# DOWNSCALED CLIMATE PROJECTIONS FOR NATIONAL ADAPTATION PLAN IN RWANDA

## TECHNICAL REPORT

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**Abbreviations and Acronyms**

| | |
|---|---|
| ARC V2.0: | Africa Rainfall Estimate Climatology Version 2.0 |
| AR5: | Fifth Assessment Report |
| CBOs: | Community Based Organizations |
| CCD: | Cold Cloud Duration |
| CDD: | Consecutive Dry Days |
| CDT: | Climate Data Tool |
| CHIRPS: | Climate Hazard Group Infra-Red Precipitation with Station data |
| CHPclim: | Climate Hazards group Precipitation climatology |
| CHRS: | Center for Hydrometeorology and Remote Sensing |
| CMIP: | Coupled Model Intercomparison Project |
| CORDEX: | Coordinated Regional Climate Downscaling experiment. |
| CORR: | Correlation |
| CPC: | Climate Prediction Center |
| CRU: | Climate Research Unit |
| CSOs: | Civil Society Organizations |
| DKRZ | German Climate Computing Centre |
| ENACTS: | Enhancing National Climate Services |
| ENSO: | El Niño-Southern Oscillation |
| ERA-40 | European Reanalysis |
| ETCCDI: | Expert Team on Climate Change Detection Monitoring Indices |
| EUMETSAT | European Organisation for the Exploitation of Meteorological Satellites |
| GCMs: | Global Climate Models |
| GGCRS: | Green Growth and Climate Resilience Strategy |
| GHCN: | Global Historical Climatology Network |
| GHG: | Greenhouse Gases |
| GSOD: | Global Summary of the Day |
| GTS: | Global Telecommunications Systems |
| IDW | Inverse Distance Weighted |
| IPCC: | Intergovernmental Panel on Climate Change |
| IRP: | Infrared Precipitation |
| JF: | January-February |
| JJA: | June-July August |
| JRA 55: | Japanese 55-year reanalysis project |
| MAE: | Mean Absolute error. |
| MAM: | March-April-May |
| Meteo Rwanda: | Rwanda Meteorology Agency |
| MINILAF: | Ministry of Land and Forestry |
| MINGRI: | Ministry of Agriculture and Animal Resources |
| MM: | Mesoscale Model |
| MK | Mann-Kendall |
| MoE | Ministry of Environment |
| NAP : | National Adaptation Plan |

| | |
|---|---|
| NGOs: | Non-Governmental Organizations |
| NOAA: | National Oceanic and Atmospheric Administration |
| PBIAS: | Percentage relative bias |
| PEI | Poverty Environment Initiative |
| PERSSIANN: | Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks |
| QM: | Quantile Mapping |
| RCMs: | Regional Climate Models |
| RCP: | Representative Concentration Pathway |
| REMA: | Rwanda Environment Management Authority |
| RFE V2.0 | Rainfall Estimate Version 2.0 |
| RMSE: | Root Mean Square Error |
| RNRA: | Rwanda Natural Resources Authority |
| RWFA: | Rwanda Water and Forestry Authority |
| SASSCAL: | Southern African Science Service Centre for Climate Change and Adaptive Land Management. |
| SEP: | Stakeholder Engagement Plan |
| SMHI-NSC: | Swedish Meteorological and Hydrological Institute-National Super-Computer |
| SOND: | September-October-November-December |
| SSP | Shared Socioeconomic Pathway. |
| TAMSAT: | Tropical Application of Meteorology using Satellite and other data |
| TIR: | Thermal Infra-Red |
| TWG | Technical Working Group |
| UCSB | University of California, Santa Barbara |
| USGS | United States Geological Survey |
| WCRP: | World Climate Research Programme |
| WMO: | World Meteorological Organization |
| WUAs | Water User Associations |

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# CHAPTER ONE

## 1 INTRODUCTION

### 1.1 Background information

Climate change is regarded as a significant global environmental threat (IPCC, 2014, IPCC, 2021), mainly to the planet's human well-being and health. According to the IPCC (2021), it is unequivocal that human influence has warmed the atmosphere, ocean, and land with widespread and rapid changes in the atmosphere, ocean, cryosphere, and biosphere. Each of the last four decades has been successively warmer than any decade since 1850, with the temperatures exhibiting considerable decadal and inter-annual variability, mainly attributable to anthropogenic activities. The IPCC (2021) reports that each of the last four decades has been successively warmer than any decade that preceded it since 1850. For example, recorded global surface temperatures for 2001-2020 and 2011-2020 were higher than in 1850–1900 by 0.99 [0.84 to 1.10] °C and 1.09 [0.95 to 1.20] °C, respectively. Previously, IPCC (2013) reported that global temperatures had been increasing between 1800 and 2012 at the rate of 0.65 to 1.06 $^{o}$C). Consequently, the continued rise in greenhouse gas concentration has been projected to increase the global average temperatures by between 1.4°C and 5.8°C by the time the 21$^{st}$ Century ends, making precipitation amount and distribution unpredictable (Kharin et al., 2013). The changing climate is expected to affect various socio-economic sectors globally (Elasha *et al.*, 2005; Zakieldeen, 2009).

Over Africa, IPCC (2013) indicates that warming is likely more remarkable than the global annual mean warming throughout the continent and in all seasons, with drier subtropical regions warming more than the moisture tropics. An increase in the number of hot days and warm nights is likely, while a decrease in the number of days and nights considered cool is also likely. Heat waves are likely to be more frequent and more prolonged. Annual rainfall is likely to decrease in much of Mediterranean Africa and the northern Sahara, with a greater likelihood of decreasing rainfall closer to the Mediterranean coast. Rainfall in southern Africa is likely to decrease in much of the winter rainfall region and western margins. There is likely to be an increase in annual mean rainfall in East and Central Africa. Thus, northern and southern Africa are likely to face increased drought, while East Africa is projected to have decreased dryness. Only East Africa is likely to see an increase in heavy precipitation. Developing nations remain the most vulnerable to changing climate (Wanyama *et al.*, 2019), with the most considerable reductions in economic growth for an increase from 1.5°C to 2.0°C of global warming projected for low- and middle-income countries in Africa (IPCC, 2018).

Rwanda remains highly vulnerable to climate change as it has experienced significantly high temperature rising phenomena over the last decades (Ngarukiyimana et al., 2021). Previous studies have reported dynamic changes in maximum (Tmax) and minimum (Tmin) temperatures over different parts of Rwanda (Henninger, 2009; Minitere, 2006; Eriksen and Rosentrater, 2008; Safari, 2012). In the last century, an increase in temperature of approximately 0.7–0.9°C over Rwanda was reported (Eriksen and Rosentrater, 2008). Similarly, Henninger (2009) reported an average of 1.5°C increase in temperature with air pollution increase in Kigali city whereby detected temperature fluctuation was attributed to the growing population, urbanization and industrialization. A study by Mohammed et al. (2016) based on six sites in Rwanda for 1964–to 2010 (over 40 years) observed a warming pattern at an average of 0.35°C per decade, whereas climate projections through the 21st century indicated increases in mean air temperature, precipitation and potential evapotranspiration under all CMIP3 models and emissions scenarios used and hence a trend towards warmer and wetter climate conditions. Mohammed et al. (2016) indicated that the projected climate was highly varied in both spatial and temporal scales in Rwanda, and thus the need to ensure that development plans included adaptation and mitigation measures to cope with potential climate change impacts.

Climate information constitutes a valuable resource for understanding the past and future space-time characteristics of all-weather parameters sensitive to socio-economic development. Climate models are suitable tools for assessing climate variability and change (Endris et al., 2013). The Global Climate Models (GCMs) have simulated changes in

atmospheric circulation (Shongwe et al., 2009). However, the coarse resolution of GCMs precludes them from capturing the effects of local forcing like terrain effects and land-sea contrasts that modulate the climate signal at finer scales (Giorgi et al., 2009; Endris *et al.*, 2016). The sub-grid scale processes which significantly affect climate include variations in vegetation, topography, soils, and coastlines. The GCM output must be downscaled to generate climate information at local scales using either statistical or dynamical techniques. Regional climate models (RCMs) downscale the outputs from general circulation models based on the dynamical downscaling technique. The number of global climate models (GCMs) used by the Intergovernmental Panel on Climate Change (IPCC) went from 23 models in the Third and Fourth Assessment reports (Randall et al., 2007) to 42 in the Fifth Assessment Report (AR5) (IPCC, 2013). There are also many sources of information on downscaling and tools for applying climate models to help assess vulnerability to climate change and adaptation options. Therefore, the Regional Climate Model output is more suited to support understanding local climate, especially in regions such as Eastern Africa with complex processes (Sun et al., 2006). The Coordinated Regional Climate Downscaling Experiment (CORDEX) provides dynamically downscaled model output and, thus, high-resolution regional climate projections suitable for impact assessment at regional scales (Giorgi et al., 2009).

There is a growing international consensus that future climate change is inevitable even if stringent emission reduction measures are adopted (Osman *et al.*, 2021). Globally, an increase in the earth's surface temperature by 0.8 °C has been observed in the last hundred years and by 0.6°C in the last thirty years (Hansen *et al.*, 2003). Effective adaptation strategies to respond to climate variability and change require reliable information at finer spatial and temporal resolution. Understanding and confidence in climate change and its potential impacts have significantly grown over the last few years. Therefore, the report aimed to analyze the downscaled information on historical and projected climate information to the country-level for the national adaptation plan in Rwanda.

### 1.2 The rationale of the report

Over the past decade, Rwanda has experienced strong economic growth across various sectors, including agriculture, energy, mining, industry, and services. By adhering to green economy principles during this growth, the country has positioned itself to become a world leader in green growth (NLUDMP 2020). The pressures from a rapidly growing population on land, water, food, and energy resources are currently threatening the sustainability of its development. Current and predicted effects of climate change are compounding these threats. The major impacts of climate change in Rwanda are i) an increased frequency of extreme flood events, ii) an increased duration and frequency of droughts, and iii) increased average temperatures. These impacts are expected to become more severe over the coming decades, with intense adverse effects on agriculture, energy production, forestry and water supplies.

To address the various threats posed by climate change, Rwanda has taken a strategic decision to pursue a green growth approach to development. Vision 2050 aspires to take Rwanda beyond high income to high living standards by the middle of the 21st century. To realise our full potential and drive towards this goal, Rwanda is committed to being a nation that has a clean and healthy environment that is resilient to climate variability and change and that supports a high quality of life for its citizens. The National Environment and Climate Change Policy provides strategic direction and responses to the emerging issues and critical challenges in environmental management and climate change adaptation and mitigation

The Green Growth and Climate Resilience Strategy (GGCRS), developed in 2011 promotes an integrated approach to climate change adaptation and provides an overarching framework for adaptation planning and implementation by all sectors, institutions, and government agencies.

Despite developing an institutional and policy-enabling environment for climate change adaptation, the mainstreaming of climate change adaptation into medium- to long-term planning remains limited in Rwanda primarily because most past and ongoing initiatives have taken a sector-specific approach instead of a coordinated, holistic approach. Other limitations to medium- to long-term climate change adaptation in Rwanda include (i) the need for enhanced capacity to generate and downscale climate projections, (ii) minimal awareness of the medium- to long-term climate change

scenarios across the country, (iii) limited information on the costs versus benefits of taking a landscape approach to adaptation (e.g., through ecosystem-based adaptation) and lack of intensive monitoring and evaluation of climate change adaptation interventions.

The availability of regional and local scale climate change scenarios is critical for assessing climate change impacts and vulnerability in various socio-economic sectors and for the development of appropriate adaptation strategies. Therefore, there is a need for standardized climate projections for Rwanda specific to its different agro-ecological zones and biophysical conditions or for guidance on which external climate information sources to use and how to use them. This information needs to be accompanied by current information and local expertise to ground and interpret the future scenarios in the context of climate-sensitive sectors, policies, and programmes[1][2]. Strengthening the technical capacity of Meteo Rwanda staff to downscale international and regional climate change model projections (such as those produced by the World Climate Research Programme, WCRP[3]) to national and sub-national scales is thus required[4].

### 1.3 Objectives of the report

The overall objective of the report is to generate and downscale climate projections from global and regional to national and sub-national levels over Rwanda based on the best available techniques and data while validating different Regional Climate Models (RCMs) to be used as the basis for national and sub-national climate change adaptation planning. The terms of Reference (ToRs) that was used to determine the objectives of the report are detailed in Annex 1.

### 1.4 Scope of the report

The report focuses on Rwanda, which is a landlocked country in East Africa and is bordered by four countries, namely: Uganda to the north, Burundi to the south, Tanzania to the east, and the Democratic Republic of the Congo (DRC) to the west and north-west (Figure 1.1). Many of Rwanda's boundaries are geographical features, i.e. Lake Kivu and the Rusizi River on the west, by the Ruhwa and Akanyaru Rivers, on the south and by the Akagera River on the east on the northwest by a chain of volcanoes. The country is divided into four provinces which include, Western, Eastern, Southern, and Northern Provinces. Each province is subdivided into districts, of which there are a total of 30 (Figure 1-1). Rwanda's topography is characterized by steep hills and high mountains, which is described as 'the land of 1000 hills. The country is situated at a high altitude with elevations ranging from 950 m above sea level (the Rusizi River) to 4,507 m above sea level (at Mount Karisimbi). Much of the western part of the country – which lies within the Albertine Rift montagne ecological region – ranges from 1,500 to 2,500 m. By comparison, central Rwanda is characterized by rolling hills, while the eastern parts of the country are dominated by savannas, plains and wetlands, all at altitudes below 1,500 m.

Rwanda's climate is temperate to tropical and is characterized by four distinct seasons: i) a short rainy season **(September–December); ii) a short dry season (January–February); iii) a long-wet season (March-May), and iv) a long dry season (June–August) (REMA 2009**). Rainfall patterns follow an east-west gradient and are determined by altitude. The western side of Rwanda is mountainous, with elevations often over 2,000 m, while the altitude of the central plateau ranges from 1,500–to 2,000 m and the altitude of the eastern plateau is mostly below 1,500 m. Consequently, the eastern region is drier and warmer than the western region. It has a mean annual rainfall of just below 700 mm and a mean annual temperature of ~20 °C (REMA 2011). In contrast, the western region has a mean annual rainfall of 1,500 mm (REMA 2011) and a mean annual temperature of <17 °C. The El Niño Southern Oscillation

1 *Ibid*.
2 REMA. 2015. Baseline Climate Change Vulnerability Index for Rwanda.
3 The WCRP's (an IPCC initiative) mission is to facilitate the analysis and prediction of earth system variability and change for use in an increasing range of practical applications of direct relevance, benefit and value to society. An objective under this mission is to determine the predictability of climate. Source: https://www.wcrp-climate.org/about-wcrp/wcrp-overview. Accessed on 20 March 2018.
4 Stakeholder consultations during the proposed project's PPG phase.

(ENSO) influences Rwanda's climate by increasing the: i) variability of seasonal rainfall and ii) frequency and intensity of flood and drought events.

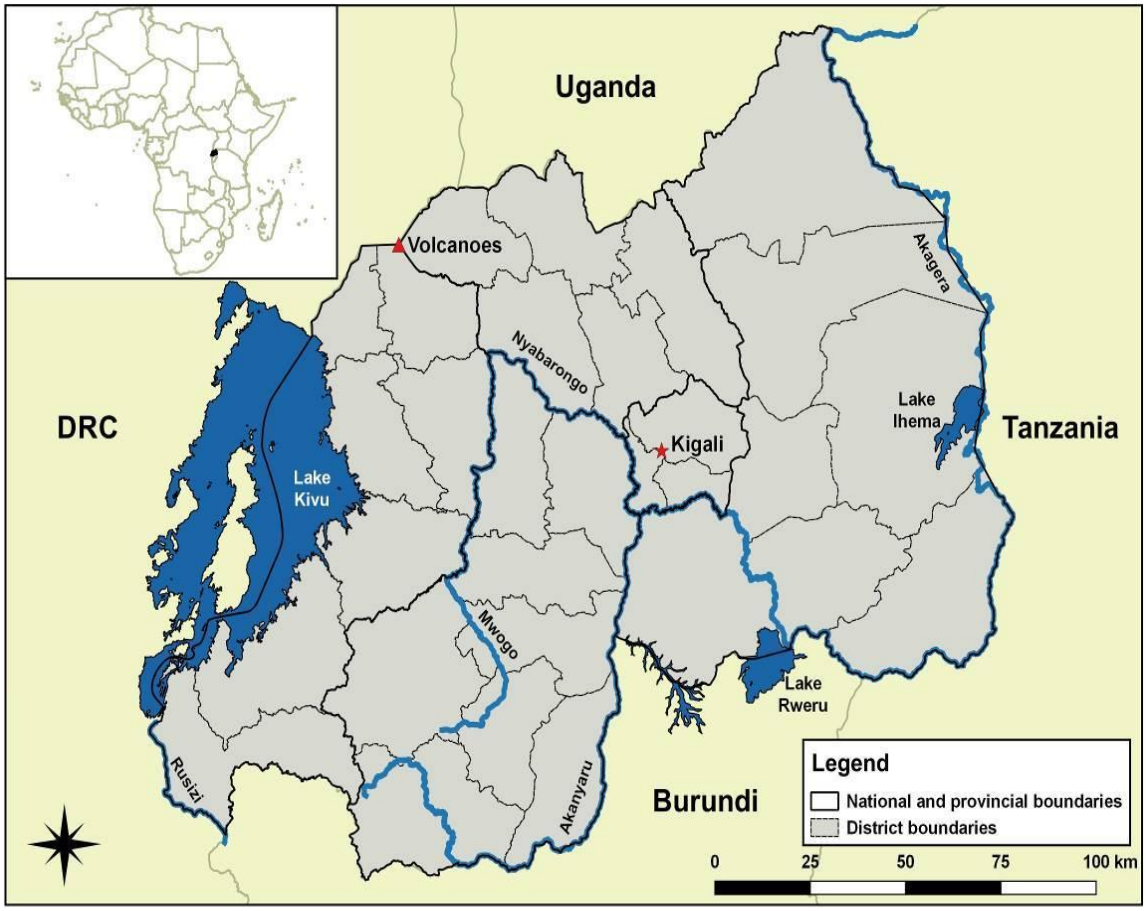



Figure 1-1. Geographical location of Rwanda in East Africa

# CHAPTER TWO

## 2 CLIMATE VARIABILITY AND CHANGE IN RWANDA

### 2.1 Observed and projected climate change over Rwanda

#### 2.1.1 *Temperature*

From 1971 to 2010, the mean annual temperature in Rwanda increased at a rate of 0.35 °C per decade (Rwanda, 2011). This increase is slightly more than the mean global increase of 0.27 °C per decade between 1979 and 2005 (IPCC, 2007). Rainfall records from 1931 to 1990 do not show a clear increasing or decreasing trend. However, an analysis of data collected since 1991 indicates an increasing occurrence of climatic extremes over time and in various country regions. The country's rainy seasons are becoming shorter and more intense, especially in the Northern and Western Provinces, while the Eastern Province experienced several severe rainfall deficits over previous decades (MER. 2015), whereas records show increased prolonged droughts since the 1980s.

In Rwanda, the high degree of interannual and interdecadal climate variability and lack of historical records have made determining climate trends difficult (GERICS, 2015).). Temperature increases have been experienced from 1971 to 2016, showing an increase in mean temperature of between 1.4°C and 2.6°C in Rwanda's southwest and eastern regions (GoR, 2020; CCKP, 2022). Additionally, increased interannual variability in recent decades was also observed, such as the average increased temperature from 2012 to 2014 increased by 0.79°C (USAID, 2018). According to an analysis from the German Climate Service Center (GERICS) of 32 Global Climate Models (GCMs), temperatures across Rwanda are expected to increase, and projections show a change in annual mean temperature from 1.1°C to 3.9°C by the end of the century. REMA (2009) also reported that average temperature had increased from 19.8°C in 1971 to 20.7°C in 2007, making an increase of 0.9°C in 27 years and the number of days of rainfall has dropped from 148 to 124 from 1971 to 2009

A study by Safari (2012) indicated a significant warming trend from 1977 to 1979, whereby the capital Kigali recorded a slope of 0.0455°C/year. The studies mentioned above have reported significant results in terms of dynamic variability of maximum and minimum temperature over some regions of Rwanda. However, most previous studies were limited to a specific area, which may fail to cover the country's general representation. Furthermore, none of those previous studies did consider the impact of topography and seasonal variation factors, which are very important in detecting and attributing climate change to Rwanda's regional differences. Previous studies have almost agreed that topography regulates temperature distribution in many regions where minimum temperature changes have been significantly related to the elevation (Revadekar et al., 2013; Sun et al., 2017).

Based on observed temperature, the IPCC reported that equatorial and southern parts of eastern Africa (where Rwanda lies) had experienced a significant increase in temperature since the early 1980s (IPCC, 2014). Over Rwanda, the average temperature increase from 1961 to 2014 is 0.45°C per decade for the whole country. In their study on projections of precipitation, air temperature and potential evapotranspiration in Rwanda under changing climate conditions, Mohamed et al. (2016) also suggested an over Rwanda.

Mohammed et al. (2016) found that average air temperature had increased by 0.35°C per decade from 1964 to 2014 whereas the ECHAM-A2 model predicted the highest increase in mean air temperature at Nyanza (+4.5°C) and potential evapotranspiration at Bugesera (+55%) while the highest precipitation increase was projected to be 29% at Kayonza under MIROC-A2. The projected climate was highly varied in both spatial and temporal scales in Rwanda, and thus the need to ensure that development plans included adaptation and mitigation measures to cope with potential climate change impacts. On the contrary, Uwimbabazi et .al. (2022) indicated that the surface air temperature experienced strong, significant increasing trends in both seasons and annual time scales. From 1981 to 2020, the annual surface air temperature increased by ~0.23 °C per decade, with MAM and OND showing an increase of ~0.19

and 0.2 °C per decade, respectively. The last decade (2010–2020) witnessed a sharp increase in surface air temperature in Rwanda.

Henninger (2009) analyzed the observed air temperature at Kigali using 3 meteorological stations maintained by the Meteo Rwanda from 1971 to 2008. The data indicated an increasing annual mean temperature of 2.6°K for nearly 40 years. Mainly, for the last 10 years, from 1998 to 2008, warming in Kigali is evident and could be attributed to global warming and to the ongoing urbanization.

A study by Ngarukiyimana et al. (2021) on the long-term temporal analysis between 1964 and 2010 indicated that maximum and minimum temperature significantly increased on seasonal and annual scales. However, the minimum temperature increased at a faster rate than the maximum temperature in the highest altitude region (stations with an altitude greater than 2,000 m) (0.27 against 0.07°C/decade in March-to-May) and (0.29 against 0.04°C/decade in October-to-December). Similarly, the spatial distribution of Tmin and Tmax shows that the warming trend in season and annual temperatures were noticeable over Rwanda, with regions which lie mainly in the east part showing a high rate in above normal temperature condition at the level of 47.85% while regions above 1,500 m of altitude recorded rate of 31.5% above average temperature.

Regarding the modeling of future climate change scenarios, several studies have been conducted since 2009 to determine projections for Rwanda. Tenge et al. (2013) also downscaled projections to 8 $km^2$ for temperature and rainfall. A stock take of studies that have been undertaken on climate change scenarios for Rwanda is presented in Table 2-1. GCMs also show an increase in mean annual rainfall of up to 20% (100–400 mm) by 2050 (Tenge et al., 2013) and 30% by 2080 (Figure 2-2).

### 2.1.2 *Rainfall*

In Rwanda, rainfall trends have shown an increased occurrence of extremes since the 1960s across various country regions, with the El Niño Southern Oscillation influencing precipitation trends during El Niño years (CCKP, 2022). The annual rainfalls in Rwanda exhibited high fluctuations from 1961 to 2016. Over this period, mean rainfall significantly decreased in January, February, May and June but significantly increased from September to December. Over this period, Rwanda's eastern region has experienced frequent dry episodes (MoE, 2018). In the country's northern and western provinces, rainy seasons are becoming shorter and more intense, which has resulted in increased erosion risk in these mountainous areas of the country. Additionally, eastern regions have experienced severe rainfall deficits for several years, alternating with rainfall excesses (NCES, 2015).

Rainfall for the country is highly variable, and GERICS analysis indicates a likely increase in annual rainfall, with the increase likely to occur during the main rainy season, December to April, with drier tendencies from July to September. Heavy rainfall intensity is expected to increase from +3% to +17%, and the frequency is expected to increase from +9% to +60% by the end of the century. An increase in the country's overall water balance is also expected. During periods of increased aridity, long-lasting dry spells are expected to increase by 0 to +8 days by the end of the century (GERICS, 2015). Frequent rainfall deficits are expected in parts of the eastern province (Bugesera, Nyagatare, Gatsibo, Kayonza, Ngoma, Kirehe) and the southern province (Nyanza, Gisagara). In contrast, increased rainfall is expected in parts of the western, northern and southern provinces (NCES, 2015). This is expected to significantly impact agriculture, water, energy, forestry, and health sectors, as well as agricultural land and freshwater resources and ecosystems (NCES, 2015).

Uwimbabazi et al. (2022) showed much variability in rainfall with a notable annual and seasonal rainfall decrease from 2010 to 2017. The rainfall exhibited an increasing trend of ~8.4 mm/decade at the annual time scale, while an increase (decrease) of ~4.5 mm/decade (−3.4 mm/decade) was observed during the OND and MAM seasons, respectively. However, the observed increases and decreases were found not to be significant at the 95% confidence level. Zhou et al. (2021) noted that during the long rainy season, the observational results showed that Rwanda's dominant intraseasonal rainfall mode possesses significant variability on the 10–25-day time scale. Based on a one-point-

correlation analysis (i.e., calculating a simultaneous correlation coefficient pattern of the 10–25-day rainfall anomaly, which is obtained against the 10–25-day anomaly over Rwanda). Further, the intraseasonal rainfall anomaly in Rwanda co-varies with that in its adjacent areas. Composite results further show that the development of the ISO of rainfall anomalies in Rwanda and its surrounding regions is associated with anomalous westerly winds, which may trace back to a pair of westward-propagating equatorial Rossby waves.

Analysis based on the CHIRPS dataset by Jonah et al. (2021) noted that the datasets skillfully captured the mean annual cycle and rainfall variability over Rwanda and revealed a decrease in annual and seasonal rainfall in the southwest of Rwanda while an increase in the northeast during SOND. ENSO had a positive influence on SOND rainfall and a negative influence on MAM rainfall. There is also a close relationship of SOND rainfall with SSTs and IOD, contributing to anomalous wet (dry) conditions in Rwanda (Jonah et al., 2021). In the past 30 years, observed climate change in Rwanda has resulted in a shift in the timing of rainfall seasons in certain regions (USAID, 2012). Rainfall seasons are invariably becoming shorter and more intense, particularly in the Northern and Western provinces, resulting from an increased threat of erosion in these mountainous areas. In the east of the country, the frequency of years with below-average rainfall has increased, resulting in reductions in agricultural production (MER, 2015). In recent decades, and in addition to these observed changes in rainfall, higher temperatures, prolonged droughts, and elevated evapotranspiration rates have been observed. Furthermore, the frequency and intensity of extreme events in Rwanda have also increased (including those associated with ENSO and La Niña) (GoR, 2015) which have lead to heavy rainfall erosion, flooding and landslides in the northern and western regions (USAID, 2012).

Most notably, Rwanda will experience an increase in the frequency of extreme flood events by up to 30% in the short rainy season (September–November) and up to 50% in the long rainy season (March-May); prolonged seasonal droughts recurring every two to three years; and an increased frequency of prolonged drought events, particularly in the southern and eastern regions of Rwanda (REMA, 2009; Tenge et al., 2013).

Sebaziga et al. (2022) indicated a higher variability in annual rainfall over Kigali city, the central-eastern part, with lower variation in the western part of the country. A significant decreasing trend was observed over the Southern part, with a decreasing trend of 9.1mm/year corresponding to – 6.7%. During the long rain season, more variability over the extreme eastern part, central and the southern region of the country was revealed, whereas a low variability was registered over northern high land with a significant decreasing slope of 3.5mm/year corresponding to – 9.8%. During the short dry season, lower variability was registered over the Northwestern high land and the western region, while pronounced variability was observed over the south-eastern part of the dry and hot lowland climatic zone. A significant increasing trend of 3.1mm/year corresponding to 4.3% was revealed over the western part while the remaining stations revealed a non-uniform trend.

East Africa experiences the dipole rainfall pattern that is characterized by increases over the northern region and decreases over the eastern and southern regions (Mutai et al. 1998; Mutai and Ward 2000; Schreck and Semazzi 2004; Anyah and Semazzi 2007; Eriksen et al. 2008; Ilunga and Muhire 2010), with Rwanda becoming wetter over the northern highlands and south-western region and warmer over the eastern lowlands and the central plateau (Muhire et al., 2014). Heavy rainfall has caused devastating floods and landslides in some parts of Rwanda in the last few years. The most affected areas are the Northern (Gakenke, Cyeru, Rulindo and Gicumbi districts) and Western (Nyamasheke, Nyamagabe, Karongi and Ngororero districts) regions in the years 2001, 2002, 2007, 2008 and 2012 (David et al. 2011). The May 2002 floods had 108 fatalities in the north western regions, while the 2007 one resulted in the displacement of more than 456 families, with hundreds of hectares of crops in Bigogwe sector in Nyabihu District destroyed (Muhire et al., 2014).

Long (March-May) and short (September–December) rains patterns over East Africa in general and Rwanda, in particular, are controlled mainly by the intertropical convergence zone (ITCZ) (Mutai and Ward 2000; Ilunga et al. 2004; Anyah and Semazzi 2007; Kizza et al. 2009). This would ideally make the respective rains variability to be associated with SST patterns over the Indian and Atlantic oceans from the ITCZ over Rwanda, and the convergence of Mascarene Anticyclones from the Indian Ocean, and Saint Helena Anticyclones from the South Atlantic Ocean (Mutai and Ward

2000; Ilunga et al. 2004; Anyah and Semazzi 2007; Kizza et al. 2009). Long and short rains were investigated because they contribute about 75 % of the rains received in Rwanda. In addition, more rainfall variability was observed during the two seasons where the long rains were markedly reduced especially in May (Muhire and Ahmed 2014). At the same time, an increase was observed during the short rains period especially over the northern highlands and south-west region of Rwanda (Muhire and Ahmed 2014).

A study by Muhire et al. (2014) on the relationships between Rwandan seasonal rainfall anomalies and El Niño-Southern Oscillation phenomenon (ENSO) events showed approximately three climatic periods, namely, dry period (1935–1960), semi-humid period (1961–1976) and wet period (1977–1992). Though positive and negative correlations were detected between extreme short rain anomalies and El Niño events, La Niña events were mostly linked to negative rainfall anomalies while El Niño events were associated with positive rainfall anomalies. The occurrence of El Niño and La Niña in the same year does not show any clear association with rainfall anomalies. However, the phenomenon was more linked with positive long rains anomalies and negative short rains anomalies. The normal years were largely linked with negative long rains anomalies and positive short rains anomalies, which is a pointer to the influence of other factors other than ENSO events. This makes the projection of seasonal rainfall anomalies in the country by merely predicting ENSO events difficult.

