Chapter 15
Impacts of Climate Change on Water Resources in the Volta River Basin: Reducing Vulnerability and Enhancing Livelihoods and Sustainable Development

George A. Manful and Yaw Opoku-Ankomah

Abstract The Volta River Basin is a transboundary basin in West Africa with a population of about 24 million people in six riparian countries (Benin, Burkina Faso, Cote d'Ivoire, Ghana, Mali and Togo) with low gross domestic products. Water resources are needed for domestic and industrial use, agriculture, hydropower generation, environmental health and sustainability and ecosystem functioning. Assessment of the impact of climate change on water resources is therefore crucial for the socioeconomic development of all six countries within the basin, including measures designed to alleviate poverty. A number of such studies assess the impacts of climate change and variability on water resources, agriculture and human health. Climate change adaptive measures and management practices to increase resilience and contribute to the Sustainable Development Goals have been analyzed using historical temperature and precipitation data to determine climate variability. Climate forcing from anthropogenic emissions of greenhouse gases is, in most cases, evaluated using Regional Circulation Models downscaled from General Circulation Models. Mid-level Representation Concentration Pathways and high-level forcing scenarios indicate that before the 1980s, the basin was cooler than the average of the reference period 1976–2005. Between 2006–2100, as GHG forcing increases, warming will increase faster than the period 1976–2005, with increases in temperature between 1.5 and 6 °C projected by 2100. Precipitation anomalies show complex patterns in the basin with high inter-annual variability. There is no clear trend for the magnitude of variation for precipitation. A shift and shortening of rainy seasons and an increase in the frequency of dry spells occurring within the rainy seasons is forecast under climate change. These changes in rainfall characteristics will have a serious impact on agricultural production, which is largely rain-fed. Agricultural productivity is a principal pathway out of the vicious cycle of poverty within the Volta river basin; negative impacts on agriculture can be averted if large scale irrigation practices are implemented as part of a comprehensive water management strategy.

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1 Introduction

The Volta River Basin is a transboundary basin that spans parts of six riparian countries in West Africa: Benin, Burkina Faso, Cote d'Ivoire, Ghana, Mali and Togo. The basin is saddled with socioeconomic challenges associated with inadequate water management practices and national development efforts. These countries depend, to a large extent, on the exploitation of their natural resources, including water, for their survival and to make progress toward their development aspirations. Throughout the basin, agriculture, a major economic activity, is predominantly rain-fed, including for cotton, millet, rice and sorghum, which are cultivated in the northern part of the basin, and yam, cassava, plantain, cocoyam and cocoa, which are predominantly grown in the south. Limited irrigation is used to grow crops like tomatoes and onions throughout the basin in the dry season. Animals are also raised alongside crop production. About 77% of water extracted from the basin is used for crop irrigation and livestock farming; the remaining 23% is used for urban and rural water supply for drinking (UNEP-GEF Volta Project 2013). Large-scale irrigation in the basin is not used and has a little socioeconomic impact. The total amount of water extracted from the basin is 928 million cubic meters per annum. However, in order to meet the agriculture demands of an increasing population coupled with variable and uncertain rainfall intensity and distribution, serious irrigation practices must be introduced across the basin. Water for irrigation alone is anticipated to increase from 69% of the total volume of water used in 2000 to about 82% in 2020 (UNEP-GEF Volta Project 2013). This proportion is subject to variation when climate change is factored into planning for water management. Complicating planning, the effects of climate change on rainfall distribution in the Volta River basin are not well understood; more research is needed in this area.

Water supply for domestic and industrial use is also important for socioeconomic development in the basin. Domestic water use there is projected to increase sharply from 360 million cubic meters in 2000 to about 1,058 million cubic meters in 2025 (UNEP-GEF Volta Project 2013). In urban and rural areas with large populations, surface water is treated and sufficient to meet human needs, and rural areas and villages with smaller populations are served by water from springs and streams, as well water. In general, urban populations have better access to safe drinking water than rural populations. In Burkina Faso, for example, only 11.5% of the urban population does not have access to safe water, compared to 35% of the rural population (Lemoalle and de Condappa 2009). The potential for climate change to reduce surface and groundwater resources can threaten the sufficient supply of water if proper management plans are not implemented. In the downstream basin, water is used for hydropower generation; reduction in flows as a result of climate change and large scale atmospheric and global oceanic phenomena like El Niño and Southern Oscillation (ENSO) would pose further serious challenges to riparian countries which jointly depend on hydropower as a renewable energy resource. The Akosombo and Kpong reservoirs downstream produce 4,800 GWh/year of hydroenergy; Bui in mid-Volta produces 980 GWh/year. Upstream in Burkina Faso, hydroenergy production is 65, 19 and 17 GWh/year at Bagre, Kompienga and Samandeni reservoirs, respectively (Sonabel 2009; VRA 2009; Lemoalle and de Condappa 2009).

The basin is underdeveloped, and economies are based predominantly on agriculture and hydropower generation. The availability of water is subject to the climate, the environment and the infrastructure available for water storage and use. The primary source of water in the basin is rainfall modulated by general circulation, evaporation and transpiration from vegetation. Rainfall becomes a surface and groundwater resource through hydrological processes. Temperature can cause water to be lost to the atmosphere without having been used. Climate change, caused to a large extent by anthropogenic activity, is impacting global climates and thus the availability of water for human survival and socioeconomic activities, including agricultural development, hydropower generation and water supply for domestic and industrial use. This literature review looks at the evolution of climate change and its impacts on water resources in the basin in the past, and projects impacts in the future. Temperature and rainfall projections for the basin developed by the IPCC and used in simulations in the Regional Climate Models (RCMs) and Global Circulation Model (GCMs) are discussed.

2 The Volta Basin

2.1 Physical and Geopolitical Settings

The Volta Basin is the ninth largest in West Africa. It lies between latitudes 5°30’N and 14°30’N and longitudes 2°00’E and 5°30’W (UNEP-GEF Volta Project 2013). It covers an area of about 400,000 km^2 and spreads over Benin, Burkina Faso, Cote d’Ivoire, Ghana, Mali and Togo. Lemoalle and de Condappa (2009) noted that 85% of the basin area is in Burkina Faso and Ghana. The Volta Basin is delimited at its eastern and western borders by a series of hills and mountain ranges. At the eastern border, there are the Akwapim ranges, Togo Mountains, Fazao Mountains and the Atakora Mountains in Benin. The Kwahu Plateau and Banfora Plateau constitute the western border. Ninety-five percent of the basin lies at an altitude below 400 m, with an average elevation of 257 m. The basin slope index is 0.25 m/km.

