Tanzania Journal of Science 48(1): 170-184, 2022
ISSN 0856-1761, e-ISSN 2507-7961

Assessment of the Impact of Climate Change on Stream Flow: The Case of Little Ruaha Catchment, Rufiji Basin, Tanzania

Joel Nobert
Department of Water Resources Engineering, College of Engineering and Technology, University of Dar es Salaam, P.O. Box 35131, Dar es Salaam, Tanzania
E-mail: jknobert@gmail.com
Received 8 Feb 2022, Revised 28 Mar 2022, Accepted 30 Mar 2022, Published Mar 2022
DOI: https://dx.doi.org/10.4314/tjs.v48i1.16

Abstract

Little Ruaha catchment has been recognized for its potential to support multi-projects including irrigated schemes, urban water supply and providing significant inflow to Mtera reservoir for hydropower generation and ultimately Julius Nyerere Hydropower Plant (JNHPP). Despite the potential, the catchment has experienced declining flows in the recent years. This study assessed the likely changes in streamflow due to future climate change in the Little Ruaha catchment for the period 2025-2060. General Circulation Model (GCM) datasets from ACCESS1.0, CNRM-CM5 and BCC-CSM1 models and RCP4.5 and RCP8.5 greenhouse gas concentration scenarios were selected as the representative scenarios. Impact of climate change on stream flows was assessed using the calibrated NAM hydrological model. The impact assessment results show that under the climate change scenario (2025–2060), the monthly maximum and minimum temperatures will increase in the range of 0.8 °C to 2 °C for both RCP4.5 and RCP8.5 scenarios. For the case of rainfall, average annual rainfall is expected to increase by about 10% compared to the baseline. However, the inter-annual variability of rainfall for the period between 2025 and 2060 shows the decreasing trend for RCP 8.5. The simulation results show that streamflow will decrease by about 30% and 6% for RCP4.5 and RCP8.5, respectively.

Keywords: Hydrological modelling; climate change scenarios; hydrological impacts; Little Ruaha.

Introduction

Uncertainties about future water demands and availability is the main concern of the water resources managers. The main effect of climate variability on water resources is to alter flow regimes in rivers (Neves et al. 2020). Alterations in stream flow quantity and timing are caused by changes in components of the water balance, mainly rainfall and evapotranspiration, the latter being dependent on the air temperature (Watts et al. 2015). These changes on the hydrologic systems have significant implications for water resources (Quansah et al. 2021). The changes will affect all aspects of modern humanity including hydrology, hydropower generation, agriculture, food security, human health, ecosystems, groundwater, irrigation water requirements, and crop yields (Qin et al. 2020, Luo et al. 2013, Shrestha et al. 2016, Masipa 2017, Lee and Huang 2014).

To effectively assess future hydrologic responses to climate change, scientists utilize hydrologic modelling integrated with future projected climate dataset derived from the World Climate Research Program (WCRP) and IPCC’s General Circulation Models (GCMs) (Quansah et al. 2021). GCMs provide geographically and physically consistent estimates of future regional climate conditions and changes throughout the planet based on physical processes involving the atmosphere, ocean, and land surface (Randall et al. 2007, IPCC 2014).

Greenhouse gas emission scenarios are the primary radiative forcing that drives the GCMs. There are a standard set of scenarios for future global greenhouse gas emissions based on land use, population growth, technology, industrialization, and other factors that are employed by climate modelers (IPCC 2014). These are the Representative Concentration Pathways (RCPs), and are expressed as the amount, by the year 2100, of the earth's radiative imbalance in watts per square meter of Earth's surface. RCPs were introduced in the Fifth IPCC Assessment and are used to prescribe radiative forcing inputs to climate models (Miao et al. 2014, IPCC 2014, Alexander and Arblaster 2017, Li and Jin 2017).

The Little Ruaha catchment located in the Southern Highlands of Tanzania has experienced water conflicts between upstream users and downstream users, including hindering hydropower production from Mtera and affecting the flow downstream to Julius Nyerere Hydropower Plant (JNHPP) and devastating impacts on the Ruaha National Park (RNP) (Mtahiko et al. 2006). The Little Ruaha River is also the main water source for expanding urban population in Iringa Region. The catchment is one of major sources of water for the Ihemi Cluster, which is one of the six clusters identified by the Southern Agricultural Growth Corridor (SAGCOT) for agricultural intensification with significant investments in irrigation planned (SAGCOT 2011).

According to historical data from the Rufiji Basin Water Board (RBWB), it has been noted that in the recent years, the dry season flow has decreased significantly. For the case of Ndiuka gauging station in Little Ruaha catchment, the average monthly discharge for the period 1972–1981 was about 5.8 m^3/s and for the current period (2012–2019), the average discharge for the station is about 2.7 m^3/s for the month of October. A recent study in the catchment by Chilagane et al. (2021) has assessed the impact of land use changes on surface runoff and sediment yields. The findings from their study indicated an increase of average annual surface runoff by 2.78 mm and decrease in average annual base flow by 2.68 mm. The impacts of climate change on stream flows were not considered in their study. The focus of this study was therefore to assess the impacts of climate change on stream flows.

Materials and Methods

Description of the study area

Little Ruaha catchment lies within longitude 35°2' E and 35°36' E and latitude 7°11' S and 8°36' S. The catchment has an estimated area of 6,210 km^2 and drains parts of Iringa Municipal, Iringa, Kilolo and Mufindi Districts in Iringa Region. The elevation for the catchment ranges from 700 to over 2,300 m above sea level (Figure 1).

Climatic characteristics

Climate in the watershed is highly variable, at both spatial and temporal scales, and is dominantly unimodal with a single rainy season from November to April and correlates with altitude. Average annual rainfall ranges from 480 mm in the lowlands as per records from the Mtera meteorological station (1971–2019) to about 700 mm in the highlands at Iringa based on average rainfall from 1979 to 2019 based on the data from the Iringa Maji meteorological station. The mean annual temperature varies from about 18 °C at higher altitudes to about 28 °C.

