Study of the Performance of a Regional Climate Model in Simulating Rainfall in Rwanda

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Study of the Performance of a Regional Climate Model in Simulating Rainfall in Rwanda

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Declaration

I declare that this research contains the results of my efforts except the special acknowledgment.

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Date……………..

This research dissertation was developed and written with our approval of university of Rwanda, College of Science and Technology Supervisor.

Prof. Safari Bonfils

Signature ………………….

Date …………………

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Abstract

High resolution models were used for simulating rainfall in Rwanda. But each model should be evaluated before using its output to assess impact. The ability of Regional climate model was evaluated using RegCM4-7 which is driven by the MPI-M-MPI-ESM-LR to simulate rainfall over Rwanda. The model output were compared to observation, to simulate rainfall in Rwanda through assessing the model performance. Bias, root mean square error (RMSE) and Pearson correlation were used to assess model skill while Mann-Kendall (MK) was used for trends analysis.

It is found that model performance in simulating rainfall both seasons over Rwanda, overestimates rainfall in October-November-December (OND) season over all part of country with positive biases but much more to north and South-West and Underestimates in March-April-May (MAM) season over the Central and Eastern part of Country with Negative biases and model simulates rainfall over the country better with less errors in MAM than OND season.

The future projection of rainfall with two scenarios RCP2.6 and RCP8.5 for near future period (2021-2050) and far future period (2051-2080) for 30 years were used and they show that the average rainfall will increase in western and Southern party of the country while a greater changes projected during OND and less in MAM under both scenarios and Periods.

Overall, the study finds that Regional climate Model (RCM) used is able to simulate rainfall climatology in Rwanda with better performance and suggesting the potential use of in further similar studies.

List of acronyms

CORDEX: Coordinated Regional climate Downscaling experiment

ENSO: El-Nino-Southern-Oscillation

GCM: Global Climate Model

ICTP: International Centre for Theoretical Physics

IOD: Indian Ocean Dipole

IPCC: Intergovernmental Panel on Climate Change

IRI: International Research Institute for Climate and Society

ITCZ: Inter-Tropical Convergence Zone

JF: January-February

JJA: June-July-August

LBCs: Lateral Boundary Conditions

MK: Mann-Kendall

MAM: May-April-May

MIDIMAR: Ministry of disaster management of Rwanda

OND: October-November-December

RCMs: Regional Climate Models

RegCNET: Regional Climate Research Network

RCPs: Representative Concentration Pathways

RMSE: Root Mean Square Error

SST: Sea Surface Temperature

WMO: World Meteorological Organization

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CHAPTER 1: GENERAL INTRODUCTION

1.1 Background and Motivation

The climate of Rwanda is a temperate climate with relatively high rainfall. Agriculture is a major economic activity that is heavily reliant on rainfall. The last report from the Intergovernmental Panel on Climate Change (IPCC) has been confirmed the variability of climate change (IPCC, 2013). The largest impacts which is considered showed an increase of the severity of extreme events. Rwanda experienced by Wet and dry events, which may result in flood and drought episodes, respectively and are considered as the main meteorological disasters that cause devastating socio-economic impacts (MIDMAR, 2012). The extreme precipitation in terms of intensity and frequency are expected to increase (Christensen et al., 2005), which will lead to an increase of the flood hazard. The researches around the world have made a great efforts to find and understand these extreme precipitation events (Xin et al., 2006). Climate change has been confirmed as major concern around the world and assessing its impact on regionally is important especially for policy makers who develop action plans to mitigate and adapt to the impacts of future climate change (Dusingizimana, 2019).

The global climate models (GCMs) are the most advanced tools currently available in simulating climate response and due to the massive computational and storage requirements, they are generally run at horizontal resolutions of 100 km (Luhunga et al., 2016;Daniels et al., 2012).

This makes GCMs to be limited during the climate simulations impacted for climate change studies on biodiversity, ecosystem, agriculture, species distribution and landscape and environmental issues to have fine scale ,GCM data are often downscaled using High regional climate models (RCMs) (Hassan et al., 2013; Xiaoduo et al., 2012). Data from RCMs are required to assess climate change impact on water resources, agriculture and natural ecosystems (IPCC, 2007).

RCM stand for numerical climate model for prediction forced by specified lateral and ocean conditions from GCMs or data set based on observation that used to simulate atmospheric and land surface processes and accounting for high resolution topographical data, land-sea contrasts, surface characteristics, and other components of the Earth system. This model has been used widely over Africa-CORDEX (Coordinated Regional Downscaling Experiment) domain to predict climate change for different regions (Almazroui, 2016).

RCMs are initialized with the initial conditions and driven with time variable along their lateral atmospheric and lower surface boundaries conditions (Sanjay et al., 2017). Almazroui et al. (2012) used ICTP regional climate model (RegCM4-7) to simulate the precipitation seasonal mean and annual cycle and the results have been quite accurate but there is big variations and biases between model of the same region and seasons. The RegCM has been historically the first limited area model developed for long term regional climate simulations (Knutti et al., 2010).

The RegCM system is a community climate model, and particular it is designed for used by a wide and varied community composed by scientists in industrialized countries as well as developing nations (Pal et al., 2007). One widely applicable method for obtaining high resolution climate data that takes into account regional patterns and valuable local knowledge is to use RCMs. These are atmospheric models run on a limited geographical area using boundary conditions from GCMs.

High resolution climate models have been widely used to provide high resolution climate simulations in different party of the world (Fowler, 2007). However, many uncertainties in these simulations are caused by boundary conditions, size of the integration domain, natural variability and RCM formulation (Xiaoduo et al., 2012).

1.2 Problem Statement

Rainfall is among the major climatic parameters that have a strong influence on the country socio economic, Rwanda economy is heavily depend on agriculture sector. Some models were used to simulate rainfall climatology but their performance was questionable, since rainfall variability still impact on socioeconomic activities of East Africa countries (Willows et al., 2003). It's very important to Policy makers, disaster managers and other among the key users of climate information to have full information of climate change in their decision making. Agriculture sector contribute around 80% of GDP and is the one sector that is strongly affected by the climate change due to the rainfall variability occurred in different party Rwanda resulted to the flooding, soil erosion, drought and landslide. High resolution model as tool used to understand these changes has become an effective way to simulate the climate accurately (Umuhoza et al., 2021).

