, and in which after this period no dry spell exceeds 6 days within the next 30 days. The mean onset of rains (represented in the figure as 0) is the 6th of May. Negative values represent the number of days the rainy season started before the mean start date (early start) while positive values represent the number of days after the mean start date (late start). R^2 represents the coefficient of determination

Tamale, and Bole) had delayed rains whilst the Sudan savanna agro-ecological zone (Wa and Navrongo) had slightly earlier rains. The onset of rains is usually considered to be the planning period for some of the main staple crops (maize, beans, and potatoes) in the Sudan savanna and Guinea savanna zones. After planting, small-scale farmers usually engage in other fringe income generating activities. Significant changes in the start of the rainy season may affect planning and decision-making for such income generating activities.

5 Cropland suitability model

Cropland suitability was modelled for sorghum and millet (staples within the two zones) using a fuzzy logic model incorporating land use, crop specific agro-climatic and agro-edaphic conditions including climate (temperature and rainfall), soil (pH, organic carbon, fertility, texture, drainage and depth), terrain, cropping system, irrigation (dams, streams and rivers) and market facilities. Climatic and soil datasets were obtained from the Ghana Meteorological Service (GMS) and Soil Research Institute, respectively. The land use map for the year 1998 was obtained from the Survey Department of Ghana. An ASTER Digital Elevation Model (DEM) 30 m resolution was downloaded from the USGS Land Processes Distributed Active Archive Centre (LP DAAC) from which slope and aspect maps were derived. Expert knowledge on agriculture, soil science and land use was also incorporated. The analytic hierarchy process (AHP), a multi-criteria decision making technique, was used in weighing crop requirements. The fuzzy AHP approach allows a more accurate description of the decision-making process (Wang et al. 2008) for crop land suitability (Nisar Ahamed 2000). In the fuzzy AHP approach, we used triangular fuzzy numbers for the fuzzification of the crisp Pairwise Comparison Matrix (PCM) as shown in equation 3. Socio-economic factors were not considered because they are less important than the physical factors in such a study area with fragile environment and relatively weak economy. All the maps were registered into ArcGIS 9.3 GIS software for Windows. Cropland suitability was divided into 5 classes, i.e. very suitable, suitable, moderately suitable, marginally suitable and not suitable. The steps involved in the land suitability analysis are shown in the flowchart (Fig. 6).

$$A = \begin{bmatrix} a12 & \cdots & a1n \\ \vdots & & \vdots \\ am1 & \cdots & amn \end{bmatrix} \tag{3}$$

The results show that very suitable and moderately suitable croplands for millet and sorghum production are evenly distributed within the two agro-ecological zones (Fig. 7). Eight percent and 14% of land within both zones is not suitable for millet production and sorghum production, respectively . Projected drier condition due to increased temperature and reduction in rainfall for the Guinea and Sudan savanna zones may further decrease suitable croplands for cultivation.

6 Discussion

7 Food security in Ghana

Climate change, land degradation and desertification will reduce the areas of fertile lands for agriculture production. This will have significant consequences on food production and