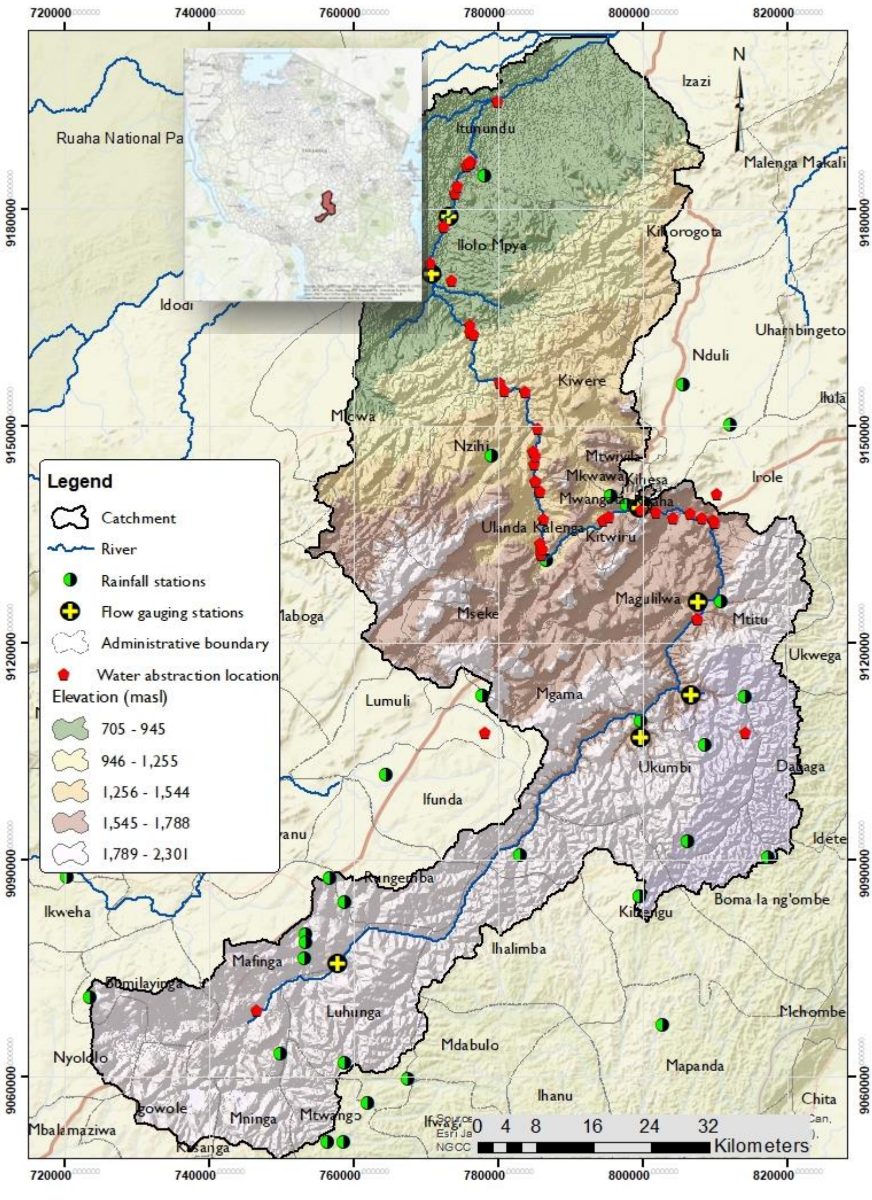

Figure 1: Little Ruaha catchment.

Data used for the analysis

Rainfall and climatic data from the stations within and close to the catchment were obtained from the Rufiji Basin Water Board (RBWB). Other data used for the analysis include streamflow, downscaled GCM data and elevation data. The study used historical climate and streamflow data (1987–2013) and statistically downscaled GCM CMIP5 climate data (daily precipitation, minimum and maximum temperatures and potential evapotranspiration) for the years 2025–2060, under medium stabilization radiative forcing emission scenario (RCP 4.5) and very high baseline emission scenarios (RCP 8.5). The details of the data used are given in Table 1.

Table 1: Details of data used in the analysis

Data	Data source	Data description
Elevation (30 m)	https://srtm.csi.cgiar.org/srtmdata/	Elevation data covering the catchment
Historical climate	Rufiji Basin Water Board	Daily rainfall, maximum and minimum temperature
Streamflow	Rufiji Basin Water Board	Daily streamflow data from Mawande and Ndiuka stations
Future climate	https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/	Downscaled General Circulation Model data. Bias Correction and Spatial Downscaling (BCSD) statistical downscaling approach

Estimation of evapotranspiration

FAO recommended Penman-Monteith method was used for computing potential evapotranspiration, ETo. The method estimates the potential evapotranspiration from a hypothetical crop with an assumed height of 0.12 m having aerodynamic resistance of (r_a) 208/u_2, (u_2 is the mean daily wind speed measured at a 2 m height over the grass) and a surface resistance (r_s) of 70 s·m^{-1} and an albedo of 0.23, closely resembling the evaporation of an extension surface of green grass of uniform height, actively growing and adequately watered. The ETo (mm·d^{-1}) was estimated following FAO-56 (Allen et al. 1998) as shown in equation 1.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

R_n is net radiation at the surface (MJ m^{-2} d^{-1}), G is ground heat flux density (MJ m^{-2} d^{-1}), γ is the psychrometric constant (kPa °C^{-1}), T is mean daily air temperature at 2 m height (°C), u_2 is wind speed at 2 m height (m/s), es is the saturation vapour pressure (kPa), ea is the actual vapour pressure (kPa) and Δ is the slope of the saturation vapour pressure curve (kPa° C^{-1}).

Hydrological modelling

Hydrological modelling for the Little Ruaha catchment was done using NAM model. The NAM is a Danish abbreviation, which stands for NedbørAffstrømnings Model, meaning a rainfall–runoff model. The NAM is deterministic, lumped and conceptual rainfall-runoff model that operates by continuously accounting for the moisture content in four different and mutually interrelated storages to describe the hydrological cycle of the land phase (DHI 2003) (Figure 2). The snow storage was excluded in this study, as there is no snow in the study catchment.

There are three main flow components, namely overland flow (QOF), interflow (QIF) and underground flow (QBF). Generally, rainfall, potential evaporation and temperature are the input data needed for the model. The result is a continuous time series of the runoff from the catchment throughout the modelling period.

