Application of Mann Kendal Sen's Slope Estimator in Trend Analysis of Historical And Future Precipitation and Temperature in the Kilombero River Basin

Ghanima Chanzi
Corresponding Author: ghanimac777@gmail.com
Magreth Bushesha
Open University of Tanzania
magreth.bushesha@out.ac.tz
Subira Munishi
[3]University of Dar es Salaam
evasubira@gmail.com
Adam Karia
Water Institute
adamkaria03@gmail.com

Abstract
This study examines historical (1981-2020) and future (2020-2070) trends in rainfall and temperature in the Kilombero Basin using the Mann-Kendall method with Sen's slope estimator. Data were obtained from the Tanzania Meteorological Agency and from simulated historical and future climate data sourced from the Coupled Model Intercomparison Project 6 (CMIP6). The CMIP6 datasets were downscaled and bias-corrected using the CMhyd tool. The basin exhibited a bimodal rainfall pattern with an average of 1400 mm, peaking around April. The CMIP6 models successfully simulated monthly rainfall, Tmax, and Tmin at most stations. No definitive trends in rainfall were observed, but Tmax and Tmin showed significant increases under both SSP2-4.5 and SSP5-8.5 scenarios. More warming is predicted under SSP5-8.5 by the mid-21st century, raising Tmax and Tmin at all stations. This rise in temperature could potentially increase evapotranspiration demand, negatively impacting freshwater availability. The average annual rainfall showed a slightly increasing trend post-2000, from 1403.96mm/year (1981-1999) to 1433.38mm/year (2000-2020), an increase of 2.05%. Sen's slope analysis, however, revealed varying trends across stations, with most showing a decreasing trend. Notably, only Ulanga Met Station showed a significant increasing trend with a slope value of 14.70 and a p-value below 0.05.

The study concluded that both temperature and precipitation in the Kilombero Basin are on the rise.

Keywords: *Kilombero basin, Mann Kendall, Precipitation, Sen's Slope Estimator, Temperature.*

INTRODUCTION

Analyzing historical and future precipitation and temperature trends is crucial for understanding climate change impacts on water resources, agriculture, and ecosystems within river basins (Islam and Kamruzzaman, 2023). The Kilombero River Basin in southeastern Tanzania exemplifies a region where such assessment is crucial for sustainable water management, land use planning, and climate adaptation strategies. This study uses the Mann-Kendall test and Sen's slope estimator to analyze historical and projected precipitation and temperature data in the basin, providing valuable insights for policymakers, researchers, and stakeholders.

The Kilombero River Basin, featuring diverse ecosystems including wetlands, forests, and agricultural land, supports rich biodiversity and essential services to local communities such as water supply, flood, and climate regulation (Seki, 2018; Mombo, 2018; Monga et al., 2018; Mtega, 2017). The regional economy primarily depends on agriculture and tourism, highlighting the importance of understanding climate-induced changes and their potential impacts on the basin's ecosystems, economy, and communities.

The Mann-Kendall test, a non-parametric statistical method extensively used in hydrology, climatology, and environmental research (Hussain and Mahmud, 2019), also detects monotonic trends in time series data without assuming a specific distribution for the underlying data, thus suitable for analyzing hydrological and meteorological datasets (Curiac and Micea,2023). Sen's slope estimator quantifies the observed trend's magnitude, enabling the quantification of changes in precipitation and temperature over time (Yunfei et al., 2023).

Rainfall is critical in defining the Kilombero Basin's water resources availability (Djan'na et al., 2023). While most parts of Tanzania receive significant rainfall and unsteady temperatures, human activities and local patterns cause annual, monthly, and extreme rainfall intensity variation (Okwir et al., 2023). Studies on rainfall and temperature trends have examined climate change and variability's impact on various sectors (Ayugi and Tan, 2018). However, a declining trend of annual and monthly rainfall has been noticed due to shifts in rainfall and temperature patterns (Sigalla et al., 2023).

Recent rainfall and temperature trends significantly affect agricultural production due to variations in rainy seasons (Alexander, 2016). Both the Mann-Kendall test and Sen's Slope Estimator revealed a downward trend in rainfall and temperature in some locations (Geressu, 2020; Deka, Mahanta, and Nath, 2019). This study aims to analyze daily, monthly, and annual rainfall and temperature trends in the Kilombero River Basin, setting the foundation for a practicable climate change adaptation and mitigation framework and management plan.

METHODS

The Study Area

The Kilombero River Basin, one of four sub-basins in the Rufiji River Basin, is situated between latitudes 7.70 and 10.10 south and longitudes 34.60 and 37.80 east. The river is replenished by multiple rivers, including Lumemo, Luipa, Mngeta, Kihansi, Mpanga, Mnyela, Ruhudji, and Furua (Koutsouris, 2016). The basin area, spanning about 40,330 square kilometers, is home to over 3 million people. Of this total area, 38,000 hectares are developed for agriculture (Näschen, 2018).

The region experiences semi-arid climatic conditions, receiving heavy annual rainfall of approximately 1400 mm. The temperature averages around 21 degrees Celsius. Given the stable rainfall, the area is primarily characterized by agricultural activities and features dense forests in the Mahenge and Udzungwa mountains (Munishi, 2013). This significant rainfall and temperate climate make the basin conducive for farming and forestry, playing a pivotal role in the region's economy and biodiversity (Kato, 2017).

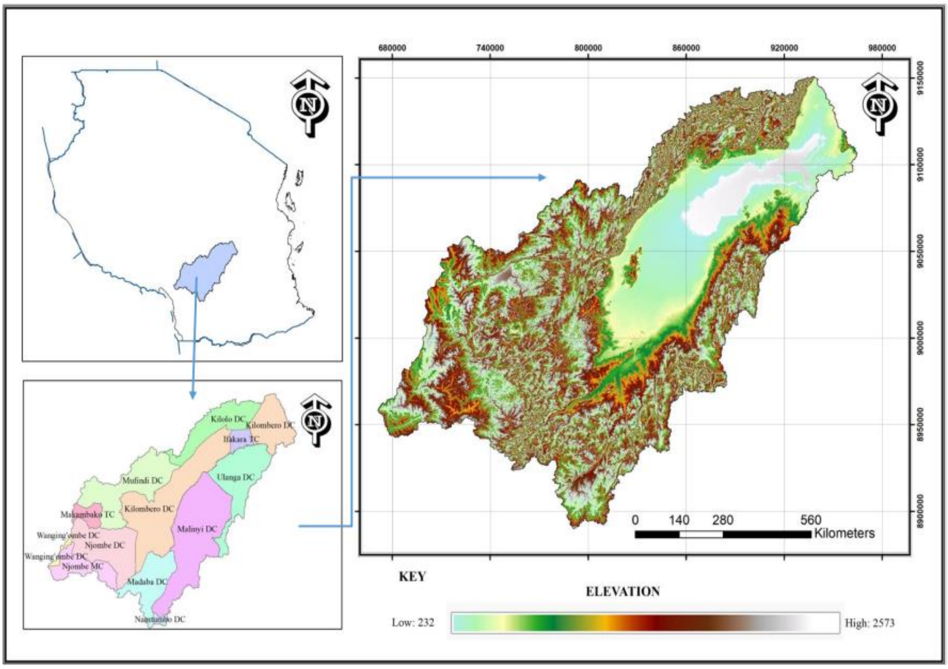


Figure 1: Location of Kilombero River Basin in Tanzania

Data Acquisition

Trend analysis requires extensive time-series data to discern changes in climate patterns and accurately identify rainfall and temperature trends. For this study, daily rainfall data spanning from 1981-2020 were sourced from six Tanzania Meteorological Agency stations within the Kilombero River Basin. For temperature analysis, data from the Iringa Meteorological Station, covering the period from 1981 to 2022, was used. In addition to monthly analysis, annual accumulation of rainfall and temperature data was also analyzed to determine trends. The specific locations of the rain and temperature stations are detailed in Table 1.

