Ghana J. Sci. **58** (2018), 23-33

IMPACTS OF CLIMATE CHANGE ON STREAM INFLOWS INTO THE VOLTA LAKE

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Abstract

The study examined the impact of climate change on future water availability in the Volta Lake from climate downscaled data using ensemble projections of two Global Climate Models (MPEH5 and HADCM3) and two emission scenarios (A1B and A2) used in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. The SWAT hydrological model was calibrated and validated and then used with the downscaled climate change data to assess the impacts of climate change on the inflows to the Lake. Results from the impact assessment showed that future mean annual streamflow into the Volta Lake could increase by about 17 and 16 percent under the A1B and A2 scenarios, respectively. However, streamflow from Geoere, Boromo and Dapola in the Black Volta basin and Nawuni in the White Volta basin could decrease. The projected increase in total annual streamflow in the basin is consistent with the increase in annual rainfall in the basin under both the A1b and A2 scenarios of between 2.0 and 8.0 percent obtained in a separate climate downscaling study. Since streamflow in some of the sub - basins were found to decrease under the climate change scenarios investigated, integrated and prudent management of the basin's water resources would be necessary to ensure sustainability in water use.

Introduction

Climate change (CC) is projected to adversely impact an already fragile food, energy and water security of most African countries. Many CC impact studies in Africa indicate that the phenomenon will impact adversely on the water resources of African countries, and put their water supply and management systems under severe stress (Obuobie *et al.,* 2012; Chinowsky *et. al*., 2011).

Several studies have been undertaken in the Volta basin to ascertain the impact of CC on the water resources of the basin. A CSIR - WRI (2000) study on CC and water resources reports a general reduction in annual river flows in Ghana including the White Volta basin by up to 20 percent for the year 2020 and up to 40 20 percent for the year 2050. Kankam - Yeboah *et al.* (2013) used SWAT driven by downscaled climate change data from the two global climate models (GCMs), ECHAM4 and CSIRO, under the Special Report on Emissions (SRES) A1FI scenario to assess the impact of climate change on streamflows in the White Volta basin. They found decreases in streamflow in the basin of about 50 percent up to 2050. In similar climate impact studies in the Volta basin, McCartney *et al.* (2012) and Obuobie *et al.* (2012) found projected decreases in streamflows in the basin. Kasei (2009) predicted 1 ^{o}C rise in annual mean temperature, 3 – 6 percent reduction in precipitation for the period 2001 – 2050 compared to 1961 – 2000, resulting in a predicted 5 percent reduction in total discharge in the Volta basin with corresponding decreases in surface, lateral and base flows.

Kuntsmann & Jung (2005) performed high - resolution regional climate simulations using explicit dynamic downscaling of the IS92a ECHAM4 global climate scenario to determine the impact of climate change on water availability in the Volta basin. Two 10 - year time slices, 1991 – 2000 (“recent climate” time slice) and 2030 – 2039 (“future climate” time slice) were used in the simulations. The study found an overall projected increase in mean annual rainfall of 5 percent for the basin resulting in a mean annual basin runoff increase by about 18 percent.

Obuobie & Diekkrüger (2008) predicted increases in mean annual flows in the White Volta basin of up to 33 percent from an increase in rainfall of 6 percent using the SWAT hydrological model. PAGEV (2005) cited other climate change impact studies in the Volta basin in which annual inflows into the lake are predicted to increase between 13 and 34 percent in one case while mean annual runoff in the White Volta basin is predicted to decrease about 16 percent and 37 percent by 2020 and 2050, respectively, in another. Awotwi *et al*. (2015) projected increase in mean annual surface runoff of about 26 percent in response to of 8 percent and 1.7 ^{o}C increase in the mean annual precipitation and temperature, respectively in the White Volta basin. This is in agreement with the study conducted by Jung & Kunstmann (2007) and Jung (2006), who predicted an increase in discharge over the White Volta basin.

Thus, the impact of global climate change on the water resources of the Volta basin is mixed and depends on the scenarios, the Global climate /Regional climate models (GCM/RCMs) and period of baseline (current climate) data used. Studies that used relatively wetter baseline periods (e.g. up to the 1960s and early 1970s) tended to have decreased streamflow projections while those that use relatively drier periods (e.g. second half of the 1970s to early 2000s) project increased streamflow. Therefore, in undertaking CC impacts on water resources assessments in the basin, consideration should be given to these factors in order to account appropriately for any deviations in the projection results from those of other studies.

