Rainfall changes in the savannah zone of northern Ghana 1961–2010

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Introduction

Rainfall variability is described as an integral part of the climatology of West Africa, especially in the dry Sahel and Savannah regions (UNFCCC, 2007; Abaje *et al*., 2012; Sarr, 2012). The region is associated with high inter-annual and multi-decadal variability of alternate dry and wet periods of between 20 and 30 years (Ellis and Galvin, 1994; Owusu and Waylen, 2009). According to the Food and Agriculture Organization (FAO, 2008), the 1930–1960 wet period, the 1970–1980 droughts and the return of rainfall in the 1990s and 2000s illustrate this clearly and also demonstrate the population's vulnerability, in particular in the Sahel zone. The West African sub-region and the savannah zone were in the dry phase in the early 1980s, when climate change discourse took centre stage. Many studies in the region have reported declining annual rainfall totals (Owusu and Waylen, 2009; Armah *et al*., 2010; Yorke and Omotosho, 2010). The picture of desiccation associated with climate change seems to constitute the public narrative with regard to the rainfall situation in the savannah zone of Ghana. However, a few studies have pointed to a recovery of annual rainfall totals since the year 2000. The FAO (2008) has argued that the change in rainfall pattern may not have necessarily stabilised, and that since the mid-1990s, a return to better rainfall conditions has been noted. Similarly, Ati *et al*. (2009) reported rainfall increases for several stations in the savannah zone of northern Nigeria in the 1990s. The subject of decadal to inter-decadal climate variability is of intrinsic importance not only scientifically, but also for society as a whole, as many livelihoods in the savannah zone are strongly linked to the monsoon pattern and its variability (Swanson and Tsonis, 2009).

The reported rainfall increases could provide welcome relief, as they will increase water availability and improve hydrological recharge. However, the increases could also harm agriculture if the prolonged drought has helped evolve an adaptation strategy involving drought tolerant crops that may not do well under conditions of increasing rainfall. According to Reynolds *et al*. (2000), a slight shift in seasonal rainfall and/or frequency of extreme rainfall events has the potential to result in resource overexploitation in drylands that could further degrade the very resource base the people depend on. For agricultural decision making and water resource management in the savannah zone, it is important to analyse the rainfall trends to determine any significant increases in rainfall in northern Ghana in the last two decades, as reported elsewhere. The objective of this study is to determine any significant changes that may have occurred in the annual rainfall totals post 2000. This is an effort at updating knowledge on annual rainfall totals in the study area and aims to inform water resource decision making.

Following this introduction, the paper is organised into sections as follows: *Study area* gives a brief description of the study area, including the rain formation mechanism of the wider West African sub-region; this is followed by a short review of recent rainfall trends of the savannah zone in the section *Rainfall trends in the savannah zone*; *Data and methods* outlines the methods employed in the study while the *Results and discussion* and *Conclusion* sections are devoted to the discussion of results and conclusion, respectively.

Study area

The region under investigation comprises the Guinea and Sudan Savannah zones of northern Ghana above latitude 8°N and located to the south of the Sahel, as shown in Figure 1. In terms of administrative regions, it covers the Upper East, Upper West and Northern regions of Ghana. Under the Ghana Meteorological Agency (GMet) agro-ecological classification, it constitutes zone D, as indicated in Figure 1. The climate of the zone is Savannah type, with alternating wet and dry seasons. In the broader classification of climates, the study area falls under the Aw (tropical wet and dry) type of