2.2 The River System

The Volta River has three main tributaries: the Black Volta, which originates from Burkina Faso as Mouhoun; the White Volta, also from Burkina Faso where it is called the Nakambe, and the Oti River, originating in Benin, where it is known as the Pendjari (Lemoalle and de Condappa 2009). The Oti passes through Togo before it joins the main Volta in Ghana. All these tributaries drain into Lake Volta, which, together with the Lower Volta downstream, also receives flows from other small tributaries, including the Pru, Sene and Afram. Therefore, the basin is considered to have four sub-basins: the lower Volta, the black Volta, the white Volta and the Oti (see Fig. 1).

2.3 Climate Conditions

The climate of the basin is determined by the north-south migration of the Inter-Tropical Convergence Zone (ITCZ), an interface between the hot, dry and dusty North-East Trade Winds blowing from the Sahara Desert, and the warm, moist tropical maritime climate from the Atlantic Ocean known as the Monsoon. In addition, squall Lines (SLs) originate over West Africa and move in a westerly direction. They are mesoscale disturbances and are the most important convective rainfall system of the West Africa Sahel region, yielding precipitation in the summer months from June to September (Peters and Tetzlaff 1988). SLs, which join larger-scale features such as the African Easterly Jet, the Easterly Waves and the Monsoon Front, produce fields of flow and moisture (Peters and Tetzlaff 1988) and generate about 80% of annual precipitation of the Sahel (Dhonneur 1981). In southern West Africa, SLs contribute to annual rainfall, but its contribution to total rainfall decreases from 71 to 56% in the coastal zone (Maranan et al. 2018).

In general, there are three types of climatic zones: the humid south, with two distinct rainy seasons (March/April-May/June, September-October), the tropical transition zone, also with two rainy seasons which (May/June, September-October) are narrowly separated, and the semi-arid north with only one season of rainfall (May-September), with a peak around August. The south-north gradient of rainfall is used to identify the main agro-climatic zones of the basin according to the FAO classification for West Africa (FAO/GIEWS 1998). They are the Sudano-Sahelian zone, the Sudanian zone and the Guinean zone. The Sudano-Sahelian zone receives rainfall between 500 and 900 mm, the Sudanian zone 900 to 1100 mm and the Guinean zone more than 1100 mm (Lemoalle and Condappa 2009).

The mean annual temperatures range from 24 °C in the South to about 36 °C in the North (Oguntunde 2004; Hayward and Oguntoyinbo 1987). The high temperatures in the basin amplify the impact of evapotranspiration, which is mainly driven by heat

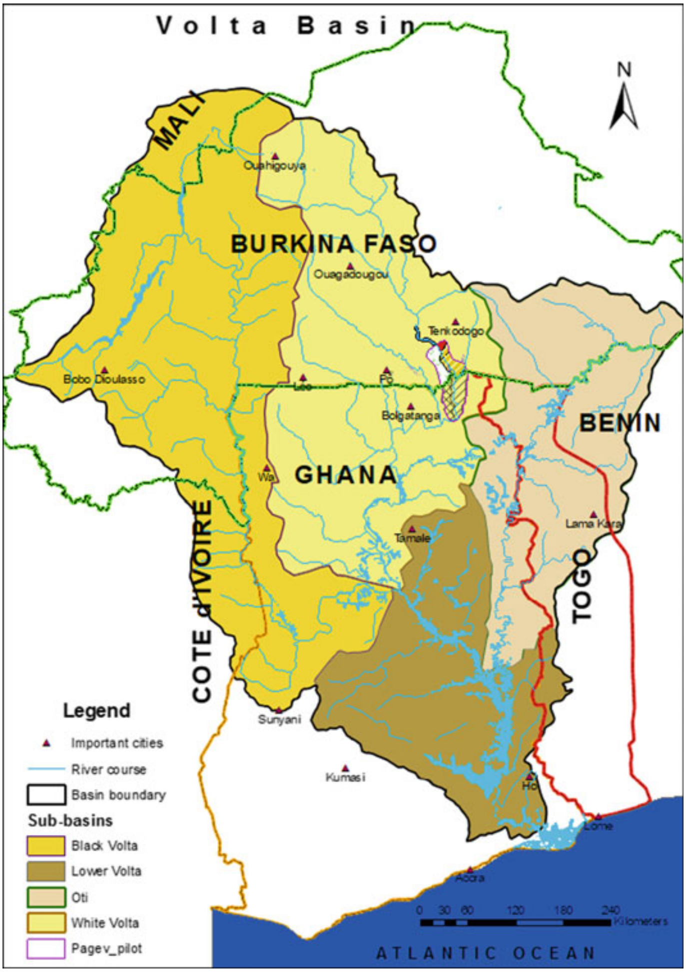

Fig. 1 The network of major rivers in the Volta Basin (*Source* Water Resources Commission, Ghana)

fluxes, wind and relative humidity. Increasing temperatures as a result of anthropogenic greenhouse gas emissions or climate change may increase water deficits via evapotranspiration.

Precipitation is the primary source of water to the hydrological cycle. Studies in the Volta basin examine the repartition of precipitation into various components: evapotranspiration, the outflow of the basin, seepage to groundwater and other losses (de Condappa et al. 2008; Lemoalle and de Condappa 2009). Lemoalle and de Condappa (2009) compute a total volume of the annual rainfall of about 395 km^3 and ET of 346 km^3 (88%), which is notably high. Outflow and groundwater recharge are only

33 km^3 (8%) and 13 km^3 (3%), respectively; various losses are 1%. Fresh water availability in the basin is thus very limited, especially in the drier northern part.

2.4 Groundwater

Aquifers in the basin are recharged directly and indirectly. Direct recharge is through fractured and fault zones as well as through sandy portions of the weathered zones. Indirect recharge occurs by infiltration through ponds in low-lying areas and also through riverbeds. Indirect recharge rates are low compared to direct recharge from rainfall after meeting evapotranspiration demand (HAP 2006; Lemoalle and de Condappa 2009). Hard rock aquifers, which are low-yielding, underlie about 90% of the basin.

Groundwater abstraction in the basin is low but with high potential for development. Climate variability and change will have serious impacts on surface waters, making groundwater use increasingly important. Currently, multiple streams and springs are drying up as a result of climate change and variability, as well as poor land use practices (Gyau-Boakye and Tumbulto 2000). Knowledge of aquifer yield and other characteristics in the basin are limited; more research in this area is needed.

3 Observed Changes in Temperature and Rainfall

Ghana and Burkina Faso make up 85% of the total area of the basin (Lemoalle and de Condappa 2009); hence temperatures and rainfall in the agro-climatic zones of the basin used for this study were taken from national statistics of these two countries sent to the UNFCCC through their national communication reports. The agro-climatic zone of the Burkina Faso part of the basin is largely Sudano-Sahelian (see Sect. 2.3), and that of Ghana is Sudanian in the north and Guinean in the midsection of the country.