Different studies have been done (Shongwe and Lennard, 2015; Enfors et al., 2008; Thornton et al., 2010; Ahmed et al., 2011) in that order to evaluate the impacts of climate change on rain fed crop production using RCMs driven by directly to GCMs but the results showed insufficient detection of model strengths and weaknesses in simulation of rainfall in different regions.

1.3 Objectives of Study

The main objective is to study the performance of a regional climate model in simulating rainfall in Rwanda. The specific objectives have been set as:

- To assess the skill of RCM model from of the CORDEX driven by GCM.
- To determine the projected changes and Future Trends of rainfall in Rwanda.

1.4 Hypothesis of the Study

The best RCM model under climate change will have high skill to simulate rainfall in Rwanda with less errors and biases.

1.5 Justification of Study

This study provided information that can be used during budget planning and is a crucial step in choosing reliable model which simulating a climate of Rwanda and its impact at particular location.

The findings of this study are expected to give a meaning contribution to the future studies for better predicting the effects of climate change in both present and future, as well as ensure adaptation and mitigation strategies for better climate resilience.

1.6 Climatology of Rwanda

Rwanda is a tropical country and is the main area considered in this study, it is a small and landlocked country with approximately area of 26,338km^2.

On its annual cycle, the country experienced by two rainfall season regimes, from March-May (MAM) and October-December (OND) as well as two dry seasons form June-August (JJA) and January to February (JF).MAM is known as long term rainy season while OND refers as short term rainy season (Ilunga et al., 2004).

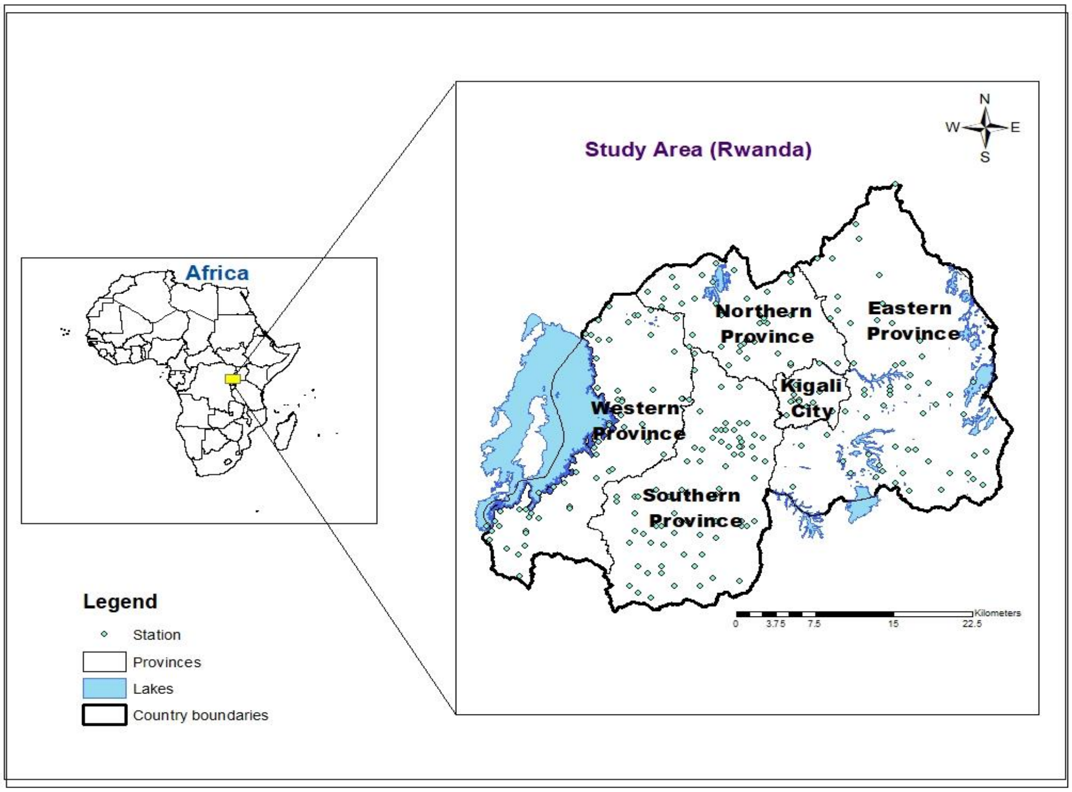

Figure 1: The left is a map of Africa, while the right is a map of Rwanda with the selected stations.

In the northwest part of the country is located by Virunga volcanic chains and Congo Nile ridges country at elevations between 1800 and 4500 m. These areas receive the high intensity of precipitation between 1300 and 1550 mm (Muhire et al., 2015). The low-lying land is located in the country's east. The characteristics of climate of the country is highly influenced by complex topographic, water bodies and vegetation while Indian Ocean Dipole (IOD) and subtropical Anticyclones are influencing OND season (Washington and Preston, 2006).

CHAPER 2: LITERATURE REVIEW

2.1 Variation of Regional Climatic Rainfall

Rwanda like the other East Africa countries has a bimodal rainfall pattern that is primarily governed by the Intertropical Convergence Zone (ITCZ) around an equator and is characterized by the most diverse geography, with enormous lakes, rift valleys, and snowcapped mountains (Kharin et al., 2007). Because of this heterogeneity, climatological mean rainfall total vary dramatically (Ogwang et al., 2014).

Rainfall variation in East Africa and the tropical regional is caused by different complex interactions and atmospheric variations such sea surface temperature (SST) forcing and synoptic scale weather disturbances like the Inter-tropical Convergence Zone (ITCZ), monsoonal wind system, trade winds and El Nino or Southern Oscillation (ENSO) events, persistent mesoscale circulations and tropical cyclones. The main elements affect climate of Rwanda to be considered are extensive forest, water bodies (lakes and river) and different air masses (Felix, 2015).

