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Rainfall and temperature projections and the implications on streamflow and evapotranspiration in the near future at the Tano River Basin of Ghana

Isaac Larbi[a,b,*], Clement Nyamekye[b], Sam-Quarcoo Dotse[a], Derrick K. Danso[c], Thompson Annor[d], Enoch Bessah[e], Andrew Manoba Limantol[a], Thomas Attah-Darkwa[f], Daniel Kwawuvi[g], Mawulolo Yomo[g]

[a] School of Sustainable Development, University of Environment and Sustainable Development, Somanya, Ghana
[b] Department of Civil Engineering, Faculty of Engineering, Koforidua Technical University, Koforidua, Ghana
[c] Université Grenoble Alpes, IRD, CNRS, Grenoble-INP, IGE, 38000 Grenoble, France
[d] Department of Physics, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
[e] Department of Agricultural and Biosystems Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
[f] Department of Agricultural Engineering, University of Energy and Natural Resources, Sunyani, Ghana
[g] Climate Change and Water Resources, West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL), Université d'Abomey-Calavi, Cotonou, Benin

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ABSTRACT

Climate change is projected to negatively affect water security which is already a challenge in many areas of Ghana including the Tano river basin (TRB). This study assessed the projections of rainfall and temperature and its impact on streamflow and actual evapotranspiration (ET) in the TRB of Ghana for 2021-2050 relative to the period 1986-2015. The impact assessment focused on how climate change under Representative Concentration Pathways (RCP 4.5 and RCP8.5) based on an ensemble mean of two regional climate models (RCMs) would affect streamflow and ET using the Soil and Water Assessment Tool (SWAT) model. Trend analysis and quantification for the streamflow and ET were analyzed using the Mann-Kendall's and Sen's slope estimators. The results show that the mean annual rainfall of 1401.9 mm would increase slightly by 0.5 % with a decreasing trend (1.22mm/yr) under the RCP4.5 scenario, but would decrease by 3.2% with a decreasing trend (0.3m mm/yr) under the RCP8.5 scenario. The mean annual temperature showed an increase (2.1 °C and 2.6 °C) with a statistically significant increasing trend of 0.07 and 0.09 °C/yr under RCP 4.5 and RCP8.5 respectively. An increase in ET with a non-significant increasing trend at a rate of 0.74 and 1.07 mm/year under RCP4.5 and RCP8.5 scenarios respectively is also projected. The mean annual streamflow is projected to decrease, with the decrease been more pronounced under the RCP8.5 (37.5%) scenario compared to the RCP4.5 scenario (19.9%). In general, the outcome of this study presents a useful perspective

* Corresponding author at: University of Environment and Sustainable Development, Ghana
E-mail addresses: ilarbi@uesd.edu.gh (I. Larbi), sqdotse@uesd.edu.gh (S.-Q. Dotse), amlimantol@uesd.edu.gh (A.M. Limantol).

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on the vulnerability of water resources to climate change and the need for better planning and management of the water resources in the basin.

Introduction

Change in global climate is reported to be associated mainly with significant alteration of local hydrological regimes resulting in changes in water availability and distribution [13]. A number of relevant studies have been conducted with regards to the impact of climate change on the hydrology and water resources of catchments and basins in different parts of the world [12,14]. Most of these studies have assessed current and projected climate change impacts on various components of the water balance including streamflow, surface run-off, evapotranspiration, groundwater recharge [2,4,11,14,34].

For example, Gosain et al. [11] reported that freshwater availability is likely to decrease significantly in many river basins in India by the year 2050. The study attributed the decrease in the freshwater to climate change, an increase in population, food, water and energy demand by different sectors. Mango et al. [23] on the other hand investigated the response of the hydrology of the Mara River basin to the impact of land use and climate change using the SWAT model. The simulated runoff response to climate change scenarios indicated that the basin is highly vulnerable under low (−3%) and high (+25%) extremes of the projected precipitation changes. The assessment of the impacts of climate change on runoff by Jin et al. [14] revealed a moderate increase in the runoff component with high variability in the future. Hasan et al. [12] discussed the runoff sensitivity to climate change in the Nile River basin. Their results show that a 10% decrease in precipitation leads to a decrease in runoff ranging between 19% in the tropical zone and 30% in the arid zones, while a 10% increase in precipitation leads to an increase in runoff estimated to be 14% in the tropical zone and 22% in the arid zone.

In the case for West Africa, different researches related to climate change impacts on water resources have highlighted a decreasing trend of river flows ranging between 40% and 60% as a result of a decrease in rainfall going from 20% to 30% [7]. In Ghana, several studies on climate change impacts on water resources have been conducted (e.g. [2,4,16,30,34]). Obuobie [30] noticed that the White Volta Basin groundwater resource is being threatened by climate change with a reduction in the amount of groundwater recharge from rainfall. Kankam-Yeboah et al. [16] carried out an impact study of climate change on streamflow in the White Volta and Pra river basins for the 2020s (2006–2035) and 2050s (2036–2075) and revealed an expected decrease in streamflow (22 %–50 %) for the two basins. Similarly, Awotwi et al. [4] used an ensemble of the REMO regional climate model data as input to the SWAT model to predict the hydrological response of the White Volta catchment to climate change and observed an increase in future precipitation and temperature of 8% and 1.7%, respectively, for the period 2030-2043 associated with an increment of 26%, 24% and 6% in the annual surface runoff, annual baseflow, and evapotranspiration, respectively. Larbi et al. [18] projected for the period 2020-2049 a decrease in the surface runoff and water yield under climate change, estimated at 42.7% and 38.7%, respectively in the Vea catchment.

In a similar study, Amisigo et al. [2] estimated future annual runoff in the Pra River Basin and reported a plausible change by - 25.9 % and +60.9 % under the Ghana dry (IPSL_CM4 B1) and wet (NCAR_PCM1 A1b) scenario respectively over the 2011–2050 period in reference to the period 1950–2000. Oti [34] projected a decrease in streamflow in the Densu River basin for the period 2051-2080 as a result of climate change and variability. According to Bodian et al. [8], the severity and magnitude of the resulting impacts of climate change are geographically and contextually based. The application of innovative research methodological approach is critical for estimating the actual severity and magnitude of such impacts at the local scale. The above information justifies the need for local assessment of the hydrological response to climate change using unconventional approach.

