



Uncertainties Associated with Climate Change Projections on Future Water Resources in Kilombero River Basin, Tanzania

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Abstract While there have been efforts in improving climate change impact uncertainty using ensembles of climate models, there has been less focus on the combined effect of climate models and hydrological model uncertainty. In this study, the impact of climate change on the hydrological regime of the Kilombero River Basin was evaluated. The hydrological model, Soil and Water Assessment Tool (SWAT) was forced with identical climate data and calibrated against river discharge using automatic calibration routine within the SWAT calibration and uncertainty program (SWAT-CUP). Satisfactory model performance result, with daily NSE value of 0.82 was obtained. The results from the hydrological models were utilized to project the effect of climate change on river discharge and other water balance components as given by ensemble mean from Regional Climate Models (RCMs) given by CORDEX-Africa for the two Representative Concentration Pathways (RCPs), namely RCP4.5 and RCP8.5 emission scenarios. The RCM projections of change in monthly rainfall, temperature, potential evapotranspiration, actual evapotranspiration, and total water yield were estimated by comparing the two future time slices (near future [2031-2060] far future [2071-2100]) climate conditions to the reference (historical) period (1957-2005). Results indicated a pronounced wetter future in combination with hotter future. Rainfall and water yield are expected to increase by 17% and 25% for the RCP4.5 and RCP8.5 respectively. The potential evapotranspiration on the other hand is expected to increase between 146 mm and 284 mm across all scenarios. In general, the Kilombero River basin is projected to experience a drier future in some parts of the dry season and moderate to severe flood events during the rainy season. Therefore, wise water management is needed within the basin to properly use and save the potentially occurring water benefit during the rainy season to make it available for consumption during the more pronounced dry periods. Such water could be used to promote the dryland agriculture thereby improving the livelihood of the people living in the study area.

Keywords: · Climate Change, Water Resources, Uncertainty, SWAT Model, Representative Concentration Pathways, Future Projection.

1 Introduction

Climate variability is one of the main active environmental factors significantly affects water resources. Specifically, climate variability brings distinct changes on hydrological regimes and influences spatio-temporal variations of water resources in a region. For example, the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) reported that, almost every region across the world had experienced a warming climate in the past half century (IPCC, 2014). The

rising temperature together with altered rainfall intensity and patterns would have substantial hydrological consequences like aggravating the hydrological cycle and increasing the number of occurrence of hydrological extremes (i.e. floods and droughts), particularly in the arid regions where the shortage of water resources substantially limits the local agricultural and economic developments.

Several studies have been conducted worldwide to investigate the impacts of climate change on water

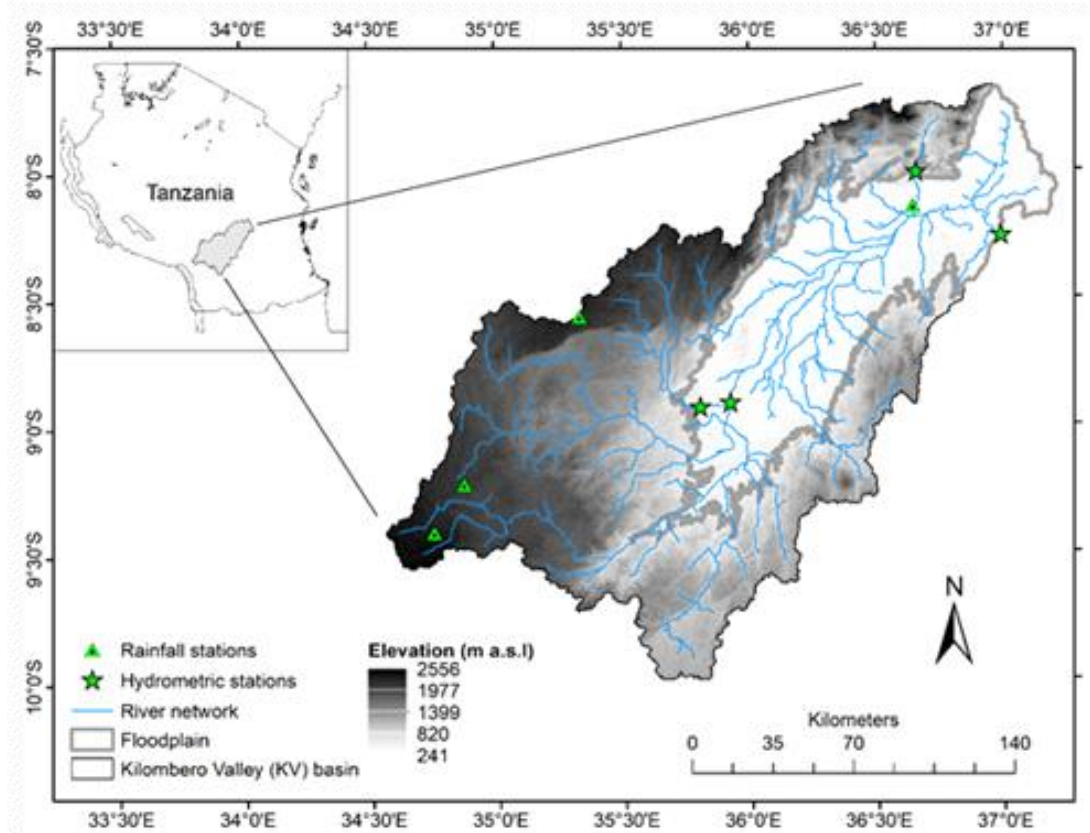


Figure 1: Location map of Kilombero River Basin

resources, agriculture and related fields (Setegn et al., 2011; Zhang et al., 2016; Adhikari et al., 2017; Getachew et al., 2021). The number of climate change studies worldwide and what have been studied in those studies have been reported in Klingelhöfer et al. (2020).

Tanzania like many other countries in Eastern Africa has experienced changes on hydrological regimes (e.g. water resources) due to climate variability. However, few studies have been conducted to investigate the impacts of climate variability on water resources in Tanzania (Tumbo et al., 2010, 2012; Natkhin et al., 2015; Näschen et al., 2019). Therefore, more studies on climate variability are needed as findings from such studies are helpful in understanding the causes of variations in hydrological regimes and in developing robust adaptation measures.