2.2 Global Climate Models (GCMs)

The climate variability is assessed by using GCMs as suitable tools, Currently GCMs have spatial resolution on the order of 100-250 km and is potential to simulate the main characteristics of general circulation at the range of this scale (Shongwe et al., 2009). Although GCM are capable of simulating atmospheric general circulation at continental level, they are not always capable of capturing the detailed processes associated with regional climate variability and changes (Giorgi et al., 2009).

This especially true in heterogeneous region like eastern Africa, where topography variation, soil and vegetation on a sub GCM grid scale have a big impact on climate (Crichton et al., 2012). Furthermore, intensity and frequency of sub-grid-scale extreme events such as heavy rainfall resulting in floods are frequently not replicated realistically at coarse grid resolutions.

GCMs are widely used to describe the climate processes of many different African regions and to generate climate data to use for a variety of socioeconomic sectors, including water, health, education and agriculture (Alley et al., 2016).

2.3 Regional Climate Models (RCMs)

Regional climate models (RCMs) is dynamically downscaled form GCMs (Sunyer et al., 2006,2012) are very useful for understanding climate patterns areas with complex topography. The number of RCM simulations has increased significantly globally (Alley et al., 2016); however, the research that carried in the East African region is largely based on a single simulation. Each model showed strength and weakness. Thus, the application of a set of RCMs is needed, but this has not been done before because of the lack of a large ensemble of RCM output (Sunyer et al., 2012).

RegCM4.7 developed by International Centre for Theoretical Physics (ICTP) has been adopted to simulate rainfall scenario of Bangladesh. The study examines model performance of rainfall simulation through the period of 1991-2018 with ERA-Interim 75 data of 75 km horizontal resolution as lateral boundaries and downscaled at 25km resolution (Rahman et al., 2021).

The RegCM is a community model and it is intended for use by a broad and diverse community of scientists from both developed and developing countries (Pal et al., 2007). As such, it is intended to be public, user friendly and open source that can be applied to any part.

2.4 RCMs Performance

The performance of model is determined by the metric used to assess them, as well as the location and climate variable (Christensen et al., 2010). It is not easy to come up with metrics to evaluate the RCM weights (Knutti, 2010). Weigel et al. (2010) investigated impacts of weighting in models and pointed out the risk of applying weights and emphasized that addition to accurate knowledge of model performance model weighting approaches should take into account the dependency between model error and internal variability. If these considerations are not are considered, using weights to combine models may result in larger errors than equal weighting.

Climate models are frequently evaluated based on the performance in historical and current climate conditions, lack of information about the future, performance is then assumed to remain constant in the future. However, according to a recent study done by Boberg and Christensen. (2012), the performance of climate models may change in the future.

2. 5 CORDEX and Rainfall Simulation

CORDX aims to improve the framework for generating regional scale climate projections that are impacted on assessment and adaptation studies in worldwide within the IPCC timeline and beyond.

Mutayoba et al. (2017) used CORDEX data to simulate precipitation characteristics over the Mbarali River Catchment in Tanzania and resulted better reproducibility of rainfall characteristics. But other study done in Rwanda by Luhunga (2016) simulated rainfall with the ensemble of models performed better than individual models.

The CORDEX ability to simulate rainfall variability in southern Africa during the austral summer showed an accuracy regional climate model with high probability of simulation with less bias toward little intensity of rainfall (Shangwe et al., 2015).

2.6 Scenarios of Fifth Assessment Report

Representative Concentration Pathways (RCPs) are grouped as four greenhouse gas concentration trajectories adopted by the IPCC for its fifth assessment report (AR5) (Moss et al., 2010). These scenarios RCP2.6, RCP4.5, RCP6 and RCP8.5 are named according to the possible range of Radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m2, respectively). They describe potential climate futures which are taught to be plausible depending on amount greenhouse gas released in coming years (Villegas et al., 2010).

CHAPTER 3: METHODOLOGY

This chapter describes methodology used to achieve the set of goals .In all analysis two types of data were used: observational and Model data, the performance of RCM driven by GCM in simulating rainfall in Rwanda were identified by Statistical metrics (Root mean square error and bias). Seasonal mean rainfall distribution, Trends and inter-annual variability were assessed. The Regional climate scenarios (RCP2.6 and RCP8.5) for Africa are available on a grid of 0.22 degrees, approximately 25km were used for Rainfall projection and changes. The performance were identified by graphically and trend comparison between observational and model data.

3.1 Data and Methodology

3.1.1 Observed Rainfall Data

Observed gridded data covering the entire country were collected from Rwanda Meteorology Agency (Meteo-Rwanda) in dataset developed by International Research Institute for Climate and Society (IRI) with collaboration Meteo-Rwanda (Dinku et al., 2016).

3.1.2 Model Data

The simulation was carried out on the rather coarse resolution of 0.22° (approx. 25 km) to enable a large ensemble of climate projections (Mutayoba et al., 2017). The simulated and projected output retrieved in CORDEX Africa portal, which is an International Coordinated Effort led by the World Climate Research Programmer Working Group on Regional Climate to provide users with uniformly produced a regional climate model output. Models chosen are ideal for climate research for Africa (Ogwang, 2015).

RegCM4-7 used, has been initiated by International Centre for Theoretical Physics (ICTP) and adopted to simulate rainfall and is driven by MPI-M-MPI-ESM-LR. It constitutes a group of simulations in Coordinated Regional Downscaling Experiment-Common Regional Experiment (CORDEX-CORE) framework.

3.1.3 Data Limitations

Climate change modeling relied on post-processed data from the CORDEX data portal. Africa region lacks high quality observation datasets with appropriate temporal and spatial resolution.

As a result, Endris et al. (2013) presents a limitations of CORDEX models for Africa domain in details.

3.2 Methodology

3.2.1 The Statistical Methods

A variety of techniques are available to assess model performance to simulate climate conditions at a specific location (Flato et al., 2013). Some statistical Methods recommended by the world Meteorological organization (WMO) such as root mean square error (RMSE), Pearson correlation coefficient (R) and Bias (Gordon and Shaykewich, 2000).

3.2.2 Root Mean square Error (RMSE)

RMSE evaluates the relative deviation between the simulation and observation in a range between 0 for a perfect match of simulation and observation towards +∞ (Dee et al., 2021).