Aim and objectives

The overarching goal of the study was to determine the impacts of CC on the inflows to the Volta Lake.

The specific objectives were to:

i. Calibrate, validate and setup an appropriate hydrological model for the Volta basin that can be used for CC impact assessments in the basin.
ii. Assess the impact of climate change on stream inflow into the Volta Lake through hydrological modeling.

Experimental

Study area

The study area is the Volta basin upstream of the Akosombo dam consisting of the White and Black Volta and Oti basins. The basin is shared by six West African countries, namely Ghana, Burkina Faso, Togo, Mali, La Cote d'Ivoire and Benin. It covers a total surface area of about 400,000 km^2 and lies between latitude 5.8°N and 14.2°N and longitude 5.8°W and 2.4°E with elevation ranging from - 23 m to 941 m above mean sea level. The climate inputs study (Obuobie *et al.* 2015) that produced the downscaled climate change input data divided the Volta basin into three climatic zones - Guinean, Sudannian and Sudano - Sahelian zones with 17 synoptic weather stations (Fig. 1). The major land uses in the catchment include savanna, cropland/woodland mosaic, grassland, pasture, urban residential and water. Mean annual rainfall in the basin is in the range 600 – 1600 mm (UNEP - GEF Volta Project, 2013).

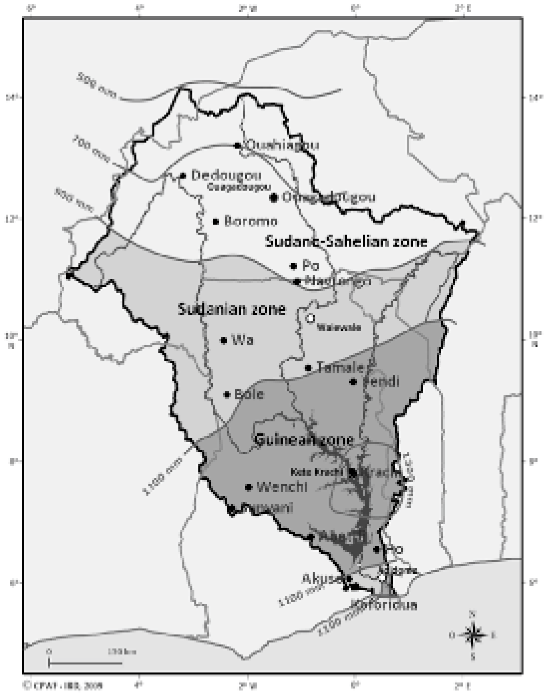


*Fig. 1. Map of the Volta basin showing the three climate zones and location of 17 synoptic stations (Black dots, red letters; Source: Obuobie et al. 2015)***.**

SWAT modelling tool

The Soil and Water Assessment Tool (SWAT) model is a physically based semi distributed hydrological model develo-ped by the United States Department of Agriculture for predicting the impact of land management practices such as land - use and land - cover changes, reservoir management, groundwater withdrawals and water transfers, in complex water-sheds over long periods of time (Neitsch *et al*., 2005). It is a rainfall - runoff model that continuously simu-lates flows and pollutant loads of a catchment. The model simulates at Hydrologic Response Units (HRU) level. The HRUs are lumped land areas within the sub - basin with unique combi-nation of soil type, land use and management, and are determined by the model using GIS interface. The results at the HRU level are lumped and routed to the outlet of the sub - basin. It is limited to working with a minimum time step of one day and at least two sub - basins. The SWAT model has been used extensively under different climatic conditions worldwide. In West Africa, SWAT has been used to simulate watershed hydrology and for estimating impacts of climate and land - use changes on runoff and sediment yield (Busche *et al*., 2005; Sintondji, 2005; Chekol, 2006; Schuol & Abbaspour, 2006; Zeray *et al*., 2007; Obuobie, 2008).