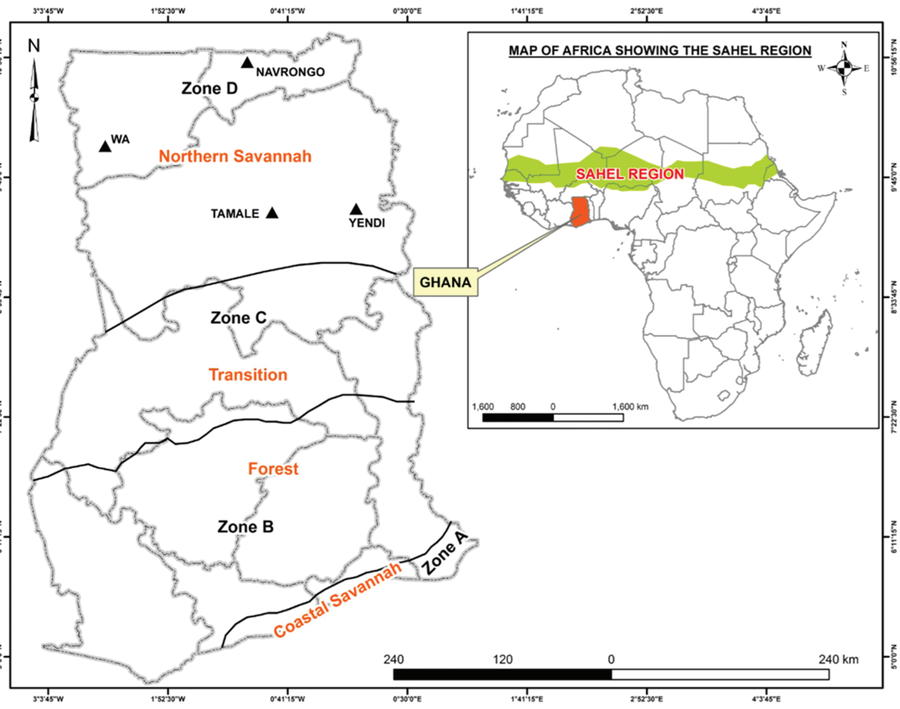

Figure 1. Map of Ghana showing the northern savannah zone D and the data sites.

RMetS
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the Koppen classification system (Rohli and Vega, 2015, p. 159). The zone experiences a unimodal rainfall regime that lasts between 5 and 6 months, as shown in Figure 2. The mean annual rainfall total is around 1000mm and 90% of the rain occurs from May to October. Rainfall in the region is highly variable, both at the annual and multi-decadal scale (CARE International, 2013). Rain onset is erratic, making forecasting for agricultural applications very difficult.

The rainfall amount diminishes from south to north and is controlled by the Inter-Tropical Discontinuity (ITD). The prolonged dry season often referred to as the Harmattan prevails from November to April. The ITD is the ground boundary between the dry Tropical Continental (cT) air mass of northern origin and the moist Tropical Maritime (mT) air mass of southern origin (Ati *et al*., 2009). Areas to the south of the ITD come under the influence of the monsoon rains, and areas to the north experience dry, dusty winds from the Sahara. As explained by Ati *et al*. (2009), the ITD itself is unable to produce sufficient vertical motion (and cloud depth) to induce rainfall (Hulme and Tosdevin, 1989). However, a number of rainfall producing systems are enclosed within the mT air mass, such as disturbance lines (especially the easterly waves), squall lines and the two tropospheric jet streams, which influence the amount and seasonal distribution of rainfall over the savannah zone (Kamara, 1986; Hayward and Oguntoyinbo, 1987; Muller and Oberlander, 1987; Hastenrath, 1991). Rainfall changes in the West African subregion have been linked to variations in the rain-producing mechanism, such as the ITD, the African easterly jet, and the tropical easterly jet, which organise thunderstorms and squall lines that account for over 70% of the total annual precipitation (Akinsanola and Ogunjobi, 2014).

Human activities within the zone have evolved around the unimodal rainfall regime, with rainfed agriculture being the dominant economic activity of the savannah zone in northern Ghana. Due to the overdependence on rainfall, agriculture in general is highly vulnerable to climate variability and change (Yaro, 2010; Owusu and Waylen, 2013). It is therefore important to gain knowledge of climate variability over the period of instrumental records and beyond on different temporal and spatial scales to understand the nature of different climate systems and their impacts on society and the environment (Oguntunde *et al*., 2012). According to Adamu (2000), the dry nature of the savannah zone, the short nature of the rainy season and endemic poverty rates limit crop production to only those crops that have short life cycles. The main crops are cereals like millet, sorghum, maize and upland rice (Shepherd *et al*., 2005). Other important crops are groundnuts, yams and cassava. Animal rearing on a small scale is also popular (Naylor, 1999), with cattle, goats and sheep being the most commonly reared ruminants, and guinea fowl and chickens the most important birds. Armah *et al*. (2010) identified erratic rainfall and non-climatic factors such as low soil fertility, inadequate irrigation facilities, lack of credit, post-harvest losses, the land tenure system, poor roads and annual wildfires as the major challenges to agricultural development in the savannah zone of northern Ghana.