Amongst the areas where impacts of climate variability need to be studied is the Kilombero River Basin of the southern central part of Tanzania. The basin is characterized by the presence of endangered Ramsar site (<https://www.ramsar.org/>) containing

considerable biodiversity resources. Additionally, the basin is amongst the four clusters designated for implementation of the Southern Agricultural Growth Corridor of Tanzania (SAGCOT) initiatives. The SAGCOT initiatives aim to provide food security in Tanzania through expansion and intensification of agriculture (Senkondo et al., 2018; Msofe et al., 2019).

The main objective of this work was to investigate uncertainties associated with climate change projections on future water resources in Kilombero River Basin, Tanzania. Specifically, this study assessed temperature and rainfall changes, and evaluated the impact of climate changes on the water balance components such as streamflow and evapotranspiration and their associated uncertainties. This was accomplished by applying the hydrological model, Soil and Water Assessment Tool (SWAT) in combination with an ensemble of four regional climate models (RCMs) simulations from the Coordinated Regional Downscaling Experiment (CORDEX) Africa project. Two representative concentration pathways (RCPs), RCP4.5 and RCP8.5 were utilized in these model simulations, to account

for uncertainty with regard to anticipated future developments within the study area.

2 Materials and Methods

2.1 Study Area

The Kilombero River Basin is located in the southern central part of Tanzania (Figure 1) between longitudes 34°33' and 37°02' E and latitudes

7°39' and 10°01' S. The area of the basin is approximately 34,000 km² up to the Swero River gauging station (1KB17) located in the downstream part of the Kilombero River. The main Kilombero River originates from a dense network of tributaries draining the Mbarika and Udzungwa Mountains, and flows through the Kilombero floodplain which contains the largest freshwater wetland (7,967 km²) in East Africa which was designated as a Ramsar site

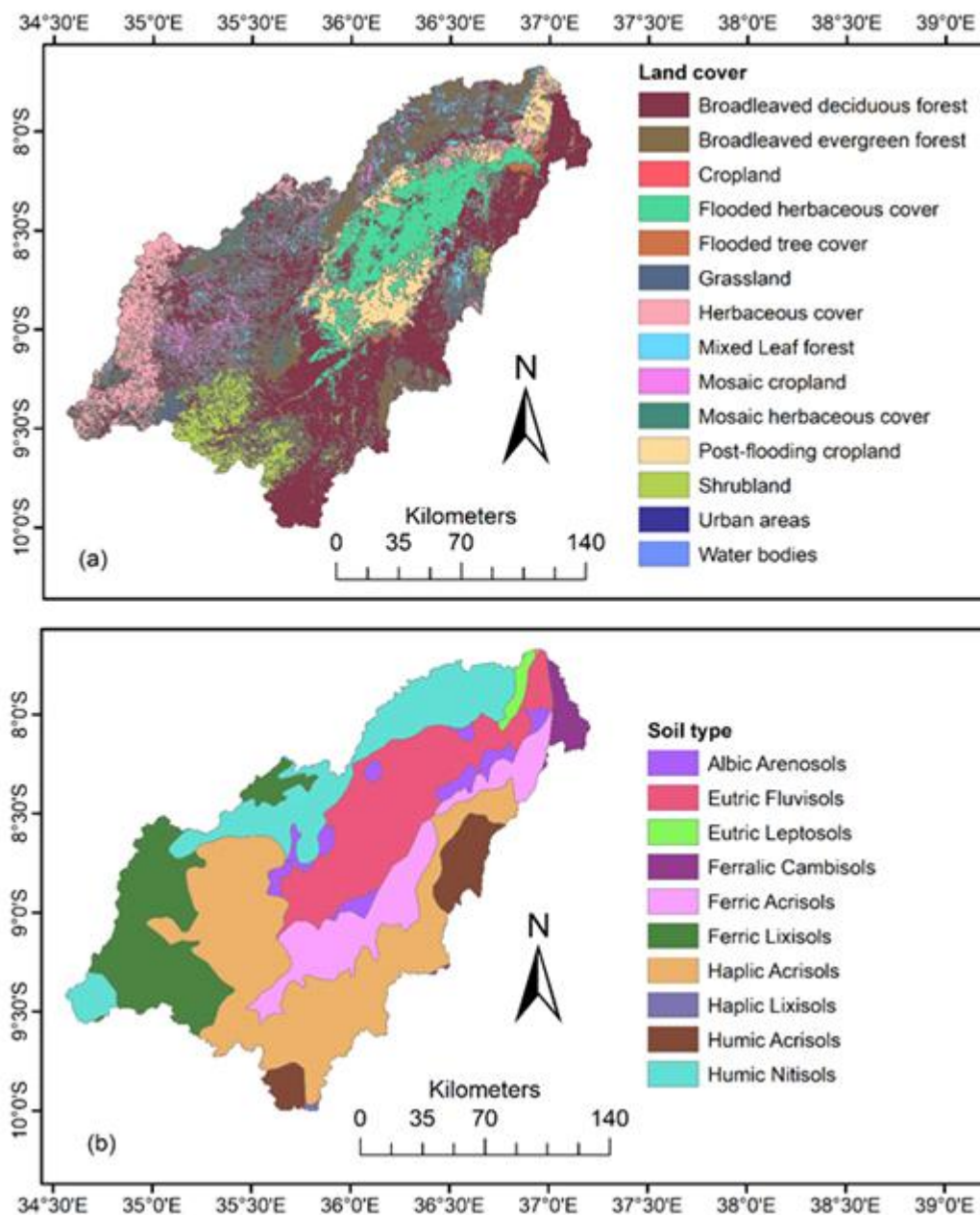


Figure 2: (a) Land use/cover map of the Kilombero River Basin for the year 2015 prepared by the European Space Agency (ESA) Climate Change Initiative Land Cover project (CCI-LC project). (b) Soil map of the Kilombero River Basin retrieved from the Harmonized World Soil Database

in 2002 (<https://www.ramsar.org/>). The north-western part of the basin is characterized by the presence of the Udzungwa Mountains which rise up to 2,576 m above mean sea level and are comprised of steep terrain and dense forests. Along the south-eastern part of the basin, there are Mahenge Plateaus and Mbarika Mountains which rise more gradually and change to a steep escarpment that reach a maximum height of 1,516 m above mean sea level (Lyon et al., 2015). The rock types in the mountainous part of the basin include gneisses, schists, graphite, and crystalline limestone. The lower parts of the basin are underlain by Karoo sediments which include conglomerates, shales, and sandstones (Beck, 1964).