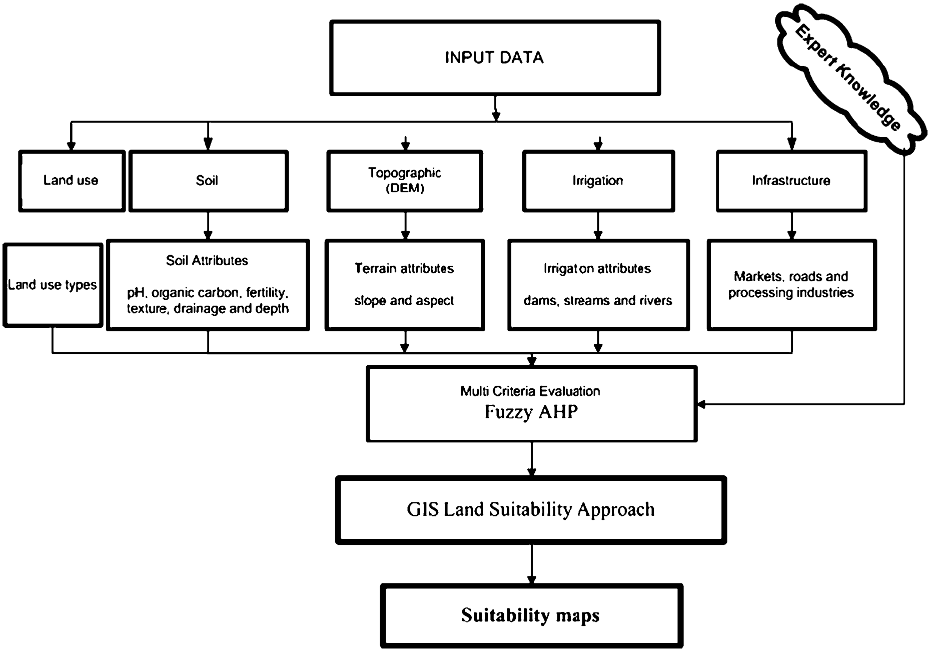


Fig 6 Fuzzy membership and GIS approach for land suitability analysis

food security in Ghana. This would further adversely affect economic growth and exacerbate malnutrition. Ghana has remained a food deficit country since 1990 and the overall performance in terms of agricultural production and productivity remains inadequate. The current agricultural growth rate of 3.1%, vis-à-vis the current annual population growth rate of 2.6% per annum presents serious implications for the attainment of food security in Ghana (MOFA 2007). The relatively high increases in the absolute population require that food production increase steadily to meet the demand.

Currently, Ghana produces only 51% of its cereal needs and this is inadequate for human and animal consumption. Ghana thus relies heavily upon commercial food imports to augment its local production. This leads to high food prices. Despite substantial overall decline in the incidence of poverty in Ghana from 52% in 1991/92 to 40% in 1998/99, poverty still has a firm grip upon rural areas, especially within the northern regions, where income levels are low, thus reducing the purchasing power of rural folk for food (Canagarajah and Pörtner 2003). As a result of malnutrition, maternal and infant mortality is high in these regions.

The slow growth of agriculture in Ghana is attributed to a combination of factors, including inappropriate policies, lack of technological change, and poor basic infrastructure. Ghana faces the challenge of making substantial progress in food security because average yields have remained stagnant over the years. With changing climate, sustainable increases in crop yields are needed for food security in Ghana. To ensure food security in Ghana, the following adaptation strategies are proposed and discussed.

7.1 Adaptation

Climate stresses on agricultural production, livelihood, and food security in Ghana means that adaptation is not an option, but a necessity. Crop management may be inadequate for