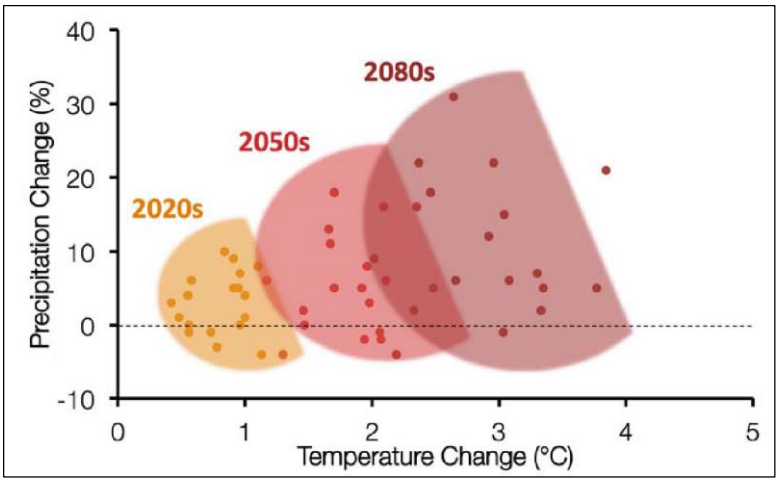



Figure 2-2: Predicted annual changes in temperature (°C) and precipitation (%) for Rwanda for the 2020s, 2050s and 2080s (REMA 2011).

**Table 2-1. Stocktake of climate change scenario analyses in Rwanda.**

| Study | Modelling method | Emissions scenario | Year modelled to | Variables modelled | Historic data | Data used | Spatial resolution |
|---|---|---|---|---|---|---|---|
| Shongwe et al. (2009) | Dynamical downscaling | SRES AIB (Med) | 2200 | Mean and extreme precipitation rates | Rainfall: Climate Research Unit (TS2.1 gridded station data; 1961–1990) | CMIP3 (12 models; GCMs) | 1.25°x1.24° |
| CSAG & SEI (2009) | Statistical downscaling | SRES A2 (High | 2065 | Temperature and rainfall | Temperature and rainfall: CSAG (station data; 1961–2009) | CSIRO Mark 3, ECHAM 5, IPSL CM 4, CCCMA CGCM 3, GFDL CM 2, CNRM CM 3, MIUB Echo, MRI CGCM 2, GISS E (9 models; GCMs) | Not specified |
| McSweeney (2011) | Dynamical and statistical downscaling | SRES A2 (High); A1B (Med); B1 (Low) | 2020, 2050, 2080, 2090 | Temperature, rainfall and climatic extremes including hot days and heavy rainfall events. | Temperature and rainfall: Rwanda METEO data bank | CMIP3 (19 models; GCMs) | 2.5°x2.5° |
| Second National Communication (2012) | Not specified | Not specified | 2020, 2050, 2100 | Temperature, rainfall and evapotranspiration. | Temperature, rainfall & evapotranspiration. MAGICC model was used to work out climate estimates (in relation to data from 1971 to 2007). Statistical correlation analysis of station data. | PCM 00, IAP 97, LMD 98 (3 models; GCMs) | Not specified |
| Haensler et al. (2013) | Bias correction and statistical downscaling | SRES A2 (High; B1 (Low) | 2065, 2100 | Temperature, rainfall and climatic extremes including cold and hot nights, cold and hot days, rainfall during rainy season, dry spells during rainy season, duration of rainy season, intensity of heavy rain events, frequency of heavy rain events, and maximum 10day rainfall sum. | Temperature: WFD dataset (1961–1990), CRU dataset (1961–1990) Rainfall: WFD dataset (1961–1990), NCDC of the NOAA (station data; 1961–1990), CRU dataset (1961–1990) | CMIP3, CMIP5, WATCH, REMO, RCA4 (77 models, GCMs and RCMs) | 0.5°x0.5° |
| Tenge et al. (2013) | Downscaling (not specified) | SRES A1B (Med) | 2050 | Temperature and rainfall | Not specified | CNRM-CM3, ECHAM 5, CSIRO Mark 3, MIROC 3.2 (4 models; GCMs) | 0.08°x0.08° |

## 2.2 Climate change impacts on key sectors

Studies have indicated that spatiotemporal changes of maximum and minimum temperature significantly affect the intensity, duration and extent of temperature extremes worldwide (Salman et al., 2017; Sun et al., 2017). Furthermore, food production, biodiversity, and ecosystems are highly affected by Tmax and Tmin changes (Qasim et al., 2016; Walther et al., 2002; Smith et al., 1999). Similarly, Parmesan et al. (2003) found that climate change affects living systems. Other studies indicate that the changes in maximum and minimum temperature have significantly impacted agriculture, health, and food security (Iqbal et al., 2016).

Rwanda is extremely vulnerable to the impacts of climate change as its economy is largely dependent on rain-fed agriculture. The agriculture sector accounts for 90% of the employed population (directly and indirectly) and represents ~31% of the country's GDP (MER, 2015). The other main sectors that have been – and will continue to be – greatly affected by climate change include water, infrastructure, and health. Estimates of medium-term costs to address future climate change impacts across the country are US$ 50 – 300 million per year by 2030 (SEI, 2009). In 2012, the Unit of Research and Public Awareness (URPA) of the Ministry of Disaster Management and Refugees (MIDIMAR) mapped which areas of Rwanda are most vulnerable to climate change. In the study, URPA identified floods and landslides as the most frequent effects of climate change that occur in Rwanda. Most sectors identified as being vulnerable to both floods and landslides are located in the north and central/west of the country (Figure 2-3). In contrast, the east and south east of Rwanda were identified as being most vulnerable to prolonged drought (Figure 2-4).

Climate change will have multiple negative effects on the Rwandan economy. For example, major flood events that occurred in the past (such as those in 1997, 2006, 2007, 2008, and 2009) resulted in many fatalities and damages to infrastructure and agricultural land (SEI, 2009). According to Rwanyiziri and Rugema (2013) findings, the rise in temperature and changes in the amount of rainfall and its distribution have altered water resources availability, consequently affecting rice productivity across Bugesera District. The economic impacts of these extreme weather events were considerable, with the 2007 flood, for example, causing an estimated direct economic cost of US$4 to US$22 million (equivalent to around 0.6% of GDP) for two districts alone (SEI, 2009). Such effects are expected to become more severe over the coming decades. Model estimations indicate that the additional net economic costs (in addition to existing climate variability) could be equivalent to a loss of almost 1% of GDP each year by 2030, though this excludes the future effects of floods and other extreme weather events (SEI, 2009). This estimate is therefore conservative. Furthermore, estimates of medium-term costs to address future climate change impacts across the country are US$50 – US$300 million per year by 2030 (SEI, 2009).

Global and regional climate models predict that the impacts mentioned above of observed climate change will intensify and become more frequent in the future (GoR, 2012). Most notably, Rwanda will experience an increase in the frequency of extreme flood events by up to 30% in the short rainy season (September–November) and up to 50% in the long rainy season (March–May); prolonged seasonal droughts recurring every two to three years; and an increased frequency of prolonged drought events, particularly in the southern and eastern regions of Rwanda.

The agriculture sector (which is predominantly rain-fed) is the most climate-vulnerable sector in Rwanda, as any climatic changes are likely to affect productivity. This sector accounts for 90% of the employed population (both directly and indirectly) and is the highest contributor to the country's GDP (~31%). Consequently, any negative effects on the agriculture sector caused by climate change will be detrimental to Rwanda's economy. The other main economic sectors that will be greatly affected by climate change include water, infrastructure, and health. The various impacts of extreme climatic events (current and expected) on several of Rwanda's sectors are summarized in Table 2- 2. To date, the impacts of climate change on Rwanda's **agricultural sector** have not been rigorously modelled or quantified. However, any adverse impacts are expected to be related to: i) further reductions in the amount of arable land as a consequence of increasing soil erosion and landslides; ii) reduced soil moisture content because of increased evaporation; iii) crop losses because of increased temperatures, flood damage and drought; and iv) damage to crops and agricultural infrastructure caused by floods (DREF, 2011). While certain projections indicate a negative impact on the sector, others suggest that impacts will be modest or even benefit the sector. For example, banana production is

likely to be unaffected as this crop grows well at higher temperatures (MER, 2015). Conversely, bean yields will decrease as the cooler temperatures (14–18 °C) required for their optimal production are no longer consistent (REMA, 2009). Rwanda's main cash crops, coffee, and tea, are expected to be negatively affected by climate change. Both require specific temperatures for efficient production (between 18 and 20°C for tea and below 25 °C for coffee) and are sensitive to erratic rainfall patterns (Ngabitsinze et al. 2011; MINAGRI, 2015). In addition, temperature increases will force farmers to plant these crops at higher altitudes, where temperature is likely to be more suited to their production. However, the steeper gradients in these areas are prone to erosion and conflicts may occur with small-scale farmers areas that may already occupy them (GoR, 2011).

In the **energy sector**, prolonged droughts (combined with increases in evaporation) and frequent flood events will compromise hydroelectric power generation. Drought will result in drier wetlands and will reduce river base flows, compromising the generating capacity of hydroelectric dams. For example, the drought in 2004 caused such a reduction in hydropower production in Rwanda that the government was forced to rent diesel hydropower plants to meet domestic demand (GoR, 2011). In addition, increased sediment load in rivers from soil erosion will further reduce base flows and result in i) the siltation of dams; and the ii) degradation of turbines and other hydroelectric infrastructure. Similarly, flooding – the intensity and frequency of which is expected to rise under future climate change conditions – will also damage infrastructure. Consequently, both floods and droughts will reduce the capacity for power generation, increasing the dependence of local communities on woodfuel. The increased usage of woodfuel will exacerbate the rate of deforestation in the country (AFDB, 2013).

The impacts on the forestry **sector** will be related to changing rainfall regimes and higher temperatures. Firstly, climate change conditions could favour the growth of alien plant species (Dukes and Mooney, 1999). A recent study indicated that alien plants adapt more easily to climate change than indigenous species (Willis et al., 2010). As a result, the invasion success of alien plants will promote homogenised ecosystems and could lead to localised extinctions of indigenous species (Winter et al., 2009). Secondly, extinctions are also likely to occur because of the increased dependence on – and exploitation of – ecosystem services by rural communities. Thirdly, the decrease in water availability in Rwanda's eastern and south-eastern regions is likely to lead to reduced tree cover. Additional factors that will lead to deforestation include: i) increased use of woodfuel (discussed in the paragraph above); and ii) declining agricultural productivity, which will require more land to be cleared by subsistence farmers.

The **water sector** is particularly vulnerable to the effects of climate change because prolonged droughts will decrease the quantity and quality of water available. The adverse impacts of reduced water availability are often immediately evident, particularly in the agricultural sector. This is because agriculture is mainly rain-fed and uses 68% of the country's annual water resources (NIS, 2011). Consequently, any decrease in water availability will reduce both agricultural productivity and food security. In addition, an increased incidence of floods and droughts will reduce water quality because of erosion and siltation. Furthermore, reduced base flows will affect downstream irrigation projects and both flood and drought events are likely to damage infrastructure for water supply.

The effects of climate change will also negatively affect the **health sector.** For example, floods will: i) increase the spread of waterborne diseases such as cholera, typhoid and diarrhoea; ii) promote the incidence of malaria; and iii) increase the number of injuries associated with extreme events. Regarding malaria, the projected temperature increases are expected to increase the risk of contraction (up to 150% by the 2050s) in rural populations living in previously malaria-free areas, such as those at high altitudes. This increase in the country's disease burden is expected to be considerable and could cost the GoR over US$50 million per year (FCFA, 2016). Additional effects of climate change include malnutrition because of decreased food security. Furthermore, damage to transport infrastructure (see below) will result in reduced accessibility of hospitals and emergency services.

Because Rwanda has few all-weather roads, flood events in Rwanda will affect the **transport sector**. Floods increase the frequency of landslides and consequently damage road infrastructure. The Rwandan economy will be affected by the financial costs required for such damages. Such costs will be exacerbated by the current reliance of the economy on a functioning road network.

Climate change will exacerbate ecosystem degradation and biodiversity loss in the environmental sector. For example, an increased intensity of rainfall and flooding will compound soil erosion in exposed areas. In addition, the effects of climate change (such as prolonged droughts) will increase mortality rates of wild animals that are sedentary or that have specific climatic requirements. It is also anticipated that local communities will overexploit natural resources (such as woodfuel and other non-timber forest products) because of declining agricultural yields and the increased vulnerability of livelihoods.

Finally, the **tourism sector** will be affected by the loss of biodiversity as described above. This sector relies primarily on the aesthetic value and unique wildlife found in the remaining natural areas. For example, mountain gorilla (*Gorilla beringei beringei*) populations are an asset to the industry. In addition, the tourism sector will be affected by: i) the loss of biodiversity as a result of deforestation, which is predicted to intensify; ii) the loss of suitable habitats for charismatic wildlife, which results in the loss of animal populations and biodiversity; and iii) an increase in climate-related natural hazards, which damages both infrastructure and the reputation of the country as an attractive tourist destination. With tourism having contributed ~11% to Rwanda's GDP in 2016, decreases in tourist numbers has the potential to affect the economy greatly[5]. In addition, tourism employs a large number of community members in areas adjacent to nature reserves and national parks. Consequently, any adverse effects on the sector will result in economic losses to local communities and increased vulnerability.

**Table 2-2: Extreme climatic events and associated impacts (Mutabazi, 2004).**

| Extreme | Area affected | Impacts |
|---|---|---|
| Drought | Livestock, wildlife, agriculture, and water resources | Deaths of people and animals, as well as a lack of food and water |
| Dry periods | Agriculture | Increased prevalence of crop disease and food shortages |
| Flooding | Agriculture, infrastructure, and health | Loss of human and animal life, increase in the occurrence of waterborne diseases, crop losses, decreases in water quality, soil erosion and landslides |
| Hail | Agriculture and infrastructure | Crop and livestock losses, as well as damage to infrastructure |
| Lightning | Agriculture and infrastructure | Loss of human and animal life, and damage to infrastructure |
| Strong winds | Agriculture and infrastructure | Crop damage, wind erosion and damage to infrastructure |
| Extreme temperatures | Agriculture and health | Loss of human and animal life, crop losses and increased occurrence of diseases (human, animal and crop |
| High humidity | Health | Human comfort and increased disease prevalence |
| Fog | Transport | Loss of human life and damage to property |

5 Source: https://knoema.com/atlas/Rwanda/topics/Tourism/Travel-and-Tourism-Total-Contribution-to-GDP/Contribution-of-travel-and-tourism-to-GDP-percent-of-GDP. Accessed on 13 March 2018.

# CHAPTER THREE

# 3 DATA AND METHODOLOGY

## 3.1 Data types and sources

### 3.1.1 *Station data*

In this report, two main climate variables namely rainfall and temperature collected from various meteorological weather stations across Rwanda were considered. However, due to 1994 genocide against Tutsi, there is a decline in number of reporting stations which created a 15-year gap in entire dataset from 1994 to 2009. This was a serious challenge for station data that may affect climate research. To overcome this challenge, Meteo Rwanda generated Enhancing National Climate Services (ENACTS) dataset which was used to validate the RCMs considered in this report. ENACTS dataset was obtained by combining the available station data with TAMSAT rainfall estimates for rainfall with a spatial resolution of approximately 4 km and Japanese 55-year reanalysis project (JRA55) for temperature dataset with a spatial resolution of approximately 5 km. The advantage of merged data is that they combine the goodness of available station data with the spatial satellite estimates and reanalysis to make a highly spatial resolution available. This approach was described by Siebert et al. (2019) as the standard ENACTS approach.Table 3.1 presents a list of selected stations used in the report.

The main advantage of station data is that they provide the most accurate climate data. Around 215 station data available between 1981 and 2017 was used to generate rainfall ENACTS and CHIRPS* data while temperature ENACTS data was produced for available temperature data for the period of 1961 to 2016. Before using this station data, they were subjected to different data quality check methods and filtration according to their availability. After filtering, the number of stations was reduced to 136 stations out of 215 stations (stations with available data greater than 33%) which was combined with satellite to generate ENACTS and CHIRPS*. Instead of selecting near homogeneous zones over Rwanda, a total of 239 stations were used (Annex 2). Table 3.1 presents a list of selected stations used in the study.

Table 3-1: List of selected station per district

| Station | DISTRICT | LONGITUDE | LATITUDE |
|---|---|---|---|
| Nyamata | Bugesera | 30.09 | -2.15 |
| Ntaruka | Burera | 29.75 | -1.46 |
| Ruganda | Gakenke | 29.88 | -1.78 |
| Masaka | Gasabo | 30.21 | -2.00 |
| Gabiro | Gatsibo | 30.40 | -1.55 |
| Byumba | Gicumbi | 30.05 | -1.60 |
| Gikonko | Gisagara | 29.86 | -2.48 |
| Butare | Huye | 29.71 | -2.60 |
| Rugobagoba | Kamonyi | 29.88 | -2.05 |
| Rubengera | Karongi | 29.41 | -2.07 |
| Kawangire | Kayonza | 30.45 | -1.81 |
| Kanombe | Kicukiro | 30.13 | -1.97 |
| Bukora | Kirehe | 30.79 | -2.31 |
| Gitarama | Muhanga | 29.76 | -2.08 |
| Busogo | Musanze | 29.55 | -1.56 |
| Ruhengeri Aero | Musanze | 29.61 | -1.48 |
| Kibungo-Kazo | Ngoma | 30.53 | -2.16 |
| Gatumba | Ngororero | 29.63 | -1.95 |
| Rwankeri | Nyabihu | 29.51 | -1.58 |
| Nyagatare | Nyagatare | 30.31 | -1.28 |
| Gikongoro Met | Nyamagabe | 29.55 | -2.48 |
| Mushubi | Nyamagabe | 29.45 | -2.36 |
| Ntendezi | Nyamasheke | 29.04 | -2.45 |
| Save | Nyanza | 29.76 | -2.53 |
| Gitega | Nyarugenge | 30.06 | -1.96 |
| Muganza | Nyaruguru | 29.50 | -2.68 |
| Gisenyi Aero | Rubavu | 29.26 | -1.68 |
| Byimana | Ruhango | 29.71 | -2.16 |
| Gisanga | Ruhango | 29.86 | -2.13 |
| Cyinzuzi | Rulindo | 30.00 | -1.76 |
| Kamembe | Rusizi | 28.91 | -2.46 |
| Rutsiro | Rutsiro | 29.40 | -1.95 |
| Rwamagana | Rwamagana | 30.43 | -1.93 |

### 3.1.2 *Satellite derived rainfall estimates*

The public data streams are the GHCN monthly, GHCN daily, Global Summary of the Day (GSOD), GTS and Southern African Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL) (Funk et al. 2015). However, only four stations transmit their data to the WMO GTS over Rwanda, limiting the CHIRPS dataset's representativeness. Rwanda Meteorology Agency (Meteo Rwanda), through the Enhancing National Climate Services (ENACTS) initiative, reconstructed rainfall data by combining station data with satellite rainfall estimates to address temporal and spatial gaps in Rwanda. Satellite rainfall estimates can provide more spatial-temporal precipitation information at extended and remote areas with no ground stations. In addition to this, many precipitation products are available and freely accessible. The qualities of satellite rainfall estimates vary from one climate region to another. Several satellite-derived rainfall estimates available over Rwanda are shown in Table 3-2 which includes but not limited to Tropical Application of Meteorology using Satellite and other data (TAMSAT) from the University of Reading, Africa Rainfall Estimate Climatology Version 2.0 (ARC V2.0) from the National Oceanic and Atmospheric Administration

(NOAA), Climate Hazard Group Infrared Precipitation (CHIRP) from the University of California-Santa Barbara, Rainfall Estimate Version 2.0 (RFE V2.0) from National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center (CPC), Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN) from Center for Hydrometeorology and Remote Sensing (CHRS) at the University of California. To generate ENACTS and CHIRPS* datasets, only TAMSAT and CHIRP were considered, respectively, due to their excellent spatial resolutions and time series that goes back long enough to be used for climate change analysis over Rwanda.

Table 3-2: Summary of satellite products available over Rwanda

| Satellite Products | Spatial Coverage | Temporal Coverage | Spatial Resolution | Temporal Resolution |
|---|---|---|---|---|
| TAMSAT Version 3 | Africa | 1983 - Present | 0.0375° (~4km) | Daily, Pentad, Dekad, Monthly |
| CHIRP | Global | 1981 - Present | 0.05° (~5km) | Daily, Pentad, Dekad, Monthly |
| RFE Version 2 | Africa | 2001 - Present | 0.1° (~10km) | Daily, Dekad |
| ARC Version 2 | Africa | 1983 - Present | 0.1° (~10km) | Daily, Dekad, Monthly |
| PERSIANN-CDR | Global | 1983 - Present | 0.25° (~25km) | Daily, Monthly |

#### 3.1.2.1 Tropical Application of Meteorology using SATellite data and ground-based observation (TAMSAT)

Tropical Application of Meteorology using Satellite data and ground-based observation (TAMSAT) was established by the University of Reading in 1977 (Seyama, Masocha, and Dube 2019). The dataset comprises high resolution (0.0375 degrees) satellite-derived daily rainfall estimates for Africa, which is derived from TAMSAT Version 3.0 pentad (5-day) rainfall estimates (1983-present). The time step for the primary rainfall estimate is 5-day (pentad) in Version 3.0, compared to 10-day (dekad) in Version 2.0. The TAMSAT rainfall estimates are based on Meteosat thermal infra-red (TIR) imagery provided by EUMETSAT (Maidment et al. 2014). TAMSAT relies on observations of the Cold Cloud Duration (CCD) and convection characteristics of tropical rainfall systems as well as infra-red imagery to spot and feed into its algorithms to provide estimations of rainfall (Tarnavsky et al. 2014).

#### 3.1.2.2 Climate Hazard Group InfraRed Precipitation with Station data (CHIRPS)

CHIRPS data (https://www.chc.ucsb.edu/data/chirps) are gridded data at 0.05°spatial resolution and daily, pentadal, dekadal and monthly temporal resolution. It is a quasi-global product available from 1981 to the present. The Climate Hazard Group InfraRed Precipitation with Station data (CHIRPS) is developed by US Geological Survey (USGS) and Climate Hazard Group at the University of California, Santa Barbara (UCSB) (Dembélé and Zwart 2016). CHIRPS uses TIR satellite rainfall estimates combined with the globally gridded satellite from National Oceanic and Atmospheric Administration (NOAA) to produce the rainfall dataset. The CHIRPS algorithm combines (i) the Climate Hazards group Precipitation climatology (CHPclim), a global precipitation climatology at 0.05-degree latitude/longitude resolution estimated for each month based on station data, averaged satellite observations, elevation, latitude and longitude (ii) TIR-based satellite precipitation estimates (IRP) (Dinku et al. 2018). The CHIRP product has the potential to produce a near-real-time satellite estimate at relatively high spatiotemporal resolution covering regions between 50_ S to 50_ N latitudes and all longitudes. The CHIRPS rainfall datasets are available for daily, pentad and dekadal time steps from the period 1981 to the present.

#### 3.1.2.3 Merged Rainfall data (ENACTS and CHIRPS*)

ENACTS and CHIRPS* rainfall data was obtained by combining the available station data with more than 33% availability with TAMSAT and CHIRP satellite estimates. The advantage of merged data is that they combine the goodness of station data with the spatial availability of satellite estimates to make a highly spatial resolution available.

This approach was described by Siebert et al. (2019) as the standard ENACTS approach, the approach for generating rainfall time series which involves the following steps:

1 Use the available data from 1981 to 1993 and 2010 to 2016 (where there is enough station data available) to calculate climatological bias adjustments factors for each Julian day or dekad.

2 Interpolate the adjustment factors via inverse distance weighting to the required grid points.

3 Apply the adjustment factors to all satellite time series from 1981 to present.

4 Combine the bias-adjusted satellite rainfall estimates with station data for each day/dekad of every year.

5 Combine output from the last merging with stations, this time at a shorter radius of influence. This is done to accommodate the different station densities over the different parts of the country and the complex topography

The generated ENACTS and CHIRPS* rainfall datasets are then validated by stations with less than 33% data available together with other dataset to choose the best dataset for model validation.

### 3.1.3 *Reanalysis Temperature*

The temperature data used includes maximum and minimum temperature metrics from the Enhancing National Climate Services (ENACTS) initiative, which strives to improve availability of climate data in areas with sparse or no observation network (Dinku et al., 2017). This is accomplished by blending quality-controlled station observations with climate model reanalysis proxies for temperature (Dinku et al., 2014; 2017). The adoption of ENACTS data were based on the fact that climatological temperatures are very consistent across the different seasons of the year and the Intra-annual variability is also small (Siebert et al. 2019). Reanalysis products systematically combine station observations with climate model forecasts using data assimilation techniques and climate models (Kalnay et al., 1996). The temperature estimate reanalysis data is taken from the Japanese 55-year reanalysis project (JRA55) at a 50 km resolution for the Rwanda ENACTS data. The reanalysis data were first downscaled from 50km to 5km. Then a similar approach to that of rainfall is used to remove climatological bias between station measurements and the reanalysis product. The corrected products are very close to station values. The correction factors were developed using data from 1981 to 1993, but the results shown are for a specific dekad of a specific year. The raw observational data underpinning the JRA55 reanalysis is taken mostly from European Reanalysis (ERA-40). Several bias correction and quality control techniques are applied, and the data assimilation time step is 6 hours (Kobayashi et al., 2015). For the temperature products, the resolution is the same as the reanalysis data and is slightly coarser at 0.05 (~5 km). There are no satellite temperature estimates going back 30 years. Thus, reanalysis data was used as a proxy for temperature. The steps used to reconstruct the temperature time series are detailed in Siebert et al. (2019).

### 3.1.4 *CMIP5/CORDEX model output datasets*

In 1995, the WMO, under its WCRP, set up a project to compare the performance of coupled global climate models under the name Coupled Model Intercomparison Project (CMIP). CMIP5 is the fifth phase of the project. In 2009, the WCRP, in response to the need for a coordinated framework for evaluating and improving regional climate downscaling initiated the Coordinated Regional Downscaling Experiment (CORDEX) program. The program sought to produce fine-scale climate projections for identified regions worldwide. The program also sought to link the climate modeling community and end users of climate information globally. Both CORDEX and CMIP5 data are available from various sources of the Earth System Grid Federation including the Swedish Meteorological and Hydrological Institute-National Super-Computer (SMHI-NSC) site https://esg-dn1.nsc.liu.se/projects/esgf-liu/ and the German Climate Computing Centre (DKRZ) site https://esgf-data.dkrz.de/projects/esgf-dkrz/. CORDEX addresses climate information needs at the regional level and builds on experience gained in the global modeling community and provides a coordinated international effort to objectively assess and compare various regional climate downscaling techniques. This provides

a more solid scientific basis for impact assessments and other uses of downscaled climate information. CORDEX provides regional climate information that is essential for decision-making on issues such as vulnerability and adaptation to a changing climate with weather extremes. It is the first international program offering a common protocol for downscaling experiments and addresses essential scientific challenges in downscaling research, becoming the main international reference framework for downscaling activities. Data from the state-of-the-art Coupled Model Intercomparison Project Phase 5 (CMIP5) GCMs using the Coordinated Regional Downscaling Experiment were used. Table 3-3 presents the RCM models used for downscaling the GCM. These model properties are detailed in Nikulin et al. (2012).

Table 3-3: List of RCMs used and their driving GCMs models

| Domain | RCM Model | Driving GCM Models |
|---|---|---|
| AFR-44 | CCLM4-8-17 | MOHC, MPI and ICHEC |
| AFR-44 | RCA4 | MOHC, MPI and ICHEC |
| AFR-44 | REMO2009 | MOHC, MPI and ICHEC |

## 3.2 Methodology

### 3.2.1 *Data management and quality control*

Management of climate datasets followed the World Meteorological Organization (WMO) guidelines on data management[6]. These included identification of the sources of data, and data types available and suitable techniques for retrieval. Coordinate and stations identification check was performed to identify misplaced coordinates and duplicated stations ID or coordinates.Consistency test helps to ascertain that the variability in the data is climatological and not due to other factors such as change of instrument over time, change in observers, instrument malfunction, or change in exposure condition of the site

Since the observed and climate model output datasets had different resolutions, they were converted to a common grid using bilinear interpolation to reduce the effects of resolution for the purposes of comparison.

### 3.2.2 *Analysis of historical and future climate*

Historical and future climate was analyzed on spatial and temporal scale . The trend analysis and their significance were performed temporally and spatially. In addition, extreme climates events were computed based on the Expert Team on Climate Change Detection Indices (ETCCDI) .

#### 3.2.2.1 Temporal Analysis

Analysis of the trend component of time series was based on Mann-Kendall (MK) trend test, Sen's Slope Estimator and Change magnitude as percentage of mean. These analyses were performed using the MAKESENS tool.

##### *3.2.2.1.1 Mann Kendall trend test*

Both parametric and non-parametric methods can be used to detect trends in a time series. Parametric methods assume that the data is free from outliers and are thus normally distributed; non-parametric methods do not have such assumptions. The Mann-Kendall method, proposed by Mann (1945), is one commonly applied non-parametric method for identifying trends in a time series. Several recent studies have used the Mann-Kendall test to identify trends in time series (Taxak et al., 2014; de Carvalho et al., 2014; Mallya et al., 2016). The Mann-Kendall method is often preferred for trend analysis because it can work with missing data, non-normality, seasonality and outliers in a time series (Oloruntade et al., 2016). Therefore, it is robust to the effect of outliers in the series and has been widely used in hydro-meteorological time series to understand the nature of the trend and quantify the magnitude of change (Rawshan & Shadan, 2019). The Mann-Kendall (MK) trend test was used to understand the nature of the trend and Sen's Slope

6 https://library.wmo.int/doc_num.php?explnum_id=7867

Estimator to quantify the magnitude of change. More information on the Mann-Kendall can be found in (Salmi, et al., 2002).

The Mann-Kendall test statistic was computed using Equation (1) (Mann, 1945; Kendall, 1975), where $x_j$ represents the successive values and *n* represents the number of data points in a set.

$$S = \sum_{i=1}^{n-1} \sum_{j=1+1}^{n} sgn\,(x_j - x_i) \quad (1)$$

$$sgn(x_j - x_i) = \{+1\ if(x_j - x_i) > 0\ 0\ if(x_j - x_i) = 0\ -1\ if(x_j - x_i) < 0 \quad (2)$$

Accordingly, S increases (or decreases) by 1 if the current variable is larger (or smaller) than the previous variable (Equation (2)). The variance statistic, Var (S), is given by Equation (3) where *r* and $t_p$represent, respectively, the number of tied clusters and data points in the $p^{th}$ tied group. *S* and *Var (S)* values are used to calculate the test *Z* value as shown in Equation 4:

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{p=1}^{r} t_p\,(t_p-1)\,(2t_p+5)}{18} \quad (3)$$

$$Z = \{\frac{S-1}{\sqrt{Var(S)}}\ if\ S > 0\ 0\ if\ s = 0\ \frac{S+1}{\sqrt{Var(S)}}\ if\ S < 0 \quad (4)$$

If the calculated value is larger than the significance level, an increasing (decreasing) trend is reported if the variable *Z* is positive (negative). The trend is insignificant if the calculated value of *Z* is smaller than the level of significance. A significance level of 5% was applied.