The Kilombero River basin has a sub-humid tropical climate, with a long-term (1998–2010) average annual rainfall between 969 mm and 1,446 mm of which 85% to 90% falls during the wet season from December to April (Koutsouris et al., 2016). This rainfall is the main driver of river discharge within the study area (Yawson et al., 2005). About 60% of rainfall goes back to the atmosphere as evapotranspiration (Näschén et al., 2018). The mean annual temperature is 24°C in the valley bottom and 17°C in the mountainous parts of the basin. According to the 300 m resolution global land cover

geology, and climate are the main factors governing groundwater recharge in the basin. This groundwater recharge originates mainly from infiltration of rainwater at the high altitude (Senkondo et al., 2017).

Recent studies show an increase in population growth, expansions and intensifications of agricultural land, and a decrease of natural vegetation (Leemhuis et al., 2017; Msofe et al., 2019). The establishment of the Southern Agricultural Corridor of Tanzania (SAGCOT) in 2010, which aimed to increase food security and improve livelihoods of people in Tanzania has recently been the main trigger of anthropogenic activities which put more pressure on water resources in the basin (Senkondo et al., 2018). Deterioration of water quality due to return flow from fertilized agricultural fields has been reported in some parts of the Kilombero River Basin (Alavaisha et al., 2019).

2.2 Hydrological Modelling

2.2.1 Overview of SWAT Model

This study used the SWAT model (Arnold et al., 1998) which is a physically-based, spatially semi-distributed, time-continuous, and computationally efficient hydrological model with capability of

Table 1: Datasets used for the hydrological modelling in this study. NA represents ‘not applicable’.

Data	Spatial (temporal) resolution	Source (URL)
Rainfall	Point (daily)	Rufiji Basin Water Office (RBWO)
Climate	Point (daily)	Rufiji Basin Water Office (RBWO)
Digital Elevation Model (DEM)	90 m (NA)	http://srtm.csi.cgiar.org/
Land cover	300 m (NA)	http://maps.elie.ucl.ac.be/CCI/viewer/
Soil	1 km (NA)	http://www.fao.org/

map delivered by European Space Agency (ESA) Climate Change Initiative (CCI) (<http://maps.elie.ucl.ac.be/CCI/viewer/>, accessed on March 15, 2021), there are 14 primary land cover classes in the study area (Figure 2), among which the forest occupies more than 80% of the total area. Cropland covers around 13% of the study area with rice, sugarcane and maize being the main crops grown in the area. Based on the Harmonized World Soil Database (Dewitte et al., 2013), the predominant soil types in the study area are Acrisols, Fluvisols, Lixisols, and Nitisols (Figure 2). Geomorphology,

simulating physical processes associated with movements of water, sediments, plant growth, nutrient cycling, and pesticides, based on weather, vegetation properties, soil properties, topography, and land management practices at the hydrological basin (watershed/catchment) scale. SWAT divides a hydrological basin into multiple sub-basins using topographical information derived from a digital elevation model (DEM). These sub-basins are further subdivided into hydrological response units (HRUs) – unique (homogeneous) combinations of land use type, soil type, and slope class – over which simulation of

the hydrological processes take place (i.e., at HRU level). Flows from different HRUs are then aggregated to sub-basin level where routing through the channel system is represented using either the Muskingum method or the variable-rate storage method (Arnold et al., 1998).

The SWAT model was selected in this study because of its relatively minimum input data requirements and its robustness in providing continuous, long-term simulations. In addition, SWAT has been widely applied in different spatial scales across different climatic conditions and ecosystems all over the world (e.g., in Gabiri et al., 2019; Wambura et al., 2018; Zhang et al., 2016; Setegn et al., 2011; Ndomba et al., 2008) and proved to be an effective tool to produce reliable information on water resources which could be used for sustainable water resources planning, development, and management. Most importantly, SWAT model has been utilized successfully in several catchments in Tanzania where the study area of this current study is located (e.g. in Näschen et al., 2019; Kishiwa et al., 2018; Alemayehu et al., 2017; Natkhin et al., 2015; Mulungu and Munishi, 2007).

2.2.2 Modelling Data

Scarcity of observed data is a major challenge for hydrological modelling in East Africa (Senkondo et al., 2018). For example, there was no recent (2010's) observed streamflow records available in the Kilombero River Valley. The longest period with reasonably good quality (quality check was analyzed based on visual inspection of the streamflow hydrograph for erroneous reported data) daily observed discharge data was monitored from 1960 to 1966. The relatively old daily observed rainfall data spanning from 1957 to 1966 for four ground-based rainfall stations (Figure 1) obtained from Rufiji River Basin Water Office (RRBWO) were used (without alterations) as meteorological forcing data in model development. Based on the modeling study conducted by Senkondo (2020) in the same study area, there was no significant change in the model performance when the relatively old data replaced the relatively new data. This study adopted the global land-use map for the year 2015 prepared by the European Space Agency

(ESA) Climate Change Initiative (CCI) in collaboration with the University of Louvain (<http://maps.elie.ucl.ac.be/CCI/viewer/>). The map has a spatial resolution of 300 m by 300 m and was prepared using satellite images of Medium Resolution Imaging Spectrometer (MERIS) sensor onboard the Environmental Satellite (ENVISAT). The soil map used for the study area was extracted from the Harmonized World Soil Database (HWSD) (Dewitte et al., 2013) established by International Institute for Applied System Analysis (IIASA) and the Food and Agriculture Organization (FAO) in partnership with ISRIC-World Soil Information, the European Soil Bureau Network, and the Institute of Soil Science, Chinese Academy of Sciences. Overview of the datasets applied in this study, their resolution, and their sources are shown in the Table 1.

2.2.3 Model Set up and Performance

Kilombero River Basin was delineated using a 90 m resolution DEM within ArcSWAT2012 (revision 664) in the ArcGIS 10.2 (ESRI) interface. The DEM was freely downloaded from the Shuttle Radar Topography Mission (STRM) website (<http://srtm.csi.cgiar.org/>). The basin was subdivided into 67 sub-basins to differentiate areas of the basin with dissimilar impact on hydrology. The sub-basins were subdivided into 912 hydrologic response units (HRUs) with unique combinations of land-use classes, soil types and land-slope classes.