The Tano river basin is reported to be one of the three basins sourcing almost half (6.33 million m^3/year as of 2010) of the water used in Ghana and contributes highly (4.9 million m^3 water up-take per year) to agriculture and food security through the Techiman/Tanoso (Techiman district) and the Akumadan (Offinso-North district) irrigation projects with more than 10,000 smallholder irrigation practitioners [40], whose livelihood depends on agricultural production. In addition, the basin is reported to be subject to series of flooding [40]. Nevertheless, there is still limited information in terms of future climate conditions and their projected impacts on the water balance components, especially the streamflow in the basin. To contribute to the efforts of reducing inadequate adaptation to climate change and variability in the basin resulting from the lack of awareness about the impacts of climate change and variability [40], this study aims to assess the future changes in rainfall and temperature and their associated impact on streamflow and evapotranspiration for the period 2021-2050 in the Tano River basin of Ghana. Disparately, the present study employs advanced methodological approach of accounting for the limited spatial distribution of climate stations and data gaps in most of the river basins in West Africa sub-region with gridded time series of climate data from satellite-based climate products. The approach is unconventional and explores a combined assessment of climate change impact on streamflow and evapotranspiration. Our study considered two different

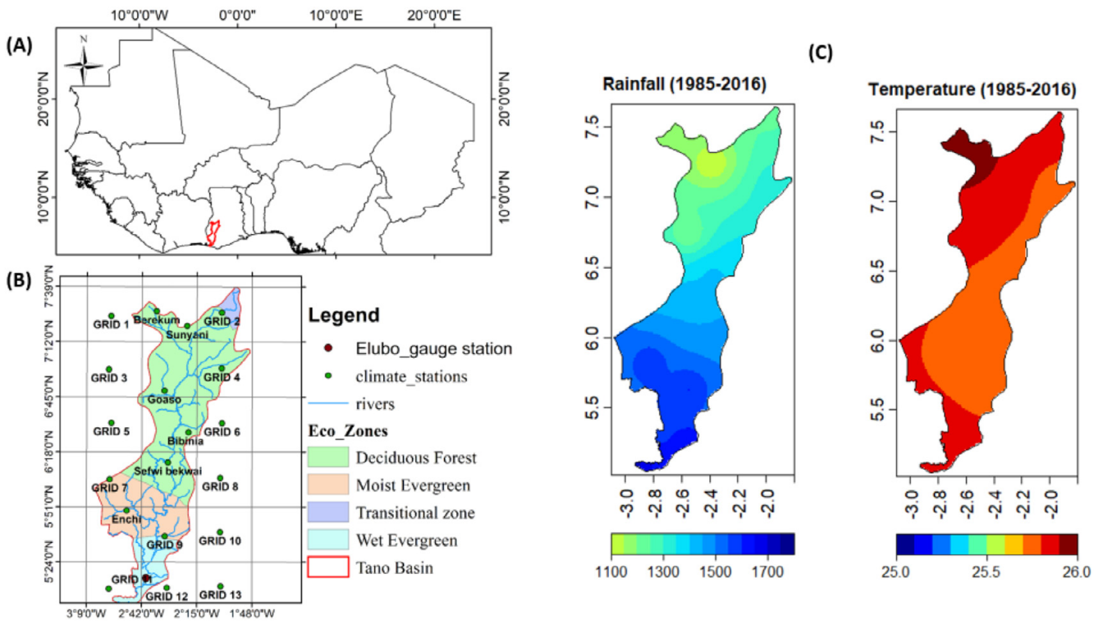

Figure 1. (A) Map of West Africa showing Ghana and the Tano basin, (B) locations of different agro-ecological zones and climate (stations and gridded points) within 50 km RCM grid, and (C) the spatial distribution of mean annual rainfall and temperature at the basin for the period 1985-2016 using station and satellite (CHIRPS and NASA POWER) data.

climate conditions (i.e. wet climate and dry climate) for the near future and how it will affect the hydrology of the Tano basin. This is the first of its kind in the study area. The following questions were investigated:

- What will be the rainfall and temperature situation in the Tano basin for the period 2021-2050 relative to the historical period (1986-2015) under RCPs 4.5 and 8.5 scenarios?
- Will streamflow and evapotranspiration increase or decrease as a result of the projected changes in the two climate variables for the period 2021-2050?

The paper follows the following structure: Section two shows the description of the study area and data used. Climate analysis and the hydrological modeling are presented in section three. The fourth section highlights the results obtained followed by the discussion which is presented in section five. The study conclusion is provided in the last section by summarizing the main points of this research.

Material and Methods

Study area

The Tano Basin, with an area of 14,852 km^2, is one of the principal south-western river basins systems in Ghana located between latitudes 4^o 30' N - 7^0 40' N and longitudes 1^o 48' W- 3^o 09' W (Figure 1). The Tano River with a length of about 400 km takes its source from the highlands at Tuobodom near Techiman in the Brong-Ahafo Region at an altitude of 518 meters above sea level [40]. The climate of the basin is controlled by the movement and interactions of the Inter-Tropical Discontinuity (ITD) and the associated West African Monsoon [40]. Located within four agro-ecological zones, the basin is characterized by a bi-modal rainfall regime from April to July (major season) and September to November (minor season). The spatial distribution of annual rainfall accumulation for the period 1985-2016 ranges from 1100 mm (north) to 1800 mm (south), with a mean value of about 1390 mm. On average, 59% of the annual rainfall falls during the major rainy season and 36% during the minor rainy season. The basin is warm and moist with relative humidity between 75%-85% throughout the year and a mean annual temperature of about 25.9°C [40]. The topography of the basin is characterized by relatively flat land in the southern half, resulting in few peaks in the mid to northern sections of the basin. The basin is mainly dominated by forests (76.9%) which are largely protected areas, followed by agriculture (15.2%), with grassland and settlements covering the rest of the area [37]. The basin has an estimated population of about 2.4 million with a population growth rate of 2.2%/year [40] which depends on the basin for their water supply. The Tano River and its tributaries provide all-year-round reliable water source which is mainly used for domestic, agriculture (irrigation) and mining/ industrial activities.