To calculate the RSME and Bias the following equations were used:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}} \quad (1)$$

$$BIAS = \frac{1}{n}\sum_{i=1}^{n}(P_i - \bar{O}) \quad (2)$$

3.2.3 Analysis of Correlation

Correlation is a statistical method for determining the similarities between different two variables (Wilks, 2006). Pearson correlation coefficient is most commonly used for calculating the degree of linear association between different variables. Mathematically, this method is as follows:

$$r = \frac{\sum_{i=1}^{n}(P_i - \bar{P})(O_i - \bar{O})}{\sqrt{\sum_{i=1}^{n}(P_i - \bar{P})^2}\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}} \quad (3\ )$$

With P and O are simulated and observed values respectively, while i refers to a simulated and observed pairs and n is the total number of such pairs.

3.2.4 Mann-Kendal Method

Mann-Kendall (MK) method is thought to be the best method for analyzing climatic changes and Trends in climatological time series (Ahmad et al., 2015). It is a nonparametric statistical test used in the analysis of climatological and hydrological trends (Mann, 1945; Kendall, 1975) and is considered highly as it can handle unexpected discontinuities caused by inhomogeneous time sequence.

It also does not require any other data assumptions distribution (Mondal et al., 2012). It is used for trend analysis (Ayugi et al., 2019; Almazroui et al., 2020) and performed at a significant level of 0.05. Null hypothesis (Ho) expressing the absence of the trend is rejected for 0.05.

The standardized test statistics (S) are calculated:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_j - x_i) \tag{4}$$

Where i and *j (j > i)*, are time series observations in the year and n is the period of the analysis and $\mathrm{sign}(x_j - x_i)$ is calculated as:

$$Sign(x_j - x_i) = \begin{cases} +1 \; if (x_j - x_i) > 0 \\ 0 \;\; if \; (x_j - x_i) = 0 \\ -1 \; if \; (x_j - x_i) < 0 \end{cases} \tag{5}$$

If the mean of the dataset is zero, variance Sv is calculated as:

$$Sv = \frac{n(n-1)\,(2n+5) \sum_{p-1}^{q} t_p (t_p - 1)(2t_p + 5)}{18} \tag{6}$$

n is the data size, q is the number of tied groups and Tp is the number of data in the tied group, Z statistics are used to determine the trend of significant as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} + 1 \; if \; S > 0 \\ 0 \;\; if \; S = 0 \\ \frac{S-1}{\sqrt{Var(S)}} - 1 \; if \; S < 0 \end{cases} \quad (7)$$

When a measured value is greater than the tabularized α –value, positive value of Z represent increasing of trend and negative value represent a decreasing of trend. Sequential MK test (Khan et al., 2020) was found to be effective in the determining change points of a significant trend and abrupt changes in the series. An unexpected shift at a point is identified when the intersection occurs outside of the tabulated α-value (±1.96).

3.2.5 Projection Techniques of Rainfall

After better performing CORDEX RCM validation, the final step is the process of future rainfall projection over Rwanda. Projections were done under two climate scenarios of RCP2.6 and RCP8.5 for 30 years for near period (2021-2050) and far period (2051 to 2080) by seasonal basis.

CHAPTER4: RESULTS AND DISCUSSION

This chapter presents study findings that correspond to the methods used to achieve the goals. All metrics are computed on a seasonal basis, considering hereinafter two rain seasons. One RCM model Driven by GCM was used while two climate scenarios was used to project the rainfall changes over Rwanda near and far period and the results are the following.

4.1 Comparison between observed and simulation

RCM model output were compared to observe from 1981-2005. Figure 2 shows that during MAM Season, Model presents the mean seasonal rainfall which is higher over the mountainous regions in North and western province than observed, most likely because of imperfect representation of the orography as well as the parameterization of the convection scheme and less over the valley Eastern and Middle region. While Figure 3, Model presents higher amount of the mean seasonal rainfall during OND over the most parts of the country.

4.2 Spatial distribution of Bias and Root mean Square Error

Figures 4 and 5 present biases and root mean square errors occurred MAM and OND season respectively during the study period. Model performance in simulating rainfall both seasons over various stations is presented; as the model overestimates rainfall in OND season over all part of country with positive biases but much more to north and south-west and Underestimates in MAM season over the central and Eastern part of Country with Negative biases as shown in Figure 4. Indeed, slight overestimation is observed over the North of the county, and almost no bias is observed over the valleys and Central regions. Meanwhile, Model simulates the rainfall over most stations better in MAM than in OND season.

Model presented biases ranging from 0-4 mm across the country in MAM while OND, model presented biases ranging from 0-8 mm across the country. Thus the precipitation bias varies according to the intensity rainfall.

Figure 5 shows RMSE model in simulating rainfall at different regions. Model simulates rainfall in both season but with less an error in MAM over the whole country with the range of 0-0.75 mm and more errors in OND especially in North and Southern part of country ranging between 1.0-1.5 mm.

Model simulates rainfall over most stations regions with less errors in MAM than OND season. By considering both RMSE and Biases presented by model, generally model used in this study shows the ability to simulate rainfall both rainy seasons in Rwanda, even it shows some biases and errors in their spatial distribution due to the extreme intensity of precipitation.

4.3. Inter-Annual Rainfall Variability

Figure 6 shows that, model accurately reproduces the inter-annual variability in MAM with strong correlations While Figure 7 shows that in OND, model fairly well to simulate the annual variability of observed rainfall, in general the simulated rainfall by the RCM is more closely related to the observed rainfall in MAM than OND season over Rwanda from 1981 to 2005.

4.4 Rainfall Projection and Changes over Rwanda

For 30 years, the study quantifies the average future rainfall under two scenarios: RCP 2.6 and RCP 8.5 in near future (2021–2050) and far future (2051–2080). Figure 8 composed by four series of maps, first and second show rainfall projected in MAM and OND season under both scenarios and periods respectively while the Third and fourth show the projected rainfall changes.

The relative changes of the rainfall is smaller in MAM comparing to OND under both scenarios and periods as shown in figure 8 for the first and second series.