#### 3.2.2.1.2 Sen's Slope Estimator

To estimate the true slope of an existing trend (as change per unit time) the Sen's estimator, $Q_i$ (Sen, 1968) was used. The slope ($T_i$) of all pairs of data is calculated using (Equation 5), in which the parameters $x_j$ and $x_k$ are the values of data at period *j* and *k*, where *j* is greater than *k*. The mean of the *n* values of $T_i$ is symbolized as the Sen's estimator of slope and computed using Equation 6.

$$T_i = \frac{x_j - x_k}{j-k} \quad (5)$$

For i=1, 2… n

$$Q_i = \{T_{\frac{n+1}{2}}\ \ if\ n\ is\ odd\ \frac{1}{2}\left(T_{\frac{n}{2}} + T_{\frac{n+2}{2}}\right)\ if\ n\ is\ even \quad (6)$$

Positive and negative values of $Q_i$ indicate, respectively, a trend that is increasing and decreasing in the time series. More information on the Sen's Slope Estimator can be found in (Salmi, et al., 2002).

#### *3.2.2.1.23.2.2.1.3 Change magnitude as percentage of mean*

Changes were calculated as percentage change over the 30-year period based on annual and seasonal rainfall series. The change percentage has been computed by approximating it with a linear trend. That is change percentage equals

median slope multiplied by the period length divided by the corresponding mean, expressed as percentage (Pc) followed by Yue and Hashino (2003).

#### 3.2.2.2 3.2.2.2 Climate extreme Indices

Computation of climate extreme indices was based on daily temperature and rainfall data using criteria set by the (ETCCDI). The Team has undertaken a set of regional analysis for understanding climate extremes and trends (Peterson et al., 2002; Easterling, 2003; Vincent, 2006; New et al., 2006). The agreed 27 core indices some of them were not applicable in the tropical areas and only 18 were used and subject them to Climate DataTool (CDT) program (Table 3-4). In this report, precipitation indices include very wet days (R95p), very heavy precipitation days (R20 mm) and Consecutive dry days (CDD) while temperature indices include Cold nights (TN10p), Cold days (TX10p), Warm nights (TN90p), and Warm days (TX90p).

Table 3-4: *Definition of indices used in the study*

| Code | Name | Definition | Unit |
|---|---|---|---|
| **Temperature indices** | | | |
| TXx | Annual maximum of daily maximum temperature | Annual maximum value of daily maximum temperature | $^0$C |
| TNx | Annual maxima of daily minimum temperature | Annual maximum value of daily minimum temperature | $^0$C |
| TXn | Annual minima of daily maximum temperature | Annual minimum value of daily maximum temperature | $^0$C |
| TNn | Annual minima of daily minimum | Annual minima value of daily minimum temperature | $^0$C |
| TN10p | Cold nights | Percentage of days when daily minimum temperature <10$^{th}$ percentile | %Days |
| TX10p | Cold days | Percentage of days when daily maximum temperature <10$^{th}$ percentile | %Days |
| TN90p | Warm nights | Percentage of days when daily minimum temperature > 90$^{th}$ percentile | %Days |
| TX90p | Warm days | Percentage of days when daily maximum temperature >90$^{th}$ percentile | %days |
| DTR | Diurnal temperature range | Annual mean difference between daily max and min temperature | $^0$C |
| **Rainfall indices** | | | |
| Rx1day | Max 1-day precipitation amount | Annual maximum 1-day precipitation | mm |
| CDD | Consecutive dry days | Number of maximum consecutive days with RR < 1 mm | Days |
| Rx5day | Max 5-day precipitation amount | Annual maximum consecutive 5-day precipitation | mm |
| R95p | Very wet days | Annual total precipitation from days >95th percentile | mm |
| R99p | Extremely wet days | Annual total precipitation from days >99th percentile | mm |
| R10 mm | Heavy precipitation days | Annual count when precipitation ≥10 mm | days |
| R20 mm | Very heavy precipitation days | Annual count when precipitation ≥20 mm | days |
| PRCPTOT | Annual total wet-day precipitation | Annual total PRCP in wet days (RR>=1mm) | mm |
| SDII | Simple daily intensity index | Annual total precipitation divided by the number of wet days (defined as PRCP>=1.0mm) in the year | mm/day |

### 3.2.3 *Downscaling Global Climate Models*

Most processes that control local climates such as the effect of terrain undulations, vegetation, and hydrological systems, are not explicitly included in GCMs because GCMs have coarse resolution. The horizontal grid sizes in GCMs are typically hundreds of kilometers (from 1°, or 111 km to 5° or 555 km at the equator). Studies over regions and formulation of policy require that climate information be available at a higher resolution (less than 50km in the horizontal). To include information from GCMs at local scales, downscaling the GCMs was needed. Downscaling is the process of relating large-scale climatic features from GCM outputs to smaller spatial scales to be relevant in various applications. Both dynamical and statistical downscaling were used to ensure that key assumptions made in statistical approach are addressed by use of dynamical downscaling approach.

#### 3.2.3.1 3.2.3.1 Dynamical Downscaling of GCMs

*Dynamical downscaling*, involves the use of a regional climate model (RCM) or mesoscale model (MM) "nested" within the GCM, or using the GCM outputs as initial and spatial boundary conditions in the RCM or MM. In dynamical downscaling GCM with coarse resolution are downscaled using RCM with higher horizontal resolution and supplementary regional information to enable the model to represent the local landscape, and possibly local atmospheric processes, better. RCMs use physical principles to try to reproduce local climates. Practically, the main benefit of RCMs is their capacity to model atmospheric procedures and land cover changes more explicitly. The downside of this method is that it uses more computing resources.

As in the case of Rwanda, the spatial resolution of GCM outputs is too coarse for informing regional and local-scale climate that is varied and complex. In this case, it is necessary to transform GCM simulations into finer resolution climate simulations. The method of dynamical downscaling, uses the output from a GCM as input to a high-resolution climate model to simulate local or regional climate (Mearns et al., 2003). The nesting method was used and is the method of dynamical downscaling that nests the RCM into the GCM, i.e. information only goes from the GCM to the RCM in a one-way mode (Ekstrom et al., 2015). The term 'nesting' describes the fact that information about initial weather conditions and weather along the boundaries of the RCM is taken from the host GCM. This system uses the GCM response in the broad-scale atmospheric circulation and ocean to large-scale forcing, such as aerosol forcing, greenhouse gases and sea surface temperatures, and the RCM simulates the sub-grid scale forcing in a physical way (Ekstrom et al., 2015).

#### 3.2.3.2 3.2.3.2 Statistical Downscaling

In statistical downscaling, the process employs two steps. The first step entails developing a statistical relationship between the climate variables at a locality and large-scale fields. For instance, the surface air temperature or precipitation and large-scale predictors like pressure fields may be related. The second step entails applying such a relationship to the output of global climate model experiments to simulate local climate characteristics in the future. Unlike RCMs that produce downscaled projections at spatial scales of tens of kilometers, statistical downscaling can provide climate information at a station. Upon establishing and validating the statistical relationship, future large-scale atmospheric conditions predicted by GCMs are used to project future climate characteristics at a location.

Despite the efficiency of statistical downscaling, its relatively lower computational demands, and a diverse range of techniques, the method makes certain assumptions that are not always true. To begin with, statistical downscaling presupposes that there exists a stationary statistical relationship between the predictor and predictand. Put differently, by stationarity, we mean that the relationship does not vary with time and that the variation is stable. Secondly, statistical downscaling assumes that the large-scale variables represent the climate system. With this assumption, the technique presupposes that the signal of the changing climate is within the predictor. Thirdly, the technique assumes that there exists a robust relationship between what is predicting (the predictor) and what is predicted (the predictand). This entails evaluation to determine whether or not the assumption has validity. Finally, statistical downscaling assumes that the GCMs are perfect in simulating the predictors, which is of course untrue.

### 3.2.4 *Validation of satellite/reanalysis data against observed climate*

Different satellite derived rainfall and temperature observations were validated against gauge-based data sourced from Meteo Rwanda. In case of precipitation, CHIRP and TAMSAT were validated against the gauge-based observations (detailed provided in section 3.1.2).

Cross validation performed for two satellite rainfall estimates over Rwanda against 239 available rain gauge data for the period of thirty (30) years starting from 1981 to 2018. Cross validation was done on a daily, and monthly basis according to time resolution of each satellite estimate. Worth noting, CHIRPS* and ENACTS were developed by combining stations with more than 33% available station data with CHIRP and TAMSAT respectively while stations with less than 33% of station data are used to validate all other observations. The performance of satellite derived rainfall estimates against station-based data were based on statistical measures. For example, the Pearson correlation coefficient (CORR) was used to indicate the agreement in terms of dynamics between the satellite estimate and the rain gauge observation. Value of correlation near 1 indicates the improvement of satellite estimates to rain gauge measurement. The bias (BIAS) was used to indicate whether satellite estimates underestimate or overestimate rain gauge measurement. The value of bias less than 1 indicates that satellites underestimate while the value greater than 1 indicates that satellites overestimate. The Percentage relative bias (PBIAS) was used to represent the relative systematic bias of the satellite rainfall from the rain gauge observation. PBIAS perfect score is 0 and the departure from zero indicates how much percentage satellites estimate departure from station measurement. The Mean absolute error (MAE) was used to provide information on the magnitude of error of satellite estimate. Less MAE indicates the satellite estimate with less error. The Root mean square error (RMSE) was used to measure the average absolute errors of satellite rainfall, with smaller values indicating the closure between the two datasets.

As there are no satellite temperature estimates going back 30 years, reanalysis data are used as a proxy. Reanalysis products are climate data generated by systematically combining climate observations (analyses) with climate model forecasts using data assimilation schemes and climate models. The Japanese 55-year Reanalysis (JRA55)[7] is used to generate a gridded temperature time series for the period 1961-2016. This product has a coarse spatial resolution of about 50km. Thus, the reanalysis data are downscaled to 5km spatial resolution using station observations and elevation maps.

Different validation statistics are used including continuous statistics, categorical validation indices and volumetric validation indices. Table 3-5 lists different statistics used in this validation, their description and perfect scores.

### 3.2.5 *Validation of climate model output against observed climate*

Models are required to correctly reproduce large climatic characteristics such as variability and change. Where these are similar between models and the observational data, the models can replicate the climatic mechanisms focusing changes over the observational area. These models are therefore more robust at simulating the observed period and are more trusted to simulate projected futures as they can capture the local driving factors. The chosen model needs to reproduce the observed climatology of the target regions and therefore project into the future the climatology. Validation is good if it picks up the trend of the station data. The seasonal signal, trends, goodness of fit and magnitude/occurrence for precipitation, temperature and extreme events from each model is assessed against the observational data.

In this report, RCMs rainfall and temperature simulations were validated against observations using various techniques indicated in Table 3.5. The validation was performed on monthly time scale.d

7 https://jra.kishou.go.jp/JRA-55/index_en.html#about

Table 3-5: Validation statistics used, their description and perfect scores

| Statistic | | Perfect score |
|---|---|---|
| Abbreviation | Description | |
| CORR | Correlation | 1 |
| BR2 | Coefficient of determination (R2) multiplied by the regression slope | 1 |
| BIAS | Bias | 1 |
| PBIAS | Percent Bias | 0 |
| ME | Mean Error | 0 |
| MAE | Mean Absolute Error | 0 |
| RMSE | Root Mean Square Error | 0 |
| NSE | Nash-Sutcliffe Efficiency | 1 |
| MNSE | Modified Nash-Sutcliffe efficiency | 1 |

### 3.2.6 *Choice of the scenario for projected future*

The future global climate is dependent on anthropogenic mitigation of greenhouse gas (GHG) emissions. To accommodate uncertainties around future GHG emissions and the success of mitigation measures, a scenario set of four possible future trajectories is commonly used for climate modeling. These four representative concentration pathways (RCPs) are based on the main forcing agents of climate change — namely GHG emissions, GHG concentrations and land-use change (Van Vuuren et al, 2011). The different RCPs, described below, are based on the relative radiative forcing (in $W/m^2$)[8] target level for 2100 (Van Vuuren et al, 2011, IPCC, 2014).

- RCP2.6 represents the best-case mitigation scenario, with a global focus on environmentally sustainable practices. Peak radiative forcing is ~3 $W/m^2$ (~490 ppm $CO_2$ equivalent) before 2100 followed by a decline to 2.6 $W/m^2$ by 2100.

- RCP 4.5 $w/m^2$ represents the likely best-case scenario with a peak radiative forcing of 45 $w/m^2$ (~650 ppm $CO_2$ equivalent) at stabilization after 2100.

- RCP6.0 represents the likely worst-case scenario with a peak radiative forcing of 6 $W/m^2$ (~850 ppm $CO_2$ equivalent) at stabilization after 2100.

- RCP 8.5 $w/m^2$ represents a very high GHG emission scenario with a peak radiative forcing of 85 $w/m^2$ (~1,370 ppm $CO_2$ equivalent) and no expected stabilization in emissions.

Based on changes or the lack thereof in recent global emissions, it is unlikely to reach the milestones of the RCP2.6 scenario. RCP 8.5 $w/m^2$ is the worst-case scenario and mitigation measures will hopefully make this an avoided reality.

### 3.2.7 *Choice of the time frame for model output*

The most recent set of widely applied scenarios for investigating climate change impacts, adaptation, and vulnerabilities (CCIAV) implemented by the Intergovernmental Panel on Climate Change (IPCC) research community (Moss et al., 2010) comprise the Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs) (van Vuuren et al., 2011; O'Neill et al., 2015; O'Neill et al., 2017). For climate change analysis, long-term anticipated changes in the climate system normally done for 30 years are recommended at the mid-century and late-century time intervals. The immediate interventions to adapt to climate changes require the development of interventions within the next 10 to 30 years. During the stakeholder engagement workshop, the use of RCP 4.5 $w/m^2$ and RCP 8.5 $w/m^2$

8 Radiative forcing refers to how much an external factor adds to the radiative energy budget of the Earth's system.

scenarios were recommended over the period 2021-2050 (Near Term), 2041-2070 (Medium term) and 2071-2100 (Long term) based on existing policy and strategies such as Vision 2050 and NDCs . To support impact assessments, a spatial resolution of $0.22^{o}$ (~25 Km) for rainfall and temperature (maximum and minimum temperature) were used.

### 3.2.8 *Bias correction of RCMs simulations*

Climate models including RCMs have been the primary source of information for constructing climate scenarios, and they provide the basis for climate change impacts assessments at all scales. . However, impact studies rarely use climate model outputs directly because they exhibit systematic error (biases) due to the limited spatial resolution, simplified physics and thermodynamic processes, numerical schemes, or incomplete knowledge of climate system processes. The errors in model simulations relative to historical observations are large. Hence, it is important to bias-correct the raw climate model outputs to produce climate projections that are better fit for impact assessments.

In case of more stochastic variables such as precipitation, Quantile Mapping method, a more sophisticated bias-correcting approach were used. Also, GCMs maynot capture realistic interannual variability associated with events such as El Niño and La Niña. Therefore, to appropriately bias-correct GCM output for monthly totals and wet-day frequency, while ensuring realistic daily and interannual variability, the use of Quantile Mapping (QM) approach with the q-map library built in R statistical software were used. The quantile mapping technique removes the systematic bias in the GCM simulations and has the benefit of accounting for GCM biases in all statistical moments

### 3.2.9 *Analysis of climate projections*

All analyses for projected futures were done using the selected RCM model to show the changes in the anticipated climate driver along the RCP 4.5 $wm^{-2}$ and RCP 8.5 $wm^{-2}$ forcing scenarios. A 25 km grid spacing that favors engagement of the wider community was also used. Analysis included future changes in climate fields, future time series and creating ensembles for future climate change for different RCPs scenarios.

### 3.2.10 *Extreme climate change*

In addition, thresholds, and analysis of extremes, creating new variables such as frequency of wet (and dry) days, calculation of percentiles and extreme indices. Generation of climate change scenario indices using the R-Climdex tool of the WMO were mainly utilized. The downscaled information would then be used as the basis for conducting the first and second-order risk assessments across different sectors

# CHAPTER FOUR

# 4 DOWNSCALED CLIMATE PROJECTIONS

## 4.1 Data management and quality control

There were many active meteorological stations in Rwanda prior to the mid-1990s. However, from around Rwanda Genocide in 1994 through the late 2000s, the number of active stations were greatly reduced. Out of a total of 243-point stations data used, 4 stations were found to have duplicated coordinates while 10 stations duplicated the names. Most outliers identified were subjected to spatial verification methods where the suspected values are compared to the recorded values at neighboring stations at the same time. The suspected values were then corrected by checking the archived datasets or removed in the dataset. The homogeneity test revealed some errors, and these erroneous measurements were either fixed or removed.

Therefore, it is noted that Meteo Rwanda has significantly improved the country's hydrometeorological observational network attributed to spatially dense ground-based weather stations equipped with multiple sensors to monitor different meteorological fields. Additionally, this system should be complemented by a series of surface-, air, and spaced-based observation platforms. Strengthening the observational network requires that Meteo Rwanda develops capability to maintain and service instruments (mainframe and software) to increase efficiency and train technicians, engineers, and data managers on required technologies. Loss of data will also be avoided by building human and technical capacities and having a modern archive for safe custody of data. With the current number of observation station having increased, it is also recommended that Meteo Rwanda establishes a mechanism for ensuring calibration of instruments and field data inter comparisons in addition to development of a strategy specifically on data observation and instruments maintenance

Considering the spatial heterogeneity of this landscape and the severe data gaps, improving the spatiotemporal climatological and meteorological information were based on merging/blending of satellite derived datasets with stations to produce a gridded complete dataset covering the period of 1981 to 2019 following a methodology detailed in Siebert et al. (2019). The produced datasets were ENACTS obtained from merging ground-based stations with more than 33% available data with TAMSAT estimates and CHIRPS* obtained by merging the ground-based stations with CHIRP estimates. The Japanese 55-year Reanalysis (JRA55) was used as a proxy for temperature datasets. The reanalysis data were first downscaled from 50km to 5km and then the mean (climatological) differences (bias) were removed between the downscaling reanalysis and station data. The corrected reanalysis data were thereafter merged with available station data to obtain the ENACTS dataset for maximum and minimum temperature time series for 1961-2016. Detailed methodological approach used to develop the temperature datasets is detailed in Siebert et al. (2019). Therefore, adoption of ENACTS methodology to fill in the existing gap significantly increased the amount of data available for impact studies.

Therefore, Meteo Rwanda needs to ensure that the ENACTS datasets remain easily accessible and regularly updated. In addition, continuous improvement to the methodology used to develop ENACTS datasets should be considered. Including topography has a significant influence on Rwanda's weather and climate and more robust interpolation techniques such as Kriging as opposed to simple IDW currently being implemented

## 4.2 Validation of satellite and reanalysis datasets against observed climate

### 4.2.1 *Validation of satellite derived rainfall estimates against observations*

Three observational rainfall datasets namely, ENACTS, CHIRPS* and CRU was selected due to its spatial and temporal coverage. In order to select the best models, these datasets were validated against the observed ground-based data. Due to the severe gap in data, ENACTS and CHIRPS* were produced by combining satellite estimates (TAMSAT for ENACTS and CHIRP for CHIRPS*) with stations with more than 33% available data for the mentioned

period and CRU contains GTS station datasets, stations with less than 33% available data was used to validate the observation datasets to avoid the influence of merging techniques. The different satellite derived observations were then merged with station data. Table 4-1 presents several output verification metrics based on ENACTS (Observed and TAMSAT), CHIRPS (Observed and CHIRP) and CRU

Table 4-1: Validation of satellite datasets against observed rainfall

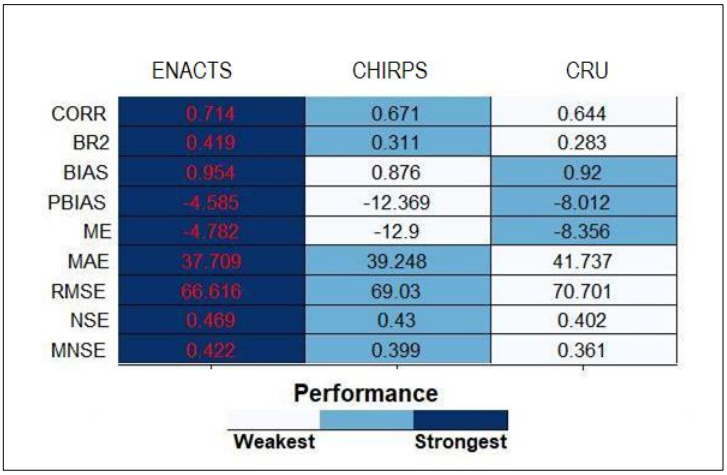



Table 7, the validation results showed strongest performance metrics based on ENACTS i.e., observation and TAMSAT and hence selected as the best dataset for validation of models. A study by Nkundimana (2016) assessed the accuracy of TAMSAT rainfall data in humid and semi-arid regions of Rwanda by comparing it with data from weather stations on ground and observed a strong correlation between observation and TAMSAT data but further noted that TAMSAT also slightly underestimated the rainfall received. The difference between the two datasets was attributed to lack of one-off local calibration to account for variations with geographic location, time of year, character of season, topography and local storm climatology.

### 4.2.2 *Validation of reanalysis temperature datasets against observations*

As there are no satellite temperature estimates going back 30 years, reanalysis data are used as a proxy. The Japanese 55-year Reanalysis (JRA55)[9] was used to generate a gridded maximum and minimum temperature time series (ENACTS) for the period 1961-2016. JRA-55 was a newly improved dataset over JRA-25 and used the same observation provided by ERA-40. The main advantages of JRA-55 are that they offer spatially completed dataset and have relatively long time series of 60+ years thus providing broader coverage over a long timeframe. Dinku et al. (2017) and Siebert et al. (2019) provide detailed description and validation analysis of ENACTS temperature data (Observations and JRA55)

## 4.3 Temporal analysis of past climate over Rwanda

### 4.3.1 *Seasonal and annual rainfall*

In Table 4-2, trend analysis showed that both seasonal and annual rainfall over Rwanda has increased, especially over North-eastern Districts such as Nyagatare and Gatsibo. However, the rainfall from January to February (JF) has been reducing in some parts of the central, namely the central Muhanga towards the eastern Ngororero and over the southern part of Congo Nile Divide (eastern Nyamasheke towards the central Nyamagabe). The trend of observed JF seasonal rainfall during the 1981-2010 period ranged from +101.59% or +3.19mm per year (significant, $\alpha \leq 0.05$) in Nyagatare to -93.30% or -5.05mm per year (significant, $\alpha \leq 0.05$) in Mushubi. In addition, most of the central parts,

9 https://jra.kishou.go.jp/JRA-55/index_en.html#about

some parts of South-East (areas of southern Kirehe and Kayonza), Northern Bugesera extending to Kigali City, part of Northern Gicumbi, Rubavu), and North-West and Congo Nile divide from March to May season (MAM) indicated a negative change. The trend of observed (1981-2010) rainfall during the MAM season ranged from +63.42% or +8.91mm per year (significant, $\alpha \leq 0.05$) in Gabiro to -15.16% or -1.63mm per year (not significant, $\alpha > 0.05$) in Bukora. The trend of observed (1981-2010) annual rainfall ranged from +71.80% or +25.41mm per year (significant, $\alpha \leq 0.05$) in Gabiro to -7.65% or -3.41mm per year (not significant, $\alpha > 0.05$) in Mushubi.

Table 4-3 shows that for the June-August (JJA) season, it was noted that most parts of Southern (areas of Ruhango, Nyanza, Gisagara and Nyamagabe) and some parts of Northern parts (Nyabihu and Burera) indicated the reduction in rainfall. The trend of observed (1981-2010) rainfall during JJA season ranged from +189.81% or +6.17mm per year (significant, $\alpha \leq 0.05$) in Masaka to -32.42% or -0.75mm per year (not significant, $\alpha > 0.05$) in Save. For the September to December season (SOND) a reduction in rainfall was observed over the central, northern, and south-western part in the areas of Rusizi. The trend of observed (1981-2010) rainfall during SOND season ranged from +83.28% or +12.30mm per year (significant, $\alpha \leq 0.05$) in Gabiro to -51.69% or -6.0mm per year (significant, $\alpha \leq 0.05$) in Gitega.

The reduction in rainfall was also observed in the central parts, Congo Nile basin, northern parts and Amayaga areas in the annual rainfall. However, Jonah et al. (2021) observed that the March to May (MAM) rainy seasons showed a decreasing trend, and September to December (SOND) rainy season, an increasing trend over Rwanda (Jonah et al., 2021). The reduction in SOND seasonal rainfall was also observed in the central and northern parts and Amayaga areas. The study also noted observed annual rain reduced over the central parts of Rwanda. Past Studies equally observed that Rwanda experienced wetter conditions over south-western and northern highlands regions, while warmer conditions were reported over the central plateau and the eastern lowlands (Muhire and Ahmed, 2014; Muhire et al., 2015). The study by Sebaziga (2018) found a significant and increasing trend of rainfall over North of the northern and southern provinces, while there is a non-significant decreasing trend over the eastern, Kigali, Northern and central-western during MAM, OND and annual time scale.

Therefore, an increasing trend in seasonal and annual precipitation in most areas while others displayed decreasing trends and thus indicating that rainfall remains highly variable in both space and time. The results of this study agree with Muhire et al. (2018), who found that the number of rainy days was expected to decrease in the central plateau, the south-eastern lowlands and increase over the south-west, the north-west, and north-east regions for the period between 2015 and 2018.

Table 4-2: Trend analysis of seasonal (JF and MAM) and annual rainfall (1981-2010)

| Stations | Annual | | | | | JF season | | | | | MAM Season | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Test Z | α level | Sen's Slope | Mean | %Δ | Z test | α level | Sen's Slope | Mean | %Δ | Z test | α level | Sen's Slope | Mean | %Δ |
| Bukora | 0.18 | | 1.71 | 842.07 | 6.08 | 0.21 | | 0.31 | 154.93 | 6.05 | -0.43 | | -1.63 | 321.57 | -15.16 |
| Busogo | 2.60 | ** | 22.84 | 1396.33 | 49.08 | 3.64 | *** | 7.50 | 222.83 | 100.97 | 2.37 | * | 6.11 | 510.07 | 35.94 |
| Butare | 1.39 | | 12.33 | 1284.63 | 28.80 | 2.16 | * | 5.33 | 253.80 | 63.04 | 1.11 | | 3.39 | 501.27 | 20.28 |
| Byimana | 1.78 | + | 13.00 | 1286.50 | 30.31 | 1.86 | + | 4.63 | 263.27 | 52.70 | 0.54 | | 1.25 | 455.67 | 8.23 |
| Byumba | 1.43 | | 5.20 | 1092.07 | 14.28 | 2.96 | ** | 2.86 | 131.10 | 65.38 | -0.23 | | -0.70 | 452.23 | -4.64 |
| Cyinzuzi | 3.89 | *** | 21.73 | 1427.23 | 45.67 | 3.16 | ** | 7.00 | 248.17 | 84.62 | 2.69 | ** | 8.94 | 511.80 | 52.43 |
| Gabiro | 5.28 | *** | 25.41 | 1061.63 | 71.80 | 1.77 | + | 1.47 | 114.80 | 38.33 | 3.87 | *** | 8.91 | 421.43 | 63.42 |
| Gatumba | 1.34 | | 6.04 | 1466.37 | 12.36 | 0.41 | | 0.57 | 240.83 | 7.12 | 1.21 | | 4.48 | 573.47 | 23.42 |
| Gikongoro | 2.71 | ** | 15.25 | 1314.73 | 34.80 | 2.57 | * | 5.25 | 266.57 | 59.08 | 0.61 | | 1.63 | 478.83 | 10.18 |
| Gisanga | 3.23 | ** | 21.25 | 1442.67 | 44.19 | 2.66 | ** | 6.44 | 311.43 | 62.08 | 0.98 | | 2.40 | 491.93 | 14.64 |
| Gisenyi | 2.77 | ** | 13.67 | 1189.20 | 34.48 | 2.36 | * | 2.25 | 173.20 | 38.97 | 0.87 | | 1.86 | 368.17 | 15.13 |
| Gitarama | 2.46 | * | 18.57 | 1247.70 | 44.65 | 2.39 | * | 4.05 | 202.50 | 60.00 | 1.46 | | 4.43 | 465.90 | 28.52 |
| Gitega | -0.48 | | -1.70 | 1032.43 | -4.94 | 1.84 | + | 3.96 | 210.07 | 56.55 | -0.05 | | -0.07 | 394.53 | -0.54 |
| Kamembe | -0.98 | | -2.58 | 1336.73 | -5.80 | -1.39 | | -1.14 | 272.97 | -12.56 | -0.91 | | -0.92 | 403.77 | -6.86 |
| Kanombe | 1.86 | + | 17.00 | 998.40 | 51.08 | 2.78 | ** | 6.38 | 207.10 | 92.41 | 1.21 | | 2.50 | 350.13 | 21.42 |
| Kansi | 2.62 | ** | 14.96 | 1217.83 | 36.86 | 3.44 | *** | 5.42 | 222.93 | 72.89 | 0.82 | | 2.50 | 413.10 | 18.16 |
| Kawangire | 3.09 | ** | 10.19 | 892.80 | 34.24 | 2.53 | * | 3.83 | 131.90 | 87.19 | 0.61 | | 1.39 | 344.07 | 12.11 |
| Kibungo | 2.59 | ** | 10.00 | 1120.70 | 26.77 | 0.52 | | 0.47 | 171.70 | 8.22 | 0.79 | | 1.77 | 423.63 | 12.53 |
| Masaka | 2.89 | ** | 18.00 | 1115.90 | 48.39 | 2.66 | ** | 4.40 | 187.90 | 70.25 | -0.05 | | -0.25 | 364.77 | -2.06 |
| Muganza | 2.39 | * | 22.88 | 1796.63 | 38.21 | 4.19 | *** | 11.38 | 391.33 | 87.28 | 0.75 | | 2.13 | 613.10 | 10.42 |
| Mushubi | -0.84 | | -3.41 | 1339.33 | -7.65 | -3.34 | *** | -5.05 | 162.23 | -93.30 | -1.04 | | -2.00 | 516.90 | -11.61 |
| Ntaruka | 3.30 | *** | 24.23 | 1401.40 | 51.87 | 2.30 | * | 3.00 | 143.30 | 62.81 | 2.18 | * | 4.00 | 426.37 | 28.14 |
| Ntendezi | 4.59 | *** | 39.60 | 1875.87 | 63.33 | 4.35 | *** | 9.14 | 395.40 | 69.37 | 3.78 | *** | 9.06 | 553.27 | 49.14 |
| Nyagatare | 4.28 | *** | 16.85 | 853.00 | 59.26 | 3.09 | ** | 3.19 | 94.27 | 101.59 | 2.68 | ** | 5.33 | 353.77 | 45.23 |
| Nyamata | 1.09 | | 5.33 | 1090.90 | 14.67 | 1.12 | | 1.82 | 154.27 | 35.36 | -0.09 | | -0.23 | 404.77 | -1.68 |
| Rubengera | 0.66 | | 4.00 | 1161.43 | 10.33 | 0.21 | | 0.16 | 169.90 | 2.83 | 0.91 | | 2.48 | 409.03 | 18.19 |
| Ruganda | 3.07 | ** | 27.62 | 1533.13 | 54.04 | 3.35 | *** | 6.00 | 243.27 | 73.99 | 2.28 | * | 8.00 | 547.43 | 43.84 |
| Rugobagoba | 3.55 | *** | 20.12 | 1311.70 | 46.01 | 1.39 | | 2.61 | 210.60 | 37.16 | 2.36 | * | 6.47 | 503.97 | 38.49 |
| Ruhengeri | 3.10 | ** | 15.83 | 1377.60 | 34.48 | 3.25 | ** | 5.22 | 197.83 | 79.19 | 1.80 | + | 4.38 | 489.63 | 26.81 |
| Rutsiro | 3.41 | *** | 17.68 | 1483.40 | 35.76 | 3.71 | *** | 7.26 | 311.13 | 70.03 | 1.45 | | 3.89 | 492.53 | 23.69 |
| Rwamagana | 3.43 | *** | 23.56 | 1124.23 | 62.88 | 3.05 | ** | 4.43 | 169.57 | 78.35 | 1.70 | + | 4.65 | 406.30 | 34.33 |
| Rwankeri | 2.68 | ** | 10.95 | 1362.40 | 24.11 | 2.98 | ** | 4.27 | 191.80 | 66.83 | 0.80 | | 2.00 | 491.93 | 12.20 |
| Save | 1.25 | | 11.47 | 1294.17 | 26.58 | 0.93 | | 1.22 | 202.50 | 18.11 | 0.32 | | 1.00 | 515.77 | 5.82 |