Rainfall trends in the savannah zone

Previous studies on rainfall in the savannah zone of West Africa have revealed a strong variability at the annual, inter-annual and multi-decadal levels. The cyclical changes have been grouped as short-term and long-term periodicities (Odekunle *et al*., 2008). Ellis and Galvin (1994) pointed out that the multi-decadal cycle in West Africa runs between 20- and 30-year rotations of a wetter and a drier rainfall phase. It has been pointed out by many studies that the 1950s and 1960s saw high annual rainfall totals (Sarr, 2012) that supported an agricultural and commodity export boom for many post-independence countries in West Africa (Owusu and Waylen, 2009). However, the following two decades entered into a dry rainfall phase which brought the economies of many of the countries in the sub-region to their knees (Benson and Clay, 1998). According to Redelsperger *et al*. (2006), the drought of the 1970s and 1980s in West Africa represents one of the world's strongest inter-decadal signals of the twentieth century. After the increasing trend towards dry conditions in the late 1980s, recent studies have emerged indicating that there has been some rainfall recovery (Nicholson and Selato, 2000; Sarr, 2012). What is not very clear in the literature, however, is the level of recovery. The recovery seems only to be an improvement on the dry phase experienced in the 1970s and 1980s, but it has not reached the levels of the high rainfall in the 1950s and 1960s and is thus unable to support the rainfed agricultural recovery which has been the mainstay of the rural economy in the study area.

Projections of future rainfall in the study area from the global models are mixed. According to McSweeney *et al*. (2010) half of the models predict rainfall increases over Ghana, while the other half predict a reduction in rainfall. This apparent contradiction is attributed to low understanding of tropical rainfall, and the Intergovernmental Panel on Climate Change (IPCC) has recommended further research to understand why there is so much uncertainty with model results over the study area (Christensen *et al*., 2007). Downscaled models have, however, generally reported a long-term decline in rainfall for the savannah zone of Ghana (Minia, 2008). In fact, Giannini *et al*. (2013) have identified this disagreement in projections of regional precipitation change (a situation common throughout the tropics) as a limiting factor in the practical application of climate information in helping short term development efforts on adaptation.

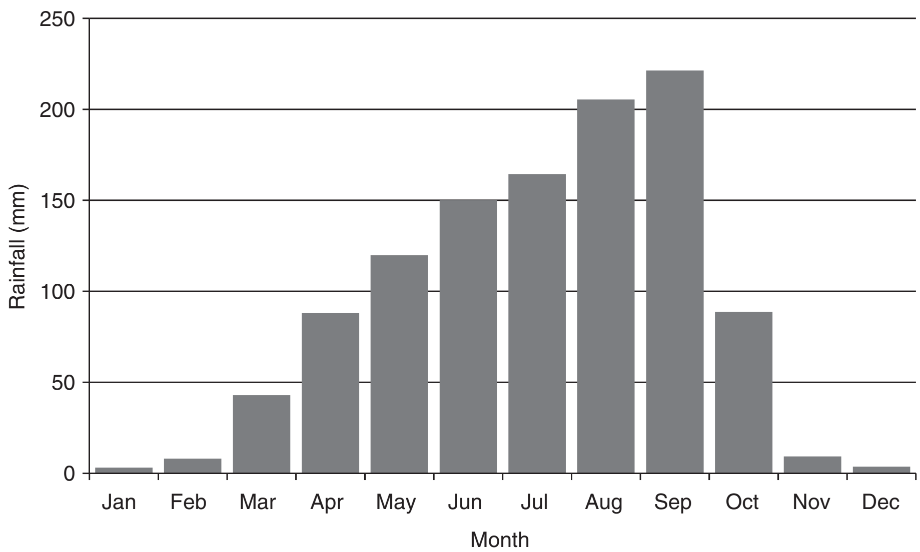

Figure 2. Unimodal rainfall regime of northern Ghana, represented by Tamale, 1960–2010.

Data and methods

Daily rainfall total data for the period 1960–2010 were obtained from the Ghana Meteorological Agency (GMet) Headquarters in Accra. Data were collected for four stations: Navrongo, Tamale, Wa and Yendi, which form a spread across the three administrative regions (Upper East, Upper West and Northern) of the savannah zone of Ghana (Figure 1). All four stations are part of a group of 22 GMet synoptic stations across the country that are well kept and have very minimal missing data. The period 1960–2010 was taken as the common period, having no missing data between the four stations.