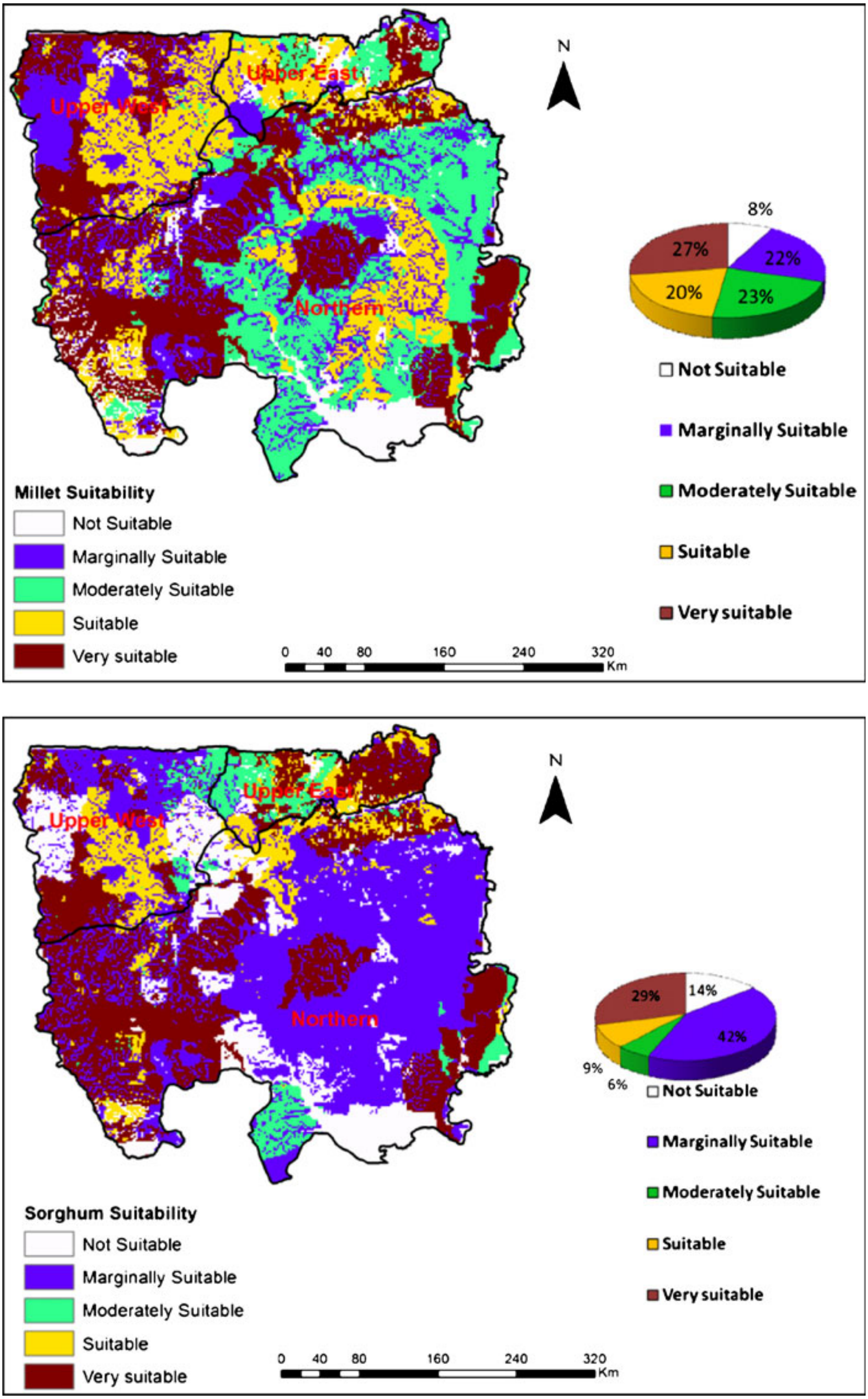


Fig. 7 Spatial distribution of suitable cropland in northern Ghana

the new climate conditions. In coping with risk due to excessive or low rainfall, drought and crop failure, farmers and rural households, on their own, have adapted options to diminish the adverse impacts of climate change. Coping strategies adopted include the cultivation of different crops and varieties, which are more drought-tolerant. However, farmers cultivating crops such as cassava, maize, and cocoyam may not be able to adjust to climate change if changes in the climate are rapid. In order to minimize the effect of climate change on food production, it is important that Ghana adopts strategies to ensure food security. Adaptations, if well designed and implemented, could then help to address issues of food productivity and security. On the basis of the above, this study identified the following adaptation options and their potential usefulness in meeting the adverse effects of climate change, especially with respect to predicted high temperatures and water stress, with the aim of promoting food security.

7.1.1 Expanding irrigated agricultural areas

Since climate change scenarios tend to show that Ghana will get warmer and drier, the question then arises, why not expand irrigation and compensate for reduced precipitation? Currently, irrigated agriculture is supplied through small and medium scale reservoirs. Only 0.2% (11,000 ha) of the cultivated land is irrigated, whereas several large irrigation schemes are underutilized. The White Volta, Black Volta, Oti, Main/Lower Volta, Daka, Coastal, and Todzie/Aka drainage basins have irrigation potential for the over one million hectares identified in Ghana. The potential of irrigation and the stages of development in Ghana are summarized by Sam-Amoah and Gowing (2001). Expanding irrigated agriculture will therefore be necessary to boost agricultural yields and outputs in order to feed the growing Ghanaian population; this will help maintain food production levels and contribute to price stability through greater control over production. A study by Dollar and Svensson (2000) predicted that about 53% of global cereal production during 2000–2050 is expected to be achieved through irrigation. They further indicated that, despite the importance of irrigation, if not well managed, irrigation could lead to adverse environmental outcomes, including excessive water depletion, particularly of groundwater resources, pollution of freshwater resources, and water logging and salinization of formerly productive crop areas.

Lack of water has a negative effect on the whole set of vital plant processes such as photosynthesis, respiration, absorption of nutrients, and assimilation and translocation. Irrigation makes water sufficiently available to crops throughout the season and crop cycle. By offsetting water stress at critical growth stages, irrigation helps crops to give optimal or maximum yield and quality of produce. Sufficient availability of water in soil, via irrigation, also aids efficient plant nutrition and therefore increases the benefits of soil amendment such as fertilizer application and overall profits. Irrigation minimizes the problem of food scarcity and hunger during periods with low rainfall or drought. However, irrigation can lead to salinization, depletion of water resources and intensifies competition for water allocation to different sectors. Excessive irrigation also increases the humidity around crops and thereby the potential for attacks by pests and diseases which can eventually lower yields. Finally, it is expensive to develop and maintain irrigation infrastructure. As a developing country, Ghana does not have the financial resources to implement a large-scale, nation-wide irrigation scheme. So far, irrigation has not been implemented on an appreciable scale due mainly to its high initial and operational cost but also due to the preponderance of small-holder farms that potentially renders irrigation unprofitable and unattractive. However, micro-irrigation and small-scale irrigation schemes, with government support, can prove sustainable to farmers. To this end, the sprinkler irrigation scheme practiced by tomato and shallot farmers in Anloga (Volta Region) of Ghana provides a useful example that can be studied, adopted and expanded as the initial step towards expanding irrigation. This notwithstanding, a commitment to long-term irrigation plan and strategy based on cost-benefit analysis and scientific projections of other variables is necessary. Farmers can also be grouped and their respective land units consolidated for the purpose of irrigation.