A homogeneity test was conducted on the rainfall data from each site using the Climatol package in R, a tool designed for climate analysis. This test, called the Standard Normal Homogeneity Test (SNHT), determined whether the selected rainfall data was randomly distributed or exhibited a specific pattern (Burghof, 2018). The SNHT test revealed no breakpoints in the data series, indicating that they were randomly distributed and homogeneous. This met the requirements for further tests and analyses in the study.

Table 1: Rain and Temperature Stations in the Study area

S/n	Name	Latitude	Longitude	Elevation	Parameter
1	Ifakara	36.68	-8.13	261	Rainfall
2	Malinyi	36.13	-8.93	912	Rainfall
3	Kidatu	36.95	-7.7	274	Rainfall
4	Mlimba	35.81	-8.79	997	Rainfall
5	Ulanga	36.92	-7.29	2509	Rainfall
6	Iringa Station	35.77	-7.633	1428	Temperature

Projection of Rainfall and Temperature Variables from 2020-2070

The Coupled Model Intercomparison Project 6 (CMIP6) is a global climate modeling initiative aimed at improving our understanding of Earth's climate system, evaluating the impacts of human-induced climate change, and informing the development of climate policies and adaptation strategies. Established in 1995 by the World Climate Research Program's (WCRP) Working Group on Coupled Modelling (WGCM), CMIP6 is the latest iteration of the project. Its predecessors, CMIP3 and CMIP5, provided crucial inputs for the Intergovernmental Panel on Climate Change (IPCC) assessment reports (IPCC, 2019).

CMIP6 involves numerous international climate modeling centers that contribute simulations using their advanced Earth System Models (ESMs), adhering to a common experimental protocol. These models represent complex interactions among the atmosphere, ocean, land surface, and cryosphere, incorporating cutting-edge climate science and computing resources. The experimental design of CMIP6 includes core experiments, known as the Diagnostic, Evaluation, and Characterization of Klima (DECK) experiments, and various Model Intercomparison Projects (MIPs) targeting specific research questions and climate phenomena (Luhunga, 2018).

The Shared Socioeconomic Pathways (SSPs) are scenario sets employed in climate change research to explore potential future developments in society, economy, and environment under varying conditions. Designed to facilitate understanding of potential challenges and opportunities related to climate change mitigation, adaptation, and impact assessment, each SSP describes a possible future in terms of demographics, economic growth, technology, energy consumption, land use, and governance.

SSP2-4.5 and SSP5-8.5, two specific SSP scenarios used in this study, are characterized by distinct socioeconomic assumptions and associated greenhouse gas (GHG) concentration pathways, known as Representative Concentration Pathways (RCPs). RCPs describe different levels of radiative forcing, reflecting the change in Earth's energy balance due to human activities, predominantly GHG emissions. In the SSP-RCP notation, the numbers 4.5 and 8.5 represent the radiative forcing in watts per square meter (W/m^2) by the end of the 21st century relative to preindustrial levels.

SSP2-4.5:
SSP2-4.5 is a "middle-of-the-road" scenario, characterized by moderate socioeconomic development and intermediate levels of greenhouse gas (GHG) emissions. This pathway envisions a world undergoing gradual changes in demographics, economic growth, and technological progress, largely following historical trends. The implementation of policies to reduce GHG emissions and adapt to climate change happens at a moderate pace, and international cooperation on climate issues remains relatively stable.

The corresponding Representative Concentration Pathway (RCP) for SSP2-4.5 is RCP4.5. This assumes a stabilization of GHG concentrations by the end of the century, achieved through the execution of moderate mitigation policies. Consequently, this scenario leads to a radiative forcing of 4.5 W/m^2 by 2100. Under the SSP2-4.5 scenario, the projected global mean temperature increase is around 2-3°C above preindustrial levels by the year 2100, although the exact value is dependent on the climate model used and the assumed level of climate sensitivity.

SSP5-8.5:
SSP5-8.5 represents a scenario of high economic growth and rapid technological development, leading to increased energy consumption and a strong reliance on fossil fuels. In this pathway, the world experiences significant improvements in living standards, especially in developing countries, but also faces high levels of income inequality and environmental degradation.

The associated RCP for SSP5-8.5 is RCP8.5, which assumes a continued increase in GHG emissions throughout the century, primarily driven by the extensive use of fossil fuels and the absence of strong climate policies. This scenario results in a radiative forcing of 8.5 W/m² by 2100. Under SSP5-8.5, global mean temperature increase is projected to be around 4-6°C above preindustrial levels by 2100, depending on the climate model used and the level of climate sensitivity assumed. This pathway is often referred to as the "business-as-usual" scenario and represents a high-risk future in terms of climate change impacts, adaptation challenges, and mitigation costs.

The SSP-RCP scenarios, including SSP2-4.5 and SSP5-8.5
These are widely used in climate change research to study the potential consequences of different socioeconomic trajectories and GHG emission levels. By exploring a range of possible futures, researchers can assess the effectiveness of various mitigation and adaptation strategies and inform the design of climate policies to reduce risks and promote sustainable development.

Two datasets are required to forecast the influence of climate change on hydrology: one for developing climate change scenarios and the other for hydrological simulation. Historical daily precipitation (P), maximum and minimum temperatures (Tmax and Tmin), solar radiation, wind speed, and relative humidity from 6 meteorological stations for the period 1985–2018, as well as projected daily precipitation (P), maximum and minimum temperatures (Tmax and Tmin), solar radiation, wind speed, and relative humidity for the period 1985–2018, were used in this study (for both RCP 4.5 and RCP 8.5). However, due to their coarse spatial resolution, the GCM results available for various global areas are inappropriate for assessing watershed-level hydrological consequences (Goyal & Ojha, 2012). Researchers have used weather generators in climate change impact studies to get around this constraint (e.g. to construct time series of climate variables, the delta change methodology with a weather generator is widely employed. Regional climate models' large-scale climatic data from GCMs is reduced to a smaller scale, closer to the catchment scale, by RCMs. Using the output of a global climate model, the regional model simulates data on a basin scale. The weather-producing model, on the other hand, can replicate climatic data from several stations throughout a basin.

Mann-Kendall Test

The purpose of the trend analysis was to evaluate if there has been a significant change in daily rainfall and temperature over the last 40 years and if the chosen timeframe represents the country's historic climatic regime. The Mann Kendall and Sen's slope tests were used to look for a pattern in each rainfall and temperature station's time series record (Nyembo *et al*., 2021). The data were pre-processed to an annual time series to represent annual climatological and hydrological characteristics. Graphical plots were then created as a quick way to spot patterns, each with its own trend line. The research used R software and Sen's slope estimator for the Mann-Kendall test for trend analysis.