The hydrological component of SWAT undertakes computation of soil water balance of a river basin, represented in equation 1 (Neitsch *et al*., 2005):

$$SW_t = SW_0 + \sum_{i=1}^{t} \left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw} \right) \quad \ldots\ldots\ldots [1]$$

where, for a daily time step, SW_t is the soil water content (mm) at time t (days), SW_0 is the initial soil water content on day I (mm), R_{day} is the amount of precipitation on day i (mm), Q_{surf} is the amount of surface runoff on day i (mm), E_a is the amount of evapotranspiration on day i (mm), W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm), and Q_{gw} is the amount of return flow on day i (mm).

SWAT set - up

The following protocol was followed in the modeling process:

i. Calibrating and validating SWAT model for the Volta Basin for river flow under current climate (1981 - 2010);
ii. Driving the calibrated SWAT model with downscaled rainfall and temperature data (A1B & A2 - ensemble mean of MPEH5 and HADCM3) to obtain river flow under future climate (2011 - 2050);
iii. Computing the difference between the outputs of (ii) and (i) to obtain the impact of climate change on the two hydrological fluxes.

The SWAT model was set up for the entire Volta basin using an ArcView extension, AVSWATX, with a graphical user interface following the procedure outlined in the SWAT user manual (Di Luzio *et al*. 2002). The basin was delineated automatically in *ArcView 3.2*, using an acquired

DEM with the projection type set as Transverse Mercator and spheroid type set as WGM 84. The characteristics of the hydro - meteorological and other data used in setting up and running the SWAT simulations are summarized in Table 1.

Downscaled data on future rainfall and temperatures under the A1B and A2 SRES scenarios were used to drive the calibrated model. Monthly historical streamflows available for some gauging stations in the Volta basin were used for the calibration and verification of the model and also as the baseline for the impact assessments. Available flow data for the periods 1961 – 1990 and 2001 – 2010 from gauging stations on the Oti, White and Black Volta Rivers, as well as from their tributaries were acquired for the modelling activities.

The Volta basin was delineated into sub - basins that will contribute to streamflow at specified flow stations. This was achieved by importing 23 streamflow locations uniformly distributed in the basin. The sub - basin delineation was followed by automatic parameterization of streams and sub - division of the sub - basins into hydrological response units (HRUs), the basic modeling unit accepted by the SWAT model. The HRUs were based on soil and land use data and a predefined threshold for soil and land use within the sub - basins.

TABLE 1

Hydro - meteorological and other data used in setting up and running the SWAT simulations

No.	*Data type*	*Description*	*Source*
1.	DEM	The digital elevation model (DEM) used was the 1 - km resolution Shuttle Radar Topography Mission (SRTM) DEM	(USGS, 2006)
2.	Soil map and data /properties	Soil type and distribution for the Volta basin was obtained at 10 km resolution with some soil properties for two layers (0 - 30 cm and 30 - 100 cm) (Schuol et al. 2008)	Modified FAO digital map of the world (FAO, 1995), CSIR Soil Research Institute (Ghana)
3.	Land use/land cover map and data	Land use type and distribution for the Volta basin with 250 m resolution was used for the project	Modified FAO map from the Hydrology group of EWAG in Sweden
4.	Climate data for baseline period (1981 - 2010)	(i) Daily minimum and maximum temperature (°C) (ii) Daily rainfall (mm) (iii) Daily mean relative humidity (%) (iv) Daily mean wind speed (m/s) (v) Number of sunshine hours per day	GMET (Ghana), Met Office of Burkina Faso, Past and ongoing climate related projects
5.	Modeled data for the current and future climates:	Minimum and maximum daily Temperature (°C) and rainfall (mm) for A1B & A2 - ensemble mean of MPEH5 and HADCM3	Obuobie et al. (2015)
6.	Streamflow data	Daily Streamflow data (??^{3}?? ^{1}) at Wiase, Pwalugu, Nawuni, Bui and Sabari used to calibrate and validate streamflows from the Volta basin.	Hydrological Services Department of the Ministry of Water Resources Works and Housing of Ghana

The sensitivity of SWAT - simulated stream flow to SWAT input parameters were assessed using the automatic sensitivity analysis tool provided in the model. The purpose of this analysis was to determine the model input parameters that influenced the model output the most and should be focused on in the calibration process.