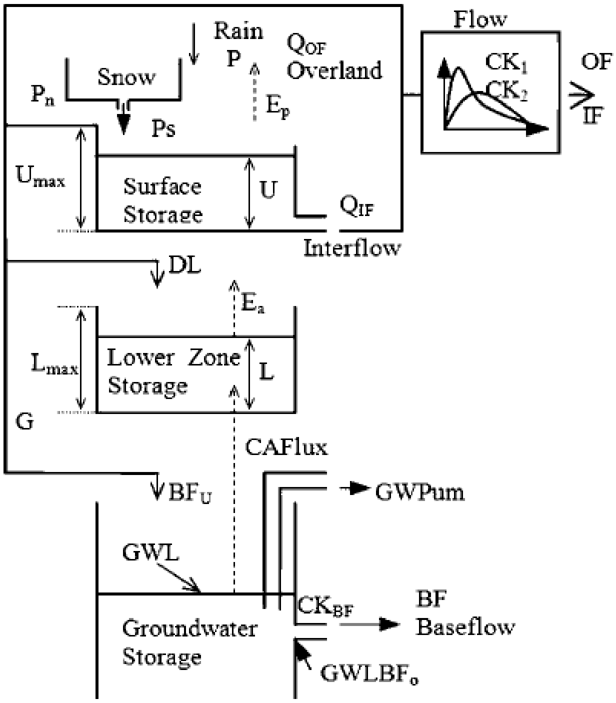

Figure 2: NAM model structure.

Surface storage represents the fraction of precipitation intercepted by plant canopy and stored in depression on the surface of the land. The water in this storage may be lost by evaporation and leakage to the stream in the form of interflow. On the other hand, if the storage is filled fully, the excess water may join the stream as the overland flow. The overland flow varies with the soil moisture (DHI, 2011/2003) as shown in Equation 2.

$$QOF = \begin{cases} CQOF \dfrac{L/L_{max} - TOF}{1 - TOF} P_N & \text{for } L/Lmax > TOF \\ 0 & \text{for } L/Lmax \le TOF \end{cases} \quad (2)$$

Lower zone storage represents the moisture stored within the root zone of the soil. Transpiration is responsible for the loss of water in this storage. The moisture content of the lower zone storage governs the amount of water that goes into overland flow, interflow and groundwater flow (Wakigari 2017). Groundwater storage is responsible for the baseflow component. The interflow was calculated as shown in equation (3) below.

$$QIF = \begin{cases} (CKIF)^{-1} \dfrac{L/L_{max} - TIF}{1 - TIF} U & \text{for } L/Lmax > TIF \\ 0 & \text{for } L/Lmax \le TIF \end{cases} \quad (3)$$

Model setup, calibration and validation

The MIKE 11 NAM model was used to simulate runoff at a daily time step. Daily rainfall data and temperature data was obtained from the Rufiji Basin Water Board (RBWB) for the stations within the catchment area. Potential evapotranspiration was estimated using Penman-Monteith model. To estimate the final NAM parameters, the model must be calibrated by a time series of hydrological observations that can be done either manually or automatic.

The auto-calibration is done to optimize water balance, overall hydrograph shape, peak flows and low flows.

Calibration of the NAM 11 RR model was done for 11 years period from 2001 to 2011, using measured flow data at Mawande flow gauging station. The first stage of the application of the NAM model for rainfall runoff estimation was the calibration process to determine the optimum values of the model parameters. The second stage was the discharge simulation and the prediction based on the estimated model parameters during the calibration process.

Model performance

The simulated and observed hydrographs, as well as the simulated and observed cumulative runoffs in the calibration and validation periods, were compared. The performance of the model was evaluated using the Nash-Sutcliff (NSE) and coefficient of determination (R^2) as shown in equations (4) and (5), respectively.

$$\mathrm{NSE} = 1 - \frac{\sum_{i=1}^{n} \left(Q_{sim,i} - Q_{obs,i}\right)^2}{\sum_{i=1}^{n} \left(Q_{obs,i} - \overline{Q}_{obs,i}\right)^2}, \qquad (4)$$

where NSE is the Nash Sutcliffe efficiency, $Q_{sim,i}$ is simulated flow, $Q_{obs,i}$ is observed flow, $Q_{obs,i}$ is the average of the observed flow, $Q_{sim,i}$ is the average of the simulated flow and n represents the length of series.

$$\mathrm{R}^2 = \frac{\left[\sum_{i=1}^{n} \left(Q_{obs,i} - \overline{Q}_{Obs}\right)\left(Q_{sim,i} - \overline{Q}_{sim}\right)\right]^2}{\sum_{i=1}^{n} \left(Q_{obs,i} - \overline{Q}_{Obs}\right)^2 \sum_{i=1}^{n} \left(Q_{sim,i} - \overline{Q}_{sim}\right)^2}, \qquad (5)$$

$$\mathrm{WBD} = \frac{\sum Q_{obs,i} - \sum Q_{sim,i}}{\sum Q_{obs,i}},$$

Impacts of climate change on streamflow

The GCMs that were selected for the analysis of climate change in Little Ruaha catchment were ACCESS1.0, CNRM-CM5 and BCC-CSM1 models and RCP 4.5 and RCP 8.5 greenhouse gas concentration scenarios were selected as the representative scenarios. The selection of the models was guided by the statistical analysis of the observed climatic variables and the historical GCM climate variables. The climate variables analysed included rainfall, temperature and potential evapotranspiration. The downscaled future climate data were used in the calibrated model to simulate future streamflow for selected GCMs under RCP 4.5 and 8.5 scenarios.

Results and Discussions

Model calibration

The final sets of NAM model parameters used for simulation of the flow are summarized in Table 2. The observed and simulated flows for the Mawande flow gauging station are as shown in Figure 3. The calibration statistics for the model also showed good fit with overall water balance difference of -0.05% and coefficient of determination (R^2) was 0.67.