The trend in the time series data was examined using the Mann-Kendall test. According to Salmi et al., 2002, stated that the non-parametric rank-based method is the most frequently used approach for the determination of the monotonic trends in climatic time series. Because it does not assume that data is disseminated in any way, it has the same clout as its competitors. The test works as follows: the null hypothesis test H_0 proposed by Mann assumed that the data come from a set of independent variables with equal distributions. Assuming X1, X2, and Xn are a series of data spanning a time period. The data from the H1 alternative hypothesis follows a monotonic pattern over time. The Mann–Kendall test statistic for H_0 is,

$$S = \sum_{i=j}^{n-1} \sum_{j=i+1}^{n} sgn(X_j - X_i) \quad (2.1)$$

Where:

$$sgn(\theta) = \begin{cases} +1 \; if \; \theta > 0 \\ 0 \; if \; \theta = 0 \\ -1 \; if \; \theta < 0 \end{cases} \quad (2.2)$$

Under H_o When n is less than 8, the statistic is roughly normal, and both the mean and variance are zero, as illustrated below:

$$\sigma^2 = \frac{n(n-1)(2n+5)}{18} \quad (2.3)$$

As a result, standardized Z statistics seek to approximate a normal distribution:

$$z = \begin{cases} \frac{S-1}{\sigma} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sigma} & if\ S < 0 \end{cases} \quad \ldots\ldots (2.4)$$

There is a trend when the computed Z value is bigger than the crucial. A positive Z number indicates an upward tendency, whereas a negative number indicates a downward trend (Salmi et al., 2002). The significance criterion for statistical trends is usually set at a 5% confidence level.

Sen's Slope Estimator

To confirm and map trends found by the Mann-Kendall approach, the Theil-Sen Approach (TSA) was used to calculate trend magnitudes. The TSA is preferred over other parametric tests like linear regression because it is more resistant to outliers (Salmi et al., 2002). The median of all pairs of points in the time series is used as the slope estimator (β).

$$\beta = \left(\frac{Yj - Yi}{Xj - Xi}\right) \ldots\ldots (2.5)$$

For all $i < j$ and $i = 1, 2...(n-1)$…………………………………...…. (2.6)
$j = 2, 3\ldots n$

Areal Rainfall

The average rainfall received by the entire catchment was calculated using Thiessen polygons method. The optimal approach to utilize was determined by the data type. Because there are few rainfall stations, the Thiessen polygon methodology was employed to calculate the areal rainfall. Rainfall is not consistently distributed all over the Kilombero basin, and its intensity and duration vary. As a result, using the equation area (2.7) below, the recorded rainfall from each rain gauge is weighted in respect to the polygon;

$$P = \sum_{n=1}^{n} \left(\frac{A_i}{A_T}\right) P_i \ldots\ldots (2.7)$$

Where:

- P - areal rainfall (mm),
- P_i - rainfall gauging station data (mm),
- A_i - an area corresponding to the particular rainfall gauging station (Km^2)

- A_T - total area of the sub-basin (Km^2)
- n - the number of Thiessen polygons.

FINDINGS AND DISCUSSION

Aerial precipitation Analysis

Aerial precipitation analysis is a method used to estimate the spatial distribution of precipitation over a geographical area. This method combines various data sources, such as rain gauge observations, remote sensing, and numerical weather prediction models, to provide a comprehensive understanding of precipitation patterns in a region. The aerial precipitation analysis is essential for a wide range of applications, including hydrological modeling, flood forecasting, drought monitoring, water resources management, and climate studies. In this section, the key components of aerial precipitation analysis was discussed including data sources, interpolation techniques, and validation methods.

Annual rainfall data from 1981 to 2020 for the Kilombero areal rainfall, Ifakara, Kidatu, Kilombero, Malinyi, Mlimba and Ulanga rainfall stations using Mann-Kendall and Sen's slope estimators, to examined the presence of a long trend in the basin and its magnitude. The trend tests were carried out at a 5% significant level. The areal rainfall was then generated based on the Thiessen polygons method (Figure 2).