Data

Climate observation and scenarios data

Observed daily rainfall, maximum and minimum temperature data for six climate stations covering the period from 1986 to 2015 were obtained from the Ghana Meteorological Agency. To account for the limited spatial distribution of climate stations within the basins and data gaps, additional gridded daily rainfall and temperature data were extracted from satellite-based climate products. The gridded rainfall data covering the same period was obtained from Climate Hazards Group Infrared Precipitation with Station data (CHIRPS) and the temperature data from the National Aeronautics and Space Administration Prediction of Worldwide Energy Resource (NASA POWER) project. CHIRPS incorporates satellite imagery with in-situ station data to create gridded rainfall time series [10]. The temperature data from the NASA POWER project are derived from Modern Era Retrospective-Analysis for Research and Applications (MERRA-2) assimilation model products and GEOS 5.12.4 near-real-time products [39]. These two satellite products have been selected based on their ability to accurately reproduce the climatology in the Vea catchment within Ghana [19]. Data quality control in terms of missing data checks for the six climate stations were performed. Less than 10% missing data records for rainfall and temperature were found for each of the six climate stations. The missing values were filled with the CHIRPS rainfall and NASA POWER temperature data extracted for the six climate stations.

The climate change scenario datasets were obtained from the Coordinated Regional Climate Downscaling Experiment (CORDEX-Africa; [28]). The 50 km resolution CORDEX-Africa RCMs are from Rossby Centre Regional Climate Model (RCA4) and are driven by two different GCMs (CCCma-CanESM2 and NCC-NorESM1-M) which are included in the Coupled Models Inter-comparison Project Phase 5 (CMIP5) [31]. The two CORDEX-Africa RCMs (CanESM2-RCA4 and NorESM1-RCA4) were selected due to their remarkable skills in reproducing the climatology of the Volta basin for the period 1971-2005 [31] which is adjacent to the Tano basin. According to the study of Okafor et al. [31], both simulations with RCMs are able to capture the mean annual surface temperature and rainfall distribution quite well, with bias/ percentage bias (PBIAS) in the range of 0.01 to 0.07°C for temperature, and 9 to 13% for rainfall. As a result, bias correction was not performed for the rainfall and temperature projections. The RCMs datasets used in this study covered the future period (2021-2050) for two representative concentration (RCP 4.5 and RCP8.5) scenarios. The RCP4.5 and RCP8.5 are mid-range and high-end emission scenarios which radiative forcing values in the year 2100 relative to the pre-industrial values are +4.5 and +8.5 W/m^2 respectively [35].

Spatial and Discharge data

Daily discharge data for the period 1999-2014 at the Elubo River gauge station were obtained from the Ghana Hydrological Service Department for the model calibration and validation. Digital elevation model (DEM) for the Tano basin (Figure SM1) at 30 m spatial resolution was obtained from the Shuttle Radar Topographical Mission (STRM). This was used for the basin and stream networks delineation, and slope definition. Soil map at 10 km spatial resolution from Harmonized World Soil Database (HWSD) provided by the Food and Agriculture Organization of the United Nations [9], together with soil texture and physical properties for the different soil types at the basin were also used. The dominant soil type (Table SM1) found at the basin is Orthic Acrisols (63.2%), followed by Eutric Nitosols (20.1%), Xanthic Ferralsols (10.7%), with the other soil types (Ferric Luvisols and Ferralic Arenosols) together occupying about 4.6%. Soil properties used for the modeling include bulk density, hydrological group, available water content, hydraulic conductivity, and organic matter content which were collected for two layers (30 cm and 100 cm). These soil properties were obtained from field surveys and attribute data in HWSD. The soil attribute data in HWSD meet most requirements for SWAT model parameterization and has been used in many studies (e.g. [25]). The land use/land cover (LULC) map (Figure SM1) for the basin for the year 2016 was obtained from an already classified land use map for Africa which is produced from a 2 m Sentinel 2A image [37]. The map legend was based on the eight classes, namely Tree cover (forest areas with tree cover larger than 10%), shrubs cover, grassland (areas dominated by grass), cropland, aquatic vegetation, bare area, built-up area, and water (water bodies and reservoirs). The land cover predominantly consists of tree cover (76.8), cropland (15.7), grassland (4.6%), and shrubs cover (1.7%). The various data types used and its characteristics are presented in Table SM2.

Hydrological modeling with the SWAT model

Model description and setup

The SWAT model is a physically-based semi-distributed hydrological model used to simulate the quantity and quality of surface water and groundwater in different local to regional scales of watersheds from short to long periods, and predict the environmental impact of climate change and land management practices [1]. The main components of the water balance simulated by the SWAT model include the surface runoff, actual evapotranspiration, lateral flow, percolation, and groundwater flow. The streamflow component, considered in this study consists of the contributions from surface runoff, lateral flow, and groundwater flow. The Soil Conservation Service (SCS) curve number equation [38] was used to compute the surface runoff in SWAT and the Hargreaves method for Potential evapotranspiration.

The SWAT model on the Interface of ArcS [40] was used to simulate the streamflow by first dividing the Tano basin into 193 sub-basins using the DEM. The land slope obtained from the DEM was categorized into 0-5%, 5-10%, 10-15%, and above 15%. Each sub-basin was then divided into homogenous units called Hydrologic Response Units (HRUs) using the 2016 land use map, soil and slope characteristics [27]. The multiple HRUs definition option was used to define 498 HRUs using thresholds for land use/soil/slope of 5/5/5% respectively. The model was run for the period of 1986-2015, and the first three years (1986-1988) were used as model spin-up period. For a detailed description of how the SWAT model simulates the water balance components and the model setup, readers may refer to SWAT documentation by Neitsch et al., [27], and the SWAT user guide by Winchell et al. [41].