It is estimated that Ghana has cultivated less than 50% of its total arable land (MOFA 2001). The greatest share of this uncultivated arable land is found in the three northern regions (which incidentally covers the study area). It is likely that the introduction of irrigation will increase crop yields and lead to expansion in area cultivated. Notwithstanding this, other constraints (such as those related to inputs acquisition, marketing and post-harvest handling) should necessarily be removed to realize this expansion. The three northern regions have a very high potential for irrigation particularly for cereals and legumes as they constitute the major production centers of cereals and legumes. Cereals and legumes are also known to respond very well to irrigation. Therefore, in considering expansion of irrigation for the study area, it is prudent to focus initially on the production of cereals and legumes.

7.1.2 Improving crop-water productivity in rain-fed agriculture

Rain-fed agriculture is not likely to phase out anytime soon in Ghana. Small-holder and subsistence farming are widespread and dominate crop production in Ghana. Since crop yields are projected to decline significantly, it makes sense to improve rain-fed agriculture. This can be achieved through improved soil and water conservation and increased crop-water productivity. For example, on-farm and small-scale rainwater harvesting, coupled with improved soil fertility management and indigenous knowledge of farmers, could help sustain higher productivity in rain-fed agriculture.

Given that the Guinea savanna and Sudan savanna agro-ecological zones, with a unimodal rainy season, clearly point toward delayed and early onset of rains, respectively, it is important that farmers cultivate with consideration of the onset of rains to prevent crop failure due to untimely rains. A study by Kottegoda et al (2004) indicated that early rain favours maize production, whilst delayed rains favor sorghum and millet. A Weather Responsive Crop Management strategy to manage response to variations in the onset of rains for agriculture production is proposed by (Stewart 1985; Sivakumar 1988).

7.1.3 Crop Improvement and Specialization

Under changing climate conditions, it is expected that farmers should experiment with different crops varieties that can withstand extreme weather conditions. Adaptation strategies need to focus on ensuring the availability of new cultivars that can mitigate the negative effects of climate change. Currently, there are efforts to develop genetically modified varieties that fulfil various physiological and other requirements. But the advantages of these genetically modified plants must be weighed against their risks to the genetic makeup of natural ecosystems. Early maturing and drought-resistant varieties need to be developed for the crops grown in the study area. It is also important to encourage farmers in the Sudan and Guinea savanna zones to focus on the production of cereals and legumes (e.g. sorghum, millet and soybeans) as the edaphic and climatic factors favour these crops and will give the farmers a competitive advantage. Consequently, it is worthy to consider the development of the study area as the main production and supply source of selected cereals and legumes for the entire country to free lands in other regions for the production of crops highly suitable for those regions on the basis of their edaphic and climatic conditions. The infrastructure that supports this specialization can also be used to produce secondary crops such as vegetables to increase profit and food and feed supply across the country. However, the spatial distribution of the production of the different crops within the study area should be based on projections that portray potential shifts in water availability and climatic and edaphic conditions which can drive shifts in crop production centres.

7.1.4 Improved Technologies

Improving mechanization as a means of enhancing agricultural productivity is an issue that is worth putting on the policy agenda. The deployment of post harvest technologies, improved efficiency of food preservation, and storage and processing of excess cassava, cocoyam, and maize to other useful products should be vigorously pursued. This adaptation option provides insurance against local supply changes, which tend to cause individuals to store the crop for a longer period and which also, guarantees a stable price for the farmers. This is a prerequisite for food security.

8 Conclusions

Characterized by drier conditions, the Sudan savanna and Guinea savanna agro-ecological zones of Ghana are susceptible to climate change, desertification and associated problems including food insecurity. Our analysis has highlighted both historical and predicted changes in climatic conditions and estimated suitable available land for selected cereal crops. With predicted climatic changes and decline in food production it is imperative for Ghana to devote significant portions of scarce financial resources to create a policy environment that mutually reinforces food security. For Ghana to cope with climate change and thereby achieve poverty reduction, it is imperative to pursue actions at sector and community levels for the poor to adapt to climate change by enhancing their resilience. It is equally necessary to strengthen the institutional capacity of research and policy implementation organizations to carry out their mandate in a sustainable manner. Research reinforces policy making in response to climate variability. Consequently, research at various spatial scales (plot level, farm household, community, and national) should be intensified, as this is necessary for the development of effective risk-coping and mitigation strategies, both of which are determinants of food security.