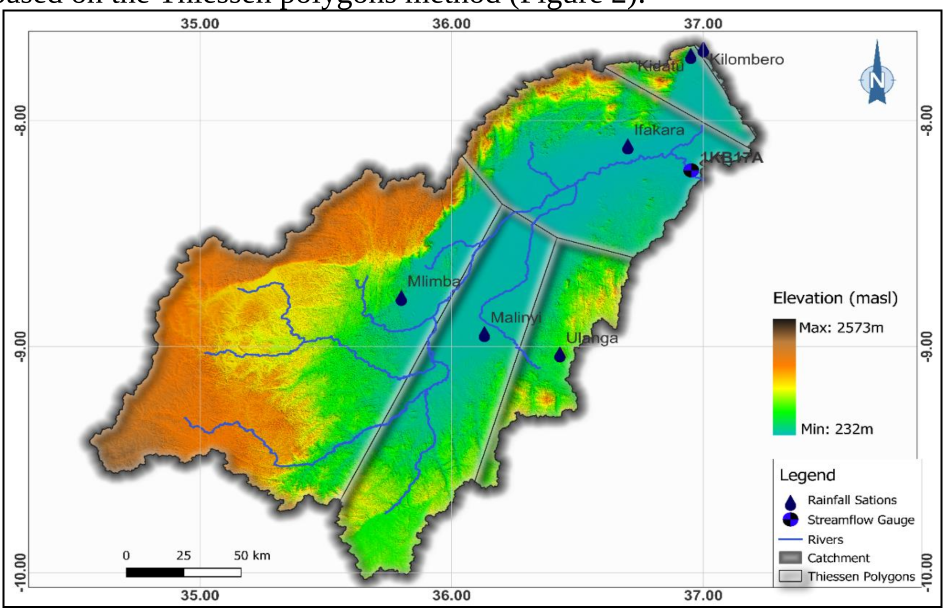


Figure 2: Hydro-climatic Stations and Thiessen polygons

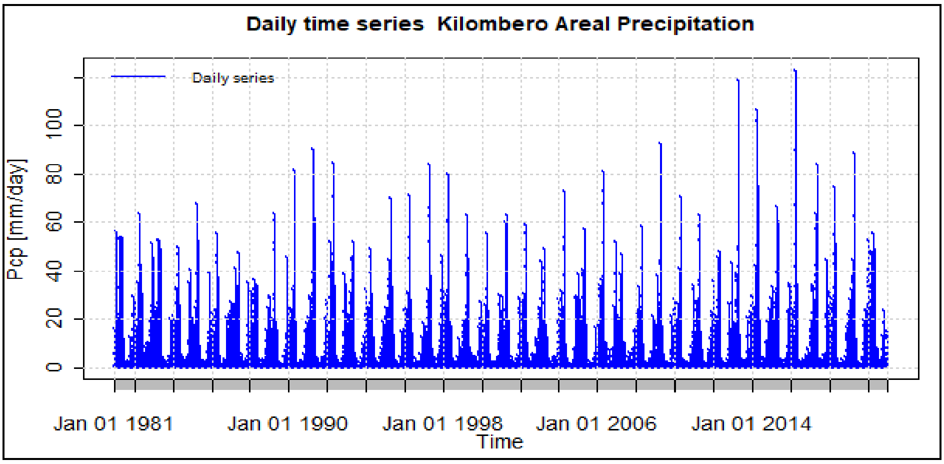


Figure 3: Daily time series of aerial precipitation

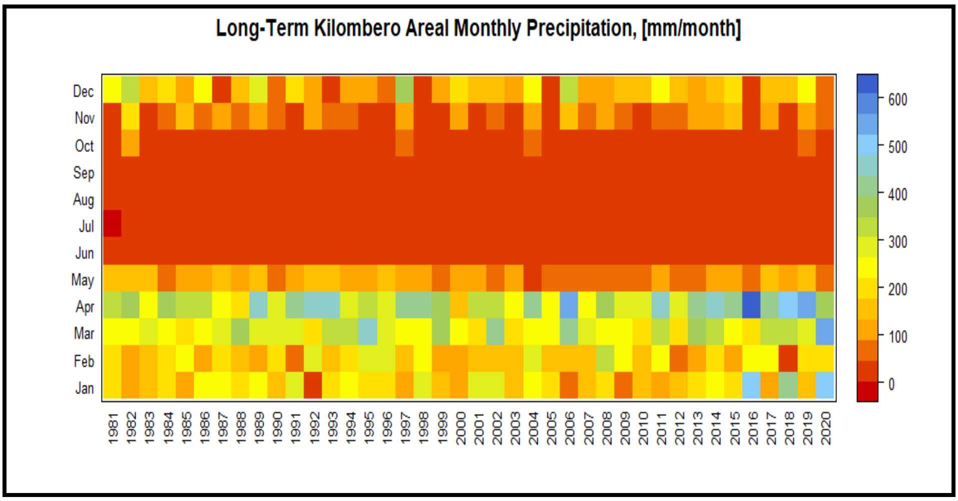


Figure 4: Monthly long term aerial precipitation

Results on the aerial rainfall showed the basin shows a bimodal rainfall pattern, with a mean aerial rainfall of roughly 1400 mm, while the peak rainfall was observed around the month of April Figure 4. The long rains fall between Januarys to May, whereas the short rains fall between Octobers to December. Similarly, Sigalla *et al*., (2023) and Kangalawe and Liwenga, (2015), showed the average rainfall within Kilombero basin range between 1000mm to 1400mm where the reported month of high rainfall intensity is April. It was only the month of April that showed the peak flow from 1989 to 2020. Commonly, rainfall was seen to be decreasing during the months of May, June, July and September while there was an increase in rainfall for the months of March, August, April, December, November and October for extended time (Smith, 2016). The results agreed with Senkondo, (2020) and Sigalla *et al*., (2023) which indicated that rainfall had shown a steady decrease in past ten years. Further, the aerial rainfall varies by more than 200mm in an analysis done for 40 years in areas.

Historical and Future Trend of precipitation

The trend tests were carried out at a 5% significant level. The results showed the Kilombero areal rainfall, Ifakara, Kidatu, Malinyi, and Mlimba stations have a significant increasing trend while Kilombero rainfall station shows a significant decreasing trend. There is significant increasing trend was observed in Ulanga Meteorological Station. Figure 4 and Table 2 shows the graphical trend for the yearly precipitation. Kilombero, Ifakara and Malinyi stations shows no increasing trend in precipitation and according to Sigalla *et al*., (2023), the possible reasons is that these stations located in the area where a lot of human activities which alter the hydrological systems conducted such as agriculture and built-up areas Figure 5. Since the basin plays a vital role in the country's water resources and supports agriculture and wildlife habitats, precipitation trends in the basin are essential to monitor, as they can impact water availability, agricultural productivity, and biodiversity. In Kilombero Basin is, climate models project increased variability in precipitation, with more intense rainfall events and prolonged dry spells in some areas. This may lead to more frequent flooding and droughts, with potential negative impacts on the environment and local communities (Chen, 2017).

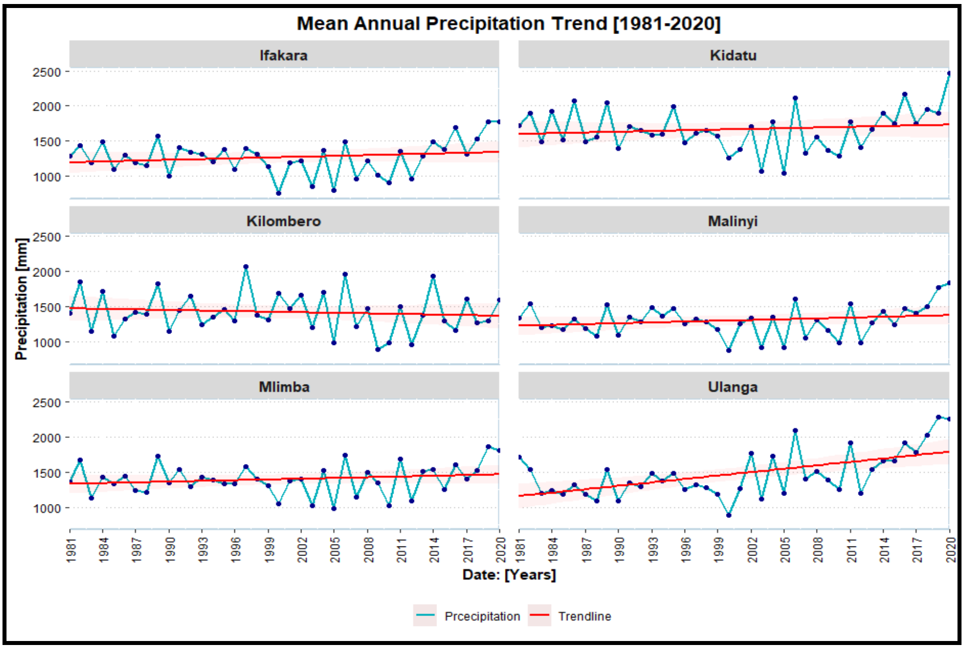


Figure 5: Precipitation trend in different meteorological stations

Table 2: Precipitation and temperature trend in Kilombero Basin Stations

Variable	Sen's Slope	Z	P-Value	Trend
Ifakara	3.68	0.99	0.3220	No Trend
Kidatu	4.44	0.76	0.4489	No Trend
Kilombero	-2.70	-0.55	0.5840	No Trend
Malinyi	3.89	1.04	0.2998	No Trend
Mlimba	4.16	1.20	0.2301	No Trend
Ulanga	14.70	3.23	0.0012	Trend
Areal Precipitation	5.13	1.34	0.1803	No Trend
Areal Max Temperature	0	0.36	0.7162	No Trend
Arael Min Temperature	0.02	1.59	0.11	No Trend
Areal Ave Temperature	0.02	3.55	0.00038	Trend

Note: Z=Mann-Kendall test statistic, β=Sen's slope (Kendall Slope), S=significant at P > 0.05, NS=insignificant at P < 0.05, Positive values of Z indicate an increasing trend, and Negative values indicate a decreasing trend.

On the contrary, according to an analysis done by Sigalla *et al*., 2023; Näschen, *et al*., (2018) and Makingi *et al*., (2017), on rainfall in individual stations from 1980 to 2020 has revealed a decreasing trend in the total precipitation in the Kilombero Basin. In addition, a study by Seki, (2018), which was done in the Kilombero Basin has shown a decreasing trend in annual rainfall with high variability within seasons, which affects farmers in decision making and agro production. Moreover, in Kilombero Basin, according to Senkondo, (2020) has been depicted that there have been variations of rainfall in different seasons which may results to affect the water resources. This also agrees with a study by Borhara, (2020) which found out the variations of rainfall in the country.

The mean annual rainfall in the catchment shows an increasing trend (Figure 5), with the change point being in 2000 where the average value in the period of 1981-1999 being 1403.96mm/year while for the 2000-2020 is 1433.38mm/year (2.05% increase) Figure 6. According to Sen's slope analysis, there are variations of trends in the basin where some of the station reveal the increase while most of them showed decreasing trend (Table 2). The results depict that only significant increasing trend manifested in Ulanga Met Station with the slope value of 14.70 and p-value less than 0.05.