Model calibration and validation

The SWAT model was calibrated and validated separately for the black Volta basin at Bui, Oti River basin at Sabari and the White Volta basin at Wiase, Pwalugu and Nawuni. These stations were selected for model calibration and validation because of the relatively better quality of the data available for the stations. However, the inadequacies (many gaps) in the daily flow data records available could only allow for calibration and validation at monthly time step. For similar reasons, calibration and validation could only be done for different periods for the different stations.

The calibration periods for the model at the five gauging stations are presented in Table 2. The areas drained by these basins are also presented in the table. The model was calibrated using the manual calibration method, which employs the trial and error approach with the help of guidelines provided by Santhi *et al*. (2001). The calibrated model was finally validated by using it to predict the monthly streamflow for the period other than the calibrated period without any further changes in model input parameters. The validation periods for the model at the five gauging stations are also presented in Table 2.

TABLE 2

Model calibration and validation periods

Item	*Basin*	*Station*	*Drainage area (km²)*	*Calibration period*	*Validation period*
1.	Black Volta	Bui	130,700	Nov 1991 – Apr 1996	Jan 1997 – May 2001
2.	Oti River	Sabari	60,250	Jan 1989 – Jul 1992	Jan 2004 – Jun 2006
		Wiase	12,600	Jun 1990 – Dec 1992	Mar 2003 – May 2006
3.	White Volta	Pwalugu	57,530	Jun 2002 – Dec 2004	Jan 2005 – May 2006
		Nawuni	96,230	Nov 1986 – Jul 1993	Jan 2000 – Aug 2006

The performance of the model at calibration and validation was evaluated using both graphical and quantitative statistics. The quantitative evaluation involved the computation and use of the coefficient of determination (R^2), Nash - Sutcliffe Efficiency (NSE) and percent bias (PBIAS). These were computed as in equations 2, 3, and 4, respectively.

$$R^2 = \left\{ \frac{\sum_{i=1}^{N} \left(O_i - \bar{O}\right)\left(P_i - \bar{P}\right)}{\left[\sum_{i=1}^{N} \left(O_i - \bar{O}\right)^2\right]^{0.5} \left[\sum_{i=1}^{N} \left(P_i - \bar{P}\right)^2\right]^{0.5}} \right\}^2 \quad \text{.......... [2]}$$

$$NSE = 1 - \frac{\sum_{i=1}^{N} (O_i - P_i)^2}{\sum_{i=1}^{N} \left(O_i - \bar{O}\right)^2} \quad \text{.......... [3]}$$

$$PBIAS = 1 - \frac{\sum_{i=1}^{N} (O_i - P_i)}{\sum_{i=1}^{N} (O_i)} \quad \text{.......... [4]}$$

The NSE and R^2 indices range from 0 to1. The closer the NSE value is to 1, the better the model will be in representing the input - output processes of the system. A model performance was deemed acceptable when $R^2 > 0.60$, NSE > 0.50, and PBIAS was within ±25% (Moriasi *et al*., 2007).

Climate change impact assessment on the Volta streamflows

The impact of climate change on streamflow in the Volta basin was assessed by driving the calibrated SWAT model with downscaled future (2011–2050) climate outputs for A1B and A2 scenarios and comparing the results with the observed for the baseline period (1981–2010). Based on the simulation results, the level of climate change impacts on streamflows were determined.

Results and discussions

Volta basin delineated into sub - catchments

Fig. 2 shows the 23 delineated sub - catchments of the Volta basin. Catchments 22 (lake catchment) and 23 (the Lower Volta) were not considered in the analysis of inflows to the lake.