Table 4-3: Trend analysis of JJA and SOND rainfall (1981-2010)

| Stations | JJA Season | | | | | SOND Season | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Z test | α level | Sen's Slope | Mean | %Δ | Z test | α level | Sen's Slope | Mean | %Δ |
| Bukora | 0.99 | | 0.89 | 51.47 | 51.81 | -0.18 | | -0.41 | 314.10 | -3.93 |
| Busogo | 1.23 | | 1.84 | 133.67 | 41.34 | 1.78 | + | 5.93 | 529.77 | 33.60 |
| Butare | -0.46 | | -0.43 | 61.13 | -21.03 | 0.95 | | 3.00 | 468.43 | 19.21 |
| Byimana | -0.30 | | -0.27 | 90.07 | -8.88 | 1.80 | + | 4.88 | 477.50 | 30.67 |
| Byumba | 0.87 | | 0.75 | 88.57 | 25.40 | 0.32 | | 0.67 | 420.17 | 4.76 |
| Cyinzuzi | 1.75 | + | 1.91 | 84.27 | 67.97 | 2.73 | ** | 7.14 | 583.00 | 36.72 |
| Gabiro | 1.30 | | 1.91 | 82.30 | 69.59 | 4.51 | *** | 12.30 | 443.10 | 83.28 |
| Gatumba | 1.20 | | 1.75 | 136.50 | 38.46 | * | | 0.25 | 515.57 | 1.45 |
| Gikongoro | 1.59 | | 3.25 | 103.53 | 94.17 | 1.59 | | 4.00 | 465.80 | 25.76 |
| Gisanga | 1.88 | + | 2.64 | 120.00 | 65.91 | 2.43 | * | 6.53 | 519.30 | 37.72 |
| Gisenyi | 2.21 | * | 4.92 | 168.87 | 87.46 | 3.25 | ** | 6.33 | 478.97 | 39.67 |
| Gitarama | 0.95 | | 1.50 | 102.80 | 43.77 | 2.94 | ** | 7.00 | 476.50 | 44.07 |
| Gitega | 0.25 | | 0.46 | 79.63 | 17.27 | -2.30 | * | -6.00 | 348.20 | -51.69 |
| Kamembe | 0.54 | | 0.86 | 92.30 | 27.86 | | | 0.12 | 567.70 | 0.61 |
| Kanombe | 1.86 | + | 2.44 | 67.43 | 108.44 | 0.57 | | 1.67 | 373.73 | 13.38 |
| Kansi | 0.72 | | 1.50 | 95.50 | 47.12 | 1.73 | + | 5.78 | 486.30 | 35.64 |
| Kawangire | 1.23 | | 1.11 | 46.17 | 72.20 | 1.80 | + | 2.77 | 370.67 | 22.41 |
| Kibungo | 1.23 | | 1.57 | 51.33 | 91.84 | 2.23 | * | 6.19 | 474.03 | 39.16 |
| Masaka | 2.86 | ** | 6.17 | 97.47 | 189.81 | 2.75 | ** | 6.91 | 465.77 | 44.50 |
| Muganza | 1.57 | | 3.17 | 104.07 | 91.29 | 1.32 | | 6.75 | 688.13 | 29.43 |
| Mushubi | -0.82 | | -0.67 | 70.20 | -28.49 | 0.32 | | 0.73 | 590.00 | 3.73 |
| Ntaruka | 0.70 | | 1.50 | 151.47 | 29.71 | 2.59 | ** | 10.01 | 680.27 | 44.10 |
| Ntendezi | 2.36 | * | 4.00 | 128.50 | 93.39 | 3.05 | ** | 9.60 | 798.70 | 36.06 |
| Nyagatare | 1.43 | | 1.57 | 54.13 | 86.74 | 3.12 | ** | 5.14 | 350.83 | 43.92 |
| Nyamata | -0.07 | | 0.00 | 57.40 | 0.00 | 0.70 | | 2.30 | 474.47 | 14.54 |
| Rubengera | 1.45 | | 2.43 | 130.33 | 55.90 | -0.25 | | -0.35 | 452.17 | -2.34 |
| Ruganda | 2.77 | ** | 6.63 | 146.20 | 135.94 | 2.41 | * | 6.84 | 596.23 | 34.43 |
| Rugobagoba | 2.61 | ** | 3.13 | 91.43 | 102.53 | 2.43 | * | 6.30 | 505.70 | 37.37 |
| Ruhengeri | 0.46 | | 0.43 | 116.63 | 11.02 | 1.96 | * | 6.18 | 573.50 | 32.32 |
| Rutsiro | 1.27 | | 1.27 | 102.40 | 37.11 | 2.14 | * | 6.92 | 577.33 | 35.96 |
| Rwamagana | 1.96 | * | 2.62 | 80.40 | 97.59 | 2.91 | ** | 10.10 | 467.97 | 64.72 |
| Rwankeri | -0.16 | | -0.33 | 125.40 | -7.97 | 2.12 | * | 4.70 | 553.27 | 25.48 |
| Save | -0.97 | | -0.75 | 69.40 | -32.42 | 1.41 | | 6.25 | 506.50 | 37.02 |

### 4.3.2 *Extreme precipitation*

Table 4-4 shows that the number of very wet and heavy precipitation days has increased, especially over the eastern parts of Rwanda. However, parts of the Eastern region, such as southern Kayonza and Kirehe, Gatsibo and northwestern Rwamagana extending to Kigali, showed a slight decrease in the number of very wet and very heavy precipitation days.

Table 4-4 shows that based on the computed change magnitude as a percentage of the mean, the number of very wet days was observed to change by ≥90%. A negative trend was also observed over several parts of north-western, southwestern and a few parts of the country's northern, central, and southern areas with computed change magnitude as a percentage of the mean for very wet days and very heavy precipitation days observed to decrease. The trend of observed (1981-2010) very heavy precipitation days ranged from +125.86% or +0.92 days per year (significant, $\alpha \leq 0.05$) in Rwamagana to -69.41% or -0.33 days per year (significant, $\alpha \leq 0.05$) in Kamembe. The trend of observed (1981-2010) very wet days ranged from +203% or +18.67days per year (significant, $\alpha \leq 0.05$) in Byumba to -93.14% or -8.10 days per year (significant, $\alpha \leq 0.05$) in Save. However, the study found that the number of consecutive dry days was high (60-90%) over western parts of Rwanda (Parts of Gakenke, Karongi, Nyamasheke and Nyamagabe) and more reduced over the areas of the eastern (Kayonza, Ngoma, Kirehe and northern Nyagatare). The trend of observed (1981-2010) consecutive dry days ranged from +48.31% or +1.14 days per year (not significant, $\alpha > 0.05$) in Kansi to -22.86% or -0.45 days per year (not significant, $\alpha > 0.05$) in Ntendezi. These findings agree with past studies that rainfall trends have shown an increased occurrence of extremes since the 1960s across various regions of Rwanda, with the El Niño Southern Oscillation influencing precipitation trends during El Niño years (World Bank Group, 2021). Some of the documented devastating landslides and floods caused by heavy rainfall were in the years 2001, 2002, 2007, 2008 and 2012 over the Northern (Gakenke, Cyeru, Rulindo and Gicumbi) and Western (Nyamasheke, Nyamagabe, Karongi and Ngororero) regions (REMA, 2013; MIDIMAR,2015).

Table 4-4: Trend analysis of very heavy precipitation days, very wet days, and consecutive dry days over Rwanda (1981-2010)

| Station | very heavy precipitation days (R20mm) | | | | | very wet days (R95pTOT) | | | | | Consecutive dry days (CDD) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Test Z | α Level | Q | Mean | %Δ | Test Z | α Level | Q | Mean | %Δ | Test Z | α Level | Q | Mean | %Δ |
| Bukora | 1.63 | | 0.27 | 13.82 | 58.39 | 1.71 | + | 5.18 | 229.71 | 67.60 | 0.61 | | 0.48 | 86.60 | 16.63 |
| Busogo | 2.63 | ** | 0.33 | 27.68 | 36.09 | 2.78 | ** | 9.08 | 397.25 | 68.59 | 0.14 | | 0.06 | 50.13 | 3.52 |
| Butare | -2.74 | ** | -0.33 | 15.29 | -65.35 | -1.82 | + | -5.41 | 328.93 | -49.31 | 0.96 | | 0.42 | 61.37 | 20.37 |
| Byimana | 3.45 | *** | 0.56 | 16.68 | 100.01 | 2.64 | ** | 11.44 | 237.00 | 144.78 | 1.05 | | 0.43 | 59.20 | 21.72 |
| Byumba | 3.13 | ** | 0.75 | 19.68 | 114.34 | 3.66 | *** | 18.67 | 275.57 | 203.22 | 0.16 | | 0.07 | 58.27 | 3.68 |
| Cyinzuzi | 3.31 | *** | 0.52 | 22.71 | 68.94 | 3.36 | *** | 17.44 | 334.46 | 156.47 | 1.11 | | 0.33 | 67.23 | 14.87 |
| Gabiro | 5.48 | *** | 0.50 | 15.57 | 96.33 | 4.60 | *** | 13.50 | 265.79 | 152.38 | 1.50 | | 0.91 | 68.33 | 39.91 |
| Gatumba | 0.16 | | 0.00 | 21.21 | 0.00 | 2.36 | * | 6.52 | 321.96 | 60.79 | 0.41 | | 0.21 | 57.83 | 11.12 |
| Gikongoro | 1.11 | | 0.14 | 27.36 | 15.68 | -0.80 | | -3.64 | 394.82 | -27.63 | 0.30 | | 0.14 | 56.13 | 7.63 |
| Gisanga | 2.72 | ** | 0.33 | 17.43 | 57.32 | 3.03 | ** | 10.36 | 304.11 | 102.24 | 1.61 | | 0.89 | 62.97 | 42.63 |
| Gisenyi | 4.44 | *** | 0.57 | 23.00 | 74.48 | 3.07 | ** | 10.75 | 301.43 | 106.99 | 1.27 | | 0.44 | 42.97 | 31.03 |
| Gitarama | 2.74 | ** | 0.50 | 18.39 | 81.55 | 3.43 | *** | 10.94 | 300.39 | 109.24 | 2.18 | * | 0.93 | 64.67 | 43.08 |
| Gitega | -0.41 | | 0.00 | 13.71 | 0.00 | -1.71 | + | -4.82 | 246.43 | -58.65 | 0.66 | | 0.27 | 61.33 | 13.04 |
| Kamembe | -2.66 | ** | -0.33 | 14.39 | -69.41 | -2.66 | ** | -9.17 | 325.36 | -84.53 | 0.07 | | 0.00 | 48.60 | 0.00 |
| Kanombe | 1.67 | + | 0.25 | 14.11 | 53.17 | 1.39 | | 4.54 | 216.93 | 62.73 | -0.62 | | -0.25 | 73.73 | -10.17 |
| Kansi | 2.39 | * | 0.27 | 14.61 | 56.07 | 3.57 | *** | 11.43 | 301.18 | 113.84 | 1.43 | | 1.14 | 70.97 | 48.31 |
| Kawangire | 3.22 | ** | 0.43 | 14.36 | 89.64 | 2.78 | ** | 6.71 | 215.75 | 93.36 | 0.70 | | 0.41 | 72.93 | 17.02 |
| Kibungo | 2.31 | * | 0.25 | 13.14 | 57.06 | 2.05 | * | 5.36 | 174.64 | 92.14 | 1.07 | | 0.53 | 64.93 | 24.32 |
| Masaka | 0.65 | | 0.09 | 16.04 | 17.02 | 0.93 | | 2.08 | 210.43 | 29.70 | 1.02 | | 0.55 | 71.83 | 22.97 |
| Muganza | 1.95 | + | 0.56 | 40.50 | 41.19 | 2.66 | ** | 15.16 | 507.79 | 89.55 | 0.64 | | 0.33 | 68.27 | 14.65 |
| Mushubi | -0.14 | | 0.00 | 20.57 | 0.00 | -1.32 | | -3.36 | 349.96 | -28.84 | 1.00 | | 0.60 | 64.93 | 27.72 |
| Ntaruka | 2.14 | * | 0.25 | 17.89 | 41.92 | 1.52 | | 2.63 | 300.39 | 26.27 | 0.23 | | 0.11 | 47.13 | 7.07 |
| Ntendezi | 0.24 | | 0.00 | 18.36 | 0.00 | 0.75 | | 3.10 | 382.86 | 24.29 | -0.91 | | -0.45 | 59.07 | -22.86 |
| Nyagatare | 3.31 | *** | 0.35 | 14.71 | 71.36 | 2.52 | * | 7.25 | 232.18 | 93.68 | -0.93 | | -0.25 | 56.67 | -13.24 |
| Nyamata | 0.70 | | 0.08 | 15.46 | 14.94 | -0.25 | | -0.57 | 275.96 | -6.21 | 1.30 | | 0.94 | 76.27 | 36.88 |
| Rubengera | 0.04 | | 0.00 | 22.68 | 0.00 | 3.32 | *** | 13.00 | 347.46 | 112.24 | 1.36 | | 0.85 | 57.50 | 44.44 |
| Ruganda | 1.06 | | 0.11 | 13.18 | 23.90 | 0.93 | | 2.88 | 285.04 | 30.26 | -0.62 | | -0.25 | 68.67 | -10.92 |
| Ruhengeri | 1.22 | | 0.12 | 15.29 | 22.57 | 1.98 | * | 5.00 | 307.39 | 48.80 | 0.57 | | 0.19 | 43.53 | 13.25 |
| Rutsiro | 1.52 | | 0.22 | 22.39 | 29.07 | 2.64 | ** | 9.00 | 316.04 | 85.43 | 1.04 | | 0.64 | 70.13 | 27.50 |
| Rwamagana | 3.31 | *** | 0.92 | 22.00 | 125.86 | 2.98 | ** | 16.29 | 300.54 | 162.63 | 1.38 | | 0.56 | 53.47 | 31.17 |
| Rwankeri | -1.69 | + | -0.14 | 11.82 | -36.29 | -1.34 | | -3.10 | 266.00 | -34.96 | 0.05 | | 0.09 | 76.00 | 3.43 |
| Save | -0.59 | | -0.06 | 16.89 | -11.19 | -3.62 | *** | -8.10 | 260.89 | -93.14 | 0.52 | | 0.22 | 74.20 | 8.98 |

### 4.3.3 *Seasonal and annual maximum temperature*

Table 4-5 shows that the trend of observed (1983-2012) for mean annual maximum temperature ranged from +1.3% or +0.01$^{O}$C per year (not significant, $\alpha > 0.05$) in Kamembe to +0.12% or +0.01$^{O}$C per year (not significant, $\alpha > 0.05$) in Bukora. The trend observed (1983-2012) for JF season mean maximum temperature ranged from +3.89% or +0.04$^{O}$C per year (significant, $\alpha \leq 0.05$) in Kamembe to -0.22% or -0.001$^{O}$C per year (not significant, $\alpha > 0.05$) in Gabiro. The trend of observed (1983-2012) MAM season mean maximum temperature ranged from +3.89% or +0.04$^{O}$C per year (significant, $\alpha \leq 0.05$) in Kamembe to -0.22% or -0.001$^{O}$C per year (not significant, $\alpha > 0.05$) in Gabiro. The trend of observed (1983-2012) JJA season mean maximum temperature ranged from +1.74% or +0.02$^{O}$C per year (not significant, $\alpha > 0.05$) in Gitega to -3.01% or -0.02$^{O}$C per year (not significant, $\alpha > 0.05$) in Rwankeri. The trend of observed (1983-2012) SOND season mean maximum temperature ranged from +2.74% or +0.03$^{O}$C per year (not significant, $\alpha > 0.05$) in Ruhango to +1.28% or +0.01$^{O}$C per year (not significant, $\alpha > 0.05$) in Rutsiro. These findings agree with other studies (Minitere, 2006; Eriksen and Rosentrater, 2008; Henninger, 2009; Safari, 2012; and Ngarukiyimana et al., 2021) that reported increased seasonal and annual maximum temperatures over different parts of Rwanda. In addition, the results are in agreement with a study by Safari (2012) who reported the significant positive trend of mean annual maximum temperature over Rwanda during the period 1958–2010 using five observatories whereby the period after 1977–1979 showed significant warming trend with a slope of 0.0455°C/year in Kigali city.
In general, the analysis showed that the trend for annual mean maximum temperature increased over Rwanda. The trend for JF, MAM seasons indicated a significant increasing trend in maximum temperature over Kamembe while a significant decreasing trend was observed over Gabiro for both seasons.

Table 4-5: Trend analysis of seasonal and annual maximum temperature (1983-2012)

| Period | Annual | | | | | January February | | | | | MAM | | | | | JJA | | | | | SOND | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stations | Z test | α level | Q | Mean | %Δ | Z test | α level | Q | Mean | %Δ | Z test | α level | Q | Mean | %Δ | Z test | α level | Q | Mean | %Δ | Z test | α level | Q | Mean | %Δ |
| Bukora | 0.10 | | 0.00 | 27.78 | 0.12 | 0.00 | | 0.00 | 27.97 | 0.00 | -0.06 | | 0.00 | 27.39 | -0.04 | 0.06 | | 0.00 | 28.16 | 0.23 | 0.97 | | 0.02 | 27.70 | 1.64 |
| Busogo | 0.18 | | 0.00 | 20.47 | 0.34 | 0.49 | | 0.01 | 21.63 | 1.83 | 0.45 | | 0.01 | 20.47 | 1.42 | -1.09 | | -0.01 | 19.42 | -2.03 | 1.32 | | 0.01 | 20.69 | 1.91 |
| Butare | 0.89 | | 0.01 | 25.01 | 1.12 | 0.81 | | 0.01 | 25.04 | 1.34 | -0.45 | | -0.01 | 24.54 | -0.82 | 0.57 | | 0.00 | 25.10 | 0.51 | 1.88 | + | 0.02 | 25.30 | 2.27 |
| Byimana | 1.01 | | 0.01 | 25.02 | 0.93 | 0.61 | | 0.01 | 25.25 | 1.03 | 0.02 | | 0.00 | 24.59 | 0.05 | 0.65 | | 0.01 | 24.97 | 0.78 | 1.84 | + | 0.02 | 25.27 | 2.29 |
| Byumba | 0.53 | | 0.00 | 21.81 | 0.49 | 0.81 | | 0.01 | 21.99 | 1.85 | -0.14 | | 0.00 | 21.19 | -0.26 | 0.10 | | 0.00 | 22.48 | 0.25 | 1.84 | + | 0.02 | 21.68 | 2.49 |
| Cyinzuzi | 0.85 | | 0.01 | 22.40 | 0.76 | 0.85 | | 0.01 | 22.87 | 1.06 | 0.06 | | 0.00 | 22.06 | 0.07 | 0.38 | | 0.01 | 22.38 | 0.64 | 1.88 | + | 0.02 | 22.45 | 2.46 |
| Gabiro | 0.34 | | 0.00 | 27.88 | 0.49 | -0.14 | | 0.00 | 27.37 | -0.22 | 0.00 | | 0.00 | 27.46 | 0.00 | 1.09 | | 0.01 | 27.94 | 1.33 | 0.89 | | 0.02 | 28.40 | 2.16 |
| Gatumba | 0.41 | | 0.00 | 22.38 | 0.54 | 0.53 | | 0.01 | 23.81 | 1.16 | 0.00 | | 0.00 | 23.37 | -0.05 | -0.06 | | 0.00 | 21.32 | -0.25 | 1.48 | | 0.02 | 21.75 | 2.25 |
| Gikongoro | 0.69 | | 0.00 | 23.19 | 0.57 | 0.85 | | 0.02 | 23.47 | 2.09 | 0.22 | | 0.00 | 22.84 | 0.19 | -0.02 | | 0.00 | 23.23 | -0.06 | 1.56 | | 0.01 | 23.28 | 1.73 |
| Gisanga | 0.73 | | 0.01 | 25.38 | 0.97 | 0.38 | | 0.01 | 25.51 | 0.72 | -0.30 | | 0.00 | 24.84 | -0.54 | 0.97 | | 0.01 | 25.34 | 1.12 | 1.84 | + | 0.03 | 25.74 | 2.74 |
| Gisenyi | 0.77 | | 0.01 | 26.33 | 0.61 | 1.17 | | 0.02 | 26.28 | 1.97 | 0.97 | | 0.01 | 26.21 | 1.53 | -0.81 | | -0.01 | 26.26 | -1.41 | 1.56 | | 0.02 | 26.49 | 2.18 |
| Gitarama | 1.01 | | 0.01 | 24.89 | 0.94 | 0.45 | | 0.01 | 24.73 | 0.83 | 0.14 | | 0.00 | 24.12 | 0.22 | 0.77 | | 0.01 | 25.03 | 1.13 | 1.80 | + | 0.02 | 25.44 | 2.16 |
| Gitega | 0.73 | | 0.01 | 26.73 | 0.96 | 0.06 | | 0.00 | 26.86 | 0.18 | -0.26 | | -0.01 | 26.13 | -0.68 | 1.28 | | 0.02 | 26.79 | 1.74 | 1.32 | | 0.02 | 27.08 | 2.24 |
| Kamembe | 1.32 | | 0.01 | 26.12 | 1.30 | 2.35 | * | 0.04 | 26.00 | 3.89 | 1.28 | | 0.01 | 26.07 | 1.56 | -1.13 | | -0.01 | 26.49 | -0.97 | 1.92 | + | 0.02 | 25.95 | 2.00 |
| Kanombe | 0.69 | | 0.01 | 26.98 | 0.83 | 0.10 | | 0.00 | 27.08 | 0.33 | -0.22 | | 0.00 | 26.35 | -0.45 | 1.17 | | 0.01 | 27.25 | 1.37 | 1.01 | | 0.02 | 27.19 | 2.02 |
| Kansi | 0.85 | | 0.01 | 26.58 | 0.94 | 0.69 | | 0.01 | 26.24 | 1.36 | -0.53 | | -0.01 | 25.82 | -0.78 | 0.57 | | 0.01 | 27.09 | 0.71 | 1.76 | + | 0.02 | 26.93 | 2.20 |
| Kawangire | 0.18 | | 0.00 | 27.03 | 0.35 | 0.10 | | 0.00 | 27.16 | 0.16 | 0.02 | | 0.00 | 26.41 | 0.06 | 1.05 | | 0.01 | 26.82 | 1.20 | 0.85 | | 0.02 | 27.60 | 2.08 |
| Kibungo | 0.22 | | 0.00 | 25.48 | 0.44 | 0.06 | | 0.00 | 25.38 | 0.32 | -0.14 | | 0.00 | 24.72 | -0.26 | 0.49 | | 0.00 | 26.13 | 0.48 | 0.89 | | 0.02 | 25.60 | 1.95 |
| Masaka | 0.34 | | 0.01 | 27.34 | 0.64 | 0.18 | | 0.00 | 27.69 | 0.39 | -0.14 | | 0.00 | 26.84 | -0.23 | 0.81 | | 0.01 | 27.54 | 1.02 | 0.97 | | 0.02 | 27.41 | 2.15 |
| Muganza | 0.53 | | 0.01 | 24.13 | 0.62 | 1.01 | | 0.02 | 24.28 | 2.08 | 0.06 | | 0.00 | 23.78 | 0.14 | 0.06 | | 0.00 | 24.24 | 0.08 | 1.52 | | 0.01 | 24.23 | 1.60 |
| Mushubi | 0.49 | | 0.00 | 22.15 | 0.61 | 0.97 | | 0.01 | 22.61 | 1.71 | 0.18 | | 0.00 | 21.88 | 0.43 | -0.53 | | -0.01 | 22.13 | -0.68 | 1.17 | | 0.01 | 22.14 | 1.56 |
| Ntaruka | 0.26 | | 0.00 | 23.97 | 0.36 | 0.77 | | 0.01 | 24.10 | 1.16 | 0.02 | | 0.00 | 23.67 | 0.03 | 0.06 | | 0.00 | 24.22 | 0.08 | 1.76 | + | 0.02 | 23.94 | 2.56 |
| Ntendezi | 0.93 | | 0.01 | 24.92 | 0.61 | 1.44 | | 0.02 | 25.01 | 2.39 | 0.34 | | 0.00 | 24.96 | 0.41 | -0.26 | | 0.00 | 25.24 | -0.43 | 1.52 | | 0.01 | 24.62 | 1.62 |
| Nyagatare | 0.32 | | 0.01 | 27.27 | 0.53 | -0.14 | | 0.00 | 26.82 | -0.22 | 0.06 | | 0.00 | 26.98 | 0.11 | 1.24 | | 0.01 | 27.32 | 1.25 | 0.81 | | 0.02 | 27.66 | 2.18 |
| Nyamata | 0.81 | | 0.01 | 27.32 | 1.00 | 0.14 | | 0.00 | 27.42 | 0.22 | -0.26 | | -0.01 | 26.66 | -0.59 | 1.05 | | 0.01 | 27.54 | 1.48 | 1.21 | | 0.02 | 27.62 | 2.05 |
| Rubengera | 0.73 | | 0.00 | 26.63 | 0.46 | 0.97 | | 0.02 | 26.10 | 2.17 | 0.34 | | 0.01 | 26.36 | 0.82 | -0.49 | | 0.00 | 26.84 | -0.45 | 1.28 | | 0.02 | 26.94 | 1.85 |
| Ruganda | 0.81 | | 0.01 | 24.51 | 0.81 | 0.53 | | 0.01 | 24.30 | 0.79 | 0.00 | | 0.00 | 23.67 | 0.02 | 0.75 | | 0.01 | 25.40 | 0.84 | 1.84 | + | 0.02 | 24.58 | 2.68 |
| Rugobagoba | 0.85 | | 0.01 | 25.55 | 0.79 | 0.22 | | 0.01 | 25.70 | 0.64 | -0.14 | | 0.00 | 25.03 | -0.35 | 1.09 | | 0.01 | 25.46 | 1.32 | 1.76 | + | 0.02 | 25.94 | 2.59 |
| Ruhengeri | 0.41 | | 0.00 | 23.33 | 0.34 | 0.57 | | 0.01 | 23.71 | 1.19 | 0.22 | | 0.00 | 22.94 | 0.55 | -0.69 | | -0.01 | 23.28 | -0.84 | 1.48 | | 0.02 | 23.48 | 2.07 |
| Rutsiro | 0.14 | | 0.00 | 22.22 | 0.14 | 0.65 | | 0.01 | 23.26 | 1.65 | 0.65 | | 0.01 | 22.96 | 0.91 | -0.73 | | -0.01 | 21.59 | -1.49 | 1.09 | | 0.01 | 21.63 | 1.28 |
| Rwamagana | 0.22 | | 0.00 | 26.90 | 0.48 | 0.10 | | 0.00 | 27.32 | 0.39 | 0.00 | | 0.00 | 26.59 | 0.01 | 1.01 | | 0.01 | 26.53 | 1.27 | 0.89 | | 0.02 | 27.20 | 1.96 |
| Rwankeri | 0.18 | | 0.00 | 18.04 | 0.51 | 0.38 | | 0.01 | 19.53 | 1.56 | 0.38 | | 0.01 | 18.20 | 1.24 | -1.32 | | -0.02 | 16.67 | -3.01 | 1.32 | | 0.01 | 18.23 | 2.12 |
| Save | 0.77 | | 0.01 | 26.14 | 1.01 | 0.61 | | 0.01 | 26.16 | 1.56 | -0.53 | | -0.01 | 25.60 | -0.98 | 0.61 | | 0.01 | 26.24 | 1.02 | 1.84 | + | 0.02 | 26.46 | 2.53 |

### 4.3.4 *Extreme maximum temperature*

Table 4-6 shows that most parts of Rwanda experienced an increasing trend in the number of cold and warm days. The trend of observed (1983-2012) annual number of cold days ranged from +32.43% or +0.12 days per year (not significant, $\alpha > 0.05$) in Kibungo to +0.0% or +0.001 days per year (not significant, $\alpha > 0.05$) in Kamembe. The trend of observed (1983-2012) annual number of warm days ranged from +54.15% or +0.19 days per year (not significant, $\alpha > 0.05$) in Save to +16.39% or +0.06 days per year (not significant, $\alpha > 0.05$) in Kamembe. The change in magnitude as a percentage of the mean indicates a larger and increasing number of warm days in the Kirehe district, Ngoma, Kayonza, Burera and the rest of the country. Similarly, the number of cold days also increased over south-eastern parts, especially over Kirehe, Ngoma and Kayonza, with other parts ranging between 30% and 60% except in western areas of Rusizi district, which showed up to 5% decrease. Muhire and Ahmed (2015) also observed more warm days in the eastern lowlands and central plateau of Rwanda. A study by Bernstain et al. (2007) also confirmed that cold days and cold nights have become less frequent while hot days and hot nights have increased in frequency over most land areas. The results showed that there is an increasing trend over most parts of the country in the number of cold days and warm days especially over southeastern parts. However, southwestern part, except Kamembe station indicated a decreasing trend in cold days.