Reference Evapotranspiration (ET_r), and surface runoff were computed using the Penman-Monteith method (Monteith, 1965) and the Soil Conservation Service Curve Number (SCS-CN) method (USDA, 1972) respectively. Streamflow (channel flow) routing was done using the variable storage method. The SWAT model was run on monthly time step for the simulation period starting from 1957 to 1966 including three years (1957–1959) of warm-up to produce the default simulation. The default simulation was then calibrated and validated automatically using the Soil and Water Assessment Tool Calibration and Uncertainty Programs (SWAT-CUP; Abbaspour, 2015). Initial model parameters selection was done by reviewing literature (e.g. Odusanya et al., 2019; Pomeon et al., 2018; Alemayehu et al., 2017; Tobin

Table 2: Ranking of the calibrated model parameters, based on their sensitivity and significance. A “v” under the method column indicates a replacement of the initial model parameter value with the given value under the fitted value column, and an “r” indicates a relative change to the initial parameter value.

Rank	Parameter	Description	Method	Fitted value
1	RCHRG_DP.gw	Deep aquifer percolation fraction [-]	v	0.349
2	ALPHA_BF.gw	Base flow alpha factor [days]	v	0.279
3	SOL_AWC().sol	Available water capacity of the soil layer [mm H ₂ O/mm soil]	r	0.196
4	GW_REVAP.gw	Groundwater “revap” coefficient [-]	v	0.031
5	GWQMN.gw	Threshold depth of water in the shallow aquifer for return flow to occur [mm]	v	2641.877
6	SOL_Z().sol	Depth from soil surface to bottom of layer [mm]	r	0.196
7	ESCO.hru	Soil evaporation compensation factor [-]	v	0.379
8	SOL_K().sol	Saturated hydraulic conductivity [mm/h]	r	1.305
9	REVAPMN.gw	Threshold depth of water in the shallow aquifer for “revap” to occur [mm]	v	495.97
10	SLSUBBSN.hru	Average slope length [m]	r	0.076
11	SURLAG.bsn	Surface runoff lag coefficient [days]	v	13.303
12	CN2.mgt	Curve number for moisture condition II [-]	r	-0.167
13	GW_DELAY.gw	Groundwater delay time [days]	v	14.872
14	FFCB.bsn	Initial soil water storage expressed as a fraction of field capacity water content [-]	v	0.36
15	OV_N.hru	Manning’s “n” value for overland flow [-]	r	138.93
16	EVLAI.bsn	Leaf area index at which no evaporation occurs from surface water [-]	v	1.296
17	CH_K2.rte	Effective hydraulic conductivity in the main channel [mm/h]	v	324.712
18	EPCO.hru	Plant uptake compensation factor [-]	v	0.766
19	CANMX.hru	Maximum canopy storage [mm]	v	11.111
20	CH_N2.rte	Manning’s “n” value for the main channel [-]	v	-0.006
21	CH_K1.sub	Effective hydraulic conductivity in the tributary channel [mm/h]	v	146.512

and Bennett, 2017; Abbaspour et al., 2015) to identify model parameters which in/directly affect flow and/or evapotranspiration (ET). The final model parameters (Table 2) selection was done based on the global sensitivity analysis (Abbaspour et al., 2015) which was performed within the SWAT-CUP. It is noteworthy, an expert judgement was also used to choose these 21 parameters to ensure that almost all dominant hydrological processes (e.g. interception, runoff, transpiration, and percolation) were represented during the model calibration.

Nash-Sutcliffe Efficiency (NSE) was used to evaluate the agreement between the simulated data and the observed data. The recommended metrics for

a monthly time step based on Moriasi et al. (2007) are $NSE > 0.50$ in which 1.0 is the perfect value. Mathematical expression for this performance metric is given in Equation 1.

$$NSE = 1 - \frac{\sum_{i=1}^n (O_i - S_i)^2}{\sum_{i=1}^n (O_i - \bar{O})^2} \quad (7)$$

Where O is the observed variable being evaluated, S is the simulated variable being evaluated, $\bar{O}$ is the mean of O , $\bar{S}$ is the mean of S , i is the index, n is the total number of observations.

2.3 Predicting future climate conditions in the Kilombero River Basin

Likely future climate conditions in the Kilombero River basin were explored using state-of-the-art regional climate models (RCM's). These were obtained by dynamically downscaling global climate models, making them better suited for describing local and regional climate conditions. To deal with inherent uncertainties connected to future climate predictions, the RCM's were combined with different greenhouse gas (GHG) emission scenarios. The input data for the climate prediction analyses originated from the CORDEX database (COordinated Regional Climate Downscaling Experiment). Overall, three different regional models (CCCma_CanESM2_SMHI, ICHEC-EC-EARTH_SMHI, and MIROC_MIROC5_SMHI) based on two different GHG emission scenarios, RCP4.5 and RCP8.5, were utilised in this study. IPCC (2014) differentiate three RCPs, namely, RCP2.6, RCP4.5 and RCP8.5, which represent very low future emissions, low to moderate future emissions, and very high future emissions

respectively. It was clearly indicated that the difference between RCP2.6 and RCP4.5 remain relatively small until the end of the century. Therefore, based on those facts, this study opted to use RCP4.5 and RCP8.5 scenario. Notably, emission scenario RCP8.5 is the business as usual scenario and is currently regarded as the most realistic, since the recent developments in greenhouse gas emissions closely follow this scenario.

Climate predictions for temperature and rainfall from the ensemble mean of these RCMs were analysed by comparing the reference (Baseline Period) period 1960–2015 with two future time slices in respectively the near future (2031–2060), and the far future (2071–2100). Results were analysed as monthly mean values for each 30-year period in order to get robust climate signals.