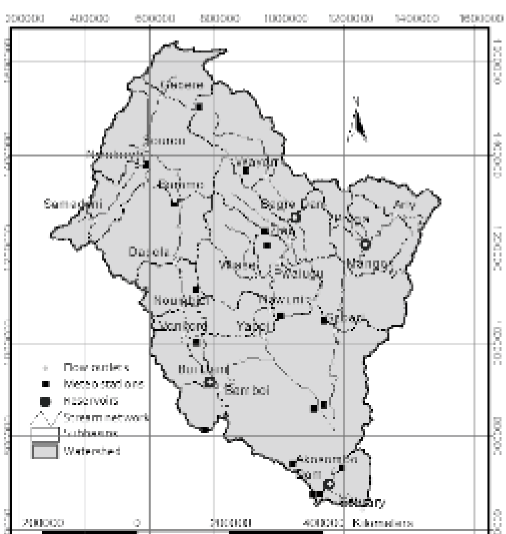
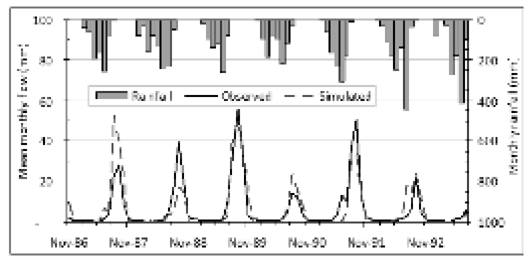


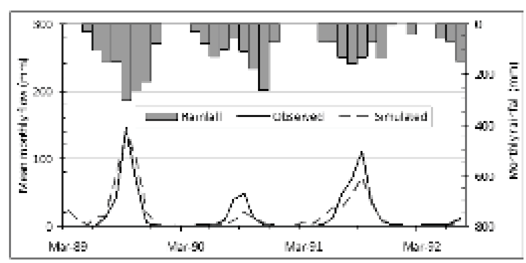
Fig. 2. Volta basin watershed delineated into sub - catchments

Model calibration

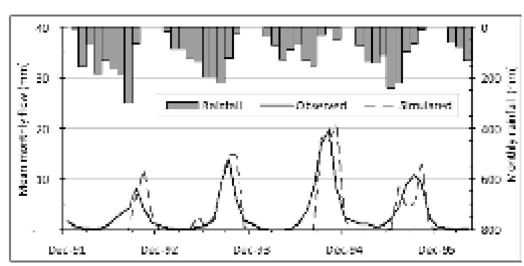
Fig. 3 shows the graphical comparison between observed and simulated streamflow hydrographs at monthly time steps after calibration. There is good correlation between the observed and simulated stream-flows at Nawuni, Sabari and Bui on the White Volta, Oti and Black Volta rivers, respectively, after calibration. The response of the model was consistent with the precipitation during these periods.



a: White Volta basin at Nawuni



b: Oti River basin at Sabari



c: Black Volta basin at Bui

Fig. 3. Rainfall hyetographs and corresponding observed and SWAT simulated hydrographs for the calibration period.

Evaluation of the average monthly streamflow between observed and simulated at calibration revealed that SWAT overestimated the streamflow by about 3.1 percent at Nawuni, and underestimated streamflows at Wiase, Pwalugu, Sabari and Bui (Table 3).

TABLE 3

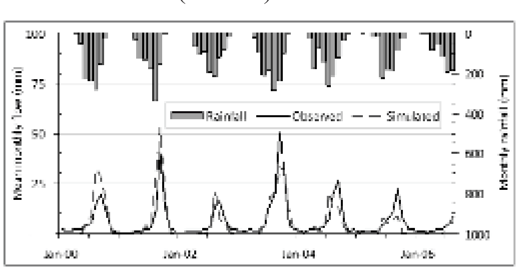
Monthly observed and SWAT simulated results after calibration

Station	Mean Flow (mm)		Difference in flow		R^2	NSE	PBIAS
	Obseved	Simulated	mm	%	-	-	-
Wiase	4.50	4.21	- 0.29	- 6.4	0.83	0.82	- 16.02%
Pwalugu	5.15	4.68	- 0.47	- 9.2	0.95	0.78	9.18%
Nawuni	6.48	6.68	0.20	3.1	0.72	0.68	- 3.08%
Sabari	16.45	16.38	- 0.07	- 0.4	0.80	0.80	0.40%
Bui	3.13	2.94	- 0.19	- 6.1	0.68	0.50	6.06%

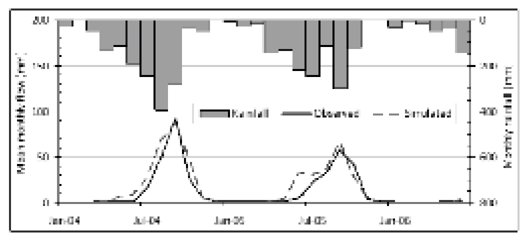
These notwithstanding, the results showed that the performance or prediction capacity of the calibrated model for the Volta basin was good with an estimated NSE value ranging from 0.50 (at Bui) to 0.82 (at Wiase). The R^2 values are also high and all values of PBIAS are within acceptable range.