These series of maps show that, during OND the average rainfall would greatly increase almost all party of the country but more than in western and Southern party of country under both scenarios and Seasons. Figure 8 shows that rainfall is expected to increase during the rainy season. In MAM and OND, precipitation is projected to increase under both scenarios and periods, similar to the findings of Almazroiu et al. (2018) and Ongoma et al. (2016).

Figure 8, the third and fourth lines show the projected changes in rainfall over Rwanda. Precipitation is projected to increase in both scenarios, seasons, and periods, with the majority of the increase occurring in OND rather than MAM. Consistently with the findings of Ayugi et al. (2021) who found an increase of rainfall in East African region while in both the near and far periods scenarios are expected to have a lower change of rainfall in OND particularly in North-Eastern party of Rwanda as shown in Figure 8 fourth series. This results consistent to the study of Adhikari et al. (2015) where a decline is projected in dry for all scenarios and periods.

4.5 Trends of Projected Rainfall

Figure 9 shows trends of projected precipitation for period 2021-2080, RCP 2.6 displays a certain trends in both season MAM and OND while RCP 8.5 indicates that there is a decreasing of trends that are non-statistically significant. The rainfall projection changes over the country and shows an increasing of rainfall from historical to both scenarios, season and periods mostly in OND than MAM as shown Figure 8. The projected rainfall trends for the same region with RCP2.6 show a significant increase in rainfall for 2059-2079 as shown in Figure 9. Increase of trend is consistently with future projection Changes from other studies that considered scenarios with maximum radiative forcing for rainfall projections (Endris et al., 2013).

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

The ability of CORDEX regional climate model (RCM) driven by GCM (MPI) and ERA-Interim data to simulate historical rainfall conditions in Rwanda is evaluated in this study. Study based on a comparison between model data and simulation. Statistical measures of model performance and validation, such as bias, root mean square error, and trend analysis were utilized. According to the results found, RCM generally simulates rainfall over Rwanda, Furthermore, the RCM well reproduce inter-annual variations and trends. Model shows reasonably errors in OND comparable with in MAM, the biases and RMSE arising from RCM in simulating are not too large in most parts of the country. The projected climatological rainfall patterns show increasing rainfall under both scenarios, periods and seasons across the country.

As recommendation, this work is very important to the climate modelers, decision makers, researches and budget planners who will depend on climate simulations and projections in their duties. Therefore others studies driven by others GCMs are recommended to make good comparison.

Due to the time constraints only one RCM model was used, therefore we would like to recommend further research to find the performance of other models to simulate Rwanda's climate.

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Addendum 1: Figures

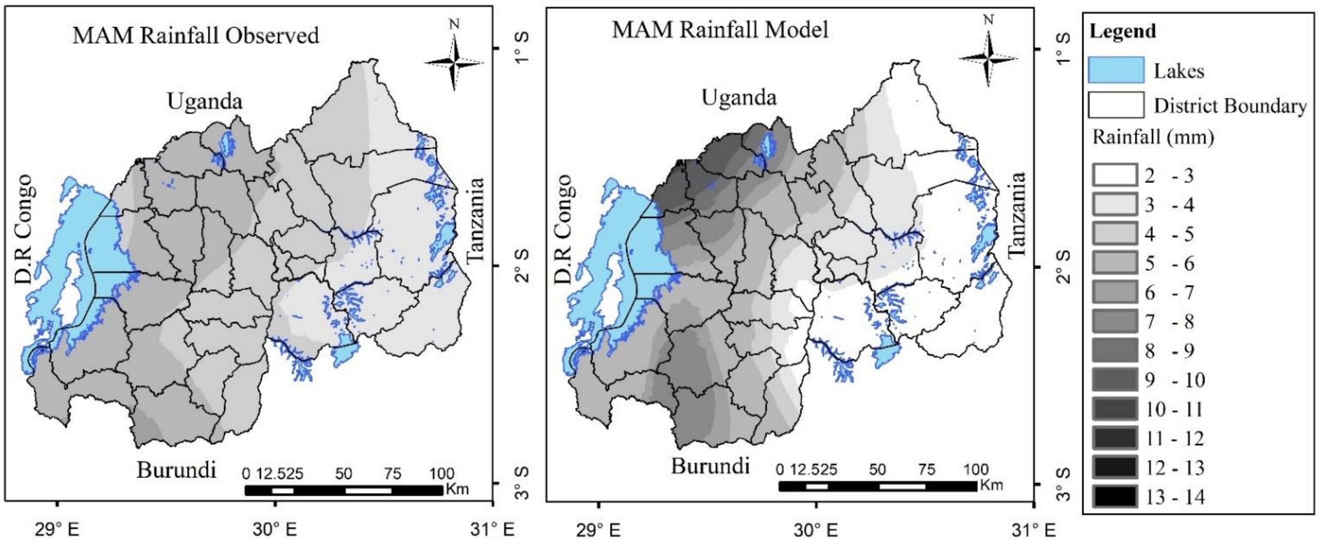

Figure 2: Comparison between observed and simulated rainfall in MAM for the period of 1981-2005.