The annual total rainfall (A_R) was calculated using Equation 1:

$$A_R = \sum_{i=1}^{12} R_i \tag{1}$$

where R is the monthly rainfall amount at each station.

Trend analyses were performed using normalised rainfall departures. Normalisation helps in separating the rainfall time series into different climatic regimes such as wet and dry periods. The normalisation was performed using Equation 2:

$$Z = \frac{x - \bar{x}}{\sigma} \tag{2}$$

where x is the amount of rainfall, $\bar{x}$ is the mean annual rainfall for the period and σ is the standard deviation.

Results and discussion

The results of statistical analysis performed on the annual rainfall dataset over the selected stations in northern Ghana are shown in Figure 3. Evidence from the four stations analysed indicates a high mean annual rainfall and high standard deviation in the 1960s. The rainfall, however, saw a decline in the 1970s and 1980s, with a minimal recovery in the late 1990s and post-2000. This finding is consistent with numerous studies that have reported increases in mean annual rainfall for the 1950s and 1960s and drier period in the 1970s and 1980s (Ozer *et al*., 2003; Mahé and Paturel, 2009; Owusu and Waylen, 2009; Sarr, 2012; Nicholson, 2013). According to Owusu and Waylen (2009), the increases in rainfall in the earlier decades promoted rainfed agricultural expansion and reliance on cash crops in the West African sub-region by many new independent countries. In the ensuing drought of the 1970s and 1980s, many of the countries in West Africa became economically and politically unstable (Benson and Clay, 1998). The present study examines the degree of recovery and the extent to which hydrological recharge may have occurred for the purpose of water resource management, especially rainfed agricultural production. To be able to do that, the mean rainfall totals were standardised in order to examine the magnitude of the post-2000 increases.

The standardised rainfall departures of the four stations shown in Figure 4 vividly illustrate the rainfall trends and the post-2000 recovery in Northern Ghana. Figure 4 shows that the decade of the 1960s was part of a period of high rainfall which prevailed throughout the northern savannah region. This was followed by the famous drought of the 1970s and 1980s. In fact, this drought was reported for the whole West African sub-region and was intensified by the 1982/1983 El Niño (Nicholson, 2013). Towards the late 1990s and post-2000 there was some recovery in the study area. Most of the earlier studies that did not have data beyond 2000 (see, for example, Nicholson and Selato, 2000; Ati *et al*., 2009; Owusu and Waylen, 2009) indicated that there may be a recovery. From this analysis, it can be shown that there has been some recovery of mean annual rainfall since the drought period of the 1980s (Figure 4). The results of this study also reveal that the magnitude of the recovery in the post-2000 period is nowhere near the wetter periods that the study area experienced during the 1950s and 1960s, which supported a rainfed agriculture boom and the growth of the rural economy of the wider West African sub-region.

The consequences of the rainfall increase over the last two decades could be beneficial and, at the same time, detrimental to water resource management, especially with respect to rainfed agriculture, which is widely practiced in the study area. As Ati *et al*. (2009) postulated in their study of the savannah region in northern Nigeria, increases in annual rainfall totals could mean an improvement in water supply to an otherwise marginal area, but it could also result in flooding that could endanger life and property. However, rainfall increases present an opportunity for hydrological recharge that could be harnessed for irrigation to prolong the short cropping season. A major concern for agriculture is the fact that increases in rainfall call for the re-calibration of crop models and the selection of new crop varieties, since most of the models and crops promoted in the study area were based on an expectation of lower rainfall volumes than were actually experienced over the last two decades.