Model validation

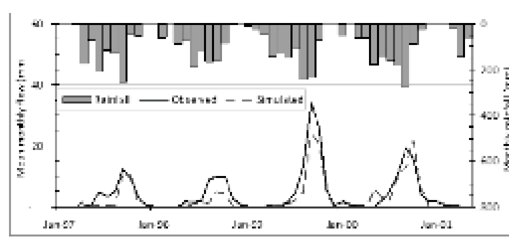
Fig. 4 shows good match between the observed and simulated streamflow in response to precipitation in the Volta basin for the validation period. However, there were slight mismatches between simulated and observed series peak flows. Evaluation of the average monthly streamflow between observed and simulated at validation revealed that SWAT overestimated the streamflow by about 22 percent at Sabari, and underestimated streamflows at Wiase, Pwalugu, Nawuni and Bui (Table 4).



a: White Volta basin at Nawuni



b: Oti Basin at Sabari



c: Black Volta basin at Bui

Fig. 4. Rainfall hyetographs and corresponding Observed and SWAT simulated hydrographs for the Validation period.

Statistical analysis of the calibrated SWAT model results indicate that the monthly streamflows were well simulated for most of the calibration and validation periods, with NSE > 0.50, $R^2 \geq 0.50$, and PBIAS well within the acceptable range of ± 25 (Table 4). Both graphical observation and statistical analysis show good performance of the SWAT model. Thus, the calibrated SWAT model was found to be adequate for streamflow prediction in the Volta basin and could, therefore, be used for climate impact studies of the basin.

TABLE 4

Monthly observed and SWAT simulated results for validation period

Station	*Mean Flow (mm)*		*Difference in flow*		*R²*	*NSE*	*PBIAS*
	Obseved	*Simulated*	*mm*	*%*	-	-	-
Wiase	4.33	3.96	- 0.37	- 8.6	0.83	0.63	6.81%
Pwalugu	3.98	3.75	- 0.23	- 5.8	0.92	0.76	5.77%
Nawuni	6.14	5.52	- 0.63	- 10.2	0.74	0.66	9.07%
Sabari	12.71	15.52	2.80	22.0	0.87	0.85	22.03%
Bui	4.68	3.16	- 1.52	- 32.5	0.83	0.78	31.97%

Climate change impacts on streamflows into the Volta Lake

Outputs from the A1B and A2 scenarios showed that streamflow will decrease at Geoere and Boromo in the Black Volta and Nawuni in the White Volta basin. Streamflow is projected to increase in the remaining sub - catchments in the Volta basin (Fig. 5).

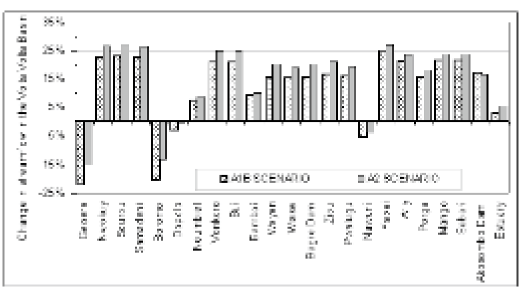


Fig. 5. Impact of climate change on mean annual streamflows in the Volta basin

Fig. 6 illustrates the changes in mean annual streamflow in the Volta basin at Bui, Nawuni and Sabari in the Black Volta, White Volta and Oti River basins, respectively. Annual streamflow in the White Volta basin at Nawuni is estimated to decrease by about 6 percent and 4 percent for A1B and A2 scenarios, respectively. Streamflow is estimated to increase in the Oti River basin at Sabari by nearly 22 percent and 24 percent for A1B and A2 scenarios, respectively. The projected streamflow in the Black Volta basin at Bui is also expected to increase by about 21 percent and 25 percent for A1B and A2 scenarios, respectively.