3.1 Changes in Historical Temperatures

Over the period 1961–2008, the average annual temperatures in Burkina Faso increased by at least 0.5 °C at all the synoptic stations (UNFCCC 2015a). The minimum and maximum temperatures also increased in magnitude. Average minimum temperatures varied between 20 and 22 °C over 1961–1990 and 1971–2000, respectively, with the variability of about 2 °C. Maximum temperatures varied between 0.4 and 3.6 °C, and minimum temperatures for the period 1960–2000 in Sudan and Guinea Savannah zones in Ghana (in the lower part of the basin) showed a 3.7% increment. For maximum temperatures, rates of change of 6.1% and 2.7% were observed for Sudan and Guinea Savannah, respectively (UNFCCC 2015b).

3.2 Changes in Historical Rainfall Amounts

Rainfall has been variable across the basin and over time (Oguntunde et al. 2006). From 1901 to 2002, the 1970s and 1980s was the driest period, while the 1930s and 1950s were the wettest (Oguntunde et al. 2006). Inter-annual variability was more pronounced in the northern part than the southern part of the basin (Kasei 2009, van de Giesen et al. 2010). The northern part has only one rainfall season from about May/June to September/October, and rainfall totals are lower in the north than in the south, with about 500 mm or less in the Sahelian zone in the far north and about 1100 mm or more in the Guinean zone in the south (Lemoalle and de Condappa 2009). Hence, rainfall variability produces stress on human lives and socioeconomic activities, especially in the upper reaches of the basin. Droughts there have become very frequent since the 1970s (van de Giesen et al. 2010). Mean annual rainfall for 1901–1969 was 1100 mm; for 1970–2002 the mean was 987 mm. Furthermore, if the year 1970 alone is eliminated from rainfall trend analysis, no rainfall trend is evident, meaning that rainfall amounts varied from 1970 to 2002 without any particular trend.

Analysis of historical data from Burkina Faso's National Communication (UNFCCC 2015a) showed a movement of isohyets for the periods 1931–1960, 1961–1990 and 1971–2000 as shown in Fig. 2. The wettest 30-year period was 1931–1960, followed by 1961–1990. 1971–2000 was the driest thirty-year period. From 1931 to 1960, a 1200 mm isohyet was discernible in the southwestern corner of the country. whereas in the latter periods it was completely absent. This observation is consistent with findings that the isohyets in the Sahel and Sudano-Sahelian zone in the Volta basin moved about 150 km south during the climate transition period of the early 1970s (L'Hote and Mahe 1996). Furthermore, even though 1971–2000 was the driest period, there was no significant change in the number of rainy days compared to 1961–1990. Because the two 30-year periods 1961–90 and 1971–2000 overlap, further research is required to validate the migration of isohyets southwards in the basin. In the southern part of the basin, the Sudan and Guinean agro-climatic zones in Ghana also show variable rates of change in rainfall without any clear trend (UNFCCC 2015b).

4 Climate Scenarios and Projection of Climate Change in the Basin

Methods for assessing climate change in the basin have been varied, and range from simple to robust. Some national climate change reports used old emission

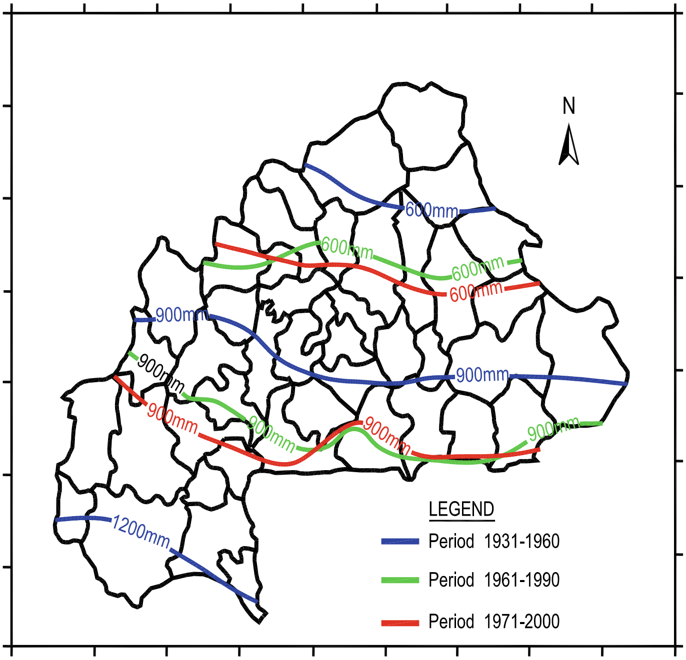

Fig. 2 Migration of isohyets from 1931 to 2000 (*Source* Third National Communication of Burkina Faso)

scenarios produced by the IPCC Special Report on Emission Scenarios (SRES) (IPCC 2000). These projections integrate emissions, climate change and climate impact data, including an assessment of their inherent uncertainties.

An advanced method is used in the IPCC Representative Concentration Pathways (RCPs). The RCPs comprise a set of four GHG concentration trajectories (RCP2.6, RCP4.5, RCP6.0, RCP8.5) spanning a large range of plausible human-caused climate forcing (van Vuuren et al. 2011). RCP2.6 is the best-case scenario, with much effective reduction of Greenhouse Gases (GHG); RCP8.5 is the worst case, used as a reference point for “business as usual” (i.e., taking no action to mitigate the effects of climate change). Regional Climate Models are applied to simulations to downscale GCMs to project future climate of the basin under different levels of anthropogenic GHG forcing. This method was used to develop climate projection in the 5th Coupled Inter-comparison Project (Taylor et al. 2012). Sylla et al. (2016) used CORDEX (Coordinated Regional Climate Downscaling Experiment; Giorgi et al. 2009) simulation to estimate climate change in the Volta Basin. CORDEX uses a number of regional climate models in downscaling GCMs at a spatial resolution of 50 km. CORDEX has also been validated over West Africa (Gbobaniyi et al. 2014 and Klutse et al. 2015). Two IPCC RCPs (RCP4.5 and RCP8.5) were used by Sylla et al. (2016) for temperature and rainfall studies under climate change for a historical period of 1951–2005 using 1976–2005 as a reference period. Plots of anomalies of temperatures from the mean of the reference period show that the basin was cooler than the average temperature before the 1980s. This was confirmed by multi-model ensembles of CORDEX RCMs and observations from Climate Research Unit (Harris et al. 2014). Also, in recent decades, warming has grown at a sharp and unprecedented rate, and is projected to increase. Warming estimates based on the two scenarios diverge in the 2040s, with RCP8.5 warming at higher rate than RCP4.5. RCP4.5 is projected to have temperature anomalies in the range of 1.5 to 4 °C and RCP8.5 in the range of 4 to 6 °C by 2100. Overall, the basin is likely to increase in temperature from 1.5 to 6 °C by 2100 (Sylla et al. 2016). These findings confirm the projection for increased temperatures in the 3rd National Communication of Ghana (UNFCCC 2015b) and 2nd National Communication of Burkina Faso (UNFCCC 2015a) submitted to the UNFCCC. Temperatures in Ghana are projected to increase between 1 and 7 °C by 2080 in all the agro-ecological zones and in Burkina Faso by 0.9 °C by 2025 and 1.5 °C by 2050 in the whole country. In addition to the different time horizons of these projections, the extent of increase in the temperatures also vary among the studies. Standardization and harmonization of studies in the basin and West Africa sub-region, in general, will be necessary.