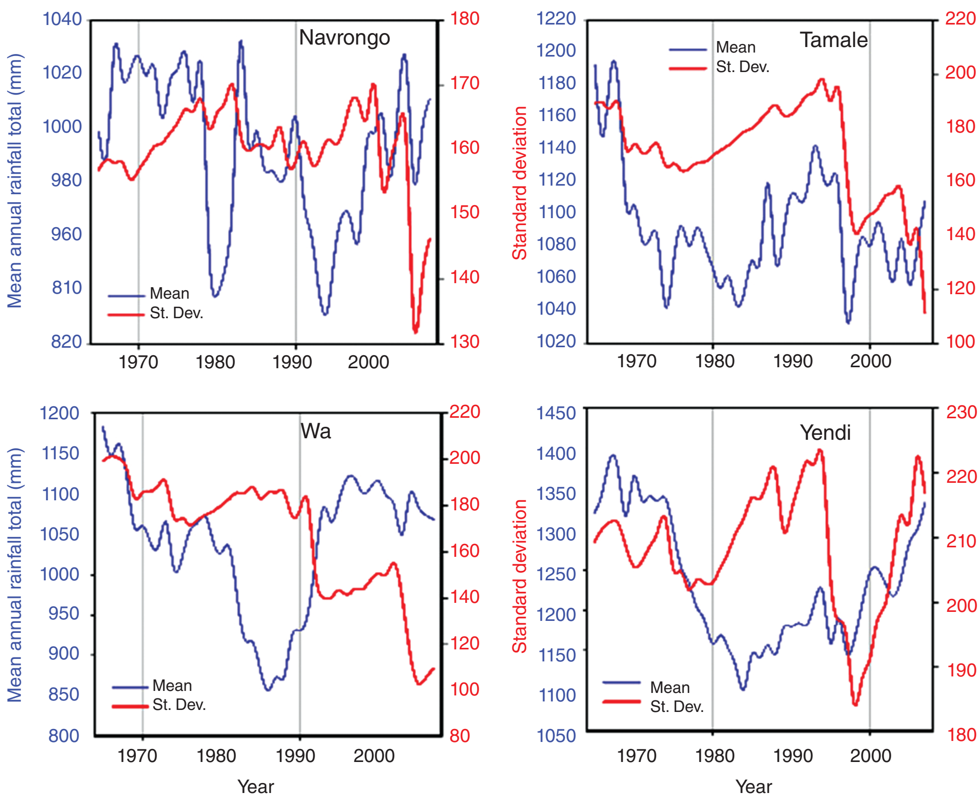

Figure 3. Mean annual rainfall total and standard deviation for northern Ghana.

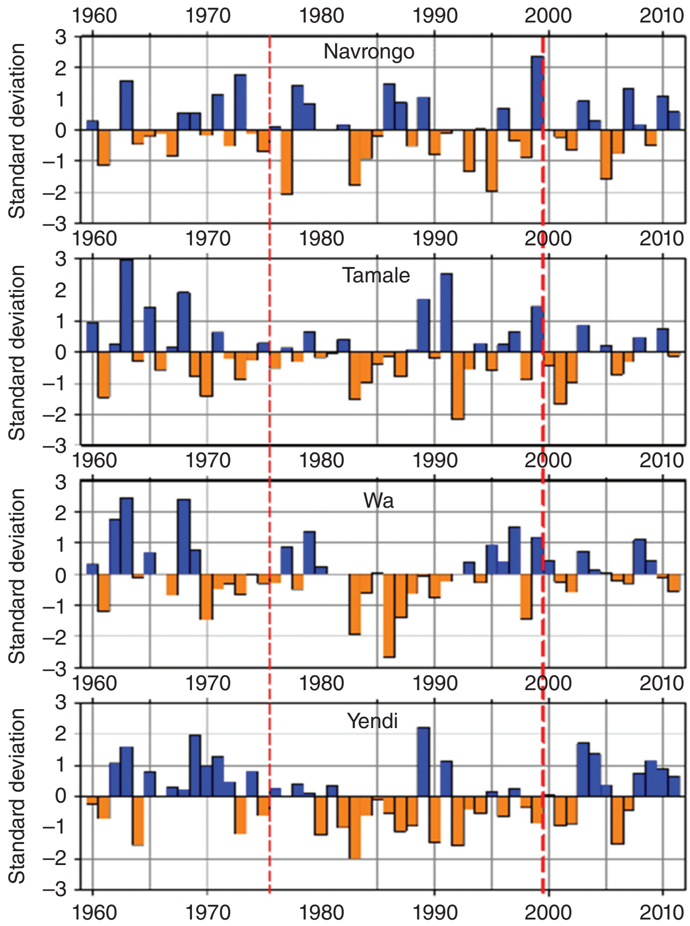

Figure 4. Standardised time series plot of annual rainfall totals for northern Ghana.