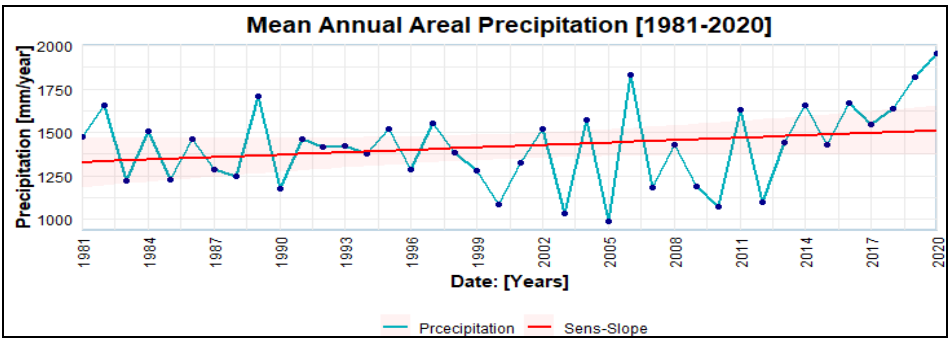
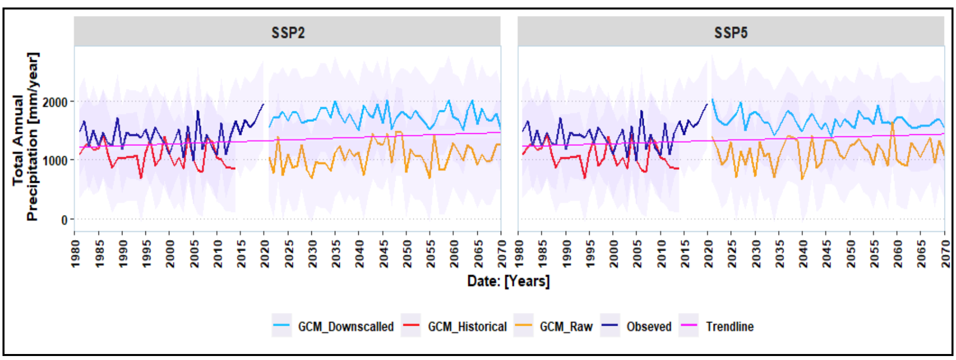


Figure 6: The Mean Areal Rainfall (1981-2020) fitted with a trend line



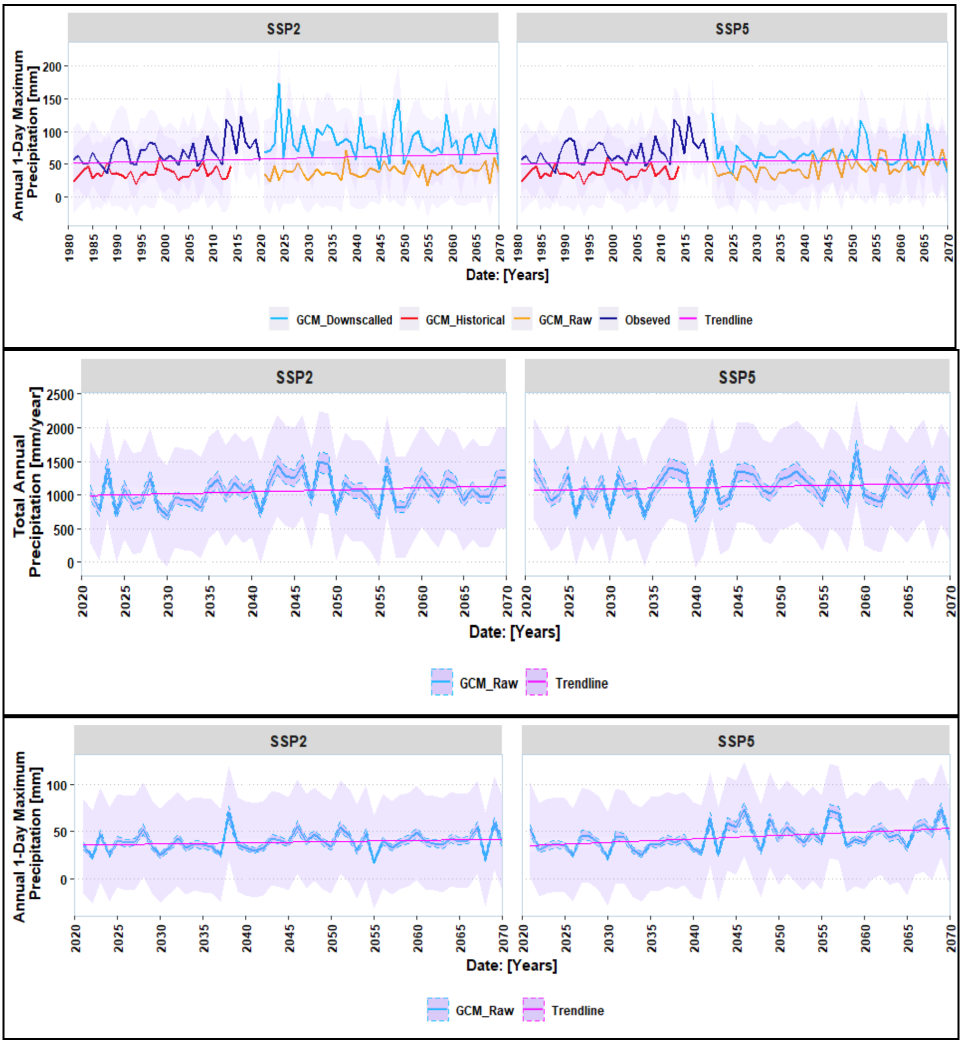


Figure 7: Historical and Future precipitation trends in different scenarios

Historical and Future Trend of Temperature

Trends of temperature was tested the t over time by the null hypothesis stated that there was is no trend in the series and alternative hypothesis that there is a trend in the series. When the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis and accept the alternative hypothesis. Trend analysis by Mann Kendall's compared the temperature data from 1981 to 2022 from the Iringa. The results show that there were temperature trends detected for most months with an exception of December, January and May. This was informed by the significant p-values (greater than the alpha value of 0.05). Also, the results showed that temperature has been increasing over time (positive Z) except for November and December where they have been decreasing.

Sen's slope

For the significant temperature trends in December, January and May, Sen's plots were as illustrated below. Generally, Sen's slope shows the magnitude of the trend.

Table 3: Sen's Slope Analysis for Temperature

	Value	Lower bound (95%)	Upper bound (95%)
Slope	0.37	0.021	0.083

The gradient of the Sen's slope shows that in the month of January, temperature levels have been increasing by 0.037 points from one year to the other. From the figure below, it was evident that there was a positive trend with varying temperature levels for the different years studied. For instance, the lowest temperatures recorded for were in the year 2001 where an average of 22^0Cwas recorded while the highest temperatures were experienced in 2016 is 31ºC.

The slope value of 0.37 indicates the estimated coefficient for the predictor variable in the linear regression model. This means that for every one-unit increase in the predictor variable, the outcome variable is estimated to increase by 0.37 units on average. The lower and upper bounds represent the 95% confidence interval for the slope coefficient. This means that the 95% confident that the true slope coefficient falls between the lower and upper bounds and the data could be interpreted accordingly.