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References

Asante A (2004) Assessment of food import and food aid against support for agricultural development: The case of Ghana; food and agriculture organization regional office Accra: Accra, Ghana

Canagarajah S, Pörtner C (2003) Evolution of poverty and welfare in Ghana in the 1990 s: achievements and challenges. World Bank, Washington

Catford J (2008) Food security, climate change and heath promotion: opening up the streams not just helping out downstream. Health Promot Int 23:105

Dietz AJ, Reuben R, Verhagen A (2004) The impact of climate change on dry lands: with a focus on West Africa. Kluwer academic, New York, pp 403–407

Dollar D, Svensson J (2000) What explains the success or failure of structural adjustment programmes? Econ J 110:894–917

Donkor AK, Bonzongo JC, Nartey VK, Adotey DK (2006) Mercury in different environmental compartments of the Pra River Basin, Ghana. Sci Total Environ 368:164–176

El-Seed AM (1987) An application of Markov chain model for wet and dry spell probabilities at Juba in southern Sudan. GeoJournal 15:420–424

Environmental Protection Agency (EPA) (2000a) National action programme to combat drought and desertification. Accra, Ghana

Environmental Protection Agency (EPA) (2000b) Ghana's initial national communication under the United Nations Framework Convention on Climate Change, Environmental Protection Agency of Ghana, Ministry of Environment, Science and Technology, Accra, Ghana

Food and Agriculture Organization of the United Nations (FAO) (2005) Fertilizer use by crop in Ghana, Land and Plant Nutrition Management Service Land and Water Development Division,Rome

Frimpong Y, Oluwoye J, Crawford L (2003) Causes of delay and cost overruns in construction of groundwater projects in a developing countries; Ghana as a case study. In, pp. 321–326.

Gabriel KR, Neumann JA (2006) Markov chain model for daily rainfall occurrence at Tel Aviv. Q J R Meteorol Soc 88:90–95

Hulme M, Doherty R, Ngara T, New M, Lister D (2001) African climate change: 1900–2100. Clim Res 17:145–168

International Consortium for Agriculture Systems Applications (ICASA) (2009) Decision Support System for Agrotechnology Transfer, ICASA News.

IPCC (2007) climate change 2007—Impacts, adaptation and vulnerability. Contribution of working group ii to the fourth assessment report of the IPCC. Cambridge University press, Cambridge

Kottegoda NT, Natale L, Raiteri E (2004) Some considerations of periodicity and persistence in daily rainfalls. J Hydrol 296:23–37

Ministry of Food and Agriculture (2001) Agricultural census report, 1992–2000. Accra, Ghana

Ministry of Food and Agriculture (2007) Food and agriculture sector development policy (FASDEP II). Accra, Ghana

Nisar Ahamed TR, Gopal Rao K, Murthy JSR (2000) GIS-based fuzzy membership model for crop-land suitability analysis. Agric Syst 63:75–95

Ofori-Sarpong E (1980) The 1975–1977 droughts in Ghana. Hydro-meteorological aspects. Bulletin de l'Institut Fondamental d'Afrique Noire, Série A. Sci Nat 42:649–661

Ofori-Sarpong E (1986) The 1981–1983 drought in Ghana. Singap J Trop Geogr 7:108–127

Parry M, Rosenzweig C, Iglesias A, Livermore M, Fischer G (2004) Effects of climate change on global food production under SRES emissions and socio-economic scenarios. Global Environ Change 14:53–67

Sagoe R (2006) Climate change and root crop production in Ghana; Crop Research Institute: Kumasi, Ghana, pp 2–37

Sam-Amoah L, Gowing J (2001) The experience of irrigation management transfer in Ghana: a case study of Dawhenya Irrigation Scheme. Irrig Drain Syst 15:21–38

Sivakumar MVK (1988) Predicting rainy season potential from the onset of rains in southern Sahelian and Sudanian climatic zones of West Africa. Agric Forest Meteorol 42:295–305

Stern N, Treasury G (2007) The economics of climate change: the Stern review. Cambridge University Press.

Stewart JI (1985) Water requirements and water use of crops. Paper presented at the international conference on African agricultural development: Technology, Ecology, and Society; California State Polytechnic University: city, state, USA

Wang YM, Luo Y, Hua Z (2008) On the extent analysis method for fuzzy AHP and its applications. In, pp 735–748