Conclusion

Evidence from the long-term rainfall data for the savannah zone of northern Ghana indicates that rainfall in the last two decades entered into a phase of slight increase compared to the previous two decades. A station-by-station analysis, however, indicates that even though all stations have seen some recovery, the magnitude of the recovery is less than that of the high rainfall phase of the 1950s and 1960s. Compared to the 1970s and 1980s, the rainfall situation in the last two decades could be described as an improvement. However, in comparison to the 1950s and 1960s, the mean annual rainfall totals are still low.

Hydrological levels may have seen recharges that could be harnessed to support the rainfed agriculture that is the mainstay of the rural economy of the savannah zone of northern Ghana. Careful selection of crop varieties could also be useful in increasing productivity and improving livelihood opportunities. It is, however, too early to rethink the development of agriculture in the northern savannah based on the assumption of the return of the rainfall as has been suggested for the savannah zones elsewhere (Ati *et al*., 2009). There is opportunity, however, to combine crop variety selection and water management, including irrigation, to improve agriculture in the northern savannah regions of Ghana. Again, as recommended for northern Nigeria, models built on the perceived decrease in rainfall must be reviewed, and the trends should still be closely monitored, as rainfall in West Africa is known to cycle between a dry and wet phase with a period of 20–30 years (Ellis and Galvin, 1994; Ati *et al*., 2009; Owusu and Waylen, 2009). There is therefore a high probability that the recovery may not be sustained.

References

Abaje IB, Ati OF, Iguisi EO. 2012. Recent trends and fluctuations of annual rainfall in the Sudano-Sahelian ecological zone of Nigeria: risks and opportunities. *J. Sustainable Soc.* **1**: 44–51.

Adamu A. 2000. Agricultural production on the Soba plains in the nineteenth century. *Zaria Archaeol. Pap.* **9:** 82–88.

Akinsanola AA, Ogunjobi KO. 2014. Analysis of rainfall and temperature variability over Nigeria. *Global J. Hum.-Social Sci.: B* **14**: 1–17.

Armah FA, Yawson DO, Yengoh GT *et al.* 2010. Impact of floods on livelihoods and vulnerability of natural resource dependent communities in Northern Ghana. *Water* **2**: 120–139.

Ati OF, Stigter CJ, Iguisi EO *et al.* 2009. Profile of rainfall change and variability in the Northern Nigeria, 1953–2002. *Res. J. Environ. Earth Sci.* **1**: 58–63.

Benson C, Clay E. 1998. The Impact of Droughts on Sub-Saharan African Economies. World Bank Technical Paper 401. The World Bank: Washington, DC, p. 80.

CARE International. 2013. *Climate Change Vulnerability and Adaptive Capacity in Northern Ghana*. An Adaptation Learning Programme Report. CARE International: Accra.

Christensen JH, Hewitson B, Busuioc A *et al.* 2007. Regional climate projections: section 11.2: Africa, in *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Solomon S, Qin D, Manning M *et al* (eds). Cambridge University Press: Cambridge, UK and New York, NY, pp. 866–871.

Ellis J, Galvin KA. 1994. Climate patterns and land-use practices in the dry zones of Africa. *BioScience* **44:** 340–349.

Food and Agriculture Organization. 2008. *Climate and climate change in West Africa, 2008.* http://www.fao.org/nr/clim/abst/clim_080502_en.htm (accessed 2 October 2016).

Giannini A, Salack S, Lodoun T *et al.* 2013. A unifying view of climate change in the Sahel linking intra-seasonal, interannual and longer time scales. *Environ. Res. Lett.* **8**: 024010.

Hastenrath S. 1991. *Climate Dynamics of the Tropics. Updated Edition from Climate and Circulation of the Tropics.* Kluwer Academic Publishers: Dordrecht, the Netherlands.

Hayward OF, Oguntoyinbo JS. 1987. *The Climatology of West Africa*. Barnes and Noble Books: Totowa, NJ.

Hulme M, Tosdevin N. 1989. The tropical easterly jet and Sudan rainfall: a review. *Theor. Appl. Climatol.* **39**: 179–187.

Kamara SI. 1986. The origins and types of rainfall in West Africa. *Weather* **41**: 48–56.