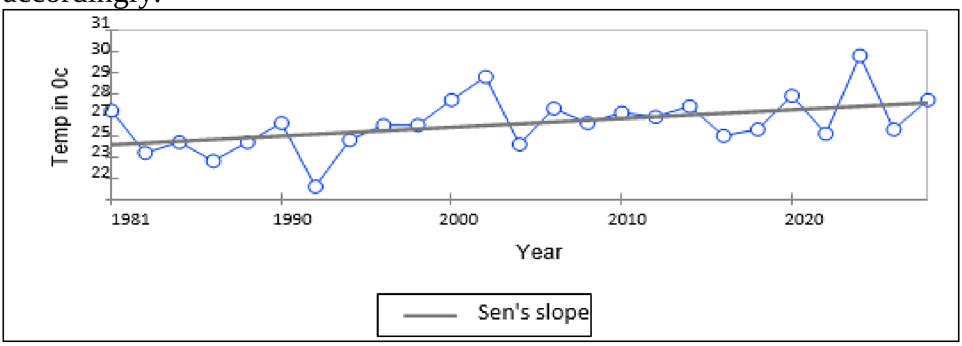
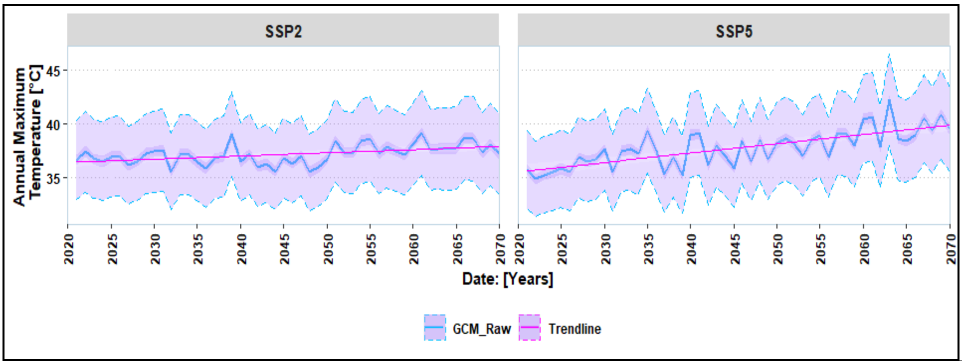
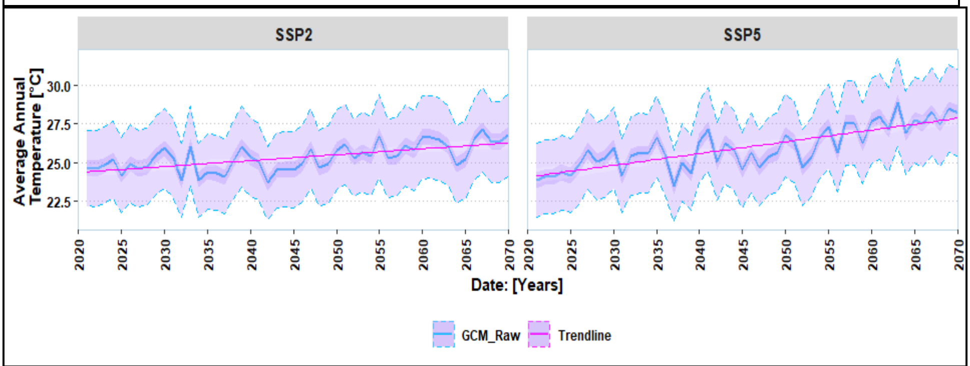
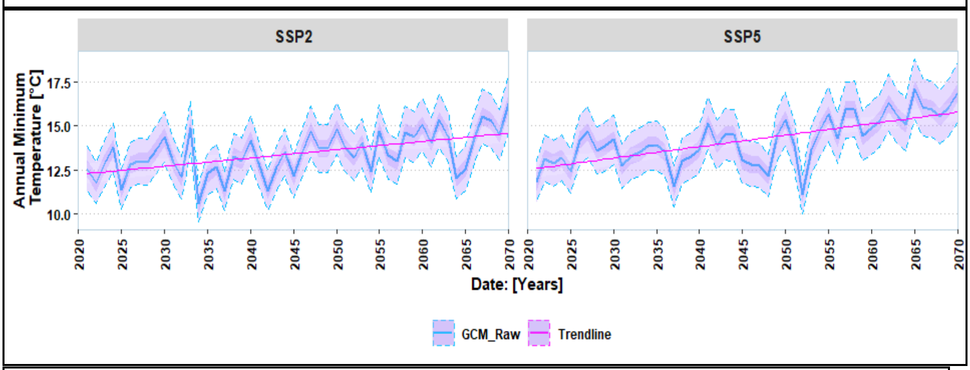
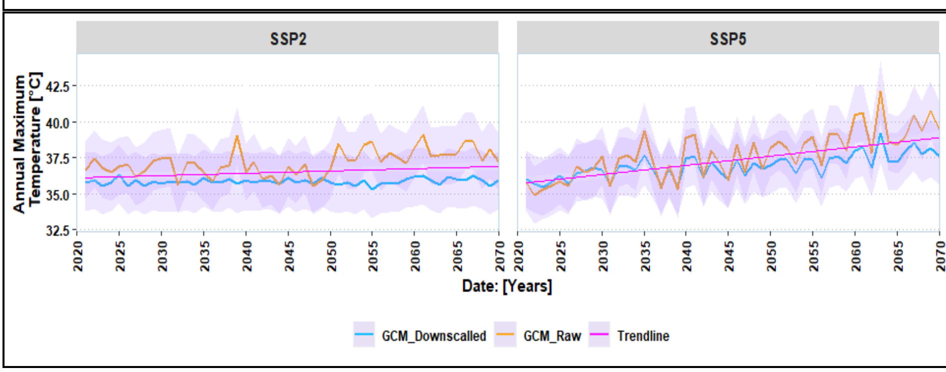


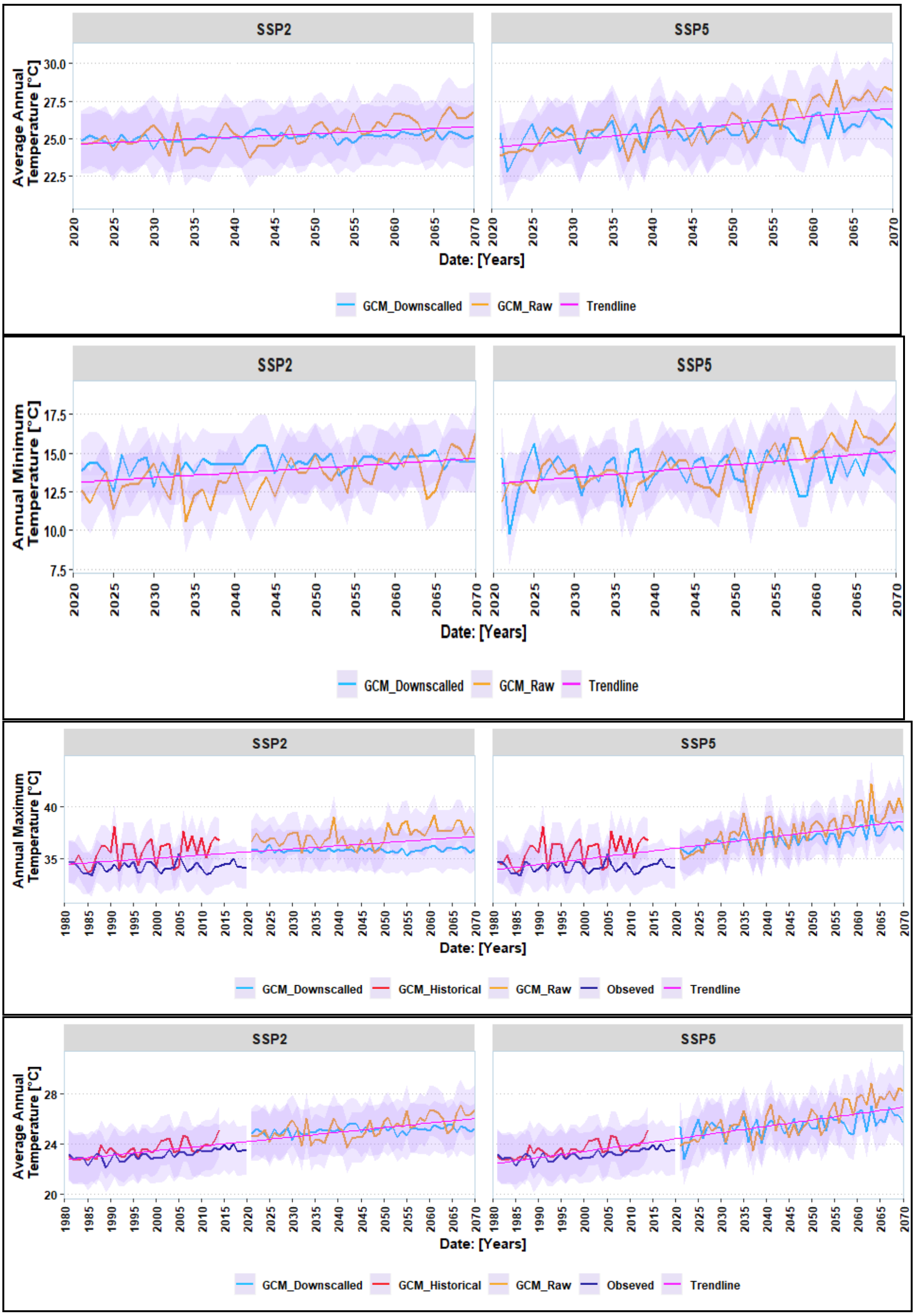
Figure 8: Sen's slope for temperature in Kilombero Basin