Relating to precipitation, Sylla et al. (2016) showed great inter-annual variability in the basin, with rainfall measured between −0.5 and 0.5 mm/decade, making detection of negative or positive trends in rainfall very difficult. However, positive anomalies dominated, even with some negative anomalies projected. This suggests that the occurrence of wetter conditions is highly probable in the basin in the future. Mean annual rainfall in the Guinea Savannah of Ghana (in the Volta Basin) is projected to decrease by 3.5% in 2021–2040, 0.9% in 2041–2060 and 3.1% in 2061–2080. However, for the Sudan Savannah, the mean annual rainfall is projected to decrease by 3.2% by 2021–2040, increase by 0.8% in 2041–2060 and decrease by 2.3% by 2061–1080. The results also show no clear trend in the decadal analysis. Available projection of rainfall in Burkina Faso's 2nd National Communication (UNFCCC 2015a) did not use GCM-RCM modeling. Moreover, the study was for the whole country and did not focus on agro-ecological zones. The results of that study indicate that rainfall could decrease by 6.4% by 2025 and by 11% by 2050 in the worst-case scenario. This result does not support evidence of a negative or downward trend in projected rainfall.

The variability of inter-annual rainfall magnitudes bears on the availability of water for socioeconomic development. Variability can impact on surface and groundwater resources needed to supply water for domestic, industrial and irrigation use, hydro-power generation and hydro-ecology for the sustenance of flora and fauna. Inadequate rainfall in the basin as experienced in 1970 and 1983–1984 can have a significant negative impact on rain-fed agriculture, a major economic activity in the basin. While inter-annual rainfall variability is important, rainfall distribution – onset, duration and intensity – and its variability within each year is also of great importance to agricultural productivity. These studies have examined the impacts of climate change on the variability of rainfall distribution, and have shown that the onset of the rainy season has been shifting forward from April to May (van de Giesen et al. 2010 and Laux et al. 2007). Knowing when the rainy season will begin is essential to farmers so that they can prepare the land and sow in order to use the early rains for crop development, especially in an environment where rainfall is not very reliable and can fail. While onset is variable, studies show that the end of the rainy season remains fixed, resulting in a shortening of rainy seasons. Furthermore, the average annual rainfall amount has not changed as the rainy season duration has decreased, meaning that there is an increase in the frequency of extreme rainfall events. Studies carried out by Sylla et al. (2016) show that extreme precipitation intensity will tend to increase across the basin in the near future (2036–65) to the late twenty-first century when greater GHG forcing will produce greater precipitation intensity. The southern part of the basin is estimated to experience an increase of more than 30%, and the northern part an increase of 10% to 20% compared to the reference period 1976–2005.

Dry spell duration during the rainy season or lack of continuity of the rainy season can disrupt rain-fed agriculture. Dry spell length is defined as the maximum number of consecutive dry days that rainfall is less than 1 mm/day. Projection of dry spell length is very small, from −5 to 5%, for mid-level GHG forcing in the near future. In contrast, dry spell length for high-level GHG forcing for the same period is about 10%, and by the late 21st century, projections for high-level GHG forcing could be up to 30% in the south and middle part of the basin. Under these conditions, farmers in the basin will have to adapt to shortened and intensified rainy seasons coupled with dry spells, through the use of crops and cultivars that are more suitable for such conditions. Climate change will also require the use of reservoirs to capture, store and use the surface runoff for irrigating crops, as well as the conjunctive use of surface water with groundwater.

5 Agriculture, Water Resources and Climate Change

5.1 Climate Change Impacts on Crop Production and Adaptation Strategies

The latest Special Report of the Intergovernmental Panel on Climate Change indicates global warming of 1.5 °C above pre-industrial levels. Related assessment of global greenhouse gas emission pathways indicates that the earth is already experiencing the adverse impacts of 1 °C of global warming through more extreme weather, among other changes, and that warming of 1.5 °C is not 'safe' for most nations, communities, ecosystems, and sectors, posing significant risks to natural and human systems due to the likelihood of increased frequency of extreme weather events coupled with land-use change resulting in increased frequency of flood events (IPCC 2018).

Using a statistical metric of multidimensional climate change to quantify the emergence of global climate change hotspots in the CMIP5 (Fifth phase of the Coupled Model Intercomparison Project climate model ensemble), Diffenbaugh and Giorgi (2012) observed that the Sahel and tropical West Africa are among the persistent regional climate change hotspots throughout the twenty-first century of the RCP8.5 and RCP4.5 forcing pathways in the 2016–2035, 2046–2065 and 2080–2099 periods. These hotspots are characterized by widespread increases in mean temperature, the intensification of extreme hot seasons and changes in intensity and distribution of precipitation. These analyses, however, did not consider non-climatic factors that will ultimately determine the impacts of climate change.

The West African region is particularly vulnerable to climate change and extreme climate events such as floods and droughts. The region is highly reliant on rain-fed agriculture and has little economic and institutional capacity to address the consequences of climate variability and change (Sultan and Gaetani 2016; Zougmoré et al. 2016). These factors make the region particularly vulnerable to frequent food crises, especially in the drier areas, including in northern sections of the Volta Basin (Caritas 2018; van de Giesen et al. 2010). These impacts invariably result in loss of human life and livelihoods, which undermine advances toward sustainable development objectives (CCAFS 2013). Poverty is defined as unacceptable deprivation in one or several dimensions of human welfare (Ravallion 1996). The African Development Bank has noted that agricultural growth in sub-Saharan Africa has been demonstrated to be a principal driver of poverty reduction and stimulus of growth across economic sectors on the continent. In fact, agricultural growth in this region has been demonstrated to be twice as effective in reducing poverty as growth based in other sectors (AfDB 2010). Between 2007 and 2017, the share of the national labor force attributed to the agricultural sector ranged from 33.6% in Mali to 47.5% in Togo, with an average of 41.6% across the six countries of the Volta basin. In 2017 alone, the sector generated about 42.5% of the basin's economic output (AfDB 2018). Several factors, including climate shocks and loss of employment in agriculture, have adversely affected agricultural productivity in Sub-Saharan Africa, which is expected to drop by nearly 10% this decade, with a corresponding increase in the numbers of people running small household businesses (World Development Report 2018).