SWAT model calibration and evaluation

The model calibration and validation were performed using daily discharge data for the period 1999-2006 and 2007-2014 respectively at the Elubo River gauge station. Both manual and semi-automatic calibration which have been used by several researchers [16,20] were used in this study. The manual calibration was first performed for some parameters known to influence surface runoff, evapotranspiration, and streamflow [20]. The manual calibration was based on previous knowledge of the area and expert's opinion by changing one parameter at a time and re-running the model. Afterward, the semi-automatic calibration was performed using the SUFI-2 algorithm of the SWAT-CUP (calibration and uncertainty program) to fine-tune the parameters [1]. In all, 9 parameters were selected for the model calibration.

The performance of the calibrated SWAT model was evaluated using model percentage bias (PBIAS), Nash-Sutcliffe model efficiency (NSE), and coefficient of determination (R^2). The model output was deemed fit according to Moriasi et al., [24] if the above-mentioned criteria have NSE $>$ 0.50, $R^2 > 0.60$, and PBIAS is within $\pm$25% for streamflow.

Climate and streamflow simulation analysis

Climate variability and change analysis

Climate analysis for the historical observation (1986-2015) and future period (2021-2050) for RCP4.5 and RCP8.5 scenarios were performed at both monthly and annual scales. The historical observation period was used as a reference or base period to determine and analyze the projected future changes over the basin. Firstly, the annual cycle of the mean monthly rainfall and temperature of the historical observation were compared with the different RCMs under both emission scenarios [7]. In both cases, the ensemble mean of the two RCMs are also determined. To determine the inter-annual variability, the 10^{th} and 90^{th} inter-percentile ranges of rainfall and temperature were also determined for both the historical observation and the projected climate. Secondly, the projected relative changes in the mean annual rainfall and temperature were estimated over the entire basin at Spatio-temporal scale by determining the difference between the mean annual value of the historical and future period for each RCM and their ensemble under the different scenarios. The significance of the projected rainfall and temperature change was assessed at a 95% confidence level using the t-test. Additionally, the degree of uncertainties in the projected changes in rainfall and temperature at the basin was presented in the form of a boxplot and discussed in terms of the interquartile range (i.e. the difference between the 75th and 25th percentiles). The wider the box, the higher the interquartile range, indicating a higher degree of uncertainty, and vice-versa [5].

Streamflow and evapotranspiration simulations under climate change

Rainfall and temperature produced by GCMs often contain considerable uncertainty due to the differences in GCMs structure, parameterization, and fluxes of heat adjustment [22]. It is therefore recommended that for climate change impact studies, an ensemble mean RCMs is used to reduce projection uncertainty [25]. In order to reduce the uncertainty in streamflow and evapotranspiration projections from the two RCMs (CanESM-RCA4 and NorESM-RCA4) which are forced by two different GCMs, the ensemble mean was used as input to the calibrated SWAT model. Two scenarios run relative to the historical (1986-2015) period were performed. The land use under climate change is assumed similar to that in the historical period to assess the impact of climate change on river flows in the study area [25]. Changes in annual streamflow and evapotranspiration over the Tano basin were analyzed to understand the Spatio-temporal distribution of the changes under projected near future (2021-2050) climates. The difference in the simulated streamflow under climate change was calculated by pixel subtraction of historical generated values from the future simulation output. Similarly, the impact of climate change on actual evapotranspiration was also assessed as a deviation of future values with respect to baseline, using a similar approach as used for streamflow.

Hydrological trend analysis and quantification

Trend detections and quantification for the streamflow and ET were analyzed using the non-parametric Mann-Kendall (MK) test and Theil-Sen's slope estimator respectively [42]. The MK test has been utilized in several studies (e.g. [19,29,32]), and proven to be suitable for non-normally distributed hydro-meteorological data. The MK test assumes a null hypothesis (Ho) that there is no trend which is tested against the alternative hypothesis (H1) of the presence of a trend [33]. Positive and negative values of the MK test indicate upward and downward trends respectively. A corresponding threshold (Z) value of $\pm$ 1.96 at a 95% confidence level was adopted.

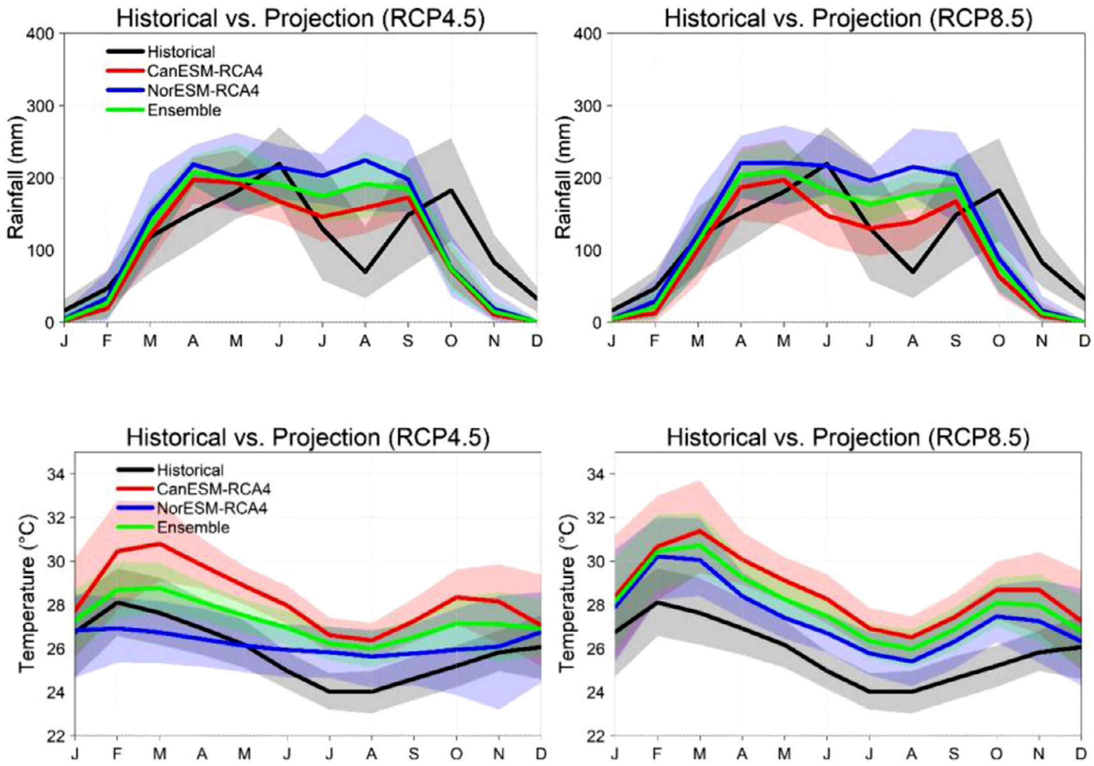

Figure 2. Annual cycle of mean monthly rainfall amount and temperature for the historical period (1986-2015) and near future (2021-2050) projections under RCP4.5 and RCP8.5 scenarios