2.4 Predicting future hydrological impacts in the Kilombero River Basin

Based on the projected future changes in temperature and rainfall, a water resources impact

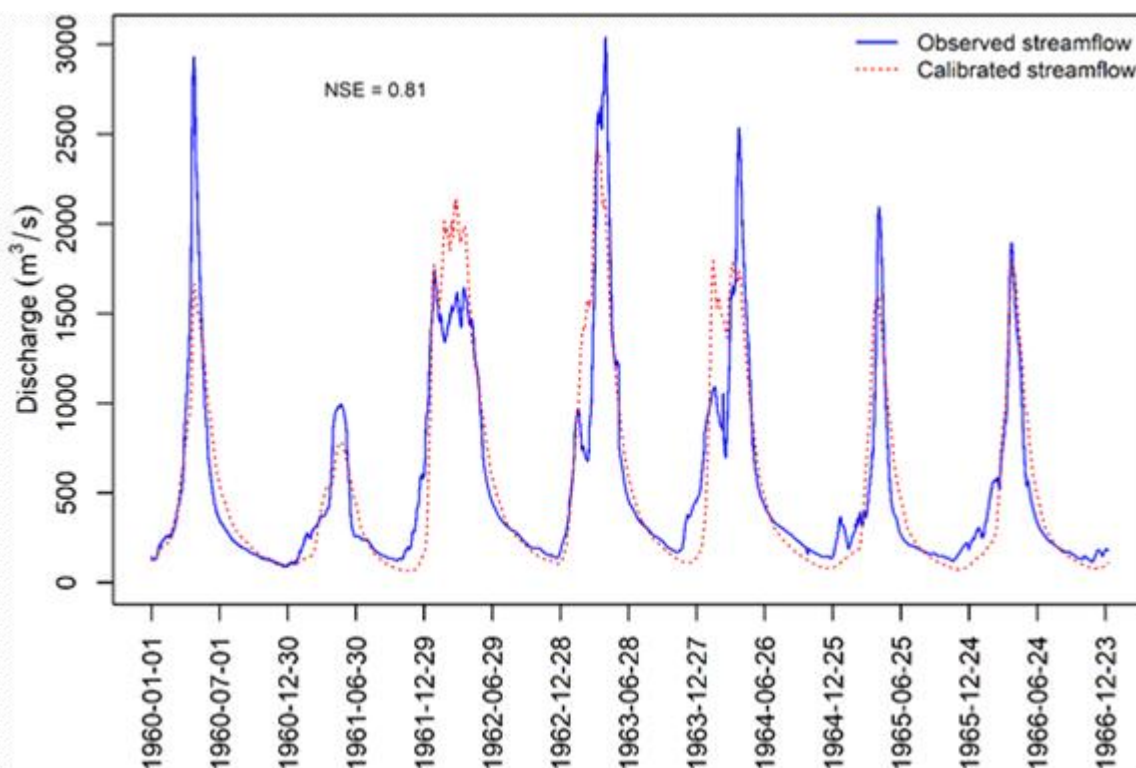


Figure 3: Streamflow hydrograph showing the observed and the calibrated streamflow for the Kilombero River at Swero gauging station. Statistical metric is shown within the graph and refer to the Nash-Sutcliffe Efficiency (NSE)

assessment was undertaken using the SWAT model, set up and calibrated specifically for the Kilombero River Basin. The impact assessment evaluated the likely future flows in the Kilombero River basin based on the future climate predictions. It only considered the changes in water resources related to climate and water use consumptions (specifically for irrigated agriculture). While such a scenario is not necessarily realistic, it gives a good idea of climate driven impacts.

3 Results and Discussion

3.1 Model Performance

The dynamics of the streamflow discharge for the calibration period is captured well (Figure 3), with reasonable model performance statistic (NSE = 0.81) recommended by (Moriassi et al., 2007). Deductions in model performance can be attributed to overestimations of streamflow discharge in some years (e.g. 1961 and 1965) and inaccuracies in simulating extremes discharge (i.e. discharge peaks and low flows). The fact that, 4 out of the first 5 most model sensitive parameters related to groundwater, the importance of groundwater contribution to the basin is paramount, which suggests the importance of proper management of the groundwater resource in the Kilombero River Basin. Similar results were reported by other researchers [e.g. (Koutsouris and Lyon, 2018; Näschen et al., 2018)]

3.2 Future Climatic Projections for the Kilombero Basin

3.2.1 Temperature

The pattern of the basin-wide average monthly temperature of the Kilombero River Basin fits very well to the sub-humid tropical system (Figure 4a). The minimum temperatures decreased from March to July, which can partly be attributed to cooling by ET and shifts in the share of latent heat and sensible heat. The minimum temperatures start to rise in July from around 16.0 °C to around 20 °C in November (Figure 4a). The maximum temperatures increase from July until the end of October, which is the beginning of the short rains in the studied area, when cooling by ET took place (Senkondo et al., 2019). A similar trend was obtained by Näschen et al. (2019), who

associated the rise of minimum and maximum temperatures around July to an increasing share of sensible heat energy together with decreasing cloud coverage in the basin. Therefore, the bias-corrected historical temperature data, captured very well the pattern of a seasonal sub-humid tropical system of the region. Additionally, water availability in the basin was indirectly captured very well by the shift in actual and potential ET.

It is clear that the future of the basin is very uncertain as the projected changes in basin-wide mean monthly temperatures for both RCP4.5 and RCP8.5 show the wide ranges [0.3 to 1.9 °C for RCP4.5 and 0.7 to 3.3 °C for RCP8.5] (Figure 4b and 4c). The changes in both minimum and maximum monthly temperatures are expected to rise above 1.7 °C under the RCP8.5 in all Months in the far future (2071 to 2100). Generally, the temperature signal shows a vivid trend of rising under both near (2031-2060 and far (2071-2100) future across both scenarios (i.e. RCP4.5 and RCP8.5), which implies the hotter future.

3.2.2 Rainfall

The behavior of the basin-wide long-term historical (1957-2005) mean monthly rainfall of the Kilombero River Basin (Figure 5a) fits very well to the temporal rainfall dynamics such as the onset and ending of dry and wet seasons (Koutsouris et al., 2016; Senkondo, 2020). The dry season starts from June and ends in October and the wet season starts in December and ends in April. May and November are transition Months from wet to dry and dry to wet seasons respectively (Koutsouris et al., 2016; Lyon et al., 2015). In July and August, the basin receives less than 5 mm of rainfall (Figure 5a), which implies that, these are the driest Months in the basin. On the other hand, the basin receives the highest rainfall (around 300 mm) in March (Figure 5a).