Mahé G, Paturel JE. 2009. 1896–2006. Sahelian annual rainfall variability and runoff increase of Sahelian Rivers. *C. R. Geosci.* **341**: 538–546.

McSweeney C, New M, Lizcano G. 2010. *UNDP climate change country profiles: Ghana*. http://www.geog.ox.ac.uk/research/climate/projects/undp-cp/UNDP_reports/Ghana/Ghana.lowres.report.pdf. (accessed 21 April 2017).

Minia Z. 2008. Climate change scenario development, in *Ghana Climate Change Impacts, Vulnerability and Adaptation Assessments*. Agyemang-Bonsu WK (ed.). Environmental Protection Agency: Accra, pp 2–13.

Muller RA, Oberlander TM. 1987. *Physical Geography Today: A Portrait of a Planet*. Random House Inc.: New York, NY.

Naylor R. 1999. Women farmers and economic change in northern Ghana. *Gend. Dev.* **7**: 39–48.

Nicholson SE. 2013. The West African Sahel: a review of recent studies on the rainfall regime and its interannual variability. *ISRN Meteorol.* **2013**: Article ID 453521, p. 32 https://doi.org/10.1155/2013/453521.

Nicholson S, Selato J. 2000. The influence of La Niña on African rainfall. *Int. J. Climatol.* **20**: 1761–1776.

Odekunle TO, Andrew O, Aremu SO. 2008. Towards a wetter Sudano-Sahelian ecological zone in twenty first century Nigeria. *Weather* **63**: 66–70.

Oguntunde PG, Abiodun BJ, Gunnar L. 2012. Spatial and temporal temperature trends in Nigeria, 1901–2000. *Meteorol. Atmos. Phys.* **118**: 95–105.

Owusu K, Waylen PR. 2009. Trends in spatio-temporal rainfall variability in Ghana (1951–2000). *Weather* **64***:* 115–120.

Owusu K, Waylen PR. 2013. Identification of historic shifts in daily rainfall regime, Wenchi, Ghana. *Clim. Change* **117**: 133–147.

Ozer P, Erpicum M, Demarée G *et al.* 2003. The Sahelian drought may have ended during the 1990s. *Hydrol. Sci. J.* **48**: 489–492.

Redelsperger JL, Thorncroft C, Diedhiou A *et al.* 2006. African monsoon multidisciplinary analysis (AMMA): an international research project and field campaign. *Bull. Am. Meteorol. Soc.* **87**: 1739–1746.

Reynolds JF, Fernández RJ, Kemp PR. 2000. Drylands and global change: rainfall variability and sustainable rangeland production, in *Proceedings of the 12th Toyota Conference: Challenge of Plant and Agricultural Sciences to the Crisis of the Biosphere on the Earth in the 21st Century*. Watanabe KN, Komanine A (eds). R. G. Landes: Austin, TX, pp 73–86.

Rohli RV, Vega AJ. 2015. *Climatology*, 3rd Edition. Jones & Bartlett Learning: Burlington, MA.

Sarr B. 2012. Present and future climate change in the semi-arid region of West Africa: a crucial input for practical adaptation in agriculture. *Atmos. Sci. Lett.* **13**: 108–112.

Shepherd A, Jebuni C, Al-Hassan R *et al.* 2005. *Economic Growth in Northern Ghana*. A report prepared for DFID Ghana by Overseas Development Institute and Centre for Policy Analysis. The Centre for Policy Analysis (CEPA), Accra.

Swanson KL, Tsonis AA. 2009. Has the climate recently shifted? *Geophys. Res. Lett.* **36**: L06711. doi:10.1029/2008GL037022.

United Nations Framework Convention on Climate Change, UNFCCC. 2007. *Climate Change: Impacts, Vulnerabilities and Adaptation in Developing Countries*. UNFCCC: Bonn, Germany. http://www.preventionweb.net/files/2759_pub07impacts.pdf (accessed 18 November 2016)

Yaro JA. 2010. Customary tenure systems under siege: contemporary access to land in Northern Ghana. *Geojournal* **75**: 199–214.

Yorke CKA, Omotosho JB. 2010. Rainfall variability in Ghana during 1961–2005. *J. Ghana Sci. Assoc.* **12**: 125–134.

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