Results

Rainfall and temperature projections under RCP 4.5 and RCP8.5 scenarios

Mean monthly projections

The mean annual cycle of monthly rainfall amounts and temperature averaged over the entire basin for the historical observation and future projections under RCP4.5 and RCP8.5 scenarios are presented in Figure 2. The cycle of the historical observations showed two distinct peaks of rainfall in June and October with a sharp decrease in August. In future projections, this bimodal rainfall pattern is not as distinct as the historical period. This is true regardless of the model or emission scenario used. Again, in both emission scenarios and for all projections, the first peek of the annual rainfall appears to occur in April, two months earlier than the historical period. In all emission scenarios, the projections showed that rainfall amounts will be significantly lower from September to December than the historical period. Moreover, the highest inter-annual variability shown in Figure 2 as the upper and lower bounds of the shaded region indicating the 90th and 10th inter-percentile range, was highest from April to October (i.e. for all projections under RCP4.5), and from April to November for RCP8.5 projections. This is similar to the historical period and shows a larger uncertainty in rainfall amounts received during these months from one year to the other.

In the case of temperature, it can be deduced from Figure 2 that the projected future mean temperature is higher in all months for the two models under both emission scenarios (except for NorESM which shows a decrease from January to May under RCP4.5). The CanESM projection presents the highest mean temperature over the basin for both emission scenarios. Moreover, the temperature projections under RCP8.5 are slightly higher than RCP4.5. Nevertheless, for all model projections, the annual cycle of temperature does not change relative to the historical period irrespective of the emission scenario considered (except for NorESM under RCP4.5).

Mean annual projections

Shown in Table SM3 is the average annual rainfall for the two future RCMs and its ensemble mean under RCP 4.5 and RCP 8.5 scenarios. The mean annual rainfall of 1394.5 mm for the observation period is projected to decrease by 9.5% and 17.1% for RCP4.5 and RCP8.5 scenarios, respectively under the dry RCM (CanESM-RCA4) rainfall scenario. Under wet RCM (NorESM-RCA4) rainfall scenario, rainfall could increase by 10.6% and 10.1% for RCP4.5 and RCP8.5 scenarios, respectively. The ensemble mean projected an increase of 0.5 % under RCP4.5 but a decrease of 3.2 % under the RCP 8.5 scenario. The

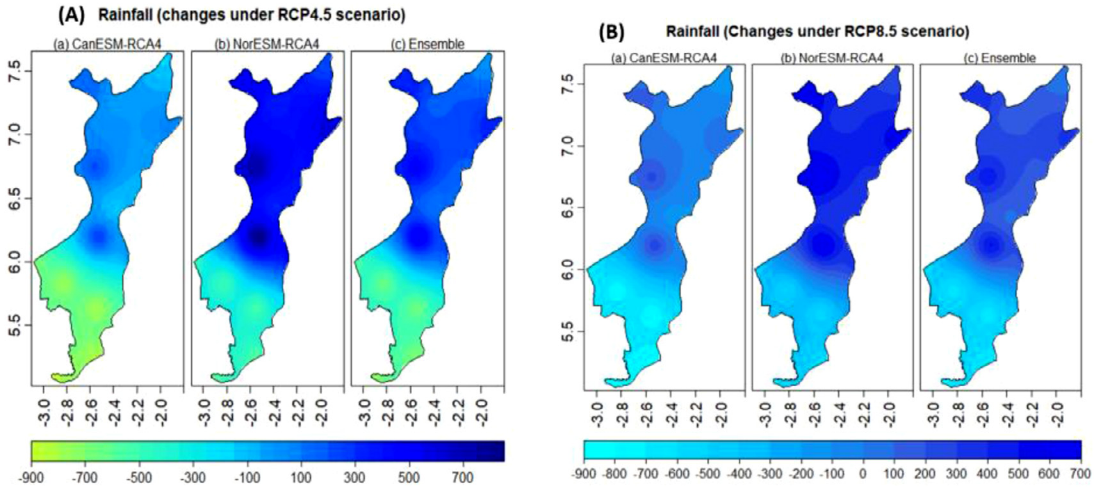

Figure 3. Spatial distribution of projected changes in mean annual rainfall (mm) for the 2021-2050 period under (a) RCP4.5 and (b) RCP8.5 scenarios relative to the baseline (1986-2015) period

increase in rainfall when subjected to a t-test was found to be significant at a 5% significance level for the individual RCMs, but not significant for the Ensemble mean. Presented in Figure SM2 are the boxplots showing the degree of uncertainty in the projected changes in the mean annual rainfall by the individual models and their Ensemble mean. CanESM-RCA4, NorESM-RCA4, and Ensemble mean had an interquartile range of -8% to -12%, 8% to 12%, and -2 to 2% respectively for RCP4.5. Similarly, the interquartile range under RCP8.5 scenario were -8% to -22% (CanESM-RCA4), 8% to 12% (NorESM-RCA4) and -2 to 2% (Ensemble mean). The small interquartile ranges under both RCPs at the basin, suggest better confidence in the future rainfall projection.

In the case of temperature, as shown in Table SM4, the mean annual temperature of 25.9 °C for the observed period is projected to increase for both RCPs. The increase in temperature was higher under RCP8.5 (2.7 °C) compared to the RCP4.5 scenario (2.4 °C) for the CanESM-RCA4. Similar situation was also projected for NorESM-RCA4. The Ensemble mean showed a temperature increase of 2.2 °C under RCP4.5 and +2.6 °C under the RCP 8.5 scenario. The temperature increase, when subjected to a t-test, was found to be significant at a 5% significance level for both the individual RCMs and their Ensemble mean.