Table 2: Model parameter values fitted

Parameters	Description	Upper bound	Lower bound	Fitted value
U_{max} (mm)	Maximum water content in surface storage	10	30	28.946
L_{max} (mm)	Maximum water content in root zone storage	100	450	400
CQOF (-)	Overland flow runoff coefficient	0.1	1	0.34511
CKIF (hr)	Time constant for routing interflow	200	1000	500
CK1,2 (hr)	Time constant for routing overland flow	10	50	44.5
TQF (-)	Root zone threshold value for overland flow	0	0.99	0.91263
TIF (-)	Root zone threshold value for interflow	0	0.99	0
TG (-)	Root zone threshold value for GW recharge	0	0.99	0
CKBF (hr)	Time constant for routing baseflow	1000	4000	3976.6

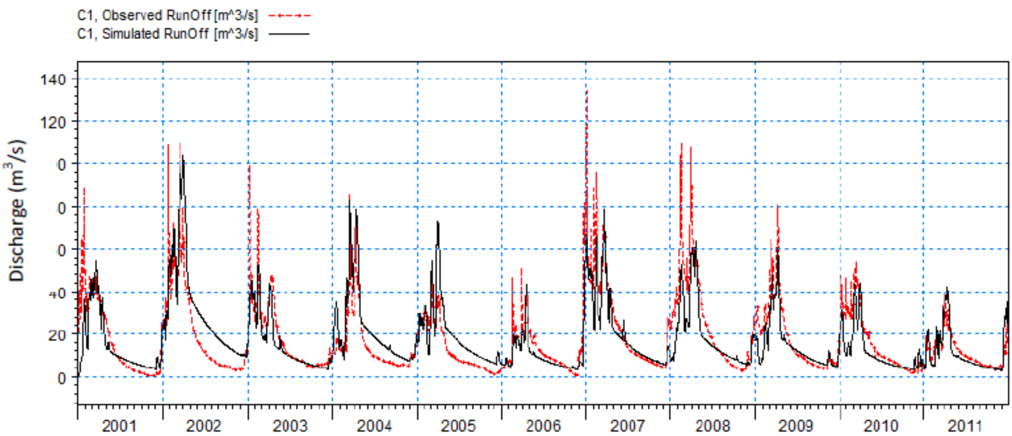

Figure 3: Simulated and observed flow data at Mawande flow gauging station.

GCM climate variables projections

Projected changes in the future mean monthly rainfall (2025–2060) compared to the baseline are as shown in Figures 4 and 5. Generally, the results is showing increasing trend with exceptions in some months for both RCP 4.5 and RCP 8.5. The annual average rainfall is projected to increase by 9.7% in the future. Figure 6 shows the annual and seasonal observed rainfall for the Iringa station (1972–2019) which does not show any clear trend. However, the future projected annual and seasonal rainfall (March-April-May (MAM), October-November-December (OND), and October-November-December-January-February-March (ONDJFM) for the period 2025–2060 under RCP 8.5 is showing the decreasing trend as shown in Figure 7. Mutayoba et al. (2018) in their study in Mbarali catchment in Rufiji basin also indicated rainfall is expected to increase in the present century (2011–2040) under both RCP 4.5 and RCP 8.5 emission scenarios. Luhunga et al. (2018) results also indicated under both (RCP 8.5 and RCP 4.5) emission scenarios most regions of the country will experience increased amount of rainfall in the range of zero to 0.25 mm/day.

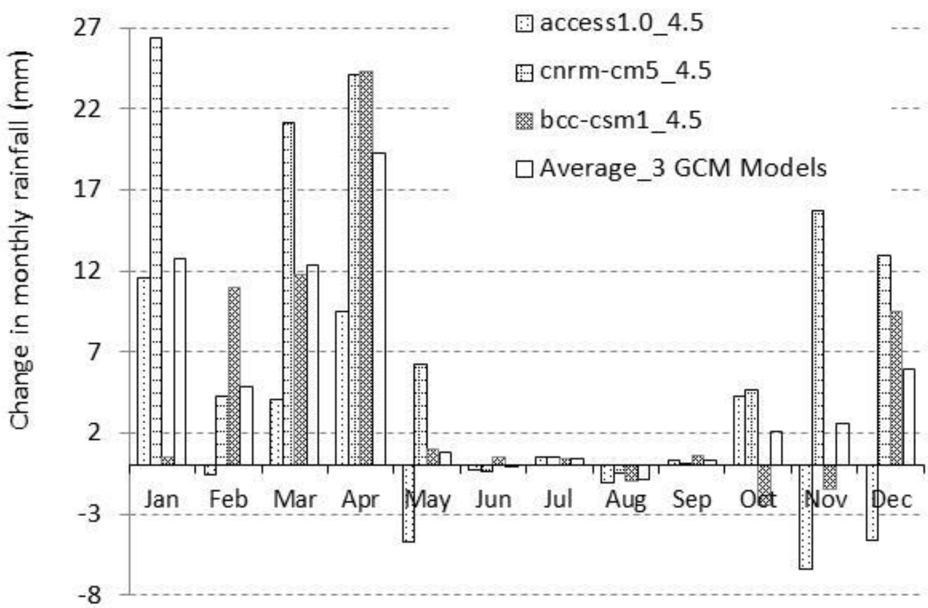

Figure 4: Changes in mean monthly rainfall for future climate scenarios (2025–2060) for RCP 4.5 compared to the baseline values (1972–2011).

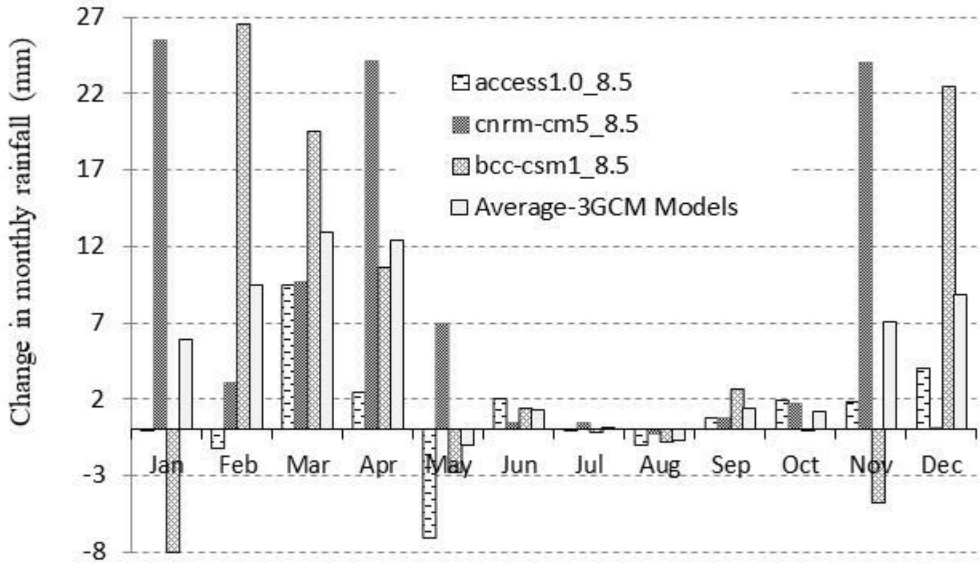

Figure 5: Changes in mean monthly rainfall for future climate scenarios (2025–2060) for RCP 8.5 compared to the baseline values (1972–2011).