Data submitted by all six riparian countries to the UNFCCC over the past 15 years reveals that increasing temperatures and changes in precipitation in the Volta Basin are very likely to reduce cereal crop productivity with the potential to undermine food security (UNFCCC 2011, 2015a, b, 2017, 2018). In spite of these challenges, agriculture continues to make an important contribution to the Gross Domestic Product (GDP) of all the Volta Basin countries (Lemoalle and de Condappa 2010). Between 2007 and 2017, the share of the national labor force of the agriculture sector ranged from 33.6% in Mali to 47.5% in Togo, with an average of 41.6% across the six countries of the Volta basin (IMF 2018).

In 2017 alone, the sector generated about 42.5% of the basin's economic output (AfDB 2018). Food crops grown in the basin include maize, millet, sorghum, rice, yam, groundnut, Bambara beans, cowpea, soybean and vegetables including tomato, onion, cabbage, pepper and okra. Cocoa, cotton and coffee are the predominant cash crops (UNFCCC 2011, 2015a, b, 2017, 2018). Planting is usually done in the wet season and the vast majority of crop farms are small in size, with farmers typically using rudimentary tools such as hoes and cutlasses with limited application of agrochemicals (Chamberlin 2008; Zougmoré et al. 2016). Total chemical fertilizer use in 2014 amounted to 558,800 metric tons, equivalent to 12.2% of African fertilizer consumption and 2% of global fertilizer consumption (FAOSTAT 2019). The Fifth Assessment Report of the IPCC confirms that climate change exacerbates prevailing stress on water availability and agricultural systems, particularly in semi-arid environments of Africa, such as the northern parts of the Volta River Basin. Increasing temperatures and changes in precipitation in the Volta Basin are very likely to reduce cereal crop productivity, with strong adverse effects on food security (Niang et al. 2014). Crop growing periods in West Africa may decrease by an average of up to 20% by 2050, resulting in cereal yield losses of 40% as well as cereal biomass losses for livestock due to a decline in rainfall and frequent, long-lasting and intense droughts (Niang et al. 2014).

In its Fifth Assessment Report, the IPCC projects increases in precipitation in West Africa to increase millet and sorghum yields; however, projected temperature increases greater than 2 °C (relative to the 1961–1990 baseline) are estimated to counteract positive effects on the yields of millet and sorghum (for B1, A1B, and A2 scenarios) (Niang et al. 2014). These adverse effects will be felt more strongly in the savannah ecological zone than in the Sahel, with new millet and sorghum varieties subject to greater adverse impacts compared to their traditional counterparts (Sultan et al. 2013). Cassava (*Manihot esculenta)* is very adaptable to relatively marginal soils, high temperatures and erratic rainfall conditions compared to many cereal crops, making tuberous root crop a better substitute for cereals as an adaptation response to climate change under rain-fed agricultural conditions. For peanuts, both positive and negative impacts have been projected by researchers under A2 and B2 scenarios. Suitable agro-climatic zones for growing economically important perennial crops such as cocoa and coffee are estimated to diminish significantly, largely as a result of the effects of rising temperatures. Under an A2 scenario, by mid-century, suitable agroclimatic zones that are currently classified as very good to good for perennial crops may become marginal, and zones that are currently marginally suitable may become unsuitable. The report further concludes that crop growing periods in West Africa may decrease by an average of 20% by 2050, causing a 40% decline in cereal yields and a reduction in cereal biomass for livestock (Niang et al. 2014); these findings have been largely confirmed by Zougmoré (2016). Detailed atmospheric modeling for the West African region shows that the onset of rainy season will shift to later in the year, roughly from April to May (van de Giesen et al. 2010). Since the end of the rainy season, as well as the total amount of rainfall, remain more or less fixed, the rainy season is decreasing in duration, leading to reduced rain-fed agriculture, the dominant mode of food production in the region. The IPCC Special Report projects that warming of up to 2 °C could result in accumulated heatwave duration up to three months; warming of up to 3 °C would lead to drastic reductions in the maize crop in Africa (IPCC 2018).

Schroth et al. (2016) observed that within the Volta Basin, cocoa is now mostly grown in climates that have a maximum of four consecutive dry months, defined as less than 100 mm of rainfall per month; in Ghana and Ivory Coast, the northern limit of the cocoa belt also coincides roughly with the 4 months of dry season. The difference between rainfall and ETP during the driest quarter is projected to decrease in the savannah in the 2050s compared to the present climate, especially in Ghana (Schroth et al. 2016). Drier-than-average years could become more frequent in West Africa than they are now, possibly increasing the risk of drought (Abiodun et al. 2013). Under present climatic conditions, it is generally assumed that drought is a greater threat to cocoa than is high temperature in West Africa (Carr and Lockwood 2011). Drought has affected cocoa yields regularly in West Africa, particularly during the severe El Niño years of the 1980s (Ruf 2011). The only practical way of protecting cocoa trees from high temperatures is through overhead shade from appropriately selected, spaced and managed companion trees and selected crops (especially bananas and plantains) co-located on the cocoa farm so that shading can reduce coca leaf temperatures by up to 4 °C (Almeida and Valle 2007). Adequate ventilation is also an important complement because it can reduce fungal disease on cocoa plantations (Zhang and Motilal 2016).

Because of drought periods and erratic rainfalls without effective water management to promote crop production, the Volta Basin countries can no longer rely on rain-fed agriculture to feed their rapidly increasing populations. Mitigation practices may include irrigation and water harvesting technologies to enhance agricultural productivity. This is especially applicable to Northern Ghana and Burkina Faso, where the rainy season lasts for only four to five months. Adaptive strategies would therefore include continued efforts to produce faster-growing rain-fed crop cultivars, mainly corn and sorghum, as well as better storage of surface run-off in small reservoirs during the wet season for use during the dry season. The use of (shallow) groundwater during the dry season is a highly complementary adaptation strategy (van de Giesen et al., 2008) for building the resilience of crop production systems against climate change. Other such strategies in the Volta Basin include conservation agriculture, alternate wetting and drying approach (AWD) for rice production, agroforestry, “zaï” water conservation technology and the development of varieties of cultivars that are resilient to higher temperatures, drought, pest, weeds, salinity, flooding, etc., with a greater emphasis on new varieties that can withstand multiple stresses.