Presented in Figure SM3 are the boxplots showing the degree of uncertainty in the projected changes in the mean annual temperature by the individual models and their Ensemble mean. Under RCP4.5, CanESM-RCA4 and NorESM-RCA4 had an interquartile range of 2.2 to 2.7 °C and 1.8 to 2.3 °C respectively. In the case of the RCP8.5 scenario, an interquartile range of 2.4 to 3.1 °C and 2.3 to 2.7 °C was obtained for CanESM-RCA4 and NorESM-RCA4 respectively. The Ensemble mean when compared to the individual models indicates an interquartile range of 2.1 to 2.4 °C and 2.0 to 2.3 °C under both RCPs, suggesting better confidence in the future temperature projection.

Spatial distribution of rainfall and temperature

Figure 3 shows the spatial distribution of the projected changes in average annual total rainfall amount for both future emission scenarios relative to the historical period over the entire basin. The projected changes in rainfall amounts differ from one part of the basin to the other. In both emission scenarios, the southern part of the basin experiences a significant reduction in the annual rainfall. At the southern part of the basin, the mean annual rainfall would decrease in the range of -900 to -300 mm under both RCPs scenarios. Under RCP4.5 scenario, a decrease of 17.6% is projected while under RCP8.5 scenario, 18.2% decrease is projected at the southern part of the basin relative to the observation. This is true for all models, though, CanESM-RCA4 shows a much larger decrease than NorESM-RCA4 while the ensemble mean presents a decrease that lies between the two RCMs. Over the northern part of the basin, CanESM-RCA4 projected about 2% increase in rainfall under RCP4.5 scenario and about 1.3% change is projected under RCP8.5 scenario. On the other hand, NorESM-RCA4 projected an increase in the amount of rainfall for both emission scenarios, although the changes appear to be slightly higher in the RCP4.5 scenario.

The spatial distribution of the difference in temperature between the projected and historical period over the basin is presented in Figure 4. The temperature increases over the entire basin for all models under both emission scenarios. Under both emission scenarios, CanESM-RCA4 projects a higher increase in temperature than NorESM-RCA4, while the ensemble mean projection lies between the two RCMs. Additionally, the highest increase in temperature is seen over the southern part of the basin in all cases.

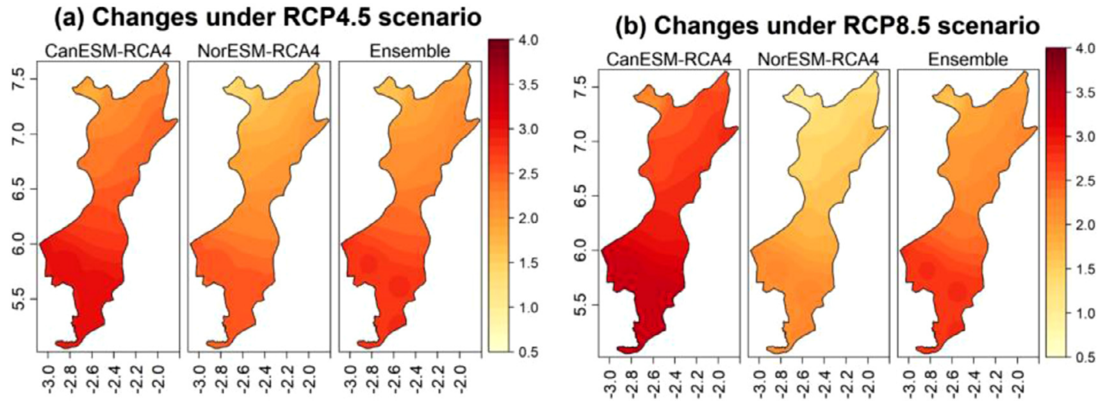

Figure 4. Spatial distribution of projected changes in mean annual temperature for the period 2021-2050 under (a) RCP4.5 and (b) RCP8.5 scenarios relative to the baseline (1986-2015) period

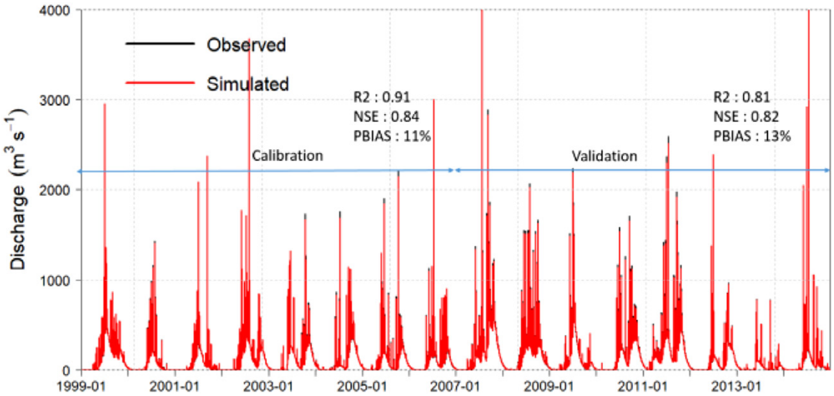

Figure 5. Simulated and observed streamflow graph at Elubo gauge station for the calibration (1999-2006) and validation period (2007-2014)

SWAT simulated streamflow and observation comparison

The simulated streamflow from the SWAT model was compared to the observed streamflow at the Elubo gauge station. Figure 5 shows the result for the SWAT model calibration and validation. The fitted parameters used for the calibration are also shown in Table SM5. The objective functions such as coefficient of determination (R^2), Nash-Sutcliffe Efficiency (NSE) and percentage bias (PBIAS) were found to be 0.88, 0.84 and 11% respectively (Figure 5) during the calibration period (1999-2006), and 0.81, 0.82 and 13% respectively for the validation period (2007-2014). This indicates the suitability of the SWAT model to be used for future simulation in the Tano basin since the obtained model statistics satisfy the satisfactory range proposed by Moriasi et al. [24].