SSP2
SSP5
Annual Maximum Temperature [°C]
Date: [Years]
GCM_Raw
Trendline


SSP2
SSP5
Average Annual Temperature [°C]
Date: [Years]
GCM_Raw
Trendline


SSP2
SSP5
Annual Minimum Temperature [°C]
Date: [Years]
GCM_Raw
Trendline


SSP2
SSP5
Annual Maximum Temperature [°C]
Date: [Years]
GCM_Downscalled
GCM_Raw
Trendline


SSP2
SSP5
Average Annual Temperature [°C]
Date: [Years]
GCM_Downscalled
GCM_Raw
Trendline
Annual Minimum Temperature [°C]
Annual Maximum Temperature [°C]
GCM_Historical
Obseved

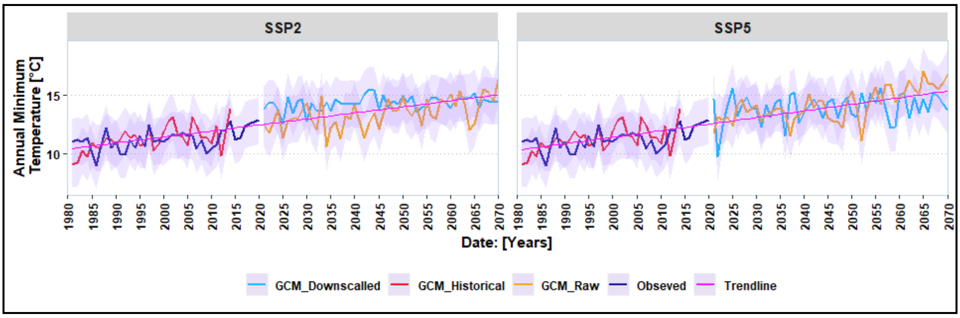


Figure 9: Historical and future temperature trend in different scenarios

Trend Influence of Downscaling to the GCM data.

Although bias correction reduces the statistical error in raw climate model datasets, this does not indicate that users should have increased confidence in the data's integrity. The goal of employing bias correction in this study was to see how it affected climate model downscaling and to account for the uncertainty it introduced. Figures 4.10 and 4.11 show the results of precipitation and temperature over the training period (2006-2018) using the eQM method contained in the climat4R software for bias correction.

Table 0: Influence of Downscaling to the GCM data

Variable	Sen's Slope	Z	P-Value	Trend
Mean Annual Precipitation-SSP2-4.5- Raw	1.24	1.32	0.188	S
Mean Annual Precipitation-SSP2-4.5- Downscaled	-0.12	-0.09	0.929	S
Mean Annual Precipitation-SSP5-8.5- Raw	-0.67	-0.63	0.526	S
Mean Annual Precipitation-SSP5-8.5- Downscaled	-1.22	-1.48	0.138	S
Average Annual Temperature-SSP2-4.5- Raw	0.033	10.205	0.000	NS
Average Annual Temperature-SSP2-4.5- Downscaled	0.000	1.234	0.217	S
Average Annual Temperature-SSP5-8.5- Raw	0.087	11.190	0.000	NS
Average Annual Temperature-SSP5-8.5- Downscaled	0.001	1.616	0.106	S
Annual Maximum Temperature-SSP2-4.5- Raw	0.035	7.564	0.000	NS
Annual Maximum Temperature-SSP2-4.5- Downscaled	0.001	0.659	0.510	S
Annual Maximum Temperature-SSP5-8.5- Raw	0.082	9.817	0.000	NS
Annual Maximum Temperature-SSP5-8.5- Downscaled	-0.004	-1.910	0.056	S
Annual Minimum Temperature-SSP2-4.5- Raw	0.038	7.094	0.000	NS
Annual Minimum Temperature-SSP2-4.5- Downscaled	0.006	1.583	0.113	S
Annual Minimum Temperature-SSP5-8.5- Raw	0.088	10.321	0.000	NS
Annual Minimum Temperature-SSP5-8.5- Downscaled	0.008	0.947	0.344	S

The table above shows the Sen's slope, Z-value, P-value, and Trend for each variable. The Sen's slope is a measure of the trend of the variable over time, the Z-value is a test statistic for the slope, the P-value is the probability of getting a Z-value as extreme as observed, and the Trend indicates whether the variable has a significant increasing (NS - Non-Stationary) or decreasing (S - Stationary) trend.

For example, the first row shows that the mean annual precipitation under SSP2-4.5 Raw scenario has a positive trend (S) with a Sen's slope of 1.24 and a Z-value of 1.32, but the trend is not statistically significant (P-value of 0.188). On the other hand, the mean annual precipitation under SSP2-4.5 Downscaled scenario has a negative trend (S) with a Sen's slope of -0.12 and a non-significant Z-value of -0.09. Similarly, the other rows show the trends for different climate variables, scenarios, and methods.

CONCLUSION

In conclusion, this study focused on the analysis of historical and future rainfall and temperature trends in the Kilombero Basin using the Mann-Kendall test with Sen's slope estimator method. The analysis relied on observed data from the Tanzania Meteorological Agency and simulated data from the CMIP6 project under SSP2-4.5 and SSP5-8.5 scenarios. The results highlighted the basin's bimodal rainfall pattern and the reasonable performance of the selected CMIP6 models in simulating rainfall, Tmax, and Tmin. The findings showed that while there were no clear trends in rainfall, Tmax and Tmin exhibited consistently significant increasing trends under both SSP2-4.5 and SSP5-8.5 scenarios. The potential impacts of these trends include intensified evapotranspiration demands, which may negatively affect freshwater availability in the basin. The analysis also revealed a slight increase in mean annual rainfall from 1981-1999 to 2000-2020.

Trend analysis at individual stations showed variations across the basin, with some stations indicating increasing trends and others showing decreasing trends. The Ulanga Met Station exhibited a significant increasing trend in precipitation.

Overall, the study highlights the importance of understanding rainfall and temperature trends in the Kilombero Basin for the effective management and monitoring of water resources systems. These findings can be crucial for informing adaptation and mitigation strategies in response to climate change and its potential impacts on the basin's water resources.