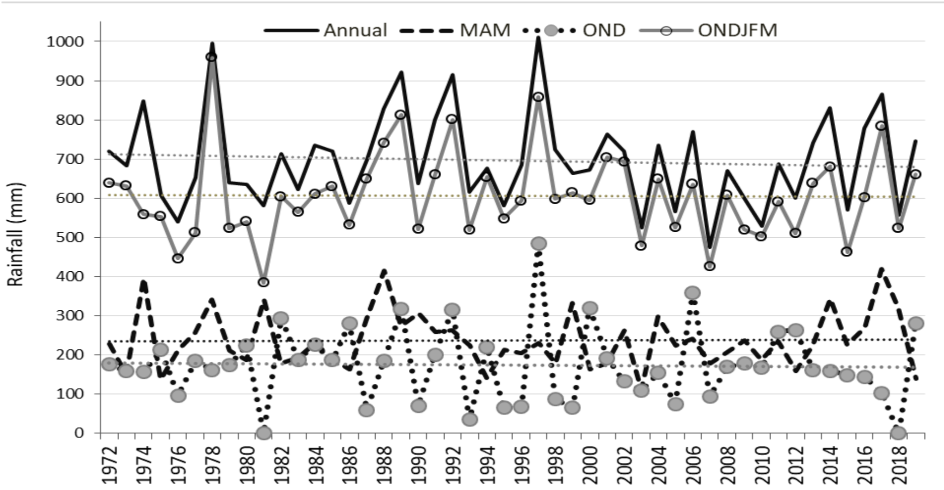

Figure 6: Annual and seasonal observed rainfall for the Iringa met station (1972–2019).

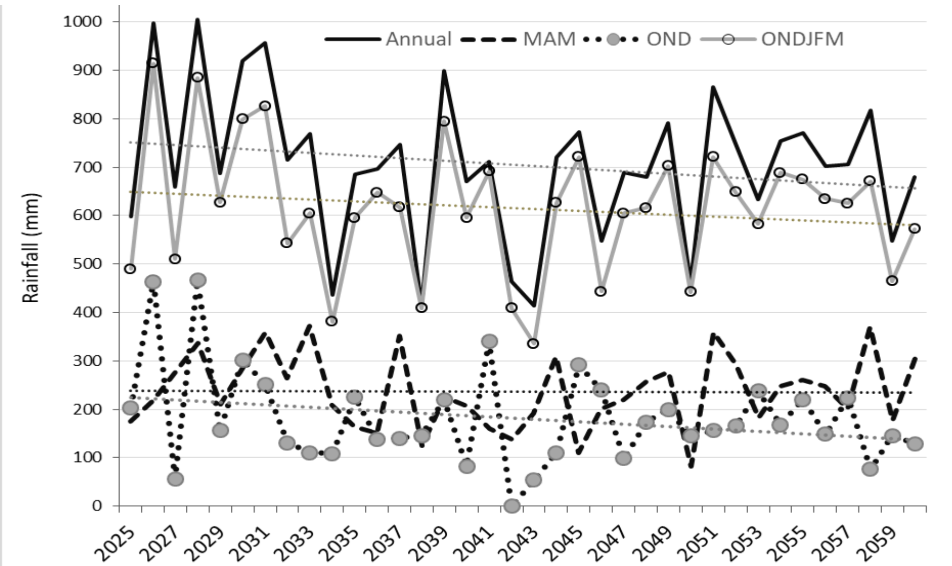

Figure 7: Predicted future annual and seasonal rainfall for 2025–2060, RCP8.5.

Temperature

Observed mean monthly maximum and minimum temperature and the projected mean monthly maximum and minimum temperature for RCP 4.5 and RCP 8.5 emission scenarios are as shown in Figures 8 and 9, respectively. The projected mean annual and seasonal average temperature trend are as shown in Figure 10 for RCP 8.5 emission scenario. The results indicate that in the future the minimum and maximum temperatures will increase compared to the present. Mutayoba et al. (2018) also indicated the minimum and maximum temperatures are expected to increase in future for Mbarali catchment under both RCP 4.5 and RCP 8.5 emission scenarios. Future climate for Africa (FCFA) 2017 also found the strong agreement for the 34 climate models used on continued future warming throughout Tanzania in the range of 0.8 ^{o}C to 1.8 ^{o}C by the 2040s. Luhunga et al. (2018) obtained similar results, in the study of climate change projections for Tanzania using outputs of high-resolution Regional Climate Models (RCMs) from the Coordinated Regional Climate Downscaling Experiment program (CORDEX). Their study indicated higher changes in the maximum temperatures in the range of 2.4 °C to 2.6 °C and 2 °C to 2.2 °C under RCP 8.5 and 4.5 emission scenarios, respectively. Also, the increase in minimum temperature in the range of 2.2 °C to 2.4 °C and 1.6 to 2 °C under RCP 8.5 and RCP 4.5 emission scenarios, respectively.

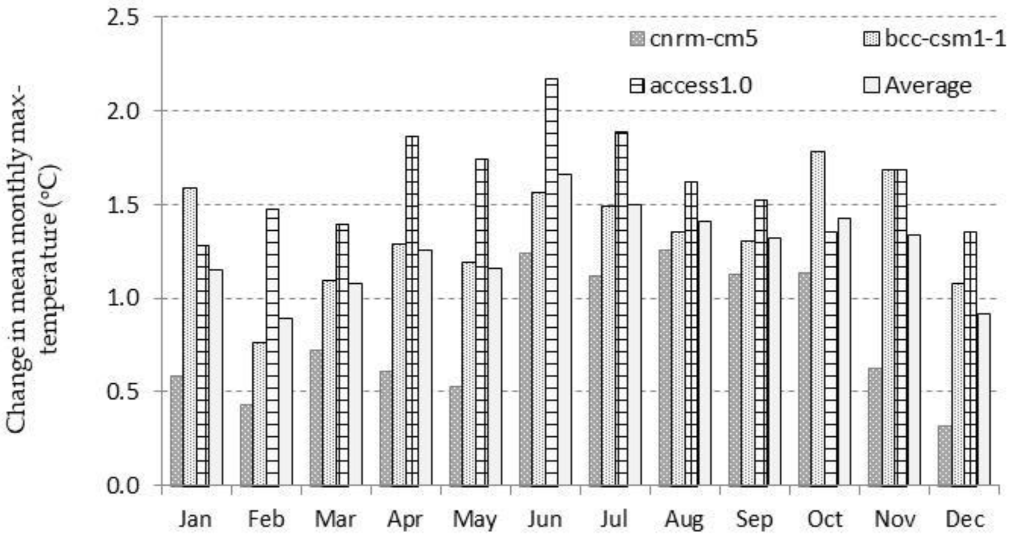

Figure 8: Change projected mean monthly maximum temperature (2025–2060) for RCP 4.5 compared to the baseline.