Table 4-6: Trend analysis of extreme maximum temperature over Rwanda for the period 1983-2012

| Station | Number of cold days (TX10p) | | | | | Number of warm days (TX90p) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Test Z | α Level | Q | Mean | %Δ | Test Z | α Level | Q | Mean | %Δ |
| Bukora | 0.87 | 0.11 | 0.08 | 9.93 | 23.41 | 0.61 | 0.11 | 0.09 | 9.98 | 25.26 |
| Busogo | 0.99 | 0.11 | 0.06 | 9.82 | 17.96 | 1.21 | 0.11 | 0.16 | 9.94 | 44.51 |
| Butare | 1.07 | 0.11 | 0.06 | 9.77 | 18.05 | 1.52 | 0.11 | 0.18 | 9.89 | 50.97 |
| Byimana | 0.69 | 0.11 | 0.05 | 10.01 | 12.59 | 1.64 | 0.11 | 0.17 | 9.84 | 47.81 |
| Byumba | 0.73 | 0.11 | 0.05 | 9.95 | 13.50 | 1.40 | 0.11 | 0.15 | 9.95 | 40.82 |
| Cyinzuzi | 0.83 | 0.11 | 0.09 | 10.10 | 24.67 | 1.50 | 0.11 | 0.19 | 9.83 | 53.54 |
| Gabiro | 0.40 | 0.11 | 0.03 | 9.97 | 7.30 | 1.27 | 0.11 | 0.16 | 9.88 | 44.52 |
| Gatumba | 0.55 | 0.11 | 0.03 | 9.97 | 8.71 | 1.92 | 0.10 | 0.19 | 9.84 | 54.09 |
| Gikongoro | 0.75 | 0.11 | 0.05 | 9.83 | 14.25 | 1.15 | 0.11 | 0.13 | 9.92 | 37.54 |
| Gisanga | 0.95 | 0.11 | 0.05 | 10.04 | 14.78 | 1.54 | 0.11 | 0.17 | 9.89 | 46.72 |
| Gisenyi | 0.69 | 0.11 | 0.04 | 9.95 | 11.26 | 1.58 | 0.11 | 0.19 | 9.96 | 53.95 |
| Gitarama | 0.55 | 0.11 | 0.05 | 10.09 | 13.32 | 1.56 | 0.11 | 0.17 | 9.76 | 47.33 |
| Gitega | 0.85 | 0.11 | 0.08 | 9.94 | 21.41 | 1.37 | 0.11 | 0.16 | 9.84 | 45.82 |
| Kamembe | -0.02 | 0.11 | 0.00 | 9.98 | 0.00 | 1.60 | 0.11 | 0.17 | 9.92 | 47.43 |
| Kanombe | 1.09 | 0.11 | 0.09 | 9.99 | 25.24 | 1.27 | 0.11 | 0.15 | 9.87 | 41.43 |
| Kansi | 1.21 | 0.11 | 0.08 | 9.80 | 21.71 | 1.48 | 0.11 | 0.17 | 9.99 | 47.93 |
| Kawangire | 1.17 | 0.11 | 0.09 | 10.00 | 26.05 | 1.05 | 0.11 | 0.12 | 9.94 | 33.24 |
| Kibungo | 1.23 | 0.11 | 0.12 | 9.93 | 32.43 | 0.95 | 0.11 | 0.09 | 9.70 | 25.68 |
| Masaka | 1.15 | 0.11 | 0.09 | 9.89 | 25.48 | 1.35 | 0.11 | 0.16 | 9.84 | 45.26 |
| Muganza | 0.99 | 0.11 | 0.06 | 9.76 | 15.78 | 1.21 | 0.11 | 0.14 | 10.10 | 38.83 |
| Mushubi | 0.73 | 0.11 | 0.04 | 9.81 | 12.56 | 1.05 | 0.11 | 0.15 | 9.86 | 41.19 |
| Ntaruka | 0.61 | 0.11 | 0.04 | 9.98 | 11.50 | 0.51 | 0.11 | 0.06 | 9.74 | 16.39 |
| Ntendezi | 0.73 | 0.11 | 0.05 | 9.88 | 15.31 | 1.78 | 0.10 | 0.16 | 9.87 | 46.25 |
| Nyagatare | 0.32 | 0.11 | 0.03 | 9.94 | 7.33 | 1.36 | 0.11 | 0.18 | 9.86 | 49.97 |
| Nyamata | 1.21 | 0.11 | 0.08 | 9.87 | 23.26 | 1.11 | 0.11 | 0.14 | 9.88 | 39.68 |
| Rubengera | 1.07 | 0.11 | 0.05 | 9.86 | 15.04 | 1.46 | 0.11 | 0.16 | 9.83 | 45.60 |
| Ruganda | 0.85 | 0.11 | 0.07 | 10.00 | 20.71 | 1.66 | 0.10 | 0.16 | 9.86 | 46.27 |
| Ruhengeri | 0.93 | 0.11 | 0.05 | 9.82 | 15.11 | 1.29 | 0.11 | 0.15 | 9.94 | 42.82 |
| Rutsiro | 1.41 | 0.11 | 0.06 | 9.91 | 16.67 | 1.29 | 0.11 | 0.17 | 9.91 | 46.60 |
| Rwamagana | 1.07 | 0.11 | 0.10 | 9.95 | 28.15 | 0.71 | 0.11 | 0.10 | 9.88 | 28.34 |
| Rwankeri | 1.35 | 0.11 | 0.10 | 10.06 | 26.71 | 0.75 | 0.11 | 0.07 | 9.94 | 19.99 |
| Save | 1.29 | 0.11 | 0.09 | 9.85 | 24.73 | 1.63 | 0.11 | 0.19 | 9.98 | 54.15 |

### 4.3.5 *Seasonal and annual minimum temperature*

Table 4-7 shows that the trend of observed (1981-2010) mean annual minimum temperature ranges from +3.04% or +0.02$^{O}$C per year (significant, $\alpha \leq 0.05$) in Gabiro to +0.79% or +0.001$^{O}$C year (not significant, $\alpha > 0.05$) in Mushubi. The trend of observed (1981-2010) mean JF minimum temperature ranges from +4.55% or +0.02$^{O}$C per year (not significant, $\alpha > 0.05$) in Gisenyi to +1.78% or +0.01$^{O}$C year (not significant, $\alpha > 0.05$) in Gitega. The trend of observed (1981-2010) mean MAM minimum temperature rangesfrom +3.21% or +0.01$^{O}$C per year (not significant, $\alpha > 0.05$) in Rwankeri to +0.08% or +0.001$^{O}$C year (not significant, $\alpha > 0.05$) in Butare. The trend of observed (1981-2010) mean JJA minimum temperature ranged from +3.99% or +0.01$^{O}$C per year (not significant, $\alpha > 0.05$) in Bukora to -5.82% or +0.02$^{O}$C year (not significant, $\alpha > 0.05$) in Rwankeri. The trend of observed (1981-2010) mean SOND minimum temperature ranges from +5.95% or +0.02$^{O}$C per year (not significant, $\alpha > 0.05$) in Rwankeri to 3.45% or +0.02$^{O}$C year (not significant, $\alpha > 0.05$) in Kamembe. These findings agree with the study by Ngarukiyamana et al. (2021) that minimum temperatures significantly increased on a seasonal and annual scale. In addition, the results are in agreement with a study by Safari (2012) who reported the significant positive trend of mean annual minimum temperature over Rwanda during the period 1958–2010 using five observatories whereby the period after 1977–1979 showed significant warming trend with a slope of 0.0455°C/year in Kigali city.

Table 4-7: Trend analysis of seasonal (JF, MAM, JJA and SOND) and annual minimum temperature over Rwanda

| Stations | LON | LAT | Annual | | | | | JF | | | | | MAM | | | | | JJA | | | | | SOND | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Z Test | α Level | Q | Mean | %Δ | Z Test | α Level | Q | Mean | %Δ | Z Test | α Level | Q | Mean | %Δ | Z Test | α Level | Q | Mean | %Δ | Z Test | α Level | Q | Mean | %Δ |
| Bukora | 30.79 | -2.31 | 2.00 | 0.05 | 0.02 | 15.58 | 2.77 | 1.44 | 0.11 | 0.01 | 15.29 | 2.71 | 0.51 | 0.11 | 0.01 | 15.55 | 0.93 | 1.80 | 0.10 | 0.02 | 15.55 | 3.99 | 1.88 | 0.10 | 0.02 | 15.78 | 3.59 |
| Busogo | 29.55 | -1.56 | 0.93 | 0.11 | 0.01 | 9.71 | 1.62 | 0.77 | 0.11 | 0.01 | 9.75 | 3.64 | 0.97 | 0.11 | 0.01 | 10.12 | 2.88 | -1.60 | 0.11 | -0.01 | 9.20 | -3.52 | 2.00 | 0.05 | 0.01 | 9.78 | 4.22 |
| Butare | 29.71 | -2.60 | 0.93 | 0.11 | 0.01 | 14.10 | 1.72 | 0.81 | 0.11 | 0.01 | 13.95 | 1.89 | 0.04 | 0.11 | 0.00 | 14.50 | 0.08 | 0.85 | 0.11 | 0.01 | 13.81 | 1.79 | 1.92 | 0.10 | 0.02 | 14.09 | 3.93 |
| Byimana | 29.71 | -2.16 | 1.44 | 0.11 | 0.01 | 14.09 | 1.98 | 0.73 | 0.11 | 0.01 | 14.10 | 2.53 | 0.22 | 0.11 | 0.00 | 14.72 | 0.67 | 1.05 | 0.11 | 0.01 | 13.10 | 1.43 | 2.00 | 0.05 | 0.02 | 14.35 | 3.96 |
| Byumba | 30.05 | -1.60 | 1.40 | 0.11 | 0.01 | 12.74 | 2.32 | 1.17 | 0.11 | 0.01 | 12.68 | 3.19 | 1.09 | 0.11 | 0.01 | 12.91 | 1.93 | 0.02 | 0.11 | 0.00 | 12.57 | 0.12 | 2.35 | 0.05 | 0.02 | 12.76 | 4.93 |
| CYINZUZI | 30.00 | -1.76 | 1.52 | 0.11 | 0.01 | 12.43 | 2.10 | 0.81 | 0.11 | 0.01 | 12.99 | 2.74 | 0.77 | 0.11 | 0.01 | 12.23 | 1.51 | 0.18 | 0.11 | 0.00 | 11.96 | 0.54 | 2.47 | 0.05 | 0.02 | 12.67 | 4.83 |
| Gabiro | 30.40 | -1.55 | 2.31 | 0.05 | 0.02 | 15.55 | 3.04 | 1.68 | 0.10 | 0.02 | 17.03 | 3.04 | 1.17 | 0.11 | 0.01 | 15.58 | 1.86 | 1.56 | 0.11 | 0.01 | 13.97 | 2.67 | 2.47 | 0.05 | 0.02 | 16.00 | 4.30 |
| Gatumba | 29.63 | -1.95 | 1.09 | 0.11 | 0.01 | 12.93 | 1.56 | 0.67 | 0.11 | 0.01 | 13.78 | 2.21 | 0.38 | 0.11 | 0.00 | 13.23 | 0.79 | 0.14 | 0.11 | 0.00 | 11.44 | 0.19 | 2.03 | 0.05 | 0.02 | 13.42 | 3.95 |
| Gikongoro | 29.55 | -2.48 | 0.81 | 0.11 | 0.01 | 13.23 | 1.18 | 0.85 | 0.11 | 0.01 | 13.20 | 2.97 | 0.10 | 0.11 | 0.00 | 13.84 | 0.58 | -0.02 | 0.11 | 0.00 | 12.81 | -0.03 | 1.80 | 0.10 | 0.02 | 13.10 | 3.82 |
| Gisanga | 29.86 | -2.13 | 1.40 | 0.11 | 0.01 | 13.36 | 1.97 | 0.81 | 0.11 | 0.01 | 13.42 | 2.05 | 0.14 | 0.11 | 0.00 | 13.72 | 0.58 | 0.89 | 0.11 | 0.01 | 12.63 | 2.01 | 2.23 | 0.05 | 0.02 | 13.62 | 4.39 |
| Gisenyi | 29.26 | -1.68 | 1.32 | 0.11 | 0.01 | 15.14 | 2.03 | 1.48 | 0.11 | 0.02 | 15.09 | 4.55 | 0.89 | 0.11 | 0.01 | 15.76 | 2.09 | -0.85 | 0.11 | -0.01 | 14.47 | -1.22 | 2.27 | 0.05 | 0.02 | 15.19 | 4.30 |
| Gitarama | 29.76 | -2.08 | 1.28 | 0.11 | 0.01 | 12.32 | 1.72 | 0.85 | 0.11 | 0.01 | 12.46 | 2.13 | 0.34 | 0.11 | 0.00 | 12.31 | 0.59 | 0.71 | 0.11 | 0.00 | 11.59 | 0.94 | 2.15 | 0.05 | 0.02 | 12.82 | 4.29 |
| GITEGA | 30.06 | -1.96 | 1.72 | 0.10 | 0.01 | 15.70 | 2.44 | 1.24 | 0.11 | 0.01 | 16.10 | 1.78 | 0.41 | 0.11 | 0.00 | 15.73 | 0.73 | 1.52 | 0.11 | 0.02 | 15.02 | 3.49 | 2.23 | 0.05 | 0.02 | 15.99 | 3.99 |
| Kamembe | 28.91 | -2.46 | 1.30 | 0.11 | 0.01 | 15.14 | 1.48 | 1.36 | 0.11 | 0.02 | 15.18 | 3.03 | 0.69 | 0.11 | 0.01 | 15.51 | 1.26 | 0.14 | 0.11 | 0.00 | 14.49 | 0.37 | 1.96 | 0.10 | 0.02 | 15.33 | 3.45 |
| KANOMBE | 30.13 | -1.97 | 1.64 | 0.11 | 0.01 | 15.56 | 2.38 | 1.13 | 0.11 | 0.01 | 15.58 | 2.28 | 0.38 | 0.11 | 0.00 | 15.86 | 0.66 | 1.52 | 0.11 | 0.02 | 15.26 | 3.40 | 2.43 | 0.05 | 0.02 | 15.56 | 4.06 |
| Kansi | 29.75 | -2.70 | 1.09 | 0.11 | 0.01 | 14.08 | 1.73 | 0.93 | 0.11 | 0.01 | 14.08 | 1.85 | 0.10 | 0.11 | 0.00 | 14.22 | 0.26 | 0.81 | 0.11 | 0.01 | 13.67 | 2.10 | 2.00 | 0.05 | 0.02 | 14.28 | 3.82 |
| Kawangire | 30.45 | -1.81 | 2.19 | 0.05 | 0.02 | 14.62 | 2.88 | 1.56 | 0.11 | 0.02 | 14.89 | 3.08 | 1.01 | 0.11 | 0.01 | 14.59 | 1.61 | 1.52 | 0.11 | 0.01 | 14.01 | 2.88 | 2.35 | 0.05 | 0.02 | 14.97 | 4.39 |
| Kibungo | 30.53 | -2.16 | 1.88 | 0.10 | 0.01 | 15.42 | 2.45 | 1.60 | 0.11 | 0.01 | 15.39 | 1.94 | 0.53 | 0.11 | 0.00 | 15.16 | 0.92 | 1.64 | 0.11 | 0.02 | 15.88 | 3.43 | 2.00 | 0.05 | 0.02 | 15.27 | 3.76 |
| Masaka | 30.21 | -2.00 | 1.68 | 0.10 | 0.01 | 15.49 | 2.37 | 1.17 | 0.11 | 0.01 | 15.26 | 2.44 | 0.38 | 0.11 | 0.00 | 15.75 | 0.73 | 1.60 | 0.11 | 0.02 | 15.19 | 3.23 | 2.47 | 0.05 | 0.02 | 15.64 | 4.01 |
| Muganza | 29.50 | -2.68 | 0.81 | 0.11 | 0.01 | 12.20 | 1.23 | 0.81 | 0.11 | 0.01 | 12.08 | 3.12 | 0.06 | 0.11 | 0.00 | 12.85 | 0.61 | -0.02 | 0.11 | 0.00 | 11.60 | -0.06 | 1.84 | 0.10 | 0.02 | 12.22 | 3.78 |
| Mushubi | 29.45 | -2.36 | 0.61 | 0.11 | 0.00 | 12.48 | 0.79 | 0.69 | 0.11 | 0.01 | 12.26 | 2.51 | 0.18 | 0.11 | 0.00 | 12.30 | 0.54 | -0.45 | 0.11 | 0.00 | 12.49 | -1.01 | 1.84 | 0.10 | 0.02 | 12.74 | 3.85 |
| Ntaruka | 29.75 | -1.46 | 1.44 | 0.11 | 0.01 | 11.69 | 1.95 | 1.21 | 0.11 | 0.02 | 11.35 | 3.72 | 1.24 | 0.11 | 0.01 | 12.15 | 1.71 | -0.22 | 0.11 | 0.00 | 11.48 | -0.55 | 2.27 | 0.05 | 0.02 | 11.67 | 4.42 |
| Ntendezi | 29.04 | -2.45 | 1.28 | 0.11 | 0.01 | 12.41 | 1.59 | 1.21 | 0.11 | 0.01 | 12.73 | 3.19 | 0.57 | 0.11 | 0.01 | 12.51 | 1.13 | 0.10 | 0.11 | 0.00 | 12.07 | 0.29 | 1.88 | 0.10 | 0.02 | 12.45 | 3.58 |
| Nyagatare | 30.31 | -1.28 | 2.43 | 0.05 | 0.01 | 14.70 | 2.84 | 1.56 | 0.11 | 0.02 | 17.00 | 2.91 | 1.09 | 0.11 | 0.01 | 14.31 | 1.70 | 1.52 | 0.11 | 0.01 | 12.85 | 2.63 | 2.59 | 0.01 | 0.02 | 15.28 | 4.45 |
| Nyamata | 30.09 | -2.15 | 1.72 | 0.10 | 0.01 | 15.63 | 2.48 | 1.09 | 0.11 | 0.01 | 15.50 | 2.24 | 0.45 | 0.11 | 0.00 | 15.84 | 0.55 | 1.52 | 0.11 | 0.02 | 15.20 | 3.62 | 2.39 | 0.05 | 0.02 | 15.87 | 3.89 |
| Rubengera | 29.41 | -2.07 | 1.24 | 0.11 | 0.01 | 15.77 | 1.95 | 1.24 | 0.11 | 0.01 | 15.61 | 2.68 | 0.47 | 0.11 | 0.01 | 16.07 | 0.91 | 0.41 | 0.11 | 0.00 | 15.23 | 0.29 | 1.88 | 0.10 | 0.02 | 16.04 | 3.47 |
| RUGANDA | 29.88 | -1.78 | 1.80 | 0.10 | 0.01 | 12.47 | 2.18 | 0.93 | 0.11 | 0.01 | 12.81 | 2.40 | 0.77 | 0.11 | 0.01 | 12.66 | 1.46 | 0.38 | 0.11 | 0.00 | 11.81 | 0.72 | 2.49 | 0.05 | 0.02 | 12.67 | 4.59 |
| Rugobagoba | 29.88 | -2.05 | 1.44 | 0.11 | 0.01 | 13.81 | 1.97 | 0.81 | 0.11 | 0.01 | 13.70 | 2.54 | 0.18 | 0.11 | 0.00 | 14.13 | 0.78 | 0.97 | 0.11 | 0.01 | 13.10 | 2.30 | 2.23 | 0.05 | 0.02 | 14.17 | 4.34 |
| Ruhengeri | 29.61 | -1.48 | 1.24 | 0.11 | 0.01 | 11.42 | 1.91 | 0.95 | 0.11 | 0.01 | 10.75 | 3.36 | 1.05 | 0.11 | 0.01 | 12.37 | 2.05 | -0.93 | 0.11 | -0.01 | 11.16 | -1.56 | 2.11 | 0.05 | 0.02 | 11.23 | 4.59 |
| Rutsiro | 29.40 | -1.95 | 1.05 | 0.11 | 0.01 | 12.40 | 1.31 | 1.05 | 0.11 | 0.02 | 13.45 | 3.42 | 0.77 | 0.11 | 0.01 | 12.71 | 1.99 | -0.77 | 0.11 | -0.01 | 10.87 | -1.82 | 1.96 | 0.10 | 0.02 | 12.81 | 4.20 |
| Rwamagana | 30.43 | -1.93 | 1.92 | 0.10 | 0.01 | 15.96 | 2.56 | 1.44 | 0.11 | 0.01 | 16.01 | 2.51 | 0.81 | 0.11 | 0.01 | 16.40 | 0.93 | 1.40 | 0.11 | 0.02 | 15.75 | 2.88 | 2.35 | 0.05 | 0.02 | 15.78 | 4.03 |
| Rwankeri | 29.51 | -1.58 | 0.61 | 0.11 | 0.01 | 8.42 | 1.99 | 0.53 | 0.11 | 0.01 | 8.93 | 3.75 | 0.81 | 0.11 | 0.01 | 8.82 | 3.21 | -1.84 | 0.10 | -0.02 | 7.72 | -5.82 | 1.80 | 0.10 | 0.02 | 8.40 | 5.95 |
| Save | 29.76 | -2.53 | 1.09 | 0.11 | 0.01 | 14.36 | 1.74 | 0.93 | 0.11 | 0.01 | 14.47 | 1.82 | 0.06 | 0.11 | 0.00 | 14.50 | 0.13 | 0.85 | 0.11 | 0.01 | 13.98 | 2.05 | 2.03 | 0.05 | 0.02 | 14.48 | 3.85 |

### 4.3.6 *Extreme minimum temperature*

Table 4-8 shows that most parts of Rwanda experienced a decreasing trend of cold nights, whereas the percentage of warm nights increased. The trend of observed (1983-2012) annual number of cold nights ranged from -7.94% or -0.03 days per year (not significant, $\alpha > 0.05$) in Rwankeri to -87.64% or -0.31 days per year (significant, $\alpha \leq 0.05$) in Gabiro. The trend of observed (1981-2010) annual number of warm nights ranged from +48.93% or +0.17 days per year (not significant, $\alpha > 0.05$) in Bukora to +0% or +0.001 days per year (not significant, $\alpha > 0.05$) in Rwankeri. The change magnitude as a percentage of the mean showed decreases in the number of cold nights from Southern areas and Congo Nile divide to parts of the north-western highland in Ngororero, Nyabihu and Musanze towards the central part, southeastern part, areas along Lake Kivu and northern part. The number of warm nights increased from west to east. The study findings were in agreement with Bernstain et al. (2007), who noted that the cold days and cold nights have become less frequent while hot days and hot nights have increased in frequency over most land areas. The Results indicated a decreasing trend over Rwanda in the number of cold nights and an increasing trend in warm nights in most parts of the country except in a few parts of northwest (Rwankeri station).

Table 4-8: Trend analysis of extreme minimum temperature.

| Station | Number of cold nights (TN10p) | | | | | Number of warm nights (TN90p) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Test Z | α Level | Q | Mean | %Δ | Test Z | α Level | Q | Mean | %Δ |
| Bukora | -1.80 | 0.10 | -0.21 | 9.94 | -58.29 | 1.25 | 0.11 | 0.17 | 9.90 | 48.93 |
| Busogo | -1.03 | 0.11 | -0.10 | 9.83 | -27.06 | 0.50 | 0.11 | 0.05 | 9.85 | 14.21 |
| Butare | -0.97 | 0.11 | -0.09 | 9.82 | -24.24 | 1.21 | 0.11 | 0.15 | 9.78 | 42.38 |
| Byimana | -1.11 | 0.11 | -0.09 | 9.79 | -26.59 | 1.09 | 0.11 | 0.11 | 9.74 | 30.75 |
| Byumba | -2.06 | 0.05 | -0.21 | 9.81 | -59.93 | 0.83 | 0.11 | 0.10 | 9.88 | 28.34 |
| Cyinzuzi | -1.88 | 0.10 | -0.17 | 9.97 | -47.75 | 1.27 | 0.11 | 0.14 | 9.96 | 39.90 |
| Gabiro | -2.14 | 0.05 | -0.31 | 9.94 | -87.64 | 1.19 | 0.11 | 0.16 | 9.75 | 45.09 |
| Gatumba | -1.21 | 0.11 | -0.08 | 9.85 | -23.87 | 0.89 | 0.11 | 0.13 | 9.89 | 35.39 |
| Gikongoro | -0.63 | 0.11 | -0.04 | 9.79 | -11.16 | 0.93 | 0.11 | 0.12 | 9.85 | 32.68 |
| Gisanga | -1.31 | 0.11 | -0.11 | 9.94 | -31.83 | 1.31 | 0.11 | 0.16 | 9.94 | 45.34 |
| Gisenyi | -1.68 | 0.10 | -0.20 | 9.86 | -56.77 | 1.15 | 0.11 | 0.14 | 9.98 | 39.27 |
| Gitarama | -1.03 | 0.11 | -0.09 | 9.78 | -26.64 | 1.05 | 0.11 | 0.12 | 9.75 | 34.16 |
| Gitega | -1.48 | 0.11 | -0.14 | 9.91 | -40.10 | 1.13 | 0.11 | 0.11 | 9.89 | 31.42 |
| Kamembe | -1.59 | 0.11 | -0.12 | 9.80 | -33.99 | 1.01 | 0.11 | 0.12 | 9.82 | 34.51 |
| Kanombe | -1.17 | 0.11 | -0.15 | 9.80 | -41.43 | 1.05 | 0.11 | 0.11 | 9.89 | 29.73 |
| Kansi | -1.27 | 0.11 | -0.12 | 9.84 | -33.01 | 1.31 | 0.11 | 0.16 | 9.75 | 45.93 |
| Kawangire | -2.18 | 0.05 | -0.28 | 10.03 | -77.31 | 1.19 | 0.11 | 0.16 | 9.72 | 47.24 |
| Kibungo | -1.21 | 0.11 | -0.17 | 9.82 | -47.61 | 1.21 | 0.11 | 0.14 | 9.81 | 40.80 |
| Masaka | -1.43 | 0.11 | -0.18 | 9.89 | -51.55 | 1.27 | 0.11 | 0.12 | 9.79 | 34.90 |
| Muganza | -0.91 | 0.11 | -0.06 | 9.72 | -17.57 | 0.99 | 0.11 | 0.13 | 9.83 | 37.62 |
| Mushubi | -0.77 | 0.11 | -0.05 | 9.74 | -14.37 | 0.49 | 0.11 | 0.06 | 9.96 | 17.71 |
| Ntaruka | -1.98 | 0.05 | -0.21 | 9.93 | -60.37 | 0.65 | 0.11 | 0.10 | 9.83 | 28.49 |
| Ntendezi | -1.03 | 0.11 | -0.12 | 9.82 | -34.79 | 1.19 | 0.11 | 0.12 | 9.85 | 34.67 |
| Nyagatare | -2.22 | 0.05 | -0.27 | 9.85 | -76.50 | 1.27 | 0.11 | 0.16 | 9.79 | 46.34 |
| Nyamata | -1.80 | 0.10 | -0.16 | 9.84 | -46.08 | 1.41 | 0.11 | 0.13 | 9.95 | 36.03 |
| Rubengera | -1.33 | 0.11 | -0.10 | 9.94 | -28.16 | 1.01 | 0.11 | 0.13 | 9.84 | 36.44 |
| Ruganda | -2.02 | 0.05 | -0.19 | 9.89 | -53.80 | 1.31 | 0.11 | 0.11 | 9.92 | 31.05 |
| Ruhengeri | -1.90 | 0.10 | -0.16 | 9.84 | -45.82 | 0.61 | 0.11 | 0.06 | 9.79 | 17.73 |
| Rutsiro | -1.17 | 0.11 | -0.12 | 9.85 | -34.11 | 0.28 | 0.11 | 0.04 | 9.80 | 11.71 |
| Rwamagana | -1.70 | 0.10 | -0.24 | 9.94 | -68.74 | 1.21 | 0.11 | 0.15 | 9.86 | 43.73 |
| Rwankeri | -0.44 | 0.11 | -0.03 | 9.88 | -7.94 | -0.08 | 0.11 | 0.00 | 9.71 | 0.00 |
| Save | -1.17 | 0.11 | -0.10 | 9.81 | -28.55 | 1.33 | 0.11 | 0.13 | 9.92 | 37.82 |

## 4.4 Spatial analysis of past climate over Rwanda

### 4.4.1 *Seasonal and annual precipitation*

The JF season (Figure 4-1 a) indicates a considerable rainfall ranging between 450-600mm over the south-western areas near Nyungwe National Park and less than 50mm over most of the eastern part. The remaining parts registered rainfall ranging between 150 and 300 mm. The MAM season (Figure 4-1 b) shows that the south-western part bordering Nyungwe National Park receives higher rainfall ranging between 700-800mm and reduced towards the southern, northern and western regions, which received amounts ranging between 450-600mm. The areas of Kigali extending to the eastern part received lower rainfall ranging between 300-450mm.

The JJA season (Figure 4-1 c) indicates that the north-western of Kayonza, south-eastern Ngoma and Kirehe Districts received less than 50mm.l. Regions surrounding the Volcano National Park, eastern Nyamasheke, and southern Karongi near Nyungwe National Park received between 300 and 450 mm rainfall. At the same time, the rest of the country experienced 50 and 150mm of rainfall. The sSOND season (Figure 4-1 d) indicates that rainfall reduces from southwestern (800-900mm) to northern highland and central plateau (450-600mm) and less rain over the eastern region (300-450 mm). On an annual basis, Figure 4-1 (e) shows that southwestern, northern highland and the areas around Volcano National Park received rainfall above 1400 mm, and reduced towards the central plateau with amounts between 1200-1400mm. Amayaga, extending to the central-eastern regions, reported between 1000-1200mm of rainfall. The areas over the eastern part boarding Akagera National Park and the western of Nyagatare received amounts ranging between 800 and 900mm. Overall, western parts of Rwanda received more rainfall during both seasonal and annual rainfall compared to the eastern regions. These findings agree with Ntwali et al. (2016), who noted that the WRF model realistically captured the observed mean rainfall to be higher over the western sector as opposed to the eastern sector of Rwanda due to the influence of the topography.

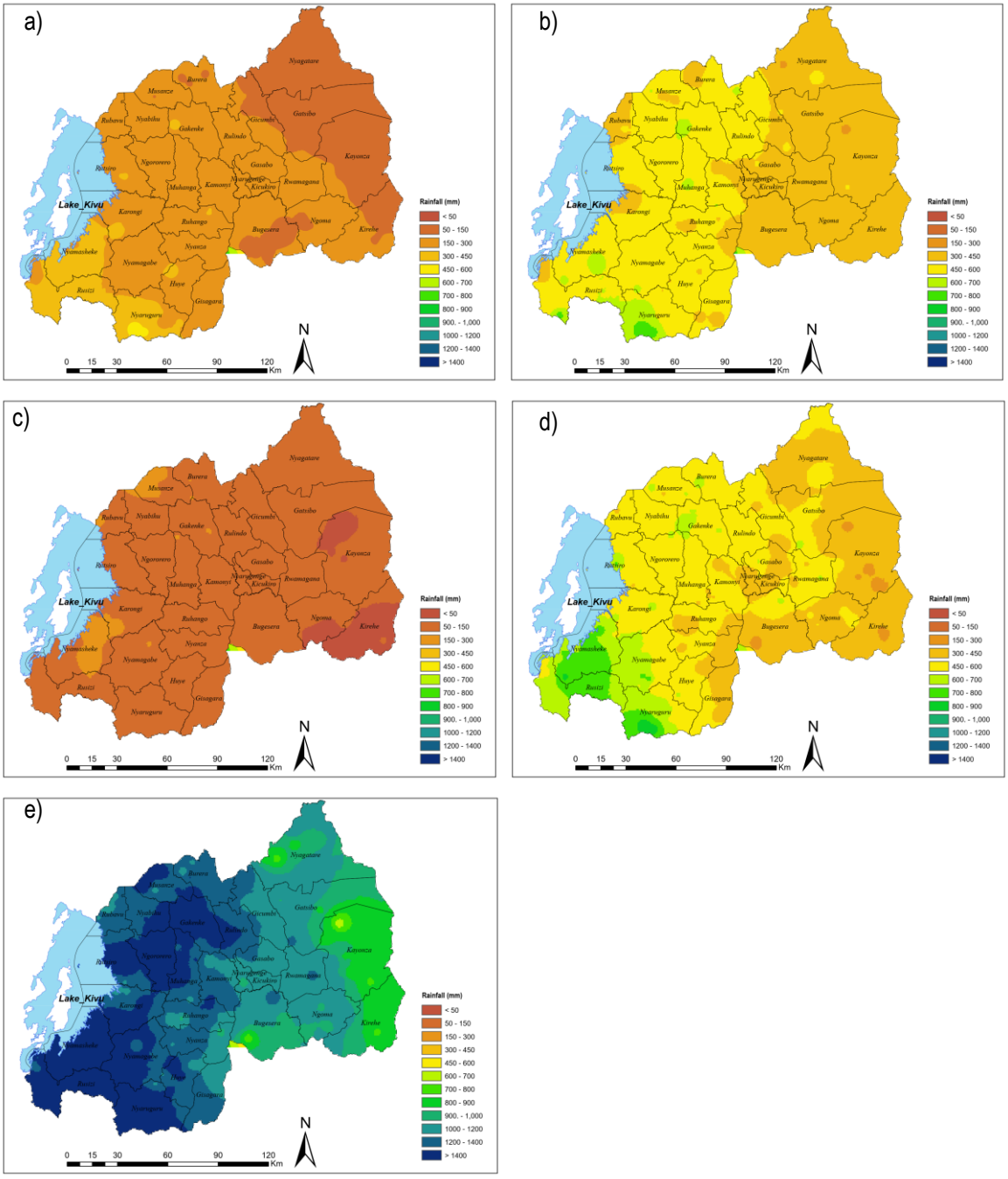



Figure 4-1: Spatial representation of mean (a) JF, (b) MAM, (c) JJA, (d) SOND, and (e) Annual rainfall over Rwanda from 1981 to 2010.