Streamflow and evapotranspiration simulation under climate change

The results for the SWAT simulated mean annual streamflow and actual evapotranspiration (ET) for the two RCPs scenarios based on the ensemble mean of the RCMs at the temporal scale are shown in Table SM6. Under the historical period, about 72% of the rainfall received at the Tano basin was lost in the form of evapotranspiration while about 24% of the rainfall was converted to streamflow. The mean annual ET is projected to increase under both RCPs, with the increase (8.0%) been higher under RCP4.5 compared to a 3.6% increase under the RCP8.5 scenario. The mean annual streamflow is projected to decrease under the two emission scenarios, with the decrease (37.5%) been more pronounced under the RCP8.5 scenario compared to the RCP4.5 scenario (19.9%). The projected changes in streamflow and ET when subjected to t-test were found to be significant at a 95% significance level under both scenarios.

The time-series results for the streamflow and ET for the historical and near-future period, together with the Mann-Kendall trend analysis are shown in Figure SM4 and Table SM7, respectively. The actual evapotranspiration showed an increasing trend at a rate of 0.74 and 1.07 mm/yr under the RCP4.5 and RCP8.5 scenarios respectively (Table SM7). On the other hand, streamflow showed a non-significant decreasing trend at the rate of 2.25 mm/yr under RCP4.5 scenario and a significant decreasing trend of 5.37mm/yr under the RCP8.5 scenario.

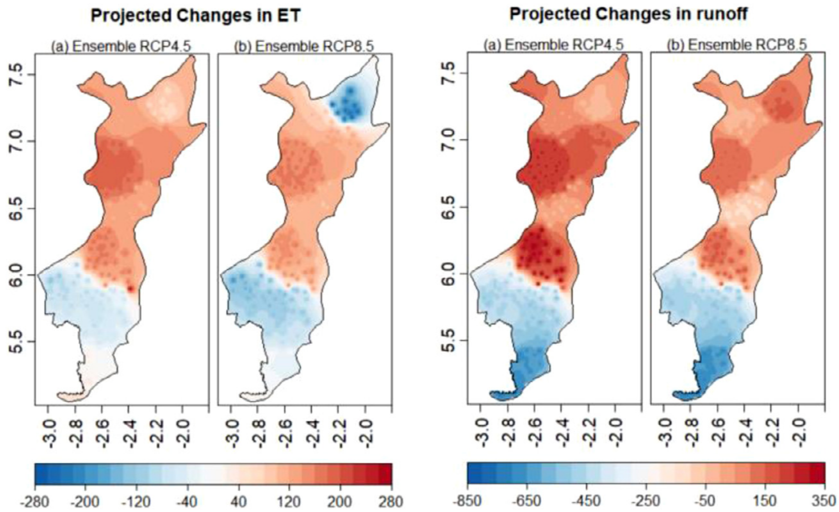

Figure 6. Spatial distribution of projected changes in the ensemble mean of mean annual evapotranspiration (ET) and streamflow (runoff) in mm between the historical (1986-2015) and near future (2021-2050) under RCP4.5 and RCP8.5 scenarios

The spatial distribution of the projected changes in the mean annual actual evapotranspiration (ET) and streamflow under RCP 4.5 and RCP8.5 scenarios for the period 2021-2050 relative to the period 1986-2015 are shown in Figure 6. The southern part of the Tano basin is expected to experience a much decrease in both evapotranspiration and streamflow in the range of -280 to -40 mm and -850 to -250 mm respectively under both RCPs. Around the central to the northern part of the basin, the streamflow is projected to increase in the range of 50 mm to 300 mm under both RCPs, with the increase been more pronounced under the RCP4.5 scenario. In the case of evapotranspiration, a similar change pattern as noticed in streamflow was also projected under both RCPs, with the exception of the North-Eastern part of the basin that showed a decrease of 24.9% under the RCP 8.5 scenario relative to the observation.

Discussion

The SWAT hydrological model together with outputs from an ensemble mean of two RCMs for RCP4.5 and RCP8.5 scenarios were used to assess climate change impact on streamflow and actual evapotranspiration after assessing the rainfall and temperature projections in the Tano river basin. The future climate under both RCPs scenarios indicated that the southern part of the Tano basin that receives a high amount of rainfall would experience a decrease while the northern part of the basin would experience an increase in rainfall. The temperature, on the other hand, was projected to increase in the near future, with the highest amount of increase in the southern part of the basin. This is an important result that could have significant effects on agricultural practices in the basin such as planting times of crops.

The SWAT simulated results showed that both streamflow in the Tano basin would decrease along the coastal area where less rainfall is received, compared to the central and northern parts of the basin that experienced an increase in rainfall. According to Kabo-bah et al. [15], the cycle of streamflow may change in the future due to its dependence on rainfall, and this has been confirmed with our study. The mean annual streamflow at the Tano basin shows a downward trend in the near future, with a visible downward trend after 2040 for the RCP8.5 scenario. For every 3.6% (98.3 mm) decrease in rainfall and 2.1 °C increase in temperature, streamflow would decrease by 37.5% (125.6 mm) on average under the RCP8.5 scenario. For the RCP4.5 scenario, for every 1.0% (14.7 mm) increase in rainfall and 2.4 °C temperature increase, streamflow would increase by 53.9% (180 mm) on average. These projected changes in streamflow under both RCPs obtained from this study relate to the findings of Amisigo et al. [2] in the Pra River Basin. According to Amisigo et al. [2], annual runoff in the Pra basin which is adjacent to the Tano basin could change by -25.9% and +60.9% under the Ghana dry (IPSL_CM4 B1) and Ghana Wet (NCAR_PCM1 A1b) scenarios, respectively, from 2011– 2050 in reference to 1950 – 2000 period. Similarly, Bessah et al. [6] found that the mean annual water yield in the future could decrease by 35% under ensemble mean climate condition (i.e. a decrease in rainfall by 1.77%) but would increase by 44% under the local climate condition (i.e. an increase in rainfall of 13.43%). The streamflow at the southern part of the basin was projected to decrease while an increase was noticed in the central to the northern parts of the Tano basin, and this can be attributed to the decrease and increase in rainfall at the southern and central part of the basin respectively. Roudier et al. [36] have found that a correlation exists between changes in rainfall and runoff in West Africa in which changes in rainfall can contribute to about 50% changes in streamflow.