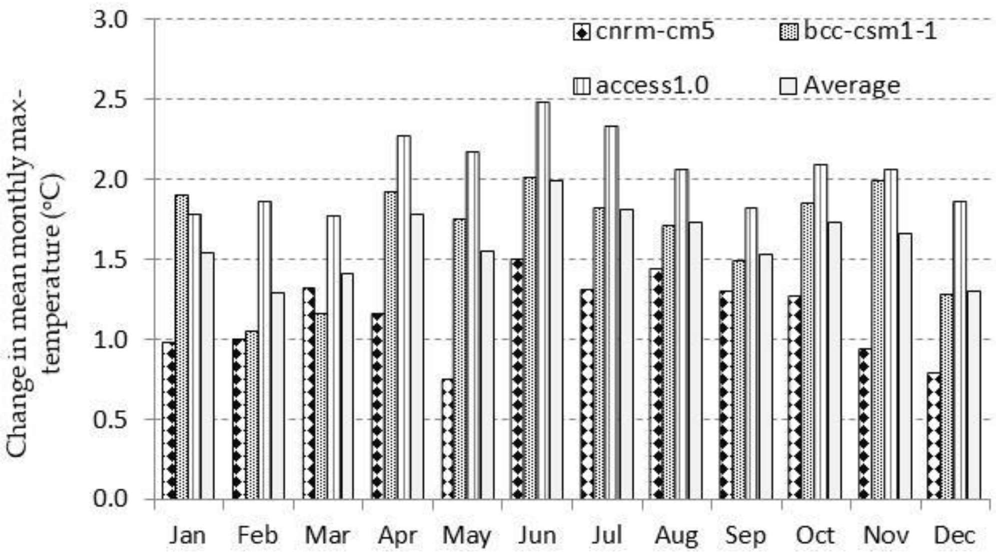

Figure 9: Change projected mean monthly maximum temperature (2025–2060) for RCP 8.5 compared to the baseline.

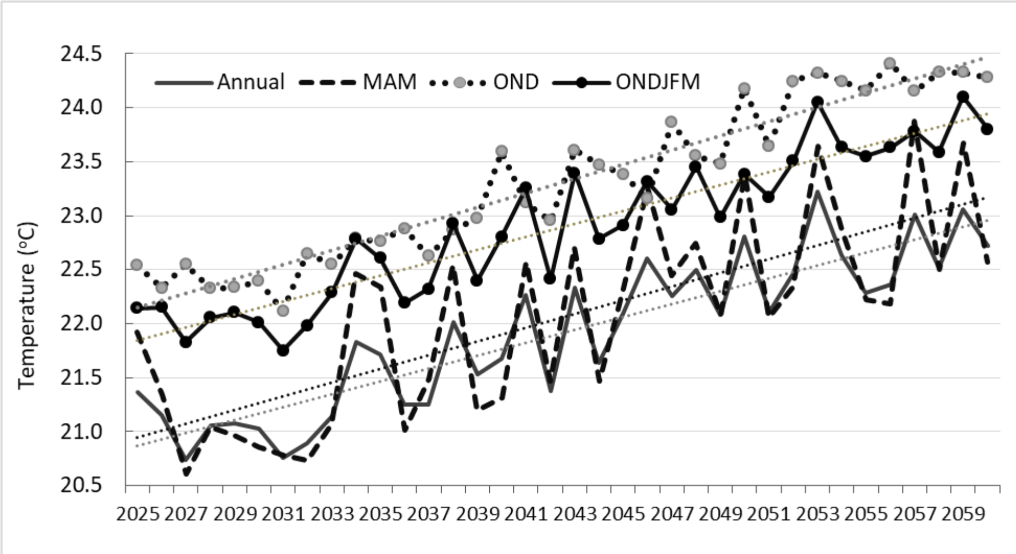

Figure 10: Projected future mean annual and seasonal average temperature (2025–2060) for RCP 8.5 emission scenario.

Potential Evapotranspiration

The projected changes in the future mean monthly potential evapotranspiration compared to the baseline for the selected GCMs and for RCP 4.5 and RCP 8.5 emission scenarios are as presented in Figures 11 and 12. Generally, the projected future evapotranspiration is showing increasing trend with exceptions in some few months as compared to historical potential evapotranspiration.

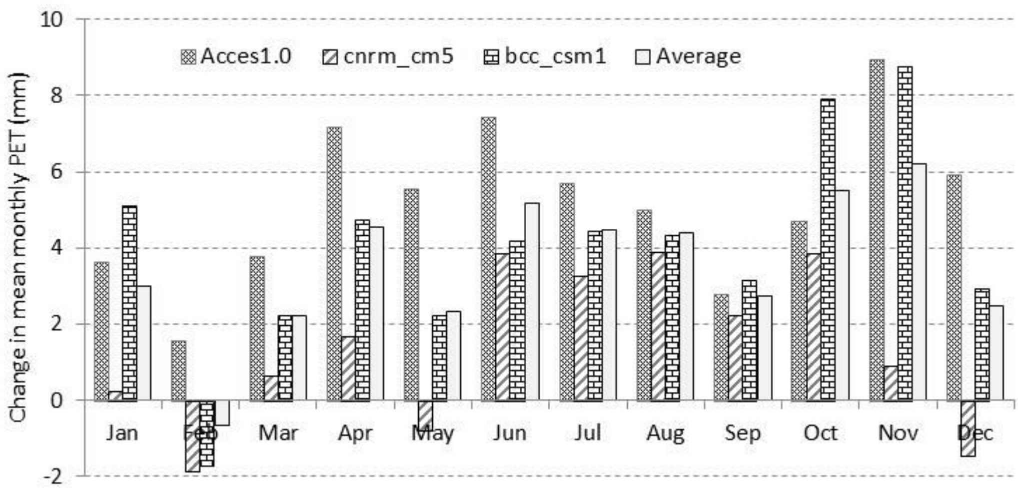

Figure 11: Change in mean monthly projected potential evapotranspiration (PET) (2025–2060) compared to the baseline values–for RCP4.5.