Trees in or near agricultural fields reduce the vulnerability of cropping systems to climate variations, so the introduction of trees in agriculture, such as in agroforestry and silvopastoralist systems, is considered to be an effective adaptation strategy. Tree roots reach into deep soil for water and nutrients, which benefits crops during droughts. Trees improve fertility and protect soils from erosion by increasing soil organic matter, porosity, infiltration and soil cover (Verchot et al. 2007). Nitrogen-fixing trees contribute to the resilience to droughts of crops due to improvements in soil nutrients and water infiltration – in, for example, Ghana and Burkina Faso (Garrity et al. 2010). Studies of agroforestry systems highlight the trade-offs of trees between increasing soil protection and reducing the light available to crops under the canopies. In agroforestry, tree ecosystems may contribute differently to the adaptation of crops to climate change depending on climate scenarios and production systems (Verchot et al. 2007). Within the Volta Basin, farmers mostly maintain agroforestry parkland systems, characterized by the deliberate retention on farmlands of economically valuable and multipurpose trees such as Shea (*Vitellaria paradoxa*), Dawadawa (*Parkia biglobosa*) and Kapok (*Ceiba pentandra*) (Poudyal 2009). There is heavy dependence on the inherent fertility of the soil due to low fertilizer application, both in terms of quantity per hectare and frequency of application. In addition, pressure on agricultural lands has reduced fallow periods and therefore decreased the quality of soil fertility.

5.2 Climate Impacts on Livestock-Rearing and Adaptation Strategies

The livestock sector remains a major contributor to both rural livelihoods and the national economies of all six Volta Basin countries, particularly in the savannah ecological zones and semi-arid regions, where the predominant livestock is cattle, sheep, goats, pigs, fowls and guinea fowls (UNFCCC 2011, 2015a, b, c, 2017, 2018). It is estimated that at least 100 million poor people in West Africa rely on livestock as part of their livelihood. In the Sahelian zone, livestock production accounts for about 30% of revenue from the agriculture sector. For both crop farmers and pastoralists, livestock serves as a productive asset to generate income, and contribute to increasing food security in the basin. Repeated droughts in the Sahel has led to the adoption of agro-pastoralism—a combination of crop farming and livestock rearing on the same farm—by pastoralists who were once solely dependent on livestock. Similarly, crop farmers have diversified into rearing livestock due to repeated crop failure associated with droughts (Thornton et al. 2014).

For both crop farmers and pastoralists, livestock rearing generates income, contributing a key element of food security in the basin, because this diversification is an effective adaptation strategy to increased prevalence of droughts and warming temperatures (Thornton et al. 2014; Turner et al. 2014; Rosenstock et al. 2016).

Livestock contributes significantly to satisfying household needs, and constitutes the second-largest export commodity for countries such as Mali and Burkina Faso (FAO and ECOWAS 2017). Livestock rearing stabilizes the socioeconomic capability of households by providing reliable income in times when prices of crops are low due to a bumper harvest. The predominant livestock reared by farmers is cattle, sheep, goats, pigs and fowl. In Burkina Faso, animal husbandry, like crop production, is an important element of the farming system in all the regions of the country. In 2011, the animal population in the West African region was estimated at 283 million head, comprising 63,128,047 cattle, 7,492,551 sheep, 130,446,369 goats, 11,225,235 pigs and 2,895,861 camels (FAO and ECOWAS 2017).

Strategies to enhance livestock-based livelihoods include the implementation of management practices suited to drought and warming temperatures; introduction and support of animal species and breeds able to adapt to drought and warming temperatures and associated synergies and trade-offs, and policy and institutional mechanisms to enhance adaptation of livestock production systems (Zougmoré et al. 2016).

5.3 Climate Change Impacts on Inland Fisheries and Adaptation Strategies

Fishing is the primary livelihood of many residents around the main surface water bodies, both natural and artificial, such as the Lake Volta (Mul et al. 2015). The majority of fish species found in the basin are edible. Along the shoreline of Lake Volta are over 1,200 fishing villages inhabited largely by impoverished rural populations whose livelihood is primarily fishing in the lake. It is estimated that over 80,000 fishers and 20,000 fish processors and traders are involved in Lake Volta fishing (UNEP-GEF Volta Project 2013). Inland fisheries are the major livelihood of many communities along the Volta River, and fish provide about 60% of total protein requirements of Ghana; inland fisheries and aquaculture contribute about 20% of Ghana's total production of fish (UNEP-GEF Volta Project 2013).

Fisheries encompass a wide range of ecological and socioeconomic components within the Volta Basin; artisanal fishery dominates employment in the fishing industry and is active year-round. Artisanal fishermen use traditional wooden boats, sometimes motorized, with a variety of gear, including nets, lines and seines. In addition to natural fish resources in the basin, aquaculture development, particularly caged fish production, is increasing, especially in Lake Volta and in downstream reaches of the river. Traditional processing methods include smoking, drying, salting and curing (UNEP-GEF Volta Project 2013).

Climate change is projected to impact fisheries and aquaculture through water stress and competition for limited water resources, which have the potential to adversely impact aquaculture operations and inland fisheries production and increase the likelihood of conflicts among water users Poff et al. (2002) and Cochrane et al. (2009). The projected impacts of climate change on fisheries are both social and economic for fishing communities.

5.4 Ecosystem-Based Adaptation Issues

The freshwater ecosystems of the Volta Basin provide a number of services that contribute to local livelihoods and larger-scale basin objectives, including food, fuel and construction materials, regulating flows (reducing peak and increasing baseflows) and habitats for animals, such as migrant birds, which may attract tourism and recreational activity.

Medicinal and pharmaceutical products are derived from various forest and wetland products in the basin. The leaves, bark, seeds and roots of a range of plant species are used for a variety of pharmaceutical and medicinal products, which are also derived from the fauna that inhabits the ecosystems in the basin. But flora species are threatened in Burkina Faso, Mali and Togo. In Burkina Faso, a study in the southern Sahelian zone (axis Kaya-Tougouri-Yalgo) corresponding to the White Volta-Nakambe watershed indicates that some flora species have shown a great decline in numbers so are considered to be at high risk (UNEP-GEF Volta Project 2013).