In the case of ET, similar result was projected by the ensemble mean of the RCMs for the basin which are in line with the projected changes in rainfall and temperature results for the basin. For example, at the southern part of the Tano basin, the projected decrease in rainfall in the range of -900 to -300 mm by the ensemble mean under RCP4.5 scenario, translated into the projected decrease in ET at that location although temperature increased in the southern part of the basin. Also, the increase in ET under both RCPs from the middle part to the northern part of the Tano basin is potentially due to the increase in rainfall and temperature in those areas. Similar result for the increase in ET due to temperature increase in the future is also reported for the Pra river basin in Ghana which is adjacent to the Tano basin [6].

Although very radical in its impact, the wide-ranging effects of climate change are now clearly seen in the agricultural sector which sustains the global food production and economy [3]. According to FAO (2009), climate variables such as precipitation, temperatures, sunshine, wind direction, and speed, etc., are some of the key determinants of crop production. However, variations in these variables are known to be among the foremost long-term threats to humans, with impact on all sectors of life generally and agriculture in particular [6]. It is worth noting that the Tano Basin which is known to support commercial farming of Cocoa, plantain, and other commercial and food crops [40], stands to be greatly impacted in terms of productivity and sustainability of agriculture. The projected increase in temperature, downward trend in rainfall and streamflow in the near future at the Tano Basin may lead to a reduction of water for agriculture and hence a decline in the production of crops [6]. This is in conformity with the study of Lobell et al. [21] who revealed that increasing temperature and decreasing precipitation in the North of China is likely to reduce the yields of several primary crops over the next two decades. On the aspect of the recorded changes in the studied climate variables and their implications on the water resource sector, a study by Nash and Gleick [26] has shown that higher temperatures lead to increased evaporation rates, reduced streamflow, and increased frequency of droughts. When this happens, the current water management practices in the Tano River Basin would be hampered, and the capacity of existing water infrastructures in the Basin to subdue climate change impact on water supply reliability would be reduced as recounted by Kundzewicz et al. [17]. This, raises great concern for the Tano River Basin management authorities. Also, to make the sectors more resilient to the changing climate, there is the need to understand the strong relationship between these climate variables, food production, and water resource management for better sustainable management of the available water in the Tano Basin.

Conventionally, annual rainfall amount and temperature increases and decreases respectively from the North to the South of Ghana latitudinally. This is true for most West Africa Countries, especially those within the Volta Basis. Accordingly, the higher projected decrease in rainfall in the southern part of the basin, compared with the projected increase from the central to the northern part of the basin was not expected and rather counter intuitive. Correspondingly, the projected increase in temperature across the entire basin with the highest increase around the southern part of the basin was also not expected. These new findings of this study could be of immediate interest for the wider research community, especially in the West Africa sub-region. The goal seven of the African Union Agenda 63 is to achieve an environmentally sustainable and climate resilient economies and communities. Among the priority areas under the goal seven is water security which our study seeks to address in the context of climate change. This study provides information on areas within the basin that will be vulnerable to climate change in terms of decrease in rainfall and streamflow, and thereby informs policy decisions on adaptation, building resilient and mitigating measures to climate change. The findings of the present study could serve as a set of common lessons for policy-makers in the West Africa sub-region along the same Ecological Zones with similar climate patterns as the study area.

Conclusions

The impact of climate change on the actual evapotranspiration and streamflow of the Tano basin, Ghana, was assessed under the RCP 4.5 and RCP8.5 scenarios using the SWAT model. The projected relative changes to the mean climate were estimated over the basin using rainfall and temperature data from two RCMs (CanESM-RCA4 and NorESM-RCA4) by determining the difference between the mean historical climate and the projected climates for each RCM and their ensemble mean. The following conclusions were drawn from the study:

(1) Under climate change, the mean annual rainfall is projected to increase by 1.0 % under the RCP4.5 scenario but would decrease by 3.2 % under the RCP8.5 scenario, while temperature showed an increase of 2.2 °C under RCP4.5 and 2.6 °C under RCP8.5.
(2) A higher decrease in rainfall in the southern part of the basin is projected, while an increase is projected from the central to the northern part of the basin. In the case of temperature, an increase across the entire basin is projected with the highest increase around the southern part of the basin.
(3) The boxplot analysis also brings out the relatively better confidence provided by the high-resolution RCMs in projecting rainfall and temperature at the basin.
(4) Due to the changes in rainfall and temperature, the SWAT model results revealed an increase in the mean annual actual evapotranspiration but a decrease in streamflow in the near future (2021-2050) under both RCPs relative to the observation period (1986-2015).
(5) A non-significantly decreasing trend was found for streamflow in the near future for the RCP4.5 scenario but under the RCP8.5 scenario, a statistically significant decreasing trend in streamflow would occur.
(6) The southern part of the Tano basin is expected to experience a decrease in both evapotranspiration and streamflow while the northern part is projected to increase under both RCPs. These findings obtained are vital information for the Tano basin water resources management board to plan location-specific climate change adaptation strategies to

ensure the sustainability of the surface water required at the basin for various activities such as domestic, agriculture (irrigation), and mining/ industrial.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.sciaf.2021.e01071.

CRediT authorship contribution statement

Isaac Larbi: Conceptualization, Methodology, Software, Writing – original draft. **Clement Nyamekye:** Supervision, Visualization, Investigation. **Sam-Quarcoo Dotse:** Visualization, Investigation. **Derrick K. Danso:** Data curation, Software, Visualization. **Thompson Annor:** Validation, Writing – review & editing. **Enoch Bessah:** Writing – review & editing. **Andrew Manoba Limantol:** Writing – review & editing. **Thomas Attah-Darkwa:** Validation, Writing – review & editing. **Daniel Kwawuvi:** Writing – review & editing. **Mawulolo Yomo:** Writing – review & editing.

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