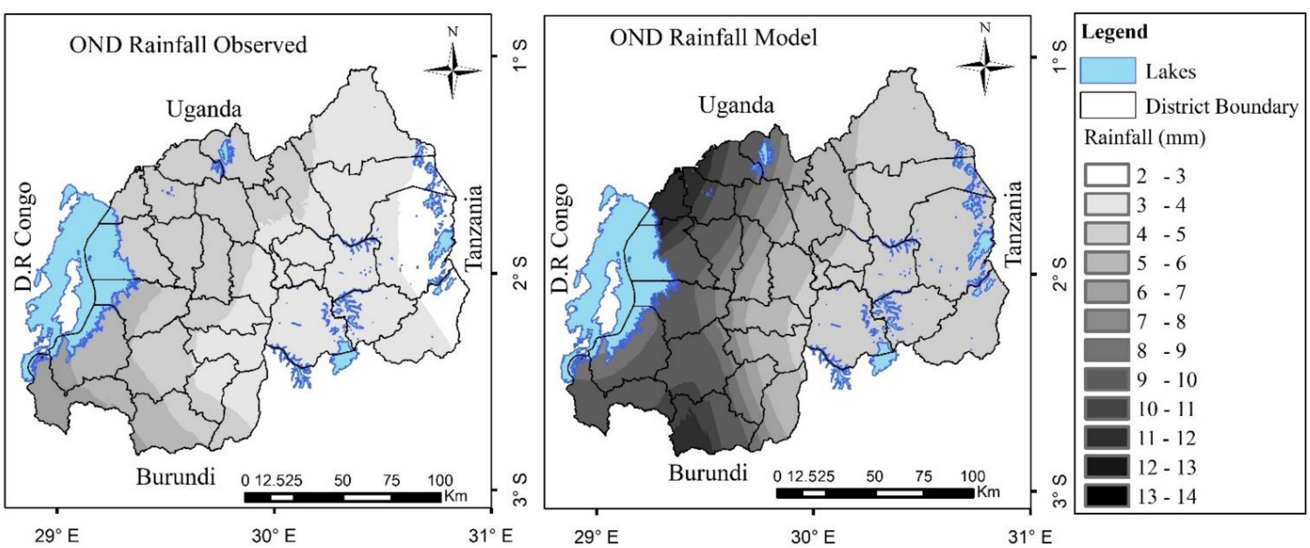

Figure 3: Comparison between observed and simulated rainfall in OND for the period of 1981-2005.

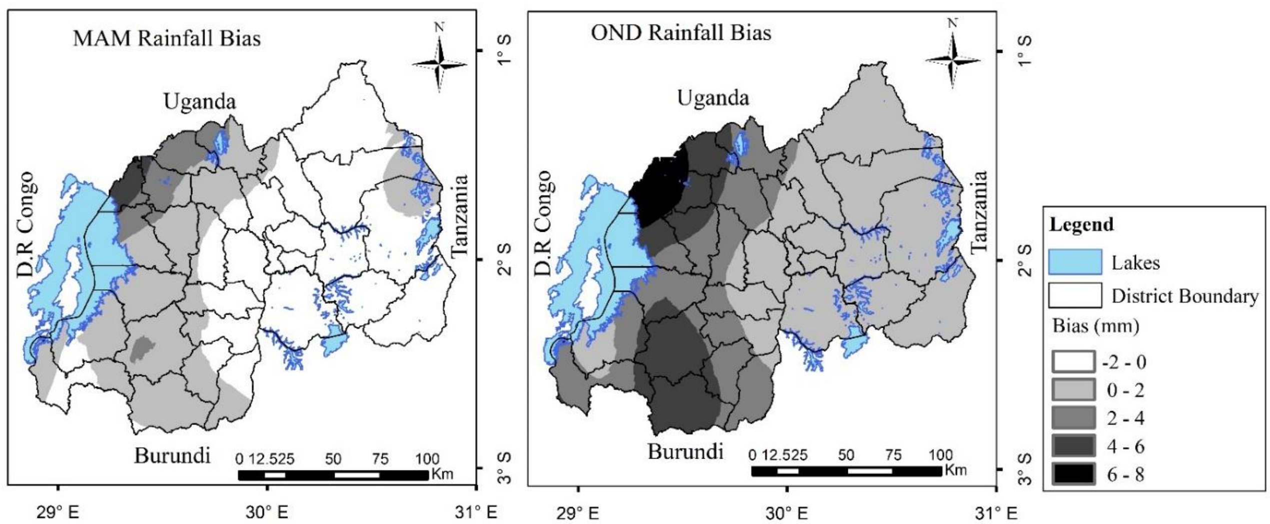

Figure 4: Bias simulated in MAM and OND over Rwanda for the period 1981-2005

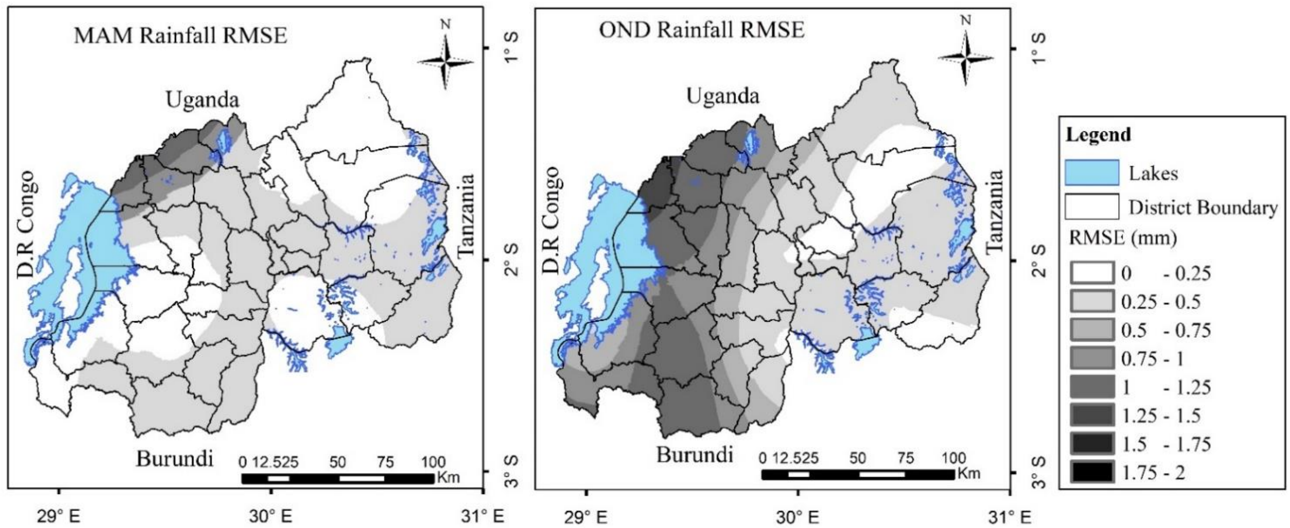

Figure 5: Root mean square error simulated in MAM and OND over Rwanda for the period 1981-2005