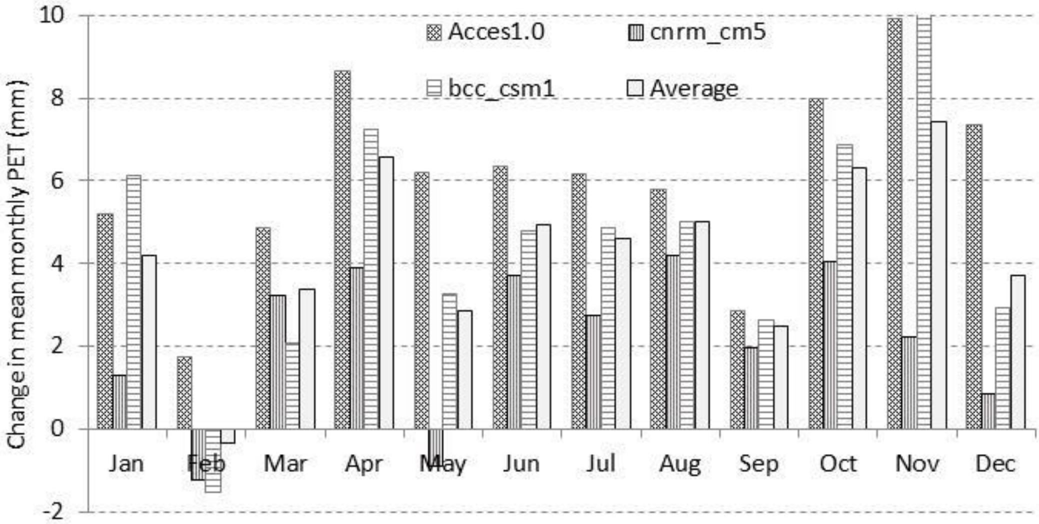

Figure 12: Change in mean monthly projected potential evapotranspiration (PET) (2025–2060) compared to the baseline values–for RCP8.5.

The summary of the future projections of annual and seasonal mean changes of climate variables (rainfall, temperature and potential evapotranspiration) as compared to the baseline data is as shown in Table 3. The annual and seasonal values for the climate variables are projected to increase in the future with the exception of long rainy season (March-April-May (MAM)), which is showing slight decrease in rainfall and maximum temperature.

Table 3: Annual and seasonal mean changes for the future (2025–2060). Results are shown for a high greenhouse gas emission scenario (RCP 8.5)-acces1-Model

	Rainfall (mm)	Temperature (°C)		Potential Evapotranspiration (PET) (mm)
		Max	min	
Annual	7.12	2.09	2.1	73.02
MAM	-0.42	-0.06	2.03	19.71
OND	7.13	2.99	3.03	25.27
ONDJFM	9.33	3.19	1.91	37.06

Impacts of climate change on river discharge

The calibrated NAM model was used to generate the future flows for RCP 8.5 emission scenario for the access1.0 GCM. The long-term projected average monthly flow is as shown in Figure 13. The flow duration curve data for the projected and observed flows is as shown in Table 4. Assessment of flow shows that, the annual average flow is projected to decline in the future by about 30% and 6% for RCP 4.5 and RCP 8.5, respectively. The low flow (Q_{95}) or the flow which is equalled or exceeded 95% of the time is also projected to decrease from 2.82 m^3/s to 2.67 m^3/s, which is equivalent to 5.3% decline and the high flows (Q_5) is expected to decline by about 4% (Table 4). Despite projected increase in the future precipitation, the decline in flow can be attributed to increased evapotranspiration and hence reduced surface water flows and groundwater recharge.

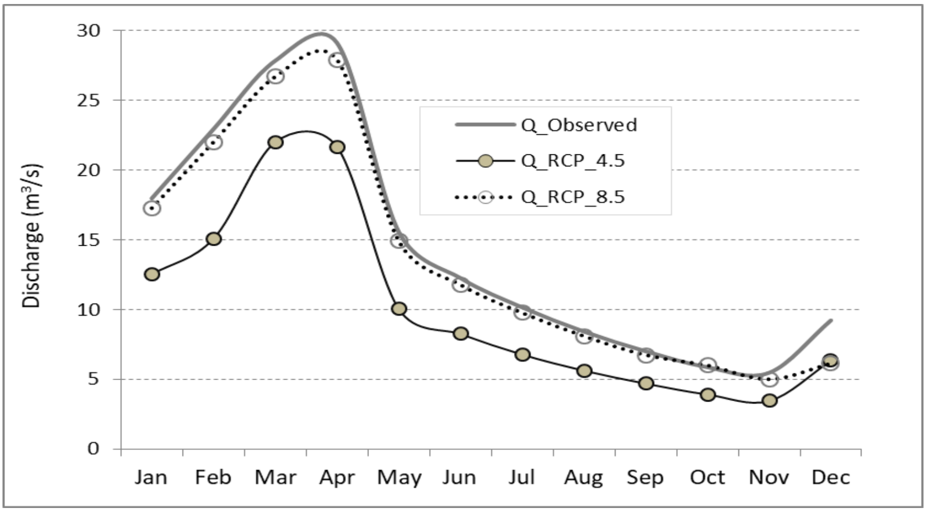

Figure 13: Observed and projected future average monthly flows for RCP 8.5.

Table 4: Flow and the corresponding exceedance probability (%) for Little Ruaha River at Ndiuka for the climate change scenario (2025–2060)

Observed discharge (m^3/s)	Simulated discharge (2025–2060) (RCP 8.5) (m^3/s)	% of time flow is equalled or exceeded
50.46	48.3	2
44.15	42.2	5
38.72	37.1	10
15.04	14.4	50
7.51	7.2	75
2.82	2.67	95
0.61	0.5	100

The review of different studies on impacts of climate change on hydrological extremes in the Blue Nile by Taye et al. (2015) concluded that most studies show the consistent increase in temperature that might lead to an increase in potential evapotranspiration (PET) and a reduction in annual streamflow in the 21st century. These trends can have critical implications for hydrology, agriculture, and water resources since increased evapotranspiration is expected to reduce surface water flows and groundwater recharge.