### 4.4.2 *Extreme precipitation*

Spatial analysis of the number of very wet days (R95p) and number of very heavy precipitation days (R20mm) is presented in Figure 4-2.

Figure 4-2 (a) shows that the number of days per year with very heavy rainfall precipitation (R20mm) was higher over south-western around Nyungwe National Park, reducing toward the central plateau than eastern areas bordering Lake Kivu and northwestern parts of Rwanda. Similarly, Figure 4-2 (b) shows that annual total precipitation from days >95th percentile mm (R95p) i.e., very wet days were higher over south-western parts reducing toward the central and less precipitation over the eastern part of Rwanda as shown in Figure 4-2 (b). These findings agree with Muhire and Ahmed (2015) that showed a spatial distribution of extreme precipitation such that highland regions, i.e., central and western Rwanda, were consequently recorded to have been experiencing more flooding, with the eastern lowlands and the central plateau becoming warmer. Moreover, MER (2015) confirmed the country's rainy seasons are becoming shorter and more intense, especially in the Northern and Western Provinces. In contrast, the Eastern Province was observed to experience severe rainfall deficits in numerous years over previous decades (MER, 2015).

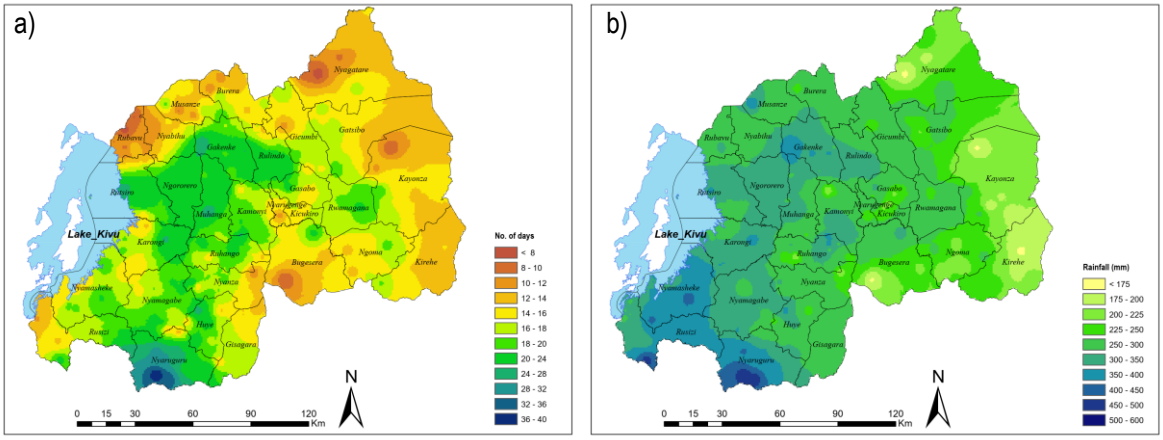



**Figure 4-2: Spatial representation of average extreme precipitation (a) very heavy precipitation days (R20mm) and (b) very wet days (R95pTOT) over Rwanda from 1981 to 2010.**

### 4.4.3 *Seasonal and annual maximum temperature*

Figure 4-3 shows that areas of higher maximum seasonal and annual temperatures are in the Bugarama valley and Kagitumba in Nyagatare district with temperature ranging between 30-32$^{o}$C, Amayaga areas and Bugesera district with temperature between 28-30$^{o}$C. Maximum temperature reduces from eastern toward the central plateau with a maximum temperature ranging between 26-28$^{o}$C. In contrast, lower maximum temperatures are observed over the western and northern highland areas, especially Musanze and Nyabihu, with less than 14$^{o}$C. Ngarukiyamana et al. (2021) noted the lowest maximum temperature at Rwankeri station, located in the northern part of the country, at 23.7°C while the highest maximum temperature was localized at Nyamata station situated in Bugesera district over the Eastern region with a temperature of 28.3°C. These confirm this study's observation that higher maximum temperatures are over the Eastern while lower maximum temperatures are over Northern highlands.

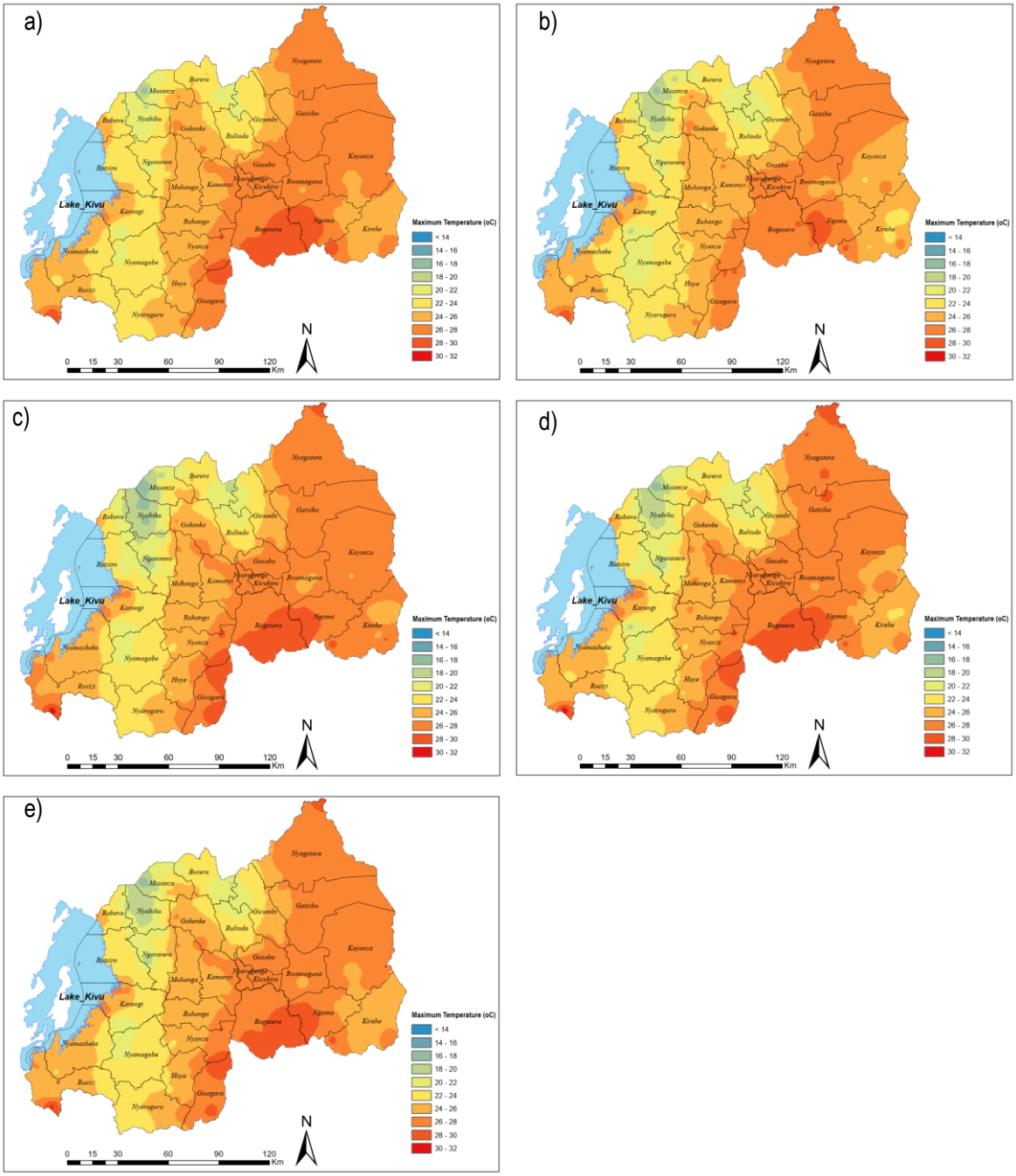



Figure 4-3: Spatial analysis of mean maximum temperature of a) JF, b) MAM, c) JJA, d) SOND and e) Annual over Rwanda.

### 4.4.4 *Seasonal and annual minimum temperature*

Overall, Figure 4-4 shows that the minimum temperature is higher over eastern parts and Bugarama Valley than in western and northern parts of Rwanda based on the mean seasonal and annual minimum temperatures. The most elevated minimum temperatures of between $16^0$C and $18^0$C were observed in North-Eastern parts (Nyagatare), Southeast and central Rwanda during JF season, and parts of Southeast (Kirehe and Kayonza), for both MAM, JJA, SOND seasons and annual timestep. The lowest temperatures were observed along the Congo-Nile divide towards

Musanze and Nyabihu areas during JF, MAM, JJA, SOND and Annual minimum temperature. Ngarukiyamana et al. (2021) noted the lowest minimum temperature at Rwankeri station, located in the northern part of the country, with 8.9°C, while the highest minimum temperature was localized at Nyamata station situated in the eastern region with 13.2°C and thus in agreement with the current study

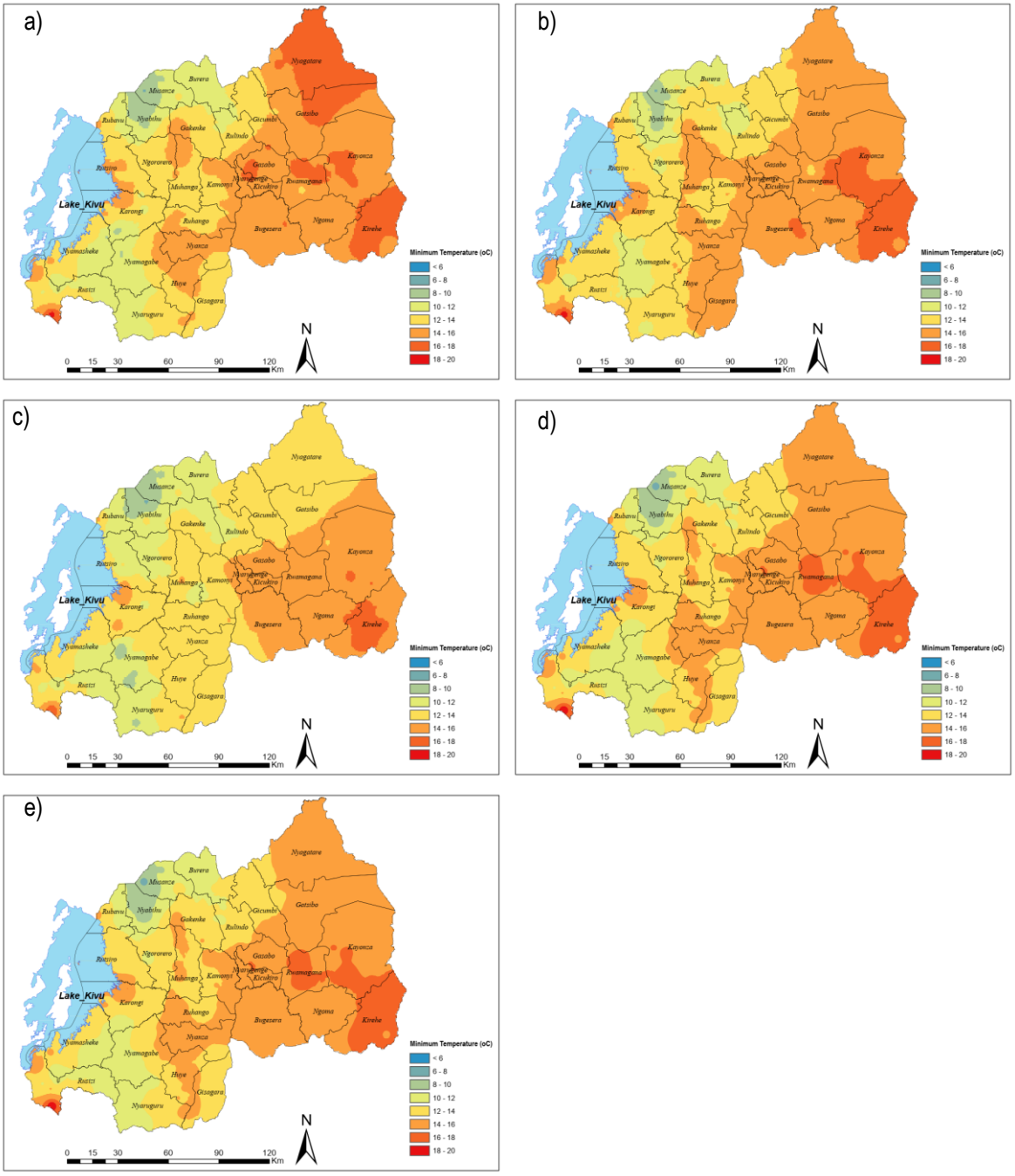



Figure 4-4: Spatial analysis of mean a) JF, b) MAM, c) JJA, d) SOND and e) Annual minimum temperature over Rwanda

### 4.4.5 *Extreme maximum temperature*

Figure 4-5 (a) shows that a higher number of cold days (10.0 to 10.2) was observed over the central parts of Gatsibo and Gicumbi extending to Rulindo Districts and the areas of Kamonyi, Ruhango and Muhanga compared to the rest of the country that reported the lowest number of colds days to range between 9.8 and 10 days. Figure 4-5 (b) shows that the number of warm days over Rwanda ranged between 9.8 and 10 days except in parts of Nyaruguru and Gisagara Districts (10.2 to 10.4). In contrast, areas of the southeast region, especially around Kirehe, experienced the lowest number of warm days. Previous studies observed spatial temperature variation in Rwanda, showing that there have been rising trends countrywide, with the maximum temperature increase compared to past decades (Nahayo et al., 2019).

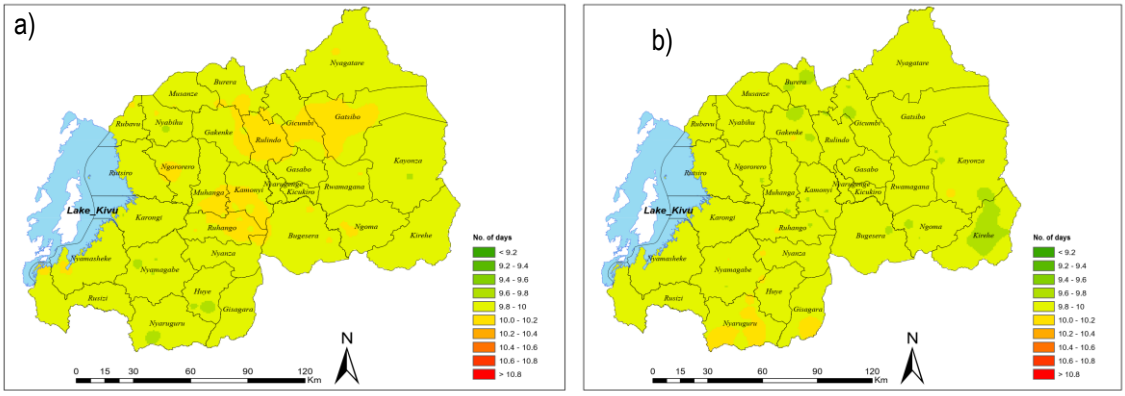



Figure 4-5: Spatial analysis average a) cold days (TX10p) and b) warm days (TX90p) over Rwanda

### 4.4.6 *Extreme minimum temperature*

Figure 4-6 shows that the number of cold and warm nights in Rwanda was approximately 9.4 and 10.2 days. Figure 4-6a shows that the southwestern areas bordering Nyungwe National Park and Amayaga western areas near Gishwati National Park register the lowest cold nights while Kayonza indicates the highest frequency with 10 to 10.2 cold nights. The warm night days (Figure 4-6 (b)) suggest that the northeast, Amayaga, and southwest areas registered a lower frequency with 9.2 to 9.4 warm nights and a higher frequency of 9.8 to 10 warm nights over the rest of the country. Other studies such as IPCC (2007), Christy et al. (2009), Stern et al. (2011), and Nicholson et al. (2013) also noted that the minimum temperatures are warming more rapidly than maximum temperatures.

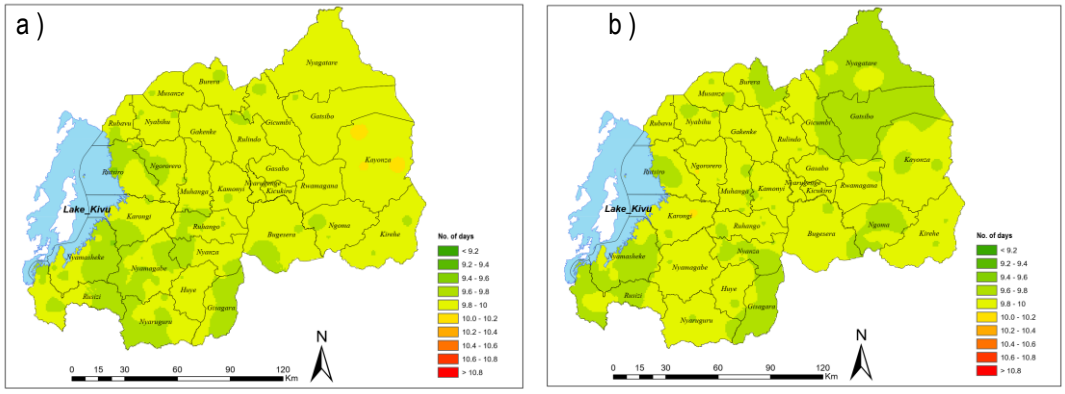



Figure 4-6: Spatial analysis average a) cold nights (TN10p) and b) Warm nights (TN90p) over Rwanda.

## 4.5 Climate model validation against observational data

### 4.5.1 *Validation of Precipitation data*

Model verification metrics shown in Table 4-9 show that MPI (driving model) downscaled by REMO2009 was the best performing model for precipitation on monthly timescales and selected for further analysis. Metrics from a previous study by Makula and Zhou (2021) agree that MPI-ESM 1-2-HR and MPI-ESM 1-2-LR models outperform the other individual models in simulating precipitation for both OND and MAM seasons. However, Umuhoza et al. (2021) ranked the MPI model downscaled by RCA4 among the least performing in simulating MAM seasonal rainfall over Rwanda

Table 4-9: validation of climate model precipitation against observational data

Performance (Weakest → Strongest)

| | MPI_RCA4 | MPI_REMO | MPI_CCLM4 | MOHC_REMO | MOHC_RCA4 | MOHC_CCLM4 | ICHEC_REMO | ICHEC_RCA4 | ICHEC_CCLM4 | REMO_ensemble | RCA4_ensemble | CCLM4_ensemble | MPI_ensemble | MOHC_ensemble | ICHEC_ensemble | All_ensemble |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CORR | 0.532 | 0.473 | 0.479 | 0.405 | 0.457 | 0.35 | 0.372 | 0.458 | 0.343 | 0.364 | 0.399 | 0.436 | 0.447 | 0.416 | 0.4 | 0.44 |
| BR2 | 0.259 | 0.187 | 0.201 | 0.129 | 0.18 | 0.105 | 0.076 | 0.184 | 0.114 | 0.105 | 0.138 | 0.163 | 0.171 | 0.151 | 0.138 | 0.166 |
| BIAS | 0.971 | 0.999 | 0.996 | 0.981 | 0.919 | 0.998 | 0.675 | 0.973 | 1.239 | 1.006 | 0.998 | 0.997 | 0.991 | 0.993 | 0.998 | 0.996 |
| PBIAS | -2.855 | -0.099 | -0.384 | -1.904 | -8.076 | -0.177 | -32.454 | -2.698 | 23.933 | 0.586 | -0.174 | -0.327 | -0.923 | -0.672 | -0.225 | -0.44 |
| ME | -3.084 | -0.107 | -0.415 | -2.057 | -8.723 | -0.191 | -35.055 | -2.914 | 25.851 | 0.634 | -0.188 | -0.353 | -0.997 | -0.726 | -0.243 | -0.476 |
| MAE | 74.721 | 63.534 | 70.041 | 65.851 | 86.26 | 90.695 | 66.053 | 78.023 | 95.055 | 68.8 | 83.957 | 72.711 | 71.655 | 80.183 | 78.648 | 72.734 |
| RMSE | 103.611 | 87.167 | 99.583 | 89.415 | 119.777 | 129.199 | 90.742 | 109.578 | 147.378 | 93.335 | 118.701 | 103.61 | 101.908 | 114.964 | 117.339 | 103.499 |
| NSE | -0.699 | -0.203 | -0.57 | -0.265 | -1.271 | -1.642 | -0.303 | -0.9 | -2.438 | -0.377 | -1.227 | -0.697 | -0.644 | -1.092 | -1.179 | -0.693 |
| MNSE | -0.162 | 0.012 | -0.089 | -0.024 | -0.341 | -0.41 | -0.027 | -0.213 | -0.478 | -0.069 | -0.305 | -0.13 | -0.114 | -0.247 | -0.223 | -0.13 |

### 4.5.2 *Validation of model output against observed maximum Temperature*

Model verification metrics shown in Table 4-10 show that MOHC (driving model) downscaled by REMO2009 was the best performing model for maximum temperature and selected for further analysis. Previous studies in Rwanda and East Africa have also used the MOHC model for Maximum temperature analysis (Mukhala et al., 2017; Umugwaneza, 2018).

Table 4-10: validation of climate model precipitation against observational data

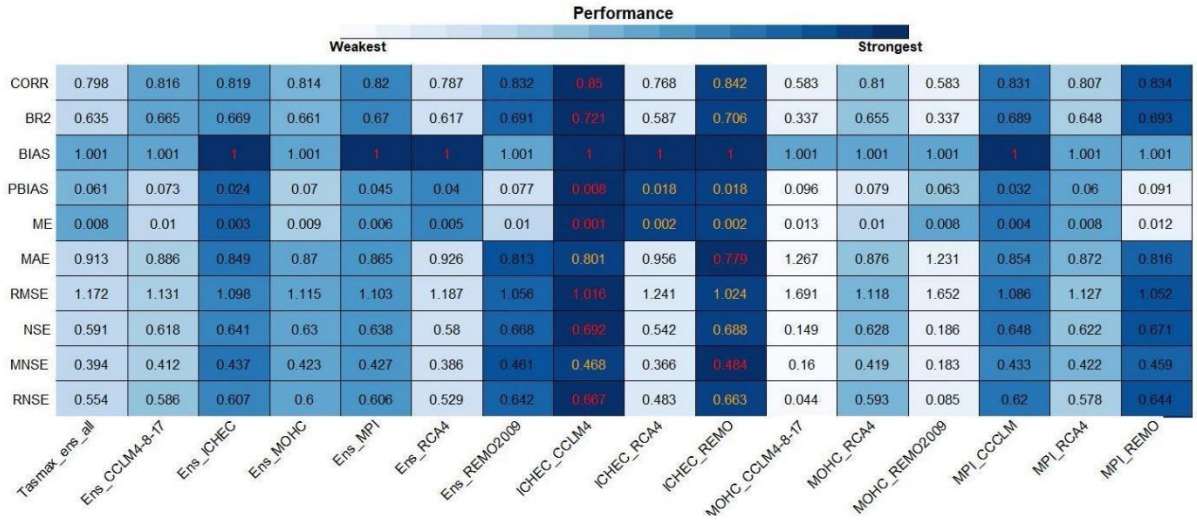
Performance (Weakest → Strongest)

| | Ens-All_Tasmax | Ens_CCLM4-8-1 | Ens_ICHEC | Ens_MOHC | Ens_MPI | Ens_RCA4 | Ens_REMO2009 | ICHEC_cclm | ICHEC_RCA4 | ICHEC_REMO | MOHC_CCLM 4-8-17 | MOHC_RCA4 | MOHC_REMO2009 | MPI_RCA4 | MPI_REMO | MPI-CCCLM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CORR | 0.531 | 0.527 | 0.547 | 0.525 | 0.558 | 0.526 | 0.551 | 0.557 | 0.543 | 0.554 | 0.732 | 0.518 | 0.795 | 0.552 | 0.573 | 0.558 |
| BR2 | 0.281 | 0.277 | 0.298 | 0.275 | 0.311 | 0.276 | 0.302 | 0.309 | 0.294 | 0.306 | 0.535 | 0.268 | 0.631 | 0.303 | 0.328 | 0.311 |
| BIAS | 1.001 | 1.001 | 1.001 | 1.001 | 1.001 | 1.001 | 1.001 | 1 | 1.002 | 1.001 | 1 | 1.001 | 1 | 1.001 | 1.004 | 1.002 |
| PBIAS | 0.087 | 0.072 | 0.116 | 0.072 | 0.082 | 0.107 | 0.099 | -0.021 | 0.151 | 0.109 | 0.016 | 0.114 | 0.032 | 0.109 | 0.413 | 0.162 |
| ME | 0.021 | 0.018 | 0.028 | 0.018 | 0.02 | 0.026 | 0.024 | -0.005 | 0.037 | 0.027 | 0.004 | 0.028 | 0.008 | 0.027 | 0.101 | 0.04 |
| MAE | 1.934 | 1.912 | 1.893 | 1.938 | 1.858 | 1.99 | 1.773 | 1.823 | 1.915 | 1.777 | 1.531 | 1.999 | 1.257 | 1.91 | 1.681 | 1.803 |
| RMSE | 2.558 | 2.542 | 2.496 | 2.536 | 2.457 | 2.594 | 2.371 | 2.424 | 2.513 | 2.36 | 1.915 | 2.582 | 1.587 | 2.49 | 2.267 | 2.422 |
| NSE | -0.096 | -0.083 | -0.04 | -0.074 | -0.008 | -0.127 | 0.058 | 0.019 | -0.054 | 0.07 | 0.388 | -0.113 | 0.579 | -0.036 | 0.142 | 0.011 |
| MNSE | 0.002 | 0.013 | 0.025 | 0.002 | 0.043 | -0.027 | 0.085 | 0.061 | 0.014 | 0.084 | 0.211 | -0.03 | 0.353 | 0.016 | 0.134 | 0.067 |
| RNSE | -0.208 | -0.214 | -0.161 | -0.191 | -0.134 | -0.206 | -0.047 | -0.111 | -0.148 | -0.039 | 0.313 | -0.195 | 0.537 | -0.137 | 0.024 | -0.125 |

### 4.5.3 *Validation of model output against observed minimum Temperature*

Model verification metrics shown in Table 4-11 show that ICHEC (driving model) downscaled by CCLM was the best performing model for minimum temperature and hence selected for further analysis. Previous studies in the region have also used the ICHEC driving model for the analysis of minimum temperature (Mukhala et al., 2017; Umugwaneza, 2018; Lawin et al., 2019).

Table 4-11: validation of climate model minimum temperature against observational data.



## 4.6 Bias corrected climate projections –precipitation

### 4.6.1 *Temporal analysis of projected seasonal and annual precipitation*

This section describes the trend of JF, MAM, JJA, SOND and Annual projected change in precipitation between 2021-2050, 2041-2070 and 2071-2100 relative to 1981 to 2010, under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ scenarios

#### 4.6.1.1 January - February (JF) Season

The projected JF seasonal rainfall (Table 4-12) for the period 2021-2050 ranges from -16.72% or -0.9mm per year (not significant, $\alpha > 0.05$) in Ruhengeri to -61.76% or -3.07mm per year (significant, $\alpha \leq 0.05$) in Gabiro under RCP 4.5 w/m$^2$. In addition, it ranged from +17.76% or 2.19mm per year (significant, $\alpha \leq 0.05$) in Muganza to -23.56% or -1.83mm per year (significant, $\alpha \leq 0.05$) in Kibungo under RCP 8.5 w/m$^2$. The projected JF precipitation shows a decreasing trend over western, Northern, Southern, Eastern, and more areas of central Rwanda under RCP 4.5 w/m$^2$ and an increasing trend over most parts of the country, except South-eastern parts and North-eastern parts under RCP 8.5 w/m$^2$.

Table 4-13 shows that projected JF seasonal rainfall for the period 2041-2070 ranged from +43.9% or +1.92mm per year (not significant, $\alpha > 0.05$) in Gabiro to -4.18% or -0.36mm per year (not significant, $\alpha > 0.05$) in Butare under RCP 4.5 w/m$^2$ and ranged from -17.59% or 1.59mm per year (not significant, $\alpha > 0.05$) in Kamembe to -69.92% or -4.38mm per year (significant, $\alpha \leq 0.05$) in Bukora under RCP 8.5 w/m$^2$. Analysis of projected JF precipitation for the period 2041-2070 shows an increasing trend over western and Eastern under RCP 4.5 w/m$^2$ and a decreasing trend mostly in southwestern parts under RCP 8.5 w/m$^2$.

Table 4-14 projected JF seasonal rainfall for the period 2071-2100 ranged from -30.76% or -4.92mm per year (significant, $\alpha \leq 0.05$) in Ntendezi to -82.76% or -3.12mm per year (significant, $\alpha \leq 0.05$) in Nyagatare under RCP 4.5 w/m$^2$ and ranged from +42.16% or +1.29mm per year (not significant, $\alpha > 0.05$) in Nyagatare to -33.88% or +1.66mm per year (significant, $\alpha \leq 0.05$) in Gisenyi under RCP 8.5 w/m$^2$. The period 2071-2100 shows a decreasing trend mostly over southwestern, western, and northern highland under RCP 4.5 w/m$^2$ and generally an increasing trend mostly over North-eastern part increase followed with Northern, central extending to eastern and Amayaga region.