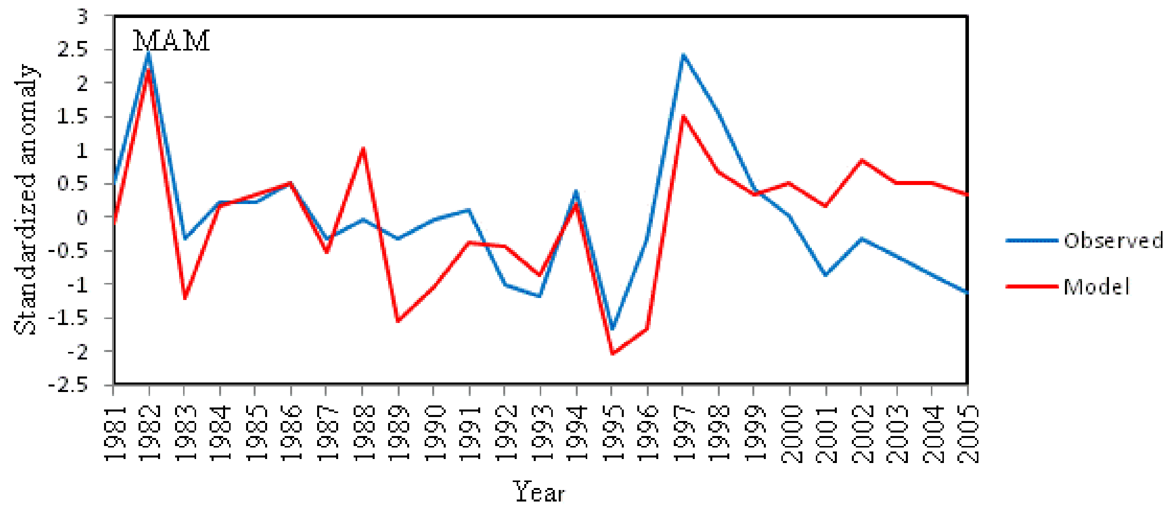

Figure 6: Inter-annual variability observed and simulated rainfall in MAM season over Rwanda from 1981-2005

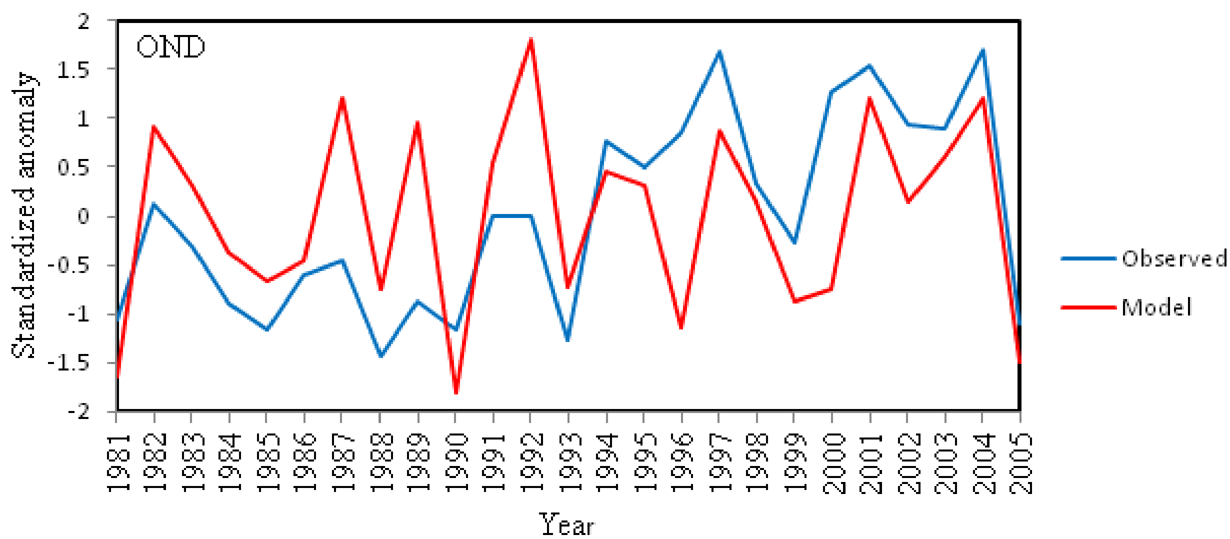

Figure 7: Inter-annual variability observed and simulated rainfall in OND season over Rwanda from 1981-2005