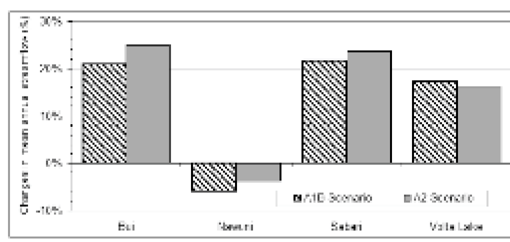


Fig. 6. Changes in mean annual streamflow in the Black Volta (Bui), White Volta (Nawuni), Oti River (Sabari) basins and into the Volta Lake.

With respect to A1B and A2 scenarios, mean annual streamflow into the Volta Lake was estimated to increase by about 17 and 16 percent, respectively (Fig. 6). However, mean monthly streamflows into the Lake are projected to decrease in July, October and November and increase for the rest of the months for both CC scenarios (Fig. 7). Thus, in the dry season, stream inflows to the Lake and water availability in the basin in general could be adversely impacted by CC.

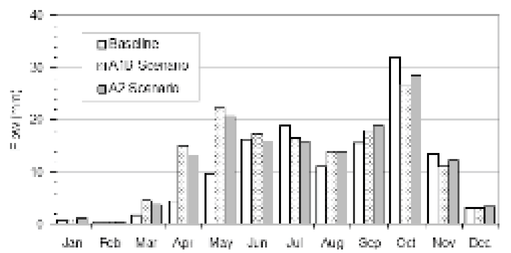


Fig. 7. Comparison between baseline and projected streamflows into the Volta Lake for the A1B and A2 scenarios.

The projected increases in streamflow into the lake are in agreement with studies such as Kuntsmann & Jung (2005), who found an overall projected increase in mean annual rainfall of 5 percent for the basin resulting in a mean annual basin runoff increase by about 18 percent. It is also in - line with results from Obuobie & Diekkrüger (2008), who predicted increases in mean annual flows in the White Volta basin of up to 33 percent from an increase in rainfall of 6 percent. However, the findings in this study are in contrast to those of CSIR - WRI (2000), McCartney *et al.* (2012), Obuobie *et al.* (2012) and Kankam - Yeboah *et al.* (2013), who all projected runoff decreases in the basin. The discrepancies in the results obtained here and those in other studies can be attributed, to a large extent, to the differences in the CC scenarios, the baseline or current climate period, the GCMs and the downscaling methods used in the various studies.

Conclusions and recommendation

The impacts of climate change on inflows into the Volta Lake have been assessed through hydrological modeling.

The SWAT model was successfully set - up, calibrated and validated for the basin and used for the CC impact assessment for 2 SRES scenarios. The annual streamflow into the Volta Lake is projected to increase under the CC scenarios investigated. However, streamflows from a few sub - basins in the Black and White Volta basins are projected to decrease due to CC. In addition, dry season flows are projected to decrease in the basin, particularly, the relatively high flow months of October and November. The discrepancy between the overall results obtained in this study and others in the literature can be attributed to the different scenario regimes and GCMs used.

What stands out from the results of this study in relation to other CC studies in the Volta basin is that there is no unanimity in the projections of the direction of change in streamflow in the basin from CC impacts. However, the increased future streamflow conditions projected in this study for the basin is well supported by Tachie - Obeng *et al.,* (2012, 2014) who noted that the improvement in the annual rainfall of the current climate in Ghana (and possibly the West African region) from the late 1990s to the 2000s may continue into the near future. Thus, the future climate in the Volta basin can be expected to be wetter than the current climate (baseline) used in this study.

The study projects decreases in future streamflow for some of the sub - basins and in the early dry season (October and November) for the entire basin. This underscores the need to put in place appropriate adaptation measures such as rainwater harvesting, water conservation and efficient water use to foster resilience to climate change and enhance water security within those sub - basins and the entire basin during the dry season. It is also recommended that future CC impact studies in the basin should consider a range of scenarios covering both dry and wet future climate conditions. This could provide a more holistic picture of future water availability in the basin for basin water resources planning and development.

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Received 3 Mar 17; revised 20 Mar 18.