Table 4-12: Projected trends of JF precipitation for the period 2021 to 2050 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| Timeframe | **2021-2050** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Scenario | **RCP 4.5 w/m$^2$** | | | | | **RCP 8.5 w/m$^2$** | | | | |
| Stations | Test Z | α level | Q | Annual | %Δ | Test Z | α level | Q | Annual | %Δ |
| Bukora | -1.68 | + | -2.35 | 188.86 | -37.34 | -1.11 | | -1.48 | 198.64 | -22.40 |
| Busogo | -1.57 | | -3.19 | 302.17 | -31.71 | 0.07 | | 0.14 | 333.42 | 1.27 |
| Butare | -1.86 | + | -4.67 | 292.43 | -47.94 | 0.82 | | 1.57 | 316.60 | 14.91 |
| Byimana | -1.96 | * | -4.17 | 248.99 | -50.26 | 0.93 | | 1.69 | 324.40 | 15.62 |
| Byumba | -2.00 | * | -3.44 | 183.90 | -56.09 | -0.18 | | -0.24 | 201.23 | -3.63 |
| Cyinzuzi | -2.14 | * | -5.29 | 269.64 | -58.82 | -0.07 | | -0.22 | 293.95 | -2.22 |
| Gabiro | -2.32 | * | -3.07 | 149.34 | -61.76 | 0.29 | | 0.19 | 160.53 | 3.51 |
| Gatumba | -1.82 | + | -3.35 | 245.17 | -41.00 | 0.46 | | 0.75 | 271.35 | 8.26 |
| Gikongoro | -2.03 | * | -4.03 | 267.41 | -45.25 | 0.46 | | 0.83 | 304.52 | 8.18 |
| Gisanga | -1.96 | * | -4.17 | 248.99 | -50.26 | 0.93 | | 1.69 | 324.40 | 15.62 |
| Gisenyi | -1.57 | | -2.65 | 186.69 | -42.58 | 0.32 | | 0.43 | 221.00 | 5.83 |
| Gitarama | -1.96 | * | -4.17 | 248.99 | -50.26 | 0.93 | | 1.69 | 324.40 | 15.62 |
| Gitega | -2.14 | * | -5.29 | 269.64 | -58.82 | -0.07 | | -0.22 | 293.95 | -2.22 |
| Kamembe | -1.25 | | -2.76 | 259.60 | -31.91 | 0.86 | | 1.41 | 291.19 | 14.51 |
| Kanombe | -2.14 | * | -5.29 | 269.64 | -58.82 | -0.07 | | -0.22 | 293.95 | -2.22 |
| Kansi | -1.93 | + | -4.61 | 290.56 | -47.55 | 0.89 | | 1.63 | 311.61 | 15.70 |
| Kawangire | -2.28 | * | -3.46 | 173.35 | -59.94 | 0.07 | | 0.08 | 191.28 | 1.20 |
| Kibungo | -1.50 | | -2.56 | 223.17 | -34.45 | -0.89 | | -1.83 | 232.59 | -23.56 |
| Masaka | -2.28 | * | -3.88 | 203.79 | -57.11 | 0.07 | | 0.06 | 223.58 | 0.75 |
| Muganza | -1.57 | | -4.43 | 347.92 | -38.18 | 1.18 | | 2.19 | 370.70 | 17.76 |
| Mushubi | -1.50 | | -4.31 | 328.29 | -39.38 | 0.39 | | 0.63 | 369.12 | 5.11 |
| Ntaruka | -1.03 | | -1.04 | 120.08 | -25.93 | 0.61 | | 0.57 | 135.95 | 12.68 |
| Ntendezi | -1.46 | | -4.93 | 488.57 | -30.28 | -0.25 | | -0.38 | 537.06 | -2.12 |
| Nyagatare | -1.64 | | -2.49 | 120.99 | -61.76 | -0.07 | | -0.11 | 129.45 | -2.62 |
| Nyamata | -2.14 | * | -4.10 | 229.50 | -53.57 | -0.18 | | -0.58 | 258.74 | -6.69 |
| Rubengera | -1.46 | | -3.37 | 220.07 | -45.94 | 0.25 | | 0.48 | 282.98 | 5.07 |
| Ruganda | -1.86 | + | -3.09 | 214.17 | -43.32 | 0.61 | | 0.78 | 237.30 | 9.88 |
| Rugobagoba | -1.96 | * | -4.17 | 248.99 | -50.26 | 0.93 | | 1.69 | 324.40 | 15.62 |
| Ruhengeri | -0.61 | | -0.90 | 162.03 | -16.72 | 0.61 | | 0.60 | 180.33 | 9.97 |
| Rutsiro | -1.57 | | -3.95 | 241.36 | -49.07 | 0.61 | | 1.13 | 284.18 | 11.88 |
| Rwamagana | -2.28 | * | -3.46 | 173.35 | -59.94 | 0.07 | | 0.08 | 191.28 | 1.20 |
| Rwankeri | -1.57 | | -3.19 | 302.17 | -31.71 | 0.07 | | 0.14 | 333.42 | 1.27 |
| Save | -1.86 | + | -4.67 | 292.43 | -47.94 | 0.82 | | 1.57 | 316.60 | 14.91 |

Table 4-13: Projected trends of JF precipitation for the period 2041 to 2070 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| Timeframe | 2041-2070 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Scenario | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| Stations | Test Z | α level | Q | Annual | %Δ | Test Z | α level | Q | Annual | %Δ |
| Bukora | 0.71 | | 1.11 | 182.63 | 18.26 | -2.55 | * | -4.38 | 187.81 | -69.92 |
| Busogo | 0.32 | | 0.44 | 274.96 | 4.80 | -1.55 | | -3.99 | 308.33 | -38.82 |
| Butare | -0.07 | | -0.36 | 257.18 | -4.18 | -2.27 | * | -4.48 | 293.91 | -45.77 |
| Byimana | 0.21 | | 0.66 | 223.65 | 8.82 | -2.09 | * | -5.87 | 289.00 | -60.96 |
| Byumba | 1.46 | | 1.55 | 165.55 | 28.04 | -1.87 | + | -3.24 | 186.23 | -52.22 |
| Cyinzuzi | 1.57 | | 2.56 | 241.78 | 31.81 | -1.66 | + | -4.31 | 272.41 | -47.51 |
| Gabiro | 1.78 | + | 1.92 | 131.09 | 43.90 | -1.59 | | -2.56 | 145.34 | -52.77 |
| Gatumba | 0.39 | | 0.68 | 220.86 | 9.21 | -1.66 | + | -4.08 | 246.90 | -49.63 |
| Gikongoro | 0.25 | | 0.57 | 242.24 | 7.07 | -2.23 | * | -5.36 | 271.94 | -59.12 |
| Gisanga | 0.21 | | 0.66 | 223.65 | 8.82 | -2.09 | * | -5.87 | 289.00 | -60.96 |
| Gisenyi | 0.86 | | 1.60 | 177.51 | 27.11 | -0.91 | | -1.64 | 204.17 | -24.09 |
| Gitarama | 0.21 | | 0.66 | 223.65 | 8.82 | -2.09 | * | -5.87 | 289.00 | -60.96 |
| Gitega | 1.57 | | 2.56 | 241.78 | 31.81 | -1.66 | + | -4.31 | 272.41 | -47.51 |
| Kamembe | 0.04 | | 0.06 | 240.96 | 0.69 | -0.77 | | -1.59 | 270.42 | -17.59 |
| Kanombe | 1.57 | | 2.56 | 241.78 | 31.81 | -1.66 | + | -4.31 | 272.41 | -47.51 |
| Kansi | -0.11 | | -0.30 | 255.92 | -3.55 | -2.27 | * | -4.26 | 289.22 | -44.22 |
| Kawangire | 1.78 | + | 2.01 | 153.32 | 39.35 | -1.66 | + | -2.74 | 175.23 | -46.94 |
| Kibungo | 0.25 | | 0.73 | 212.43 | 10.28 | -2.59 | ** | -4.57 | 218.67 | -62.74 |
| Masaka | 1.78 | + | 2.30 | 180.10 | 38.38 | -1.59 | | -3.36 | 205.41 | -49.12 |
| Muganza | 0.29 | | 0.78 | 307.99 | 7.55 | -1.37 | | -3.63 | 342.64 | -31.76 |
| Mushubi | 0.21 | | 0.48 | 294.14 | 4.93 | -1.12 | | -3.66 | 328.30 | -33.47 |
| Ntaruka | 0.82 | | 0.76 | 107.32 | 21.37 | -0.87 | | -1.40 | 131.98 | -31.73 |
| Ntendezi | 0.04 | | 0.06 | 441.67 | 0.41 | -1.52 | | -4.40 | 488.86 | -27.00 |
| Nyagatare | 1.32 | | 1.36 | 100.80 | 40.58 | -1.20 | | -1.25 | 119.63 | -31.37 |
| Nyamata | 0.64 | | 1.69 | 208.47 | 24.35 | -2.16 | * | -4.97 | 236.87 | -62.96 |
| Rubengera | 0.36 | | 0.74 | 197.23 | 11.21 | -1.09 | | -3.13 | 248.37 | -37.75 |
| Ruganda | 0.25 | | 0.45 | 191.34 | 7.09 | -1.70 | + | -3.67 | 215.37 | -51.12 |
| Rugobagoba | 0.21 | | 0.66 | 223.65 | 8.82 | -2.09 | * | -5.87 | 289.00 | -60.96 |
| Ruhengeri | 0.54 | | 0.66 | 147.76 | 13.46 | -0.80 | | -1.58 | 178.65 | -26.54 |
| Rutsiro | 1.00 | | 2.73 | 228.18 | 35.94 | -0.73 | | -1.89 | 259.60 | -21.81 |
| Rwamagana | 1.78 | + | 2.01 | 153.32 | 39.35 | -1.66 | + | -2.74 | 175.23 | -46.94 |
| Rwankeri | 0.32 | | 0.44 | 274.96 | 4.80 | -1.55 | | -3.99 | 308.33 | -38.82 |
| Save | -0.07 | | -0.36 | 257.18 | -4.18 | -2.27 | * | -4.48 | 293.91 | -45.77 |

Table 4-14: Projected trends of JF precipitation for the period 2071 to 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| Timeframe | **2071-2100** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Scenario | **RCP 4.5 w/m$^2$** | | | | | **RCP 8.5 w/m$^2$** | | | | |
| Stations | Test Z | α level | Q | Annual | %Δ | Test Z | α level | Q | Annual | %Δ |
| Bukora | -2.53 | * | -4.12 | 172.27 | -71.82 | -0.04 | | -0.08 | 173.48 | -1.39 |
| Busogo | -2.43 | * | -5.89 | 298.99 | -59.07 | -0.29 | | -0.60 | 257.34 | -7.01 |
| Butare | -2.03 | * | -4.50 | 303.23 | -44.48 | 0.11 | | 0.15 | 270.66 | 1.65 |
| Byimana | -2.50 | * | -6.12 | 267.23 | -68.67 | -0.18 | | -0.47 | 266.11 | -5.34 |
| Byumba | -2.32 | * | -4.36 | 185.93 | -70.39 | 0.71 | | 0.53 | 150.86 | 10.57 |
| Cyinzuzi | -2.28 | * | -6.83 | 274.51 | -74.61 | 0.79 | | 1.11 | 221.13 | 15.02 |
| Gabiro | -2.39 | * | -4.05 | 154.53 | -78.66 | 1.03 | | 1.15 | 119.77 | 28.91 |
| Gatumba | -2.57 | * | -5.37 | 247.97 | -65.02 | 0.14 | | 0.30 | 211.29 | 4.22 |
| Gikongoro | -2.64 | ** | -5.16 | 278.84 | -55.54 | -0.36 | | -0.76 | 241.80 | -9.44 |
| Gisanga | -2.50 | * | -6.12 | 267.23 | -68.67 | -0.18 | | -0.47 | 266.11 | -5.34 |
| Gisenyi | -2.00 | * | -3.24 | 194.84 | -49.92 | -0.96 | | -1.66 | 146.62 | -33.88 |
| Gitarama | -2.50 | * | -6.12 | 267.23 | -68.67 | -0.18 | | -0.47 | 266.11 | -5.34 |
| Gitega | -2.28 | * | -6.83 | 274.51 | -74.61 | 0.79 | | 1.11 | 221.13 | 15.02 |
| Kamembe | -2.07 | * | -4.07 | 263.76 | -46.34 | -0.79 | | -1.55 | 211.18 | -22.06 |
| Kanombe | -2.28 | * | -6.83 | 274.51 | -74.61 | 0.79 | | 1.11 | 221.13 | 15.02 |
| Kansi | -1.96 | * | -4.37 | 300.10 | -43.64 | 0.14 | | 0.26 | 264.41 | 2.90 |
| Kawangire | -2.39 | * | -4.54 | 178.11 | -76.43 | 0.82 | | 1.22 | 142.93 | 25.70 |
| Kibungo | -2.43 | * | -4.38 | 200.75 | -65.43 | 0.14 | | 0.18 | 190.45 | 2.81 |
| Masaka | -2.36 | * | -5.26 | 210.76 | -74.81 | 0.79 | | 1.39 | 168.47 | 24.67 |
| Muganza | -1.93 | + | -6.28 | 358.58 | -52.52 | 0.68 | | 1.80 | 294.74 | 18.30 |
| Mushubi | -2.11 | * | -4.45 | 327.88 | -40.72 | -0.21 | | -0.57 | 268.59 | -6.42 |
| Ntaruka | -1.64 | | -2.51 | 122.00 | -61.76 | 0.79 | | 1.01 | 99.96 | 30.17 |
| Ntendezi | -1.96 | * | -4.92 | 479.48 | -30.76 | -0.79 | | -2.38 | 394.43 | -18.08 |
| Nyagatare | -2.00 | * | -3.12 | 113.01 | -82.76 | 1.00 | | 1.29 | 91.52 | 42.16 |
| Nyamata | -2.64 | ** | -5.97 | 244.35 | -73.34 | -0.07 | | -0.03 | 220.69 | -0.40 |
| Rubengera | -1.96 | * | -3.37 | 223.25 | -45.26 | -0.18 | | -0.28 | 202.37 | -4.12 |
| Ruganda | -2.53 | * | -4.97 | 218.44 | -68.24 | 0.36 | | 0.56 | 184.03 | 9.11 |
| Rugobagoba | -2.50 | * | -6.12 | 267.23 | -68.67 | -0.18 | | -0.47 | 266.11 | -5.34 |
| Ruhengeri | -1.64 | | -2.64 | 162.97 | -48.63 | 0.18 | | 0.41 | 138.37 | 8.88 |
| Rutsiro | -2.18 | * | -4.81 | 250.50 | -57.63 | -0.93 | | -1.91 | 178.35 | -32.09 |
| Rwamagana | -2.39 | * | -4.54 | 178.11 | -76.43 | 0.82 | | 1.22 | 142.93 | 25.70 |
| Rwankeri | -2.43 | * | -5.89 | 298.99 | -59.07 | -0.29 | | -0.60 | 257.34 | -7.01 |
| Save | -2.03 | * | -4.50 | 303.23 | -44.48 | 0.11 | | 0.15 | 270.66 | 1.65 |

#### 4.6.1.2 March-April-May (MAM) Season

Table 4-15 shows that projected MAM seasonal rainfall for the period 2021-2050 ranged from +2.1% or +0.28mm per year (not significant, $\alpha > 0.05$) in Kamembe to -16.76% or -2.38mm/year (not significant, $\alpha > 0.05$) in Gikongoro under RCP 4.5 w/m$^2$ and ranged from -51.16% or -2.33mm per year (significant, $\alpha \leq 0.05$) in Ruhengeri to -169.2% or -1.57mm per year (significant, $\alpha \leq 0.05$) in Nyamata under RCP 8.5 w/m$^2$. Notably, 2021-2050 under RCP 4.5 w/m$^2$ showed a decreasing trend over most parts compared to areas of Bugarama, which had a slightly increasing trend. There is an increasing trend under RCP 8.5 w/m$^2$ of between 0% (northern parts) and 2.0% (southern parts) of Rwanda.

Table 4-16 projected MAM seasonal rainfall for the period 2041-2070 ranged from -3.21% or -0.57mm per year (not significant, $\alpha > 0.05$) in Busogo to -46.82% or -4.65mm per year (not significant, $\alpha > 0.05$) in Bukora under RCP 4.5 w/m$^2$ and ranged from +10.51% or +1.29mm per year (not significant, $\alpha > 0.05$) in Kamembe and -8.97% or -1.48mm per year (not significant, $\alpha > 0.05$) in Gatumba under RCP 8.5 w/m$^2$. All areas of Rwanda will receive decreasing precipitation ranging between -0% (in areas of Congo-Nile divide such as parts of Nyabihu, Musanze and Gakenke) and -60% (highest in karongi, Kayonza and Kirehe) under RCP 4.5 w/m$^2$ during the period 2041-2070. The western and South-eastern parts have a decreasing trend over the whole Northern parts and the rest of the country. The increasing trend under RCP 8.5 w/m$^2$ was reported over southwestern and north-eastern parts, while the rest of the country is expected to experience a decreasing trend.

Table 4-17 shows that projected MAM seasonal rainfall for the period 2071-2100 ranged from +25.41% or -+3.64mm per year (not significant, $\alpha > 0.05$) in Gikongoro to +2.81% or +0.34mm per year (not significant, $\alpha > 0.05$) in Gugobagoba under RCP 4.5 w/m$^2$ and ranged from +5.6% or +0.78mm per year (not significant, $\alpha > 0.05$) in Byumba and -8.97% or -1.48mm per year (not significant, $\alpha > 0.05$) in RGatumba under RCP 8.5 w/m$^2$. Projected MAM precipitation for the period 2071-2100 shows an increasing trend under RCP 4.5 w/m$^2$ over Eastern, Southern and parts of central, Northern and South-eastern and western parts. An increasing trend under RCP 8.5 w/m$^2$ over Southwestern parts, especially in Nyaruguru district, and a decreasing trend over South, Amayaga, South-eastern, North-eastern and National Volcanic area, while the remaining parts registered a decreasing trend.

Overall, MAM precipitation remains highly variable under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ during 2021-2050, 2041-2070 and 2071-2100 over Rwanda. Ntikubitubugingo's (2018) study projected a climatological decrease in MAM rainfall between 2021 and 2050 under RCP 4.5 w/m$^2$. Further, Sebaziga (2018) indicated a projected increase in rainfall in all the regions except Nyamagabe and Rubavu under RCP 8.5 w/m$^2$ and RCP 4.5 w/m$^2$ during the MAM rain season for the period of 2020 to 2049. Other studies have also projected a decline in MAM in all scenarios and periods over the East African region (Adhikari et al., 2015; Ngoma et al., 2021; Ayugi et al., 2021).

Table 4-15: Projected trends of MAM precipitation for the period 2021-2050 under ) RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| Stations | 2021-2050 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | Annual | %Δ | Test Z | α level | Q | Annual | %Δ |
| Bukora | -0.18 | | -0.65 | 352.34 | -5.49 | 1.11 | | 1.69 | 303.31 | 16.75 |
| Busogo | -0.29 | | -1.00 | 618.16 | -4.86 | 0.71 | | 2.28 | 569.66 | 12.02 |
| Butare | -0.54 | | -0.84 | 392.59 | -6.44 | 1.11 | | 1.92 | 362.07 | 15.94 |
| Byimana | -0.82 | | -2.20 | 405.19 | -16.30 | 1.14 | | 2.16 | 409.53 | 15.79 |
| Byumba | -0.25 | | -1.14 | 397.32 | -8.58 | 0.54 | | 0.92 | 356.30 | 7.72 |
| Cyinzuzi | -0.36 | | -1.25 | 591.01 | -6.33 | 0.46 | | 1.51 | 526.11 | 8.60 |
| Gabiro | -0.25 | | -0.71 | 345.85 | -6.14 | 0.82 | | 1.22 | 291.15 | 12.62 |
| Gatumba | -0.43 | | -1.38 | 539.56 | -7.66 | 0.82 | | 1.86 | 487.16 | 11.44 |
| Gikongoro | -0.75 | | -2.38 | 425.52 | -16.76 | 1.00 | | 1.44 | 383.21 | 11.26 |
| Gisanga | -0.82 | | -2.20 | 405.19 | -16.30 | 1.14 | | 2.16 | 409.53 | 15.79 |
| Gisenyi | -0.25 | | -1.28 | 407.46 | -9.42 | 0.21 | | 0.29 | 376.38 | 2.31 |
| Gitarama | -0.82 | | -2.20 | 405.19 | -16.30 | 1.14 | | 2.16 | 409.53 | 15.79 |
| Gitega | -0.36 | | -1.25 | 591.01 | -6.33 | 0.46 | | 1.51 | 526.11 | 8.60 |
| Kamembe | 0.14 | | 0.28 | 399.16 | 2.10 | 0.71 | | 1.19 | 368.06 | 9.71 |
| Kanombe | -0.36 | | -1.25 | 591.01 | -6.33 | 0.46 | | 1.51 | 526.11 | 8.60 |
| Kansi | -0.68 | | -0.90 | 388.77 | -6.92 | 1.18 | | 1.74 | 355.39 | 14.70 |
| Kawangire | -0.36 | | -1.07 | 394.05 | -8.14 | 0.61 | | 1.25 | 344.85 | 10.88 |
| Kibungo | 0.00 | | 0.04 | 383.63 | 0.33 | 0.93 | | 1.67 | 338.27 | 14.80 |
| Masaka | -0.36 | | -1.28 | 461.82 | -8.33 | 0.54 | | 1.57 | 403.67 | 11.68 |
| Muganza | -0.11 | | -0.12 | 416.49 | -0.89 | 1.57 | | 2.79 | 397.97 | 21.01 |
| Mushubi | -0.39 | | -0.45 | 468.00 | -2.87 | 0.89 | | 1.58 | 440.48 | 10.73 |
| Ntaruka | -0.04 | | -0.08 | 455.22 | -0.54 | 0.82 | | 1.50 | 424.34 | 10.64 |
| Ntendezi | -0.29 | | -0.93 | 681.38 | -4.11 | 0.86 | | 1.66 | 654.03 | 7.63 |
| Nyagatare | 0.00 | | -0.04 | 404.10 | -0.32 | 0.46 | | 0.78 | 374.15 | 6.24 |
| Nyamata | -0.50 | | -1.49 | 413.26 | -10.85 | 1.07 | | 2.16 | 357.26 | 18.14 |
| Rubengera | -0.29 | | -0.49 | 319.91 | -4.62 | 1.03 | | 1.12 | 333.69 | 10.03 |
| Ruganda | -0.43 | | -1.38 | 479.60 | -8.63 | 0.89 | | 1.64 | 432.58 | 11.36 |
| Rugobagoba | -0.82 | | -2.20 | 405.19 | -16.30 | 1.14 | | 2.16 | 409.53 | 15.79 |
| Ruhengeri | -0.04 | | -0.21 | 533.35 | -1.19 | 0.64 | | 1.07 | 504.03 | 6.34 |
| Rutsiro | 0.00 | | -0.10 | 547.50 | -0.54 | 0.29 | | 0.48 | 500.36 | 2.89 |
| Rwamagana | -0.36 | | -1.07 | 394.05 | -8.14 | 0.61 | | 1.25 | 344.85 | 10.88 |
| Rwankeri | -0.29 | | -1.00 | 618.16 | -4.86 | 0.71 | | 2.28 | 569.66 | 12.02 |
| Save | -0.54 | | -0.84 | 392.59 | -6.44 | 1.11 | | 1.92 | 362.07 | 15.94 |

Table 4-16: Projected trends of MAM precipitation for the period 2041-2070 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| Stations | 2041-2070 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | Annual | %Δ | Test Z | α level | Q | Annual | %Δ |
| Bukora | -1.78 | + | -4.65 | 297.77 | -46.82 | -0.32 | | -0.60 | 303.02 | -5.92 |
| Busogo | -0.11 | | -0.57 | 535.62 | -3.21 | -0.18 | | -0.81 | 568.82 | -4.28 |
| Butare | -0.89 | | -2.28 | 357.07 | -19.19 | -0.25 | | -0.36 | 360.59 | -3.00 |
| Byimana | -0.54 | | -0.92 | 346.13 | -7.94 | 0.04 | | 0.14 | 408.42 | 1.01 |
| Byumba | -0.36 | | -1.18 | 334.61 | -10.62 | 0.14 | | 0.39 | 359.75 | 3.28 |
| Cyinzuzi | -0.39 | | -1.96 | 495.85 | -11.83 | 0.25 | | 1.07 | 535.38 | 5.97 |
| Gabiro | -0.43 | | -1.19 | 283.35 | -12.63 | 0.36 | | 0.84 | 311.58 | 8.10 |
| Gatumba | -0.32 | | -1.07 | 466.43 | -6.89 | -0.32 | | -1.48 | 494.11 | -8.97 |
| Gikongoro | -0.46 | | -1.27 | 365.16 | -10.46 | -0.25 | | -0.42 | 380.18 | -3.35 |
| Gisanga | -0.54 | | -0.92 | 346.13 | -7.94 | 0.04 | | 0.14 | 408.42 | 1.01 |
| Gisenyi | -1.36 | | -2.78 | 333.02 | -25.05 | -1.18 | | -0.95 | 363.41 | -7.87 |
| Gitarama | -0.54 | | -0.92 | 346.13 | -7.94 | 0.04 | | 0.14 | 408.42 | 1.01 |
| Gitega | -0.39 | | -1.96 | 495.85 | -11.83 | 0.25 | | 1.07 | 535.38 | 5.97 |
| Kamembe | -2.07 | * | -2.78 | 348.24 | -23.91 | 1.00 | | 1.29 | 368.71 | 10.51 |
| Kanombe | -0.39 | | -1.96 | 495.85 | -11.83 | 0.25 | | 1.07 | 535.38 | 5.97 |
| Kansi | -0.96 | | -2.17 | 353.94 | -18.43 | -0.14 | | -0.24 | 354.23 | -2.06 |
| Kawangire | -0.50 | | -1.71 | 325.38 | -15.79 | 0.50 | | 0.94 | 359.33 | 7.86 |
| Kibungo | -1.71 | + | -4.16 | 324.81 | -38.38 | -0.39 | | -0.65 | 331.75 | -5.89 |
| Masaka | -0.57 | | -1.91 | 383.13 | -14.97 | 0.43 | | 1.37 | 422.77 | 9.70 |
| Muganza | -1.36 | | -3.04 | 369.89 | -24.63 | 0.25 | | 0.60 | 406.80 | 4.46 |
| Mushubi | -1.82 | + | -3.67 | 390.81 | -28.19 | -0.29 | | -0.35 | 426.54 | -2.47 |
| Ntaruka | -0.50 | | -1.40 | 399.02 | -10.53 | -0.14 | | -0.20 | 428.99 | -1.40 |
| Ntendezi | -1.64 | | -3.92 | 583.38 | -20.18 | -0.32 | | -0.93 | 628.49 | -4.42 |
| Nyagatare | -0.36 | | -1.02 | 364.23 | -8.38 | 0.54 | | 0.97 | 396.94 | 7.34 |
| Nyamata | -0.68 | | -2.02 | 350.16 | -17.33 | -0.25 | | -0.59 | 351.27 | -5.01 |
| Rubengera | -1.68 | + | -2.80 | 261.52 | -32.11 | -0.43 | | -0.57 | 324.31 | -5.31 |
| Ruganda | -0.29 | | -0.89 | 413.81 | -6.44 | -0.32 | | -1.08 | 440.68 | -7.33 |
| Rugobagoba | -0.54 | | -0.92 | 346.13 | -7.94 | 0.04 | | 0.14 | 408.42 | 1.01 |
| Ruhengeri | -0.25 | | -0.61 | 472.94 | -3.84 | -0.21 | | -0.77 | 500.77 | -4.63 |
| Rutsiro | -1.53 | | -3.86 | 442.92 | -26.15 | -0.89 | | -1.15 | 480.56 | -7.19 |
| Rwamagana | -0.50 | | -1.71 | 325.38 | -15.79 | 0.50 | | 0.94 | 359.33 | 7.86 |
| Rwankeri | -0.11 | | -0.57 | 535.62 | -3.21 | -0.18 | | -0.81 | 568.82 | -4.28 |
| Save | -0.89 | | -2.28 | 357.07 | -19.19 | -0.25 | | -0.36 | 360.59 | -3.00 |

Table 4-17: Projected trends of MAM precipitation for the period 2071-2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| Stations | 2071-2100 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **RCP 4.5 w/m$^2$** | | | | | **RCP 8.5 w/m$^2$** | | | | |
| | Test Z | α level | Q | Annual | %Δ | Test Z | α level | Q | Annual | %Δ |
| Bukora | 0.75 | | 1.91 | 350.16 | 16.40 | -0.14 | | -0.60 | 342.83 | -5.29 |
| Busogo | 0.89 | | 1.88 | 394.17 | 14.27 | -0.21 | | -1.28 | 398.49 | -9.61 |
| Butare | 0.82 | | 2.12 | 344.41 | 18.43 | -0.21 | | -0.72 | 367.80 | -5.89 |
| Byimana | 0.89 | | 1.95 | 353.94 | 16.54 | -0.07 | | -0.27 | 342.03 | -2.39 |
| Byumba | 0.89 | | 2.62 | 434.52 | 18.10 | 0.18 | | 0.78 | 416.67 | 5.60 |
| Cyinzuzi | 0.89 | | 2.62 | 434.52 | 18.10 | 0.18 | | 0.78 | 416.67 | 5.60 |
| Gabiro | 0.89 | | 1.90 | 361.45 | 15.79 | -0.04 | | -0.05 | 348.26 | -0.39 |
| Gatumba | 1.25 | | 1.98 | 320.90 | 18.50 | 0.11 | | 0.17 | 307.05 | 1.68 |
| Gikongoro | 1.82 | + | 3.64 | 429.18 | 25.41 | -0.57 | | -1.36 | 407.28 | -10.01 |
| Gisanga | 1.61 | | 3.25 | 390.81 | 24.93 | -0.57 | | -1.25 | 372.87 | -10.06 |
| Gisenyi | 1.61 | | 3.25 | 390.81 | 24.93 | -0.57 | | -1.25 | 372.87 | -10.06 |
| Gitarama | 0.89 | | 1.88 | 394.17 | 14.27 | -0.21 | | -1.28 | 398.49 | -9.61 |
| Gitega | 0.79 | | 1.88 | 346.13 | 16.31 | -0.21 | | -0.62 | 400.57 | -4.64 |
| Kamembe | 0.79 | | 1.88 | 346.13 | 16.31 | -0.21 | | -0.62 | 400.57 | -4.64 |
| Kanombe | 0.75 | | 2.16 | 366.91 | 17.68 | -0.18 | | -0.62 | 406.21 | -4.58 |
| Kansi | 0.89 | | 2.15 | 399.47 | 16.14 | -0.18 | | -1.15 | 401.43 | -8.63 |
| Kawangire | 0.86 | | 1.80 | 329.02 | 16.45 | -0.18 | | -0.68 | 317.63 | -6.44 |
| Kibungo | 1.61 | | 2.10 | 261.52 | 24.08 | -0.54 | | -1.44 | 281.71 | -15.38 |
| Masaka | 1.32 | | 2.41 | 319.58 | 22.62 | -0.71 | | -1.98 | 324.00 | -18.34 |
| Muganza | 1.86 | + | 2.35 | 356.99 | 19.78 | -0.21 | | -0.44 | 338.14 | -3.92 |
| Mushubi | 0.57 | | 2.17 | 545.50 | 11.92 | -0.89 | | -2.40 | 560.69 | -12.85 |
| Ntaruka | 0.57 | | 2.17 | 545.50 | 11.92 | -0.89 | | -2.40 | 560.69 | -12.85 |
| Ntendezi | 0.32 | | 1.19 | 413.81 | 8.61 | -0.68 | | -1.89 | 432.58 | -13.07 |
| Nyagatare | 1.39 | | 2.56 | 472.94 | 16.24 | -1.32 | | -3.31 | 466.87 | -21.29 |
| Nyamata | 1.18 | | 2.31 | 399.02 | 17.40 | -1.39 | | -3.52 | 398.76 | -26.46 |
| Rubengera | 0.21 | | 1.04 | 464.61 | 6.70 | -1.14 | | -3.46 | 468.34 | -22.16 |
| Ruganda | 0.57 | | 1.75 | 325.38 | 16.14 | -0.75 | | -1.24 | 346.11 | -10.72 |
| Rugobagoba | 0.18 | | 0.34 | 364.23 | 2.81 | -1.21 | | -2.63 | 369.99 | -21.32 |
| Ruhengeri | 0.21 | | 0.60 | 376.90 | 4.77 | -1.28 | | -2.85 | 380.65 | -22.45 |
| Rutsiro | 0.57 | | 1.75 | 325.38 | 16.14 | -0.75 | | -1.24 | 346.11 | -10.72 |
| Rwamagana | 0.57 | | 1.35 | 217.63 | 18.61 | -0.61 | | -1.70 | 265.49 | -19.21 |
| Rwankeri | 0.29 | | 0.49 | 256.49 | 5.76 | -0.46 | | -0.44 | 238.56 | -5.53 |
| Save | 0.96 | | 2.11 | 341.37 | 18.51 | -0.46 | | -1.04 | 333.89 | -9.35 |

#### 4.6.1.3 June-July-August (JJA) Season

Table 4-18 shows that projected JJA seasonal rainfall for the period 2021-2050 ranged from +19.24% or +0.65mm per year (not significant, $\alpha > 0.05$) in Rutsiro to -31.7% or -0.59 mm per year (not significant, $\alpha > 0.05$) in Nyagatare under RCP 4.5 w/m$^2$ and ranged from -51.16% or -2.33mm per year (significant, $\alpha \leq 0.05$) in Ruhengeri to -169.2% or -1.57mm per year (significant, $\alpha \leq 0.05$) in Nyamata under RCP 8.5 w/m$^2$. In general, projected JJA precipitation for the period 2021-2050 under RCP 4.5 w/m$^2$ showed a decreasing trend over southwestern areas of Rusizi, Nyamasheke, western Nyamagabe and areas surrounding Nyungwe National Park, Northern areas of Volcano National Park and an increasing trend over north-western highland, Eastern Nyaruguru and parts of Kirehe region. In contrast, under RCP 8.5 w/m$^2$, a decreasing trend was observed progressing from north-west (Congo-Nile divide and north) southwards

Table 4-19 shows that projected JJA seasonal rainfall for the period 2041-2070 ranged from +39.95% or 1.7mm per year (not significant, $\alpha > 0.05$) in Ntendezi to -22.19% or -0.18mm per year (not significant, $\alpha > 0.05$) in Kibungo under RCP 4.5 w/m$^2$ and ranged from +34.29% or +0.13mm per year (not significant, $\alpha > 0.05$) in Butare to -28.03% or -0.23mm per year (not significant, $\alpha > 0.05$) in Rubengera under RCP 8.5 w/m$^2$. Generally, projected JJA precipitation for the period 2041-2070 under RCP 4.5 w/m$^2$ showed a decreasing trend over eastern toward the central parts and increasing over Central toward the South, and North-western, North-eastern, and westward toward the Southwestern parts. A decreasing trend under RCP 8.5 w/m$^2$ over central parts, south-eastern in the areas of Bugesera and Ngoma Districts and northwards) and increasing over eastern and southwards towards Nyaruguru and Rusizi Districts.