Results of projected changes in rainfall under both near (Figure 5b) and far (Figure 5c) futures across both scenarios RCP4.5 and RCP8.5, show no significant signal towards shortening or an extension of the wet or dry seasons. In the far future, under the RCP8.5 (Figure 5b), rainfall amounts seem to increase (between around 17 mm [in December] and around 130 mm [in March]) within the rainy season, which

implies the wetter future. In contrast, the rainfall amounts primarily decrease (between around -18 mm season and drier future during the dry season) to some extent, show uncertainty in the projected rainfall

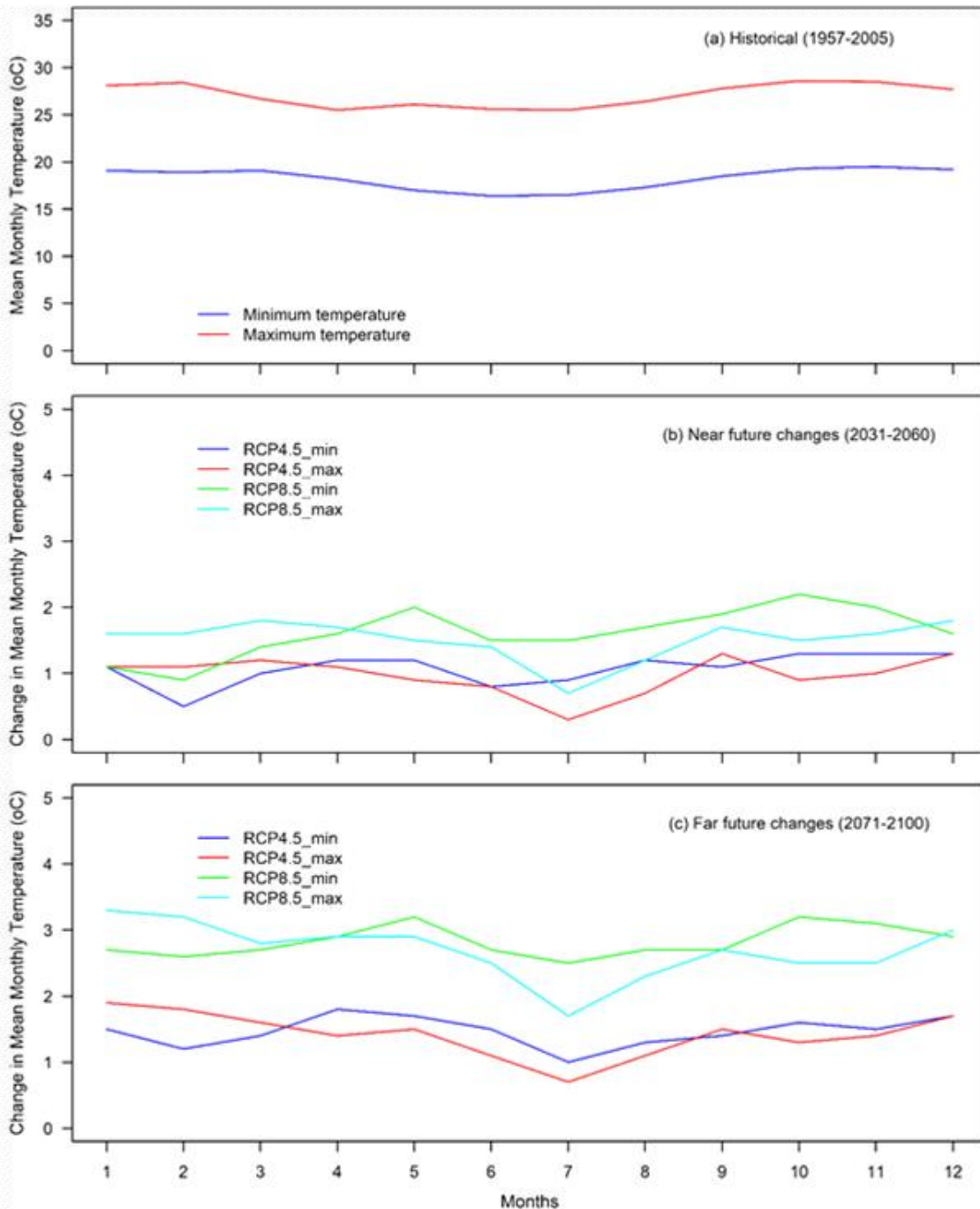


Figure 4: Bias-corrected historical (1957-2005) mean monthly temperature (a), near future (2031-2060) temperature change signal for scenarios RCP4.5 and RCP8.5 (b), and far future (2071-2100) temperature change signal for scenarios RCP4.5 and RCP8.5 (c) in the Kilombero River Basin. All values represent basin-wide average.

[in May] and around 0.0 mm [in August] within the dry season, which implies the drier future. These two antagonistic results (i.e. wetter future during the wet

signals based on the RCMs provided by the CORDEX-Africa. Nevertheless, these results suggest that, the increased amount of water during the wet

season should be stored (e.g. by construction of dams) and carefully used (e.g. for irrigation, water supply, hydropower, etc.) during the dry season.

3.2.3 Water Resources

The changes in rainfall indicate the wetter future

(Table 3) with an increase ranging between 17% (for the RCP4.5 [2071-2100]) and 25% (for the RCP8.5 [2071-2100]). The changes in water yield also show similar trend as the changes in rainfall, which highlights consistent in the projected wetter future. The potential evapotranspiration is increasing across