REFERENCES

Ayugi, B. O. and Tan, G. (2018). Recent trends of surface air temperatures over Kenya from 1971 to 2010. Meteorology and Atmospheric Physics https://doi.org/10.1007/s00703-018-0644-z

Alexander L.V (2016). Global observed long-term changes in temperature and precipitation extremes: a review of progress and limitations in IPCC assessments and beyond. Weather Clim. Extremes 11:4–16. https://doi.org/10.1016/j.wace.2015.10.007

Ayugi, B. O and Tan, G. (2019). Recent trends of surface air temperatures over Kenya from 1971 to 2010. Meteorology and Atmospheric Physics, 131, 1401-1413.

Borhara, K. (2020). 'On Tanzania's precipitation climatology, variability, and future projection', Climate, 8(2), p. 34.

Burghof, S. (2018). 'Development of a hydrogeological conceptual wetland model in the data-scarce north-eastern region of Kilombero Valley, Tanzania', Hydrogeology Journal, 26(1), pp. 267–284.5.

Chen, H. (2017). 'Historical temporal trends of hydro-climatic variables and runoff response to climate variability and their relevance in water resource management in the Hanjiang basin', Journal of hydrology, 344(3–4), pp. 171–184.9.

Curiac, C. D., and Micea, M. V. (2023). Identifying Hot Information Security Topics Using LDA and Multivariate Mann-Kendall Test. IEEE Access, 11, 18374-18384.

Djan'na, K. H., Atchonouglo, K., Adounkpe, J. G., Diwediga, B., Lombo, Y., Kpemoua, K. E., & Agboka, K. (2023). Changes In Land Use/Cover And Water Balance Components During 1964–2010 Period In The Mono River Basin, Togo-Benin. Geography, Environment, Sustainability, 15(4), 171-180.

Deka, R. L., Mahanta, C., & Nath, K.K. (2019). Trends and Fluctuations of Temperature Regime of North East India. ISPRS Archives XXXVIII-8/W3 Workshop Proceedings: Impact of Climate Change on Agriculture, 376-380

Geressu, R. (2020). 'Assessing river basin development given water-energy-food-environment interdependencies, Earth's Future, 8(8), p. e2019EF001464.1147.

Hussain, M. M. and Mahmud, I. (2019). 'MannKendall: a python package for non-parametric MannKendall family of trend tests.' Journal of Open-Source Software, 4(39), p. 1556.22.

IPCC (2019). IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems. Summary for Policymakers. Approved Draft, IPCC SRCCL.

Islam, D. S.A. and Kamruzzaman, M. (2023). Assessment of climate change impact on temperature extremes in a tropical region with the climate projections from CMIP6 model. Climate Dynamics, 60(1-2), 603-622

Kangalawe, R. Y. M. and Liwenga, E. T. (2015). 'Livelihoods in the wetlands of Kilombero Valley in Tanzania: Opportunities and challenges to integrated water resource management', Physics and chemistry of the Earth, Parts A/B/C, 30(11–16), pp. 968–975.

Kato, F. (2017). 'Development of a major rice cultivation area in the Kilombero Valley, Tanzania', African study monographs. Supplementary issue. 36, pp. 3–18.2.

Koutsouris, A. J., Chen, D. and Lyon, S. W. (2016). 'Comparing global precipitation data sets in eastern Africa: a case study of Kilombero Valley, Tanzania', International Journal of Climatology, 36(4), pp.2000–2014.30.

Luhunga, P. M. (2018). 'Climate change projections for Tanzania based on high-resolution regional climate models from the Coordinated Regional Climate Downscaling Experiment (CORDEX)-Africa', Frontiers in Environmental Science, 6, p. 122.32.

Makingi, G. and Urassa, J. K. (2017). 'Socio-economic factors influencing use of improved technologies by smallholder paddy farmers in Kilombero District, Tanzania'.34.

Mombo, F. (2011). 'Ratification of the Ramsar convention and sustainable wetlands management: Situation analysis of the Kilombero Valley wetlands in Tanzania'.35.

Monga, E., Mangora, M. M. and Mayunga, J. S. (2018). 'Mangrove cover change detection in the Rufiji Delta in Tanzania', Western Indian Ocean Journal of Marine Science, 17(2), pp. 1–10.

Mtega, B. (2017). Agriculture and wildlife conservation Udzungwa-Selous corridor: a case study of Kilombero District, Morogoro. The University of Dodoma.37.

Muhati, G. L., Olago, D. & Olaka, L. (2018). Past and projected rainfall and temperature trends in a sub-humid montane forest in Northern Kenya based on the CMIP5 Model ensemble. Global ecology &conservation, 16, retrieved from https://doi.org.//10.1016/j.gecco.2018.e0049

Munishi-kongo, S. (2013). Ground and Satellite-Based Assessment of Hydrological Responses and Land Cover Change in the Kilombero River Basin, Tanzania. November.

Näschen, K. (2018) 'Hydrological modeling in data-scarce catchments: The Kilombero floodplain in Tanzania', Water, 10(5), p. 599.40.

Nyembo, L. O., Larbi, I. and Rwiza, M. J. (2021). 'Analysis of spatio-temporal climate variability of a shallow lake catchment in Tanzania', Journal of Water and Climate Change, 12(2), pp. 469–483.42.

Ochieng, J. and Mathenge, M. (2016). Effects of climate variability and change on agricultural production: The case of small-scale farmers in Kenya. NJAS- Wageningen journal of life sciences, 77, 71-78

Okwir, G., Kumar, S., Pramod, K. S., Gao, H., & Njau, K. N. (2023). Conceptualization of groundwater-surface water interaction with evidence from environmental isotopes and hydro geochemistry in Lake Babati Basin in Northern Tanzania. Groundwater for Sustainable Development, 100940.

Salmi, T., Maatta, A., Anttila, P., Ruoho-Airola, T. and Amnell, T. (2012). Detecting Trends of Annual Values of Atmospheric Pollutants by the Mann-Kendall Test and Sen's Slope Estimates—The Excel Template Application MAKESENS. Finnish Meteorological Institute, Publications on Air Quality No. 31, Helsinki.

Seki, H. A. (2018). 'The impact of land use and land cover change on biodiversity within and adjacent to Kibasira Swamp in Kilombero Valley, Tanzania', African Journal of Ecology, 56(3), pp.518–527.4.

Senkondo, W., Tumbo, M., Lyon, S.W., (2020). 'Modelling water resources despite data limitations in Tanzania's Kilombero Valley, Water, 9(12), p. 948.4.

Sigalla O, Valimba P, Tumbo M, (2023). Analysis of Spatial and Temporal Trend for Hydro-climatic Parameters in the Kilombero

River Catchment, Tanzania. Available DOI: https://doi.org/10.21203/rs.3.rs-2493187/v1 [accessed Jan 24 2023].

Smith, C. D. M. (2016) 'Environmental Flows in Rufiji River Basin assessed from the perspective of Planned Development in the Kilombero and Lower Rufiji Sub-Basins', Report to the United States Agency for International Development. 146p. Available for download at: https://dec. usaid.gov/dec/content/search. aspx, p. 4.51.

Yunfei, L., Dongwei, G., Changjun, Y., Lei, Z., Dongping, X., Yi, L., & Xiaoping, C. (2023). Estimating the Temporal and Spatial Variations in Evapotranspiration with a Nonlinear Evaporation Complementary Relationship Model in Hyper-arid Areas. Water Resources Management, 37(1), 521-535.