6 Sustainable Development Issues

In 2013, the United Nations Economic Commission for Africa conducted a country-level survey on sustainable development priorities in the member states of the Economic Community of West African States (ECOWAS). These were then aligned with the Poverty Reduction Strategies (PRSs) that integrate the economic, social and environmental pillars of sustainable development. This analysis revealed that the priorities for sustainable development, in order, are: education; health; sustainable infrastructure development (energy, water, transport); inclusive economic growth, diversification and transformation; good governance and the rule of law; agriculture and food security; environment and natural resource management (forest, water and soils); social protection for the poor and vulnerable; sanitation and urban management; peace and security. Poverty is recognized as an overarching issue, while the others are considered interrelated (UNECA 2015 and World Bank 2015).

In September 2015, UN Member States adopted the 2030 Agenda for Sustainable Development, otherwise known as the Global Goals to end poverty, fight inequality and injustice, and tackle climate change by 2030, and more commonly called the Sustainable Development Goals (SDGs). These build on the Millennium Development Goals (MDGs) adopted in 2000. Countries within the basin have made good progress toward the MDGs, but the indignity of poverty is the reality for millions of people within the basin. The SDGs go much further than the MDGs, addressing the root causes of poverty and the universal need for development that works for all people. The SDGs also set higher goals, seeking to eradicate, and not just reduce, poverty, as well as embracing higher aspirations to meet obligations for future generations. The SDGs seeks for no one to be left behind and is considered an agenda for shared prosperity, peace and partnership. It conveys the urgency of climate action, underscoring the potential for dire consequences of mismanagement of natural resources in the Volta Basin. Moreover, the SDGs emphasize that poverty is not merely a lack of income but also takes the form of low educational attainment, poor health and nutrition, exposure to physical insecurity and natural hazards, and substandard living conditions. Poor people also lack access to improved water sources, better sanitation facilities and electricity, the shortage of all of which contribute to poor labor productivity, amplifying the cycle of income poverty (see Table 1).

The Sustainable Development Goals include a goal on water (SDG6) with ambitious targets for universal access to drinking water and sanitation (targets 6.1 and 6.2, respectively) by 2030. Achieving sustainable universal access under the influence of climate change will be a defining challenge for the SDGs. SDG6 also includes targets to improve water quality (6.3), improve water-use efficiency (6.4), implement integrated water resources management (IWRM) (6.5), and restore water ecosystems

Table 1 Selected water and sanitation indicators in the six riparian countries

Countries	HDI[1] 2017	Mortality rate attributed to unsafe water, sanitation and hygiene Services (per 100,000 population) SDG 3.9	Population using improved water sources (%) (2015) SDG 6.1	Population using improved sanitation facilities (%) (2015) SDG 6.2
Benin	0.515	59.7	67.0	13.9
Burkina Faso	0.423	49.6	53.9	22.5
Cote d'Ivoire	0.492	47.2	73.1	29. 9
Ghana	0.592	18.8	77.8	14.3
Mali	0.427	70.7	74.3	31.3
Togo	0.503	41.6	62.8	13.9

http://hdr.undp.org/sites/default/files/2018_human_development_statistical_update.pdf

(6.6). All of these will be impacted by climate change and in turn, influence the resilience of drinking water and sanitation services. Inadequate water supply and limited sanitation services have important consequences for human health: the WHO (2014) estimates that globally nearly 1,000 children under five years die every day as a result of diarrhea caused by poor water and sanitation. At the end of the MDG period in 2015, it was estimated that while 91% of the world's population has access to an improved water supply (UNICEF and WHO 2015), only 68% has access to improved sanitation. The corresponding figures within the Volta River Basin for access of the population to an improved water supply and improved sanitation were 68% and 16%, respectively (IMF 2018), indicating that these six countries have a long way to go toward improving water and sanitation services. Open defecation remains a major public health concern, and its elimination has been explicitly targeted in the SDGs.

Notwithstanding the ongoing challenges, there have been significant advances in human development over the past decades in all six countries. For the period 2000–2017, the human development index (HDI) increased by 18.4% for Togo and by 47.9% for Burkina Faso (IMF 2018). In 2010, the HDI score for Ghana rose to 0.554, making it the only country within the Volta River Basin to transition from low human development to medium human development, with the HDI growing at an average annual rate of 1.14% for the past 17 years (IMF 2018). On average, all six countries within the basin achieved modest positive economic growth rates. Over the period 2000–2016, the average annual real GDP growth rate for the subregion was 4.51%; the most progress was made by Ghana, followed by Burkina Faso. Ivory Coast and Togo made the least progress in the period. Despite these moderate gains, all basin countries still face the challenge of raising and sustaining economic growth over the long term (IMF 2018). Growth over this decade may be due to strong global demand for export commodities such as oil and cocoa, better macroeconomic management and new mining ventures. Increased agricultural productivity and transition of the labor force to higher earning sectors of manufacturing and services is essential to create higher earnings, employment and demand for the value chain of outputs from other sectors. This transition will lead to a reduction in the share of agriculture to national economies and the increase in the share of manufacturing and services, which has the potential to increase employment and incomes and reduce poverty (IMF 2018).

Across the basin countries, people are living longer and have greater livelihood opportunities than 20 years ago, but they still lag behind most countries in the world in human development measures, including education, health and access to drinking water and other basic infrastructure services. These persistent social challenges have hampered the efforts of these countries to accelerate growth and reduce poverty, as envisaged in the national Poverty Reduction Strategies (PRSs) of each country. According to World Bank revised estimates of global poverty from 1981 to 2015 based on 2011 Purchasing Power Parities (PPPs) released in September 2018, the proportion of the population living on less than US$1.90/day (SDG 1.1) in Ghana, Ivory Coast, Burkina Faso, Mali, Togo and Benin are 12.0%, 28.2%, 43.7%, 49.7%, 49.2% and 49.6%, respectively (IMF 2018). Another indicator of poverty is the global Multidimensional Poverty Index (MPI), an international measure of acute poverty that goes beyond income poverty and takes into account multiple deprivations at the household level, including health, education and standard of living. As expected, computed MPI figures may vary significantly from SDG 1.1 values. MPI values, taking into account broader parameters of deprivation, are 9.6%, 24.5%, 24.5%, 38.1%, 56.7% and 64.8% for Ghana, Ivory Coast, Togo, Benin, Mali, and Burkina Faso, respectively (IMF 2018). Note that the MPI assesses poverty at the individual level, and also permits comparisons both across countries and within countries by ethnic group and urban/rural location. National life expectancy figures in the basin countries are 63 years in Ghana, 61.2 years in Benin, 60.8 years in Burkina Faso, 60.5 years in Togo, 58.5 years in Mali and 54.1 years in Cote d’Ivoire.