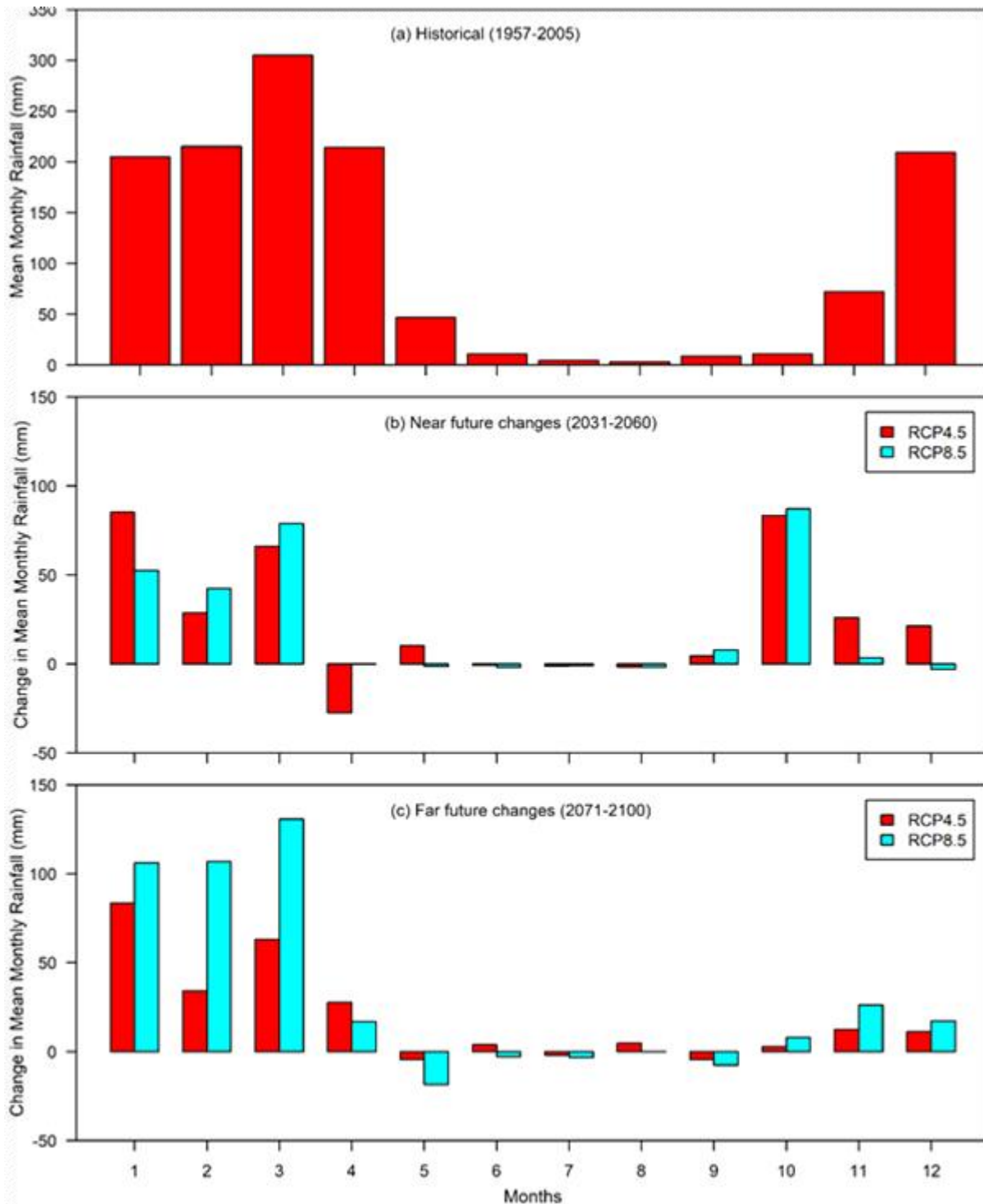


Figure 5: Bias-corrected historical (1957-2005) monthly rainfall (a), near future (2031-2060) rainfall change signal for scenarios RCP4.5 and RCP8.5 (b), and far future (2071-2100) rainfall change signal for scenarios RCP4.5 and RCP8.5 (c) in the Kilombero River Basin. All values represent basin-wide long-term average monthly rainfall for the given periods.

all scenarios between 146 mm and 284 mm. In contrary, changes in the actual evapotranspiration show the mixing results among the RCPs scenarios with the relatively higher values under the RCP4.5 (for both near and far futures) scenarios compared to their corresponding values under the RCP8.5 scenarios. The relatively low values in the actual evapotranspiration, might partly be attributed to the increase in temperature and the spatio-temporal water deficit (Figure 4).

The projected streamflow discharge at the outlet of the Kilombero River Basin, shows consistent increasing across all scenarios with the clear increase during the wet season and little increase during the dry season (Figure 6). Unlike Näschen et al. (2019), who found a temporal shift in the peak of high flow from April to May, this current study finds no temporal shift in peak of the high flow. Our finding is similar to the findings reported by other researchers who study climate changes across the regions (e.g. Adhikari et al., 2017; Getachew et al., 2021).

3.3 Uncertainties Associated with Climate Change Impacts on Water Resources

It is clear that there are several uncertainties in the

evaluations (Abbaspour et al., 2007; Blöschl et al., 2019; Kapangaziwiri et al., 2012; Tumbo and Hughes, 2015; Westerberg and McMillan, 2015), the fact that this study compare the future projections to the historical simulation (which is the standard approach in the climate change studies), to some extent, suggests the cancelation of most of the aforementioned uncertainties. Therefore, most of uncertainties found in this study could be associated with climate change impacts.

Overall, the simulated scenarios in this study suggests a pronounced wetter future for the Kilombero River Basin (Table 3). The consistent increasing in the average annual rainfall in both near and far future time slices and across all scenarios, and the increasing in the water yield (Table 3) underline the wetter future. Similar finding was also reported by (Näschen et al., 2019). The rising of temperature across RCPs scenarios (Figure 4) causes the increase in the potential evapotranspiration, within the basin (Table 3). The relatively low actual evapotranspiration (Table 3) could partly be explained by temporally availability of water (Koutsouris et al., 2016) and the higher sensible heat compared to latent heat which is responsible for evaporation (Tadesse

Table 3: Historical mean annual rainfall based on the ensemble mean of bias-corrected RCM simulations (1957–2005) and the absolute and relative changes of rainfall, and corresponding impacts on selected water balance components in SWAT model simulations for near future (2031-2060) and far future (2071-2100) time horizons based on the projections under the RCP4.5 and RCP8.5 scenarios. The numbers in parentheses represent the percentage changes. P represents the rainfall, PET the potential evapotranspiration, ETa the actual evapotranspiration, and WYLD the total water yield.

Scenario/Variable	RCP4.5	RCP8.5		
	(near)	RCP4.5 (far)	(near)	RC8.5 (far)
Historical P (mm)	1351.1	1351.1	1351.1	1351.1
Change in P [mm (%)]	244.4 (18.1)	236.7 (17.5)	262.9 (19.5)	346.8 (25.7)
Change in PET [mm (%)]	146.8 (11.8)	183.4 (14.7)	190.9 (15.3)	284.3 (22.9)
Change in ETa [mm (%)]	20 (3.9)	13.4 (2.6)	1.9 (0.4)	-0.8 (-0.2)
Change in WYLD [mm]				

results presented in this study. For example, estimates of water balance components under RCP4.5 and RCP8.5 scenarios for the same simulation period (e.g. 2031-2060) are different (Table 3). Though to some extent these uncertainties could partly be attributed to uncertainty in model parameter, uncertainty in input data (climate data), uncertainty in model structure, and uncertainty in observed flow data used for model

Alemayehu et al., 2017; Alemu et al., 2014; Senkondo et al., 2019).