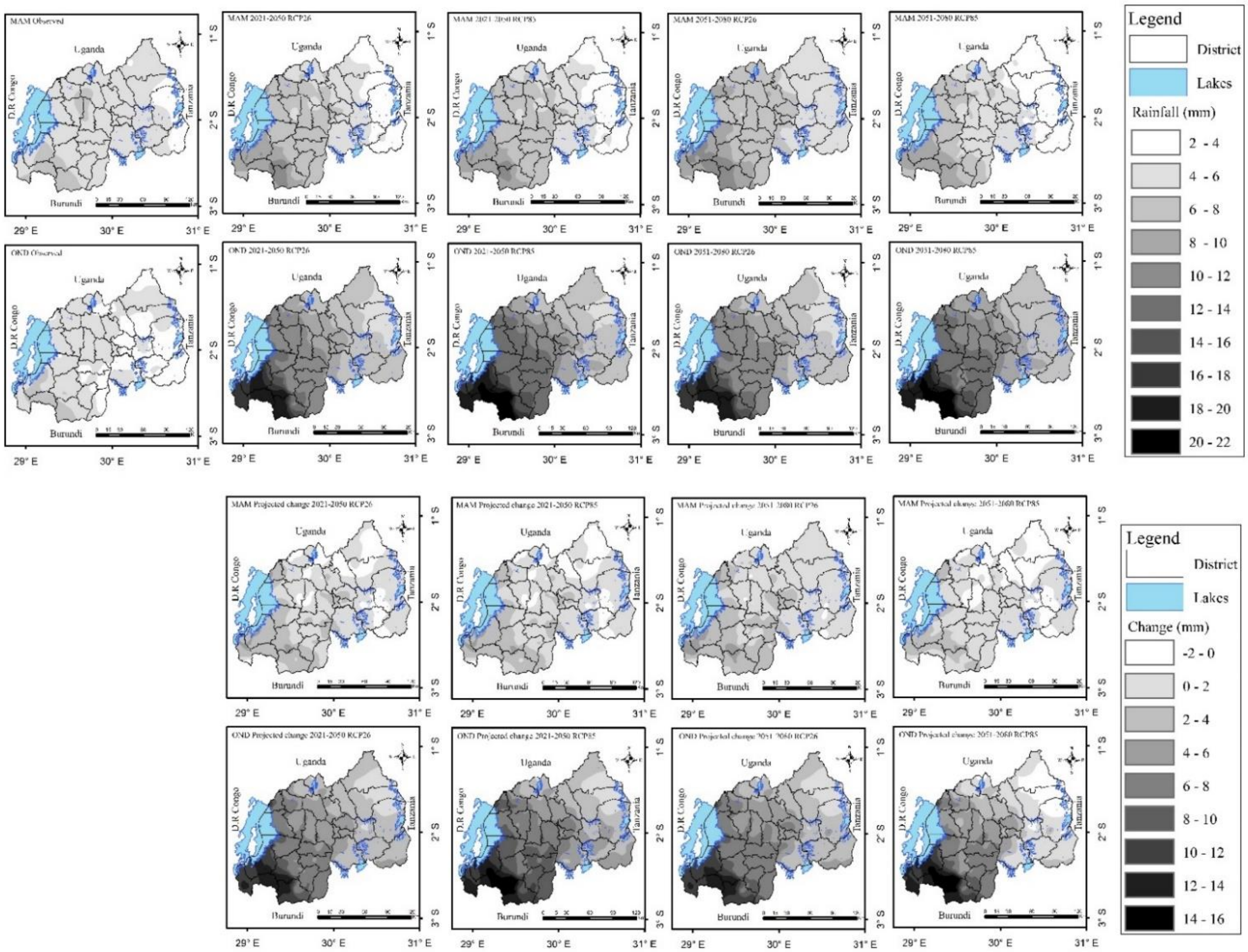

Figure 8: Projected and Changes season rainfall in the 2021-2050 and 2051-2080 under RCP2.6 and RCP 8.5

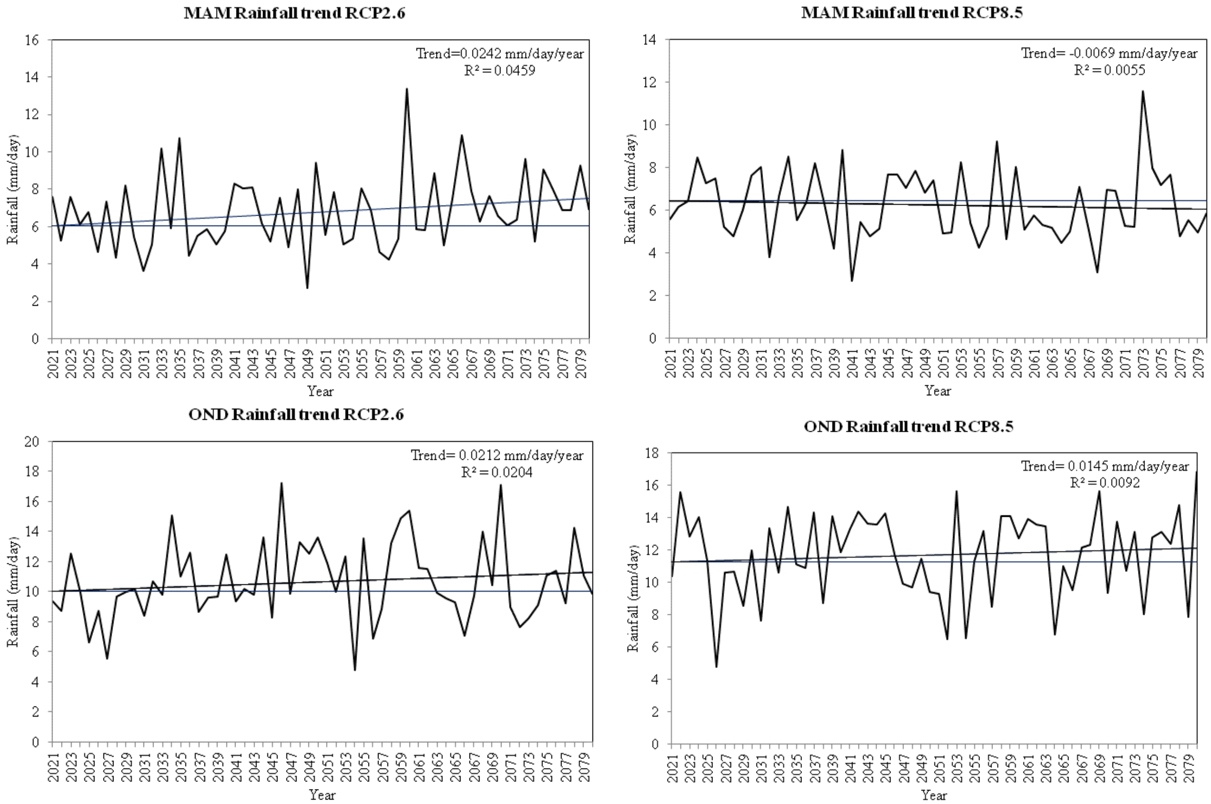

Figure 9: Trends of projected rainfall for RCP2.6 and RCP 8.5 scenarios for period 2021-2080.

Addendum 1: Tables

Table 1: CORDEX RCM used in this study is described below.

Domain	Model	Institution	Driving Model	Short name
AFR -22	ICTP-RegCM4-7	-Abdus Salam International Centre for Theoretical Physics (Italy)	MPI-M-MPI-ESM-LR	-RegCM

Table 2: Trends of rainfall for RCP2.6 and RCP 8.5 scenarios for the period 2021-2080 and their significance level alpha. Trend is significant at α = 0.05; (+): trend is significant at α= 0.1; and (.): trend is not significant.

	MAM rcp2.6	OND rcp2.6	MAM rcp8.5	OND rcp8.5
Trend	0.0242	0.0212	-0.0069	0.0092
Significance	(+)	(.)	(.)	(.)