7 Climate Change, Water, Health and Sanitation

All six riparian countries within the basin have witnessed some improvement in access to sanitation over the past few decades. Notwithstanding, about 30% of the populations of Mali and Ivory Coast, and only 15% of the populations of Benin, Togo and Ghana, had access to improved sanitation facilities as of 2015. Significant progress has been made by all the riparian countries to provide their citizens with improved water sources. As of 2015, Ghana, Mali and Ivory Coast had provided about 78%, 74% and 73% of their populations with improved water sources, respectively, with Burkina Faso providing up to 54% of the population with improved water sources, the lowest in the river basin (see Table 1) (UNECA 2015). In the Upper East and Upper West regions of Ghana, the water supply used for drinking and other domestic purposes, serving approximately 80% of rural and urban populations, comes from groundwater sources (Johnston and McCartney 2010).

African women are particularly vulnerable to the impacts of climate change because they shoulder an enormous but imprecisely recorded portion of responsibility for subsistence agriculture, the productivity of which can be expected to be adversely affected by climate change and overexploited soil (Viatte et al. 2009). Global financial crises, such as the one experienced in 2007–2008, as well as downturns in economic trends at the national level, may cause job losses in the formal sector, driving men into the informal sector to compete for jobs that were previously performed by women, increasing the vulnerability of women (AfDB et al. 2010).

The health implications of the projected rise in temperature and rainfall variability are alarming, and include an increase in the incidence rate of measles, diarrheal disease, guinea worm infestation, malaria, cholera, cerebral-spinal meningitis and other water-related diseases. These impacts of climate change and variability worsen the plight of the poor, who are mostly women and children (Niang et al. 2014). Climate change amplifies existing health vulnerabilities, including insufficient access to safe water and improved sanitation, food insecurity and limited access to health care and education. The most effective strategies to build resilient development integrate consideration of climate change risks with land and water management and disaster risk reduction. Oppressive temperatures and increasing heatwave duration will also likely impact human health, mortality and productivity directly. With the warming of up to 2 °C, there is a substantial increase in the risk of potentially deadly heatwaves.

Climate change also poses significant risks to water and sanitation services. Risks to water services include damage to infrastructure due to flooding, loss of water sources and increasing water demand as a result of growth in the population *and* economy and as well as changes in water quality. Adverse impacts on sanitation services also include damage and loss of services from floods and reduced carrying capacity of waters receiving wastewater. Measures to reduce risks may include the integration of climate resilience strategies into water safety plans, as well as improved accounting and management of water resources. Technological options for enhancing service delivery and changes in management models offer the potential to reduce risk, particularly in low-income settings.

The IPCC-projected global warming of 1.5 °C clearly states that the earth is already experiencing the adverse impacts of 1 °C of global *warming* through more extreme weather, among other impacts. It further asserts that warming of 1.5 °C is not considered “safe” for most nations, communities, ecosystems and sectors, and poses significant risks to natural and human systems. It is clear from the report that warming of 1.5 °C or higher increases the risk associated with long-lasting or irreversible changes, such as the loss of some ecological systems (IPCC 2018). With the increased frequency of extreme weather events, coupled with land-use change-related flood events and continued growth of settlements, people will be exposed to the negative consequences of climate change increasingly (Milly et al. 2002, Jiménez Cisneros et al. 2014).

Howard et al. (2016) assert that the impacts of climate change on sanitation infrastructure can be both positive and negative, depending on the nature of the impacts as well as changes in the types of technologies employed by households. In the drier parts of the basin, the impact on rudimentary onsite sanitation infrastructure may be positive due to the fact that groundwater pollution risks may be minimized as the distance between the base of pits and groundwater (and hence travel time for pathogens) increases (Mahmud et al. 2007). Seasonal groundwater flooding of pits become less frequent (Sherpa et al. 2014), but increased flooding will pose major threats to sewage and septic systems that rely on water (Howard et al. 2016).

Various policy options could address the resilience of water and sanitation services. In rural areas, where small water supplies continue to be the norm, key policy decisions revolve around which technologies are acceptably resilient. Howard et al. (2010) suggest that some, such as dug wells, are less resilient because they are vulnerable to contamination, drought and/or long-term reduction in water volume, and inability to prevent damage during flooding. Other technologies, such as raising the wellheads of tubewells, may be more resilient, though they have yet to be demonstrated to be effective.

Groundwater resources are widely expected to be less vulnerable to climate change because of their inherent buffer against unpredictable rainfall, and are therefore believed to form the basis of adaptation programs (Rockström et al. 2009 and Jaliffer-Verne et al. 2015). In fact, groundwater resources are likely to be impacted as much by increases in demand for groundwater as by changes to groundwater recharge (Kundzewicz and Döll 2009). A caveat is that detection of and attribution to climate change are difficult, given that surface and groundwater hydrology are governed by multiple, interacting drivers and factors, such as land use change, water withdrawals, and natural climate variability.

8 Conclusions

Studies have shown that the climate of the basin has been warming since the 1980s when the temperature anomalies from the mean of the reference period of 1976–2005 are examined for the entire historical period of 1951–2005, with temperatures projected to increase by as much as 1.5 to 6 °C by the end of 2100 under mid-level and high-level IPCC greenhouse gas forcing scenarios relative to 1976–2005. Precipitation has also varied, with the 1930s and 1950s being relatively wet and 1970s and 1980s being dry. There is some evidence of migration of isohyets southwards during some decades, however, a trend has not been established with available information. There have been positive and negative anomalies in rainfall records without any clear trend, even though positive anomalies appear to dominate in the recent past. The onset of the rainy season has been shifting forward without any significant change in rainfall amount, even though there is an increase in the number of extreme rainfall events. Projections using IPCC scenarios show an increase in future extreme rainfall events and an increase in periods of dry spells within rainy seasons, which may be detrimental to rain-fed agriculture.

Although agricultural productivity is a principal driver out of the vicious cycle of poverty within the Volta basin, all six riparian countries have agricultural systems that are highly vulnerable to climate change and climate variability with associated extreme climate events such as floods and droughts. This is due to a great reliance on rain-fed agriculture, and little economic and institutional capacity to effectively manage environmental and natural resources. The sub-region, therefore, requires well designed and adequately funded adaptation strategies, such as changes in crop varieties, sowing dates and density, enhanced water harvesting and irrigation techniques, fertilizer management, access to technologically appropriate agricultural mechanization, emphasis on crop and livestock breeding to address multiple biotic and abiotic stresses, livelihood diversification and crop substitution to enhance food security and livelihood. Higher costs of food production due to climate change impacts within the basin will have a major adverse impact on food security in these countries. Climate change is a threat multiplier requiring greater investment to reach the aspirations of the Sustainable Development Goals.

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