Based on the changes in the rainfall signals as described under the section 3.2.2 above together with the increasing in high flow (Figure 6), the future of Kilombero River Basin might experience moderate to severe floods especially during the rainy season. On

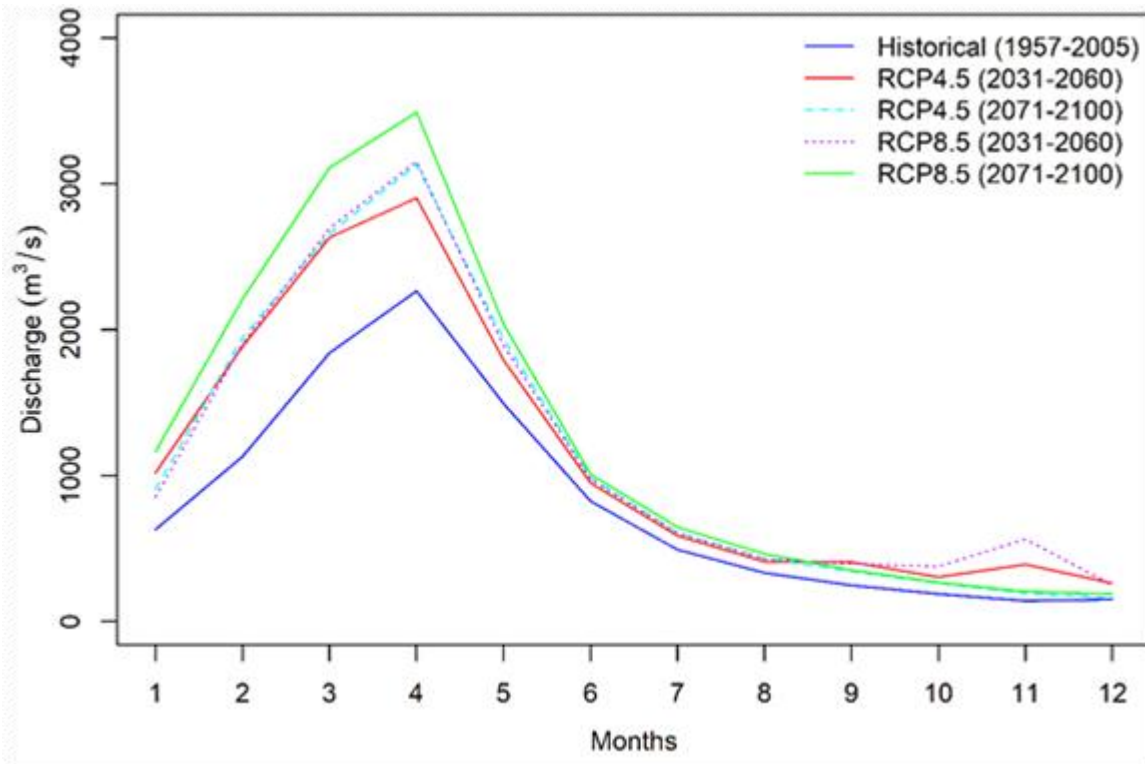


Figure 6: The long-term simulated monthly average for the ensemble mean of RCMs historical (1957-2005) climate data, and the long-term simulated monthly average discharges for the near future (2031-2060) and far future (2071-2100) based on the RCP4.5 and RCP8.5 scenarios.

the other hand, the consistent rising of temperature within the basin due to climate change in combination with low flows during the dry season, suggests the possibility of drought-related risks. Therefore, relevant strategies to manage water resources wisely have to be formulated and implemented. These should go hand to hand with community sensitization on the possible impacts of climate changes on the water resources and the relevant ways to alleviate the negative ones.

The ranges of model results between the two RCPs (RCP4.5 and RCP8.5) for the given time slice (e.g. 2031-2060) or between the single RCP (e.g. RCP8.5) under different time slices (i.e. 2031-2060 and 2071-2100) could be considered as the range of uncertainties in the future of the Kilombero River Basin. For the given variable (e.g. water yield), the lowest and the highest estimates could be taken as the two opposite extremes, when making informed decision(s) on the water resources of the region. Decisions made based on the comparison of these projected extreme estimates will provides a picture of

the uncertainty that water management within the basin has to deal with.

It is worth noting that, there other factors which will pose impacts on the future water resources of the Kilombero River basin. Some of these factors include land use and land cover changes (LULC), dams construction and operations, and water abstractions (Jaramillo and Destouni, 2014). For example, LULC has a tendency of changing the soil hydraulic properties, which in turn influences the amount of water retention, infiltration, surface runoff, flood generation, and soil erosion. The later has negative impact on the water quality (Setegn et al., 2009; Worku et al., 2017). Therefore, there is a need to use climate change results presented in this study in conjunction with LULC change scenarios and other relevant studies to narrow the range of the aforementioned uncertainties.

4 Conclusion

This study predicted the impact of climate change (specifically rainfall and temperature changes) on the

water resources of the Kilombero River Basin using the bias-corrected CORDEX Africa projections for the two future time slices in respectively the near future (2031-2060), and the far future (2071-2100). It applied the two RCPs (RCP4.5 and RCP8.5) to evaluate the outputs. The SWAT model was used to investigate the consequences of climate change on the water resources of Kilombero River Basin. Overall result of the climate impact analysis on water resources suggests a pronounced wetter future especially during the wet season and the relatively hotter future during the dry season compared to the historical simulation. Further insight from the current study suggests a relatively drier future during the dry season compared to the dry season of the historical simulation, which suggests the importance of saving the extra water generated during the wet season for utilization during the dry season. Authors believe that the modelling results presented in this work are plausible estimates of future impacts of climate change in the Kilombero River Basin. Therefore, these results could be used as future indicators to decision makers and other practitioners working in the Kilombero River Basin. Future research should focus on analyzing the best water management strategy to be adopted across the Kilombero River Basin for sustainable agriculture and other water-dependent socio-economic activities.

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