Conclusions

The main objective of this study was to assess the impacts of climate change on hydrologic responses. General Circulation Model (GCM) datasets from ACCESS1.0, CNRM-CM5 and BCC-CSM1 under CMP5 models were used for the future climate scenarios analysis. The downscaled GCM data were then used in the calibrated NAM hydrological model to predict the future flows. The projected climate conditions were compared with the baseline period based on the available stations in the catchment. All the GCMs indicated projected increases in average minimum and maximum temperature between 0.8 °C and 2 °C for the future climate conditions. Likewise, the average monthly potential evapotranspiration is expected to increase by around 4%. For the case of rainfall, average annual rainfall is expected to increase by about 9% compared to the baseline. It was projected that the changes in future climate scenarios will have negative changes in the average monthly flows in the catchment compared to the baseline years. The flows are projected to decrease in the future under both medium emission scenarios (RCP 4.5) and high emission scenario (RCP 8.5). Apart from climate change, it should also be noted that the changes in stream flows could be contributed by other non-climatic factors such as increased abstractions and land use changes. The decrease in stream flows and hence water availability could have adverse impacts on competing water demand activities in the catchment such as irrigation, urban water demands, environmental flow and hydropower systems. Despite the inherent uncertainties in the downscaled GCM data, the simulated dynamics in streamflow and water availability provide critical information for stakeholders to develop sustainable water management and climate change adaptation options for the catchment.

Acknowledgements
The study was supported by the Rufiji Basin Water Board, Ministry of Water by providing relevant data used in the analysis.

References

Alexander LV and Arblaster JM 2017 Historical and projected trends in temperature and precipitation extremes in Australia in observations and CMIP5. *Weather Climate Extremes* 15: 34-56.

Allen RG, Pereira LS, Raes D and Smith M 1998 Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. *FAO, Rome* 300(9): D05109.

Chilagane NA, Kashaigili JJ, Mutayoba E, Lyimo P, Munishi P, Tam C and Burgess N 2021 Impact of land use and land cover changes on surface runoff and sediment yield in the Little Ruaha River Catchment. *Open J. Modern Hydrol.* 11: 54-74.

Future Climate for Africa (FCFA) 2017 Future climate projections for Tanzania. *Country Climate Brief.*

IPCC 2014 Climate change synthesis report summary for policymakers. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Lee JL and Huang WC 2014 Impact of climate change on the irrigation water requirement in northern Taiwan. *Water* 6(11): 3339-3361.

Li Z and Jin J 2017 Evaluating climate change impacts on streamflow variability based on a multisite multivariate GCM downscaling method in the Jing River of China. *Hydrol. Earth Syst. Sci.* 21: 5531-5546.

Luhunga PM, Kijazi AL, Chang'a L, Kondowe A, Ng'ongolo H and Mtongori H 2018 Climate change projections for Tanzania based on high-resolution regional climate models from the Coordinated Regional Climate Downscaling Experiment (CORDEX)-Africa. *Front. Environ. Sci.* 6: 122.

Luo Y, Ficklin DL, Liu X and Zhang M 2013 Assessment of climate change impacts on hydrology and water quality with a watershed modelling approach. *Sci. Total Environ.* 450-451: 72-82.

Masipa TS 2017 The impact of climate change on food security in South Africa: Current realities and challenges ahead. *Jamba:* 9(1): 411.

Miao C, Duan Q, Sun Q, Huang Y, Kong D, Yang T, Ye A, Di Z and Gong W 2014 Assessment of CMIP5 climate models and projected temperature changes over Northern Eurasia. *Environ. Res. Lett.* 9(5): 055007.

Mtahiko MGG, Gereta E, Kajuni AR, Chiombola EAT, Ng'umbi GZ, Coppolillo P and Wolanski E 2006 Towards an ecohydrology-based restoration of the Usangu wetlands and the Great Ruaha River, Tanzania. *Wetlands Ecol. Manage.* 14: 489-503.

Mutayoba E, Kashaigili JJ, Kahimba FC, Mbungu W and Chilagane NA 2018 Assessment of the impacts of climate change on hydrological characteristics of the Mbarali River sub catchment Using high resolution climate simulations from CORDEX regional climate models. *Appl. Phys. Res.* 10(5): 61-73.

Neves GL, Barbosa MA, Anjinho PS, Guimarães TT, Filho JV, Mauad FF 2020 Evaluation of the impacts of climate change on streamflow through hydrological simulation and under downscaling scenarios: case study in a watershed in Southeastern Brazil. *Environ. Monit. Assess.* 192(11): 707.

Qin P, Xu H, Liu M, Du L, Xiao C, Liu L and Tarroja B 2020 Climate change impacts on Three Gorges Reservoir impoundment and hydropower generation. *J. Hydrol.* 580: 123922.

Quansah JE, Naliaka AB, Fall S, Ankumah R and Afandi GE 2021 Assessing future impacts of climate change on streamflow within the Alabama River basin. *Climate* 9: 55.

Randall DA, Wood RA, Bony S, Colman R, Fichefet T, Fyfe J, Kattsov V, Pitman A, Shukla J and Srinivasan J 2007 Climate models and their evaluation. The physical Science Basis, Cambridge University Press, Cambridge, United Kingdom and New York.

SAGCOT 2011 Southern Agricultural Growth Corridor of Tanzania Investment Blueprint. Dar es Salaam.

Shrestha S, Bajracharya AR and Babel MS 2016 Assessment of risks due to climate change for the upper Tamakoshi hydropower project in Nepal. *Clim. Risk Manage.* 14: 27-41.

Taye MT, Willems P and Block P 2015 Implications of climate change on hydrological extremes in the Blue Nile basin: a review. *J. Hydrol.: Region. Stud.* 4: 280-293.

Wakigari SA 2017 Evaluation of conceptual hydrological models in data scarce region of the Upper Blue Nile Basin: Case of the Upper Guder catchment. *Hydrology* 4(4): 59.

Watts G, Battarbee RW, Bloomfield JP, Crossman J, Daccache A, Durance I, Elliott JA, Garner G, Hannaford J, Hannah DM, Hess T, Jackson CR, Kay AL, Kernan M, Knox J, Mackay J, Monteith DT, Ormerod SJ, Rance J, Stuart ME, Wade AJ, Wade SD, Weatherhead K, Whitehead PG, and Wilby RL 2015 Climate change and water in the UK–past changes and future prospects. *Progr. Phys. Geogr.: Earth Environ.* 39(1): 6-28.