Table 4-20 shows that projected JJA seasonal rainfall for the period 2071-2100 ranged from +106.95% or +0.75mm per year (not significant, $\alpha > 0.05$) in Muganza to -14.17% or -0.26mm per year (not significant, $\alpha > 0.05$) in Kamembe under RCP 4.5 w/m$^2$ and ranged from -51.42% or -0.61mm per year (not significant, $\alpha > 0.05$) in Gabiro to -117.82% or -0.61mm per year (significant, $\alpha \leq 0.05$) in Kibungo under RCP 8.5 w/m$^2$. Generally, projected JJA precipitation for the period 2071-2100 showed an increasing trend under RCP 4.5 w/m$^2$ over Rwanda except over Nyamasheke with a decreasing trend and a decreasing trend under RCP 8.5 w/m$^2$ over East toward central and in the remaining parts of the country

Overall, the projected JJA precipitation indicates that under RCP 4.5 w/m$^2$, changes in rainfall will increase and become positive towards 2100. In contrast, under RCP 8.5 w/m$^2$, positive changes in precipitation are expected in some parts of Rwanda from 2041 to 2070. The study findings agree with Umugwaneza et al. (2021), who found JJA precipitation decreases between 2020 and 2050 and increases between 2050 and 2100.

Table 4-18: Projected trends of JJA precipitation for the period 2021 to 2050 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| **Timeframe** | **2021-2050** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **RCP 4.5 w/m$^2$** | | | | | **RCP 8.5 w/m$^2$** | | | | |
| Stations | Test Z | α level | Q | Annual | %Δ | Test Z | α level | Q | Annual | %Δ |
| Bukora | 0.47 | | 0.08 | 15.12 | 15.61 | -2.79 | ** | -0.94 | 18.37 | -153.72 |
| Busogo | 0.11 | | 0.19 | 80.82 | 7.18 | -2.68 | ** | -2.70 | 91.51 | -88.60 |
| Butare | 0.00 | | 0.00 | 20.29 | 0.00 | -3.15 | ** | -0.85 | 19.69 | -130.18 |
| Byimana | 0.12 | | 0.00 | 30.42 | 0.39 | -3.00 | ** | -1.62 | 34.48 | -141.05 |
| Byumba | -0.21 | | -0.10 | 37.37 | -8.00 | -2.64 | ** | -1.67 | 39.01 | -128.78 |
| Cyinzuzi | -0.18 | | -0.14 | 52.39 | -8.21 | -2.75 | ** | -2.37 | 54.38 | -130.90 |
| Gabiro | -0.09 | | -0.03 | 25.68 | -3.61 | -2.84 | ** | -1.36 | 26.70 | -152.70 |
| Gatumba | 0.11 | | 0.05 | 55.09 | 2.53 | -2.68 | ** | -1.87 | 60.05 | -93.51 |
| Gikongoro | 0.00 | | 0.00 | 34.64 | 0.00 | -2.93 | ** | -1.55 | 35.76 | -129.91 |
| Gisanga | 0.12 | | 0.00 | 30.42 | 0.39 | -3.00 | ** | -1.62 | 34.48 | -141.05 |
| Gisenyi | 0.46 | | 0.26 | 86.16 | 8.89 | -2.43 | * | -2.10 | 101.83 | -61.87 |
| Gitarama | 0.12 | | 0.00 | 30.42 | 0.39 | -3.00 | ** | -1.62 | 34.48 | -141.05 |
| Gitega | -0.18 | | -0.14 | 52.39 | -8.21 | -2.75 | ** | -2.37 | 54.38 | -130.90 |
| Kamembe | -0.07 | | -0.08 | 55.22 | -4.24 | -3.18 | ** | -2.24 | 62.33 | -107.60 |
| Kanombe | -0.18 | | -0.14 | 52.39 | -8.21 | -2.75 | ** | -2.37 | 54.38 | -130.90 |
| Kansi | -0.07 | | 0.00 | 20.41 | 0.00 | -3.07 | ** | -0.85 | 19.42 | -131.36 |
| Kawangire | -0.32 | | -0.09 | 30.78 | -8.81 | -2.80 | ** | -1.59 | 32.56 | -146.88 |
| Kibungo | 0.07 | | 0.03 | 21.41 | 4.15 | -2.63 | ** | -1.34 | 23.87 | -168.33 |
| Masaka | -0.14 | | -0.12 | 37.85 | -9.60 | -2.78 | ** | -1.88 | 39.88 | -141.45 |
| Muganza | -0.43 | | 0.00 | 23.89 | 0.00 | -2.27 | * | -0.70 | 22.94 | -91.89 |
| Mushubi | -0.36 | | -0.17 | 56.11 | -9.17 | -2.78 | ** | -2.32 | 64.75 | -107.67 |
| Ntaruka | -0.43 | | -0.29 | 88.00 | -9.98 | -2.28 | * | -2.13 | 93.47 | -68.25 |
| Ntendezi | -0.54 | | -0.59 | 105.76 | -16.62 | -2.68 | ** | -3.76 | 123.84 | -91.08 |
| Nyagatare | -0.64 | | -0.59 | 56.00 | -31.70 | -2.78 | ** | -1.64 | 56.29 | -87.67 |
| Nyamata | -0.18 | | -0.10 | 27.38 | -11.10 | -3.03 | ** | -1.57 | 27.89 | -169.20 |
| Rubengera | -0.14 | | -0.03 | 34.28 | -2.82 | -2.93 | ** | -1.78 | 42.74 | -124.82 |
| Ruganda | 0.23 | | 0.20 | 43.88 | 13.62 | -2.75 | ** | -1.69 | 47.93 | -106.00 |
| Rugobagoba | 0.12 | | 0.00 | 30.42 | 0.39 | -3.00 | ** | -1.62 | 34.48 | -141.05 |
| Ruhengeri | -0.46 | | -0.44 | 125.85 | -10.51 | -2.28 | * | -2.33 | 136.35 | -51.16 |
| Rutsiro | 0.43 | | 0.65 | 100.85 | 19.24 | -2.36 | * | -2.74 | 116.05 | -70.80 |
| Rwamagana | -0.32 | | -0.09 | 30.78 | -8.81 | -2.80 | ** | -1.59 | 32.56 | -146.88 |
| Rwankeri | 0.11 | | 0.19 | 80.82 | 7.18 | -2.68 | ** | -2.70 | 91.51 | -88.60 |
| Save | 0.00 | | 0.00 | 20.29 | 0.00 | -3.15 | ** | -0.85 | 19.69 | -130.18 |

Table 4-19: Projected trends of JJA precipitation for the period 2041 to 2070 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| **Timeframe** | **2041-2070** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **RCP 4.5 w/m$^2$** | | | | | **RCP 8.5 w/m$^2$** | | | | |
| Stations | Test Z | α level | Q | Annual | %Δ | Test Z | α level | Q | Annual | %Δ |
| Bukora | -0.48 | | -0.12 | 18.54 | -19.86 | 0.20 | | 0.00 | 10.18 | 0.00 |
| Busogo | 0.00 | | 0.00 | 95.81 | 0.07 | -0.29 | | -0.26 | 67.69 | -11.73 |
| Butare | 0.71 | | 0.19 | 26.64 | 21.13 | 0.68 | | 0.13 | 11.66 | 34.29 |
| Byimana | 0.43 | | 0.32 | 40.65 | 23.48 | -0.14 | | -0.03 | 20.69 | -4.66 |
| Byumba | -0.18 | | -0.15 | 41.72 | -10.55 | 0.21 | | 0.08 | 24.41 | 9.59 |
| Cyinzuzi | -0.21 | | -0.23 | 59.07 | -11.82 | 0.21 | | 0.11 | 32.65 | 10.42 |
| Gabiro | -0.16 | | -0.11 | 29.82 | -11.03 | 0.43 | | 0.07 | 14.17 | 15.74 |
| Gatumba | 0.11 | | 0.09 | 67.93 | 3.95 | -0.50 | | -0.22 | 39.75 | -16.23 |
| Gikongoro | 0.54 | | 0.41 | 44.19 | 27.72 | -0.14 | | -0.08 | 22.33 | -10.92 |
| Gisanga | 0.43 | | 0.32 | 40.65 | 23.48 | -0.14 | | -0.03 | 20.69 | -4.66 |
| Gisenyi | 0.07 | | 0.08 | 101.72 | 2.28 | 0.11 | | 0.16 | 76.58 | 6.18 |
| Gitarama | 0.43 | | 0.32 | 40.65 | 23.48 | -0.14 | | -0.03 | 20.69 | -4.66 |
| Gitega | -0.21 | | -0.23 | 59.07 | -11.82 | 0.21 | | 0.11 | 32.65 | 10.42 |
| Kamembe | 0.57 | | 0.60 | 65.01 | 27.87 | 0.21 | | 0.17 | 41.12 | 12.56 |
| Kanombe | -0.21 | | -0.23 | 59.07 | -11.82 | 0.21 | | 0.11 | 32.65 | 10.42 |
| Kansi | 0.79 | | 0.22 | 26.64 | 24.91 | 0.64 | | 0.13 | 11.60 | 33.71 |
| Kawangire | -0.14 | | -0.09 | 35.51 | -7.66 | 0.41 | | 0.10 | 17.70 | 16.16 |
| Kibungo | -0.68 | | -0.18 | 24.32 | -22.19 | -0.05 | | -0.01 | 13.41 | -1.23 |
| Masaka | -0.21 | | -0.13 | 43.25 | -8.70 | 0.25 | | 0.11 | 22.92 | 14.93 |
| Muganza | 0.83 | | 0.26 | 34.09 | 23.22 | -0.20 | | 0.00 | 13.85 | 0.00 |
| Mushubi | 0.96 | | 0.94 | 71.18 | 39.77 | -0.29 | | -0.23 | 41.55 | -16.26 |
| Ntaruka | 0.61 | | 1.14 | 98.98 | 34.63 | -0.11 | | -0.08 | 66.11 | -3.78 |
| Ntendezi | 1.18 | | 1.70 | 127.58 | 39.95 | 0.04 | | 0.02 | 90.83 | 0.76 |
| Nyagatare | 0.18 | | 0.07 | 59.74 | 3.42 | 0.11 | | 0.06 | 36.49 | 4.65 |
| Nyamata | 0.04 | | 0.05 | 32.61 | 4.47 | -0.64 | | -0.14 | 16.62 | -24.54 |
| Rubengera | 0.68 | | 0.55 | 45.12 | 36.54 | -0.50 | | -0.23 | 24.44 | -28.03 |
| Ruganda | 0.04 | | 0.02 | 55.85 | 1.21 | -0.18 | | -0.09 | 30.20 | -8.89 |
| Rugobagoba | 0.43 | | 0.32 | 40.65 | 23.48 | -0.14 | | -0.03 | 20.69 | -4.66 |
| Ruhengeri | 0.64 | | 1.13 | 137.59 | 24.67 | -0.21 | | -0.18 | 107.28 | -5.15 |
| Rutsiro | 0.29 | | 0.30 | 123.06 | 7.42 | 0.14 | | 0.20 | 79.54 | 7.66 |
| Rwamagana | -0.14 | | -0.09 | 35.51 | -7.66 | 0.41 | | 0.10 | 17.70 | 16.16 |
| Rwankeri | 0.00 | | 0.00 | 95.81 | 0.07 | -0.29 | | -0.26 | 67.69 | -11.73 |
| Save | 0.71 | | 0.19 | 26.64 | 21.13 | 0.68 | | 0.13 | 11.66 | 34.29 |

Table 4-20: Projected trends for JJA precipitation for the period 2071 to 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| **Timeframe** | **2071-2100** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **RCP 4.5 w/m$^2$** | | | | | **RCP 8.5 w/m$^2$** | | | | |
| Stations | Test Z | α level | Q | Annual | %Δ | Test Z | α level | Q | Annual | %Δ |
| Bukora | 0.84 | | 0.15 | 14.43 | 30.99 | -2.46 | * | -0.40 | 12.02 | -98.82 |
| Busogo | 0.75 | | 0.84 | 86.13 | 29.29 | -2.18 | * | -1.53 | 56.25 | -81.51 |
| Butare | 1.43 | | 0.43 | 20.71 | 62.93 | -2.17 | * | -0.41 | 15.96 | -77.14 |
| Byimana | 0.71 | | 0.29 | 26.90 | 32.88 | -2.23 | * | -0.65 | 23.18 | -83.99 |
| Byumba | 0.75 | | 0.20 | 35.70 | 17.19 | -2.21 | * | -0.75 | 24.95 | -89.71 |
| Cyinzuzi | 0.82 | | 0.38 | 49.75 | 23.19 | -1.96 | * | -0.96 | 34.91 | -82.92 |
| Gabiro | 0.27 | | 0.12 | 24.52 | 14.78 | -1.52 | | -0.29 | 17.09 | -51.42 |
| Gatumba | 0.68 | | 0.71 | 58.75 | 36.32 | -2.00 | * | -0.81 | 36.04 | -67.22 |
| Gikongoro | 0.75 | | 0.41 | 31.83 | 38.83 | -2.25 | * | -0.67 | 23.01 | -87.08 |
| Gisanga | 0.71 | | 0.29 | 26.90 | 32.88 | -2.23 | * | -0.65 | 23.18 | -83.99 |
| Gisenyi | 0.57 | | 0.58 | 101.63 | 17.03 | -2.50 | * | -1.82 | 61.64 | -88.76 |
| Gitarama | 0.71 | | 0.29 | 26.90 | 32.88 | -2.23 | * | -0.65 | 23.18 | -83.99 |
| Gitega | 0.82 | | 0.38 | 49.75 | 23.19 | -1.96 | * | -0.96 | 34.91 | -82.92 |
| Kamembe | -0.18 | | -0.26 | 54.75 | -14.17 | -2.00 | * | -1.00 | 36.57 | -81.80 |
| Kanombe | 0.82 | | 0.38 | 49.75 | 23.19 | -1.96 | * | -0.96 | 34.91 | -82.92 |
| Kansi | 1.43 | | 0.42 | 20.65 | 60.77 | -2.14 | * | -0.40 | 15.78 | -76.64 |
| Kawangire | 0.54 | | 0.26 | 29.44 | 26.26 | -1.55 | | -0.39 | 20.68 | -56.97 |
| Kibungo | 0.61 | | 0.20 | 20.01 | 29.64 | -2.70 | ** | -0.61 | 15.59 | -117.82 |
| Masaka | 0.54 | | 0.27 | 36.20 | 22.26 | -2.00 | * | -0.62 | 25.60 | -72.20 |
| Muganza | 1.79 | + | 0.75 | 21.03 | 106.95 | -2.51 | * | -0.53 | 16.75 | -94.65 |
| Mushubi | 0.00 | | 0.09 | 54.69 | 4.86 | -2.50 | * | -1.14 | 34.19 | -100.12 |
| Ntaruka | 1.11 | | 1.38 | 96.91 | 42.74 | -2.32 | * | -1.82 | 64.75 | -84.32 |
| Ntendezi | -0.25 | | -0.25 | 106.64 | -7.06 | -2.60 | ** | -1.95 | 67.86 | -86.26 |
| Nyagatare | 1.32 | | 0.77 | 57.01 | 40.51 | -2.25 | * | -1.01 | 39.19 | -77.67 |
| Nyamata | 1.00 | | 0.40 | 24.97 | 47.57 | -2.37 | * | -0.50 | 20.45 | -73.87 |
| Rubengera | 0.25 | | 0.10 | 31.50 | 9.64 | -2.36 | * | -0.76 | 22.62 | -100.27 |
| Ruganda | 0.79 | | 0.55 | 47.45 | 35.00 | -1.82 | + | -0.59 | 28.42 | -61.85 |
| Rugobagoba | 0.71 | | 0.29 | 26.90 | 32.88 | -2.23 | * | -0.65 | 23.18 | -83.99 |
| Ruhengeri | 0.61 | | 0.91 | 137.00 | 20.00 | -2.53 | * | -2.81 | 95.31 | -88.37 |
| Rutsiro | 0.71 | | 1.13 | 116.56 | 29.20 | -2.07 | * | -2.19 | 64.74 | -101.45 |
| Rwamagana | 0.54 | | 0.26 | 29.44 | 26.26 | -1.55 | | -0.39 | 20.68 | -56.97 |
| Rwankeri | 0.75 | | 0.84 | 86.13 | 29.29 | -2.18 | * | -1.53 | 56.25 | -81.51 |
| Save | 1.43 | | 0.43 | 20.71 | 62.93 | -2.17 | * | -0.41 | 15.96 | -77.14 |

#### 4.6.1.4 September October November (SOND) Season

Table 4-21 shows that projected SOND seasonal precipitation for the period 2021-2050 ranged from -2.1% or -3.9mm per year (not significant, $\alpha > 0.05$) in Gisenyi to -25.11% or -3.52 mm per year (not significant, $\alpha > 0.05$) in Kibungo under RCP 4.5 w/m$^2$ and ranged from -13.73% or -2.47mm per year (significant, $\alpha \leq 0.05$) in Butare to -35.98% or -9.01 mm per year (significant, $\alpha \leq 0.05$) in Rutsiro under RCP 8.5 w/m$^2$. Overall, projected SOND precipitation for the period 2021-2050 under RCP 4.5 w/m$^2$ indicates a decreasing trend over Rwanda, with the highest decrease over southeastern parts (Kirehe, Ngoma and Kayonza) and northern parts of the Congo-Nile basin near Burera and lowest decrease over parts of Amayaga areas, South (Ruhango, Muhanga, Kamonyi), central parts of Congo-Nile divide (Ngororero, Rutsiro, Nyabihu, Rubavu, Musanze) and extending towards Northeast (Nyagatare). On the contrary, the projected SOND precipitation for the period 2021-2050 under RCP 8.5 w/m$^2$ indicates an increasing trend over Rwanda with the lowest increase over southern and northern parts of the Congo-Nile divide, Bugarama plains, Western parts along Lake Kivu, with the rest of the country expected to experience increased precipitation.

Table 4-22 shows that projected SOND seasonal rainfall for the period 2041-2070 ranges from +6.95% or +0.96mm per year (not significant, $\alpha > 0.05$) in Byumba to -9.79% or -1.67mm per year (not significant, $\alpha > 0.05$) in Rubengera under RCP 4.5 w/m$^2$ and ranges from +0.93% or +0.12mm per year (not significant, $\alpha > 0.05$) in Bukora to -18.08% or -3.32mm per year (not significant, $\alpha > 0.05$) in Byimana under RCP 8.5 w/m$^2$. Worth noting, that SOND precipitation for the period 2041-2070 under RCP 4.5 w/m$^2$ is projected to increase (0% to 10%) over the south (Nyaruguru, Huye, Nyanza and Ruhango), parts of the north towards Northeastern (Gicumbi, Rulindo, Gatsibo, Nyagatare) and Rubavu areas while most of the areas around Kirehe, Nyamasheke, Nyamagabe, Karongi and Rutsiro) expected to experience a decreasing precipitation. However, a decrease in projected precipitation is shown under RCP 8.5 w/m$^2$ except for Kirehe, which is expected to experience increased rainfall. The highest decrease under RCP 8.5 w/m$^2$ is expected over the eastern parts of Rwanda.

Table 4-23 shows that projected SOND seasonal rainfall for the period 2071-2100 ranges from +1.09% or +0.18mm per year (not significant, $\alpha > 0.05$) in Rubengera to -36.92% or -4.73mm per year (not significant, $\alpha > 0.05$) in Gabiro under RCP 4.5 w/m$^2$ and ranges from +31.59% or +4.12mm per year (not significant, $\alpha > 0.05$) in Gabiro to +0.99% or +0.24mm per year (significant, $\alpha \leq 0.05$) in Kamembe under RCP 8.5 w/m$^2$. Notably, projected precipitation for 2071-2100 shows a decreasing trend under RCP 4.5 w/m$^2$ from the west (Karongi) towards the east (Kirehe). In contrast, the decrease under RCP 8.5 w/m$^2$ shows a northwest to southeast progression. Overall, the projected SOND precipitation is expected to remain wet between 2041 and 2070 under RCP 4.5 w/m$^2$. In addition, SOND precipitation is likely to remain dry from 2021 to 2050 and 2071 to 2100. In the case of projected SOND precipitation under RCP 8.5 w/m$^2$, wetter conditions are expected for the period 2021-2050, which will decrease towards 2100.

Past studies (Ongoma et al., 2018; Almazroui, et al., 2020; Umugwaneza et al.,2021) indicated that October, November, and December (OND) will experience an increased rainfall by 1.63–4.62% per decade under the SSP1-2.6 and SSP5-8.5 scenarios for the period 2020–2050 and 2051–2100 and thus affirming the current study that the projected SOND rainfall for the period 2041-2070 under RCP 4.5 w/m$^2$ and 2021-2050 under RCP 8.5 w/m$^2$ but disagree with the other results that project a decreasing trend. A study by Sebaziga (2018) also indicated a projected decrease in rainfall over the southern, central part, western and northern areas. Additionally, the eastern regions showed a projected rain under both RCP 8.5 w/m$^2$ and RCP 4.5 w/m$^2$ during the OND season from 2020 to 2049.

Table 4-21: Projected SOND precipitation trends for 2021 to 2050 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| Stations | 2021-2050 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **RCP 4.5 w/m$^2$** | | | | | **RCP 8.5 w/m$^2$** | | | | |
| | Test Z | α level | Q | Annual | %Δ | Test Z | α level | Q | Annual | %Δ |
| Bukora | -0.82 | | -2.30 | 381.58 | -18.10 | -0.86 | | -1.77 | 364.33 | -14.54 |
| Busogo | -0.14 | | -0.66 | 671.99 | -2.97 | -2.21 | * | -7.42 | 691.49 | -32.17 |
| Butare | -0.32 | | -1.35 | 514.58 | -7.85 | -0.96 | | -2.47 | 540.19 | -13.73 |
| Byimana | -0.18 | | -0.49 | 495.54 | -2.97 | -1.18 | | -3.61 | 581.98 | -18.60 |
| Byumba | -0.32 | | -1.11 | 388.63 | -8.58 | -1.21 | | -2.85 | 403.99 | -21.18 |
| Cyinzuzi | -0.36 | | -1.42 | 576.27 | -7.38 | -1.00 | | -4.01 | 593.86 | -20.28 |
| Gabiro | -0.29 | | -0.62 | 331.73 | -5.64 | -0.71 | | -1.58 | 326.80 | -14.49 |
| Gatumba | -0.14 | | -0.90 | 561.58 | -4.82 | -1.75 | + | -5.62 | 566.48 | -29.77 |
| Gikongoro | -0.29 | | -1.52 | 515.37 | -8.86 | -1.89 | + | -3.70 | 539.29 | -20.57 |
| Gisanga | -0.18 | | -0.49 | 495.54 | -2.97 | -1.18 | | -3.61 | 581.98 | -18.60 |
| Gisenyi | -0.11 | | -0.39 | 562.99 | -2.10 | -2.43 | * | -6.06 | 568.81 | -31.94 |
| Gitarama | -0.18 | | -0.49 | 495.54 | -2.97 | -1.18 | | -3.61 | 581.98 | -18.60 |
| Gitega | -0.36 | | -1.42 | 576.27 | -7.38 | -1.00 | | -4.01 | 593.86 | -20.28 |
| Kamembe | -1.18 | | -2.39 | 720.28 | -9.95 | -2.00 | * | -5.83 | 741.52 | -23.57 |
| Kanombe | -0.36 | | -1.42 | 576.27 | -7.38 | -1.00 | | -4.01 | 593.86 | -20.28 |
| Kansi | -0.54 | | -1.50 | 509.20 | -8.86 | -1.03 | | -2.49 | 530.39 | -14.08 |
| Kawangire | -0.39 | | -0.75 | 379.41 | -5.95 | -0.79 | | -2.52 | 386.16 | -19.56 |
| Kibungo | -1.14 | | -3.52 | 421.07 | -25.11 | -1.18 | | -3.07 | 413.59 | -22.27 |
| Masaka | -0.43 | | -1.06 | 452.44 | -7.01 | -0.79 | | -2.66 | 455.48 | -17.54 |
| Muganza | -0.57 | | -2.27 | 688.52 | -9.89 | -1.32 | | -3.73 | 728.00 | -15.36 |
| Mushubi | -0.96 | | -2.01 | 735.57 | -8.20 | -2.46 | * | -5.95 | 780.69 | -22.86 |
| Ntaruka | -0.57 | | -1.95 | 511.68 | -11.46 | -1.89 | + | -5.67 | 516.67 | -32.93 |
| Ntendezi | -1.14 | | -3.45 | 1055.83 | -9.81 | -2.85 | ** | -7.72 | 1113.79 | -20.79 |
| Nyagatare | -0.21 | | -0.39 | 401.27 | -2.94 | -0.96 | | -3.08 | 410.04 | -22.51 |
| Nyamata | -0.46 | | -1.14 | 447.38 | -7.64 | -1.00 | | -3.38 | 452.92 | -22.36 |
| Rubengera | -0.61 | | -0.98 | 506.44 | -5.82 | -2.46 | * | -5.26 | 601.10 | -26.25 |
| Ruganda | -0.11 | | -0.71 | 493.35 | -4.33 | -1.68 | + | -4.95 | 498.20 | -29.84 |
| Rugobagoba | -0.18 | | -0.49 | 495.54 | -2.97 | -1.18 | | -3.61 | 581.98 | -18.60 |
| Ruhengeri | -0.50 | | -1.25 | 626.42 | -5.99 | -2.57 | * | -7.43 | 635.77 | -35.05 |
| Rutsiro | -0.11 | | -0.53 | 739.77 | -2.15 | -2.43 | * | -9.01 | 751.41 | -35.98 |
| Rwamagana | -0.39 | | -0.75 | 379.41 | -5.95 | -0.79 | | -2.52 | 386.16 | -19.56 |
| Rwankeri | -0.14 | | -0.66 | 671.99 | -2.97 | -2.21 | * | -7.42 | 691.49 | -32.17 |
| Save | -0.32 | | -1.35 | 514.58 | -7.85 | -0.96 | | -2.47 | 540.19 | -13.73 |

Table 4-22: Projected SOND precipitation trends for the period 2041 to 2070 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| Stations | 2041-2070 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **RCP 4.5 w/m$^2$** | | | | | **RCP 8.5 w/m$^2$** | | | | |
| | Test Z | α level | Q | Annual | %Δ | Test Z | α level | Q | Annual | %Δ |
| Bukora | -0.21 | | -1.19 | 403.24 | -8.89 | 0.04 | | 0.12 | 375.15 | 0.93 |
| Busogo | -0.18 | | -0.45 | 695.87 | -1.92 | -0.39 | | -1.06 | 656.29 | -4.85 |
| Butare | 0.11 | | 0.68 | 538.47 | 3.76 | -0.32 | | -0.85 | 532.68 | -4.81 |
| Byimana | 0.21 | | 0.47 | 522.10 | 2.72 | -0.82 | | -3.32 | 551.50 | -18.08 |
| Byumba | 0.21 | | 0.96 | 414.36 | 6.95 | -0.14 | | -0.29 | 386.80 | -2.23 |
| Cyinzuzi | 0.25 | | 1.09 | 616.33 | 5.30 | -0.11 | | -0.65 | 569.98 | -3.40 |
| Gabiro | 0.11 | | 0.62 | 360.65 | 5.13 | -0.21 | | -0.61 | 316.93 | -5.73 |
| Gatumba | -0.18 | | -0.72 | 594.17 | -3.64 | -0.46 | | -2.02 | 540.05 | -11.24 |
| Gikongoro | 0.21 | | 0.36 | 539.26 | 2.02 | -0.68 | | -1.98 | 507.49 | -11.71 |
| Gisanga | 0.21 | | 0.47 | 522.10 | 2.72 | -0.82 | | -3.32 | 551.50 | -18.08 |
| Gisenyi | 0.00 | | 0.27 | 566.98 | 1.44 | -0.29 | | -0.70 | 528.07 | -3.96 |
| Gitarama | 0.21 | | 0.47 | 522.10 | 2.72 | -0.82 | | -3.32 | 551.50 | -18.08 |
| Gitega | 0.25 | | 1.09 | 616.33 | 5.30 | -0.11 | | -0.65 | 569.98 | -3.40 |
| Kamembe | 0.00 | | -0.03 | 715.89 | -0.12 | -0.36 | | -0.79 | 699.41 | -3.39 |
| Kanombe | 0.25 | | 1.09 | 616.33 | 5.30 | -0.11 | | -0.65 | 569.98 | -3.40 |
| Kansi | 0.14 | | 0.66 | 531.73 | 3.70 | -0.43 | | -0.84 | 523.49 | -4.80 |
| Kawangire | 0.18 | | 0.54 | 410.32 | 3.98 | -0.25 | | -0.55 | 372.57 | -4.42 |
| Kibungo | -0.32 | | -1.40 | 433.86 | -9.70 | -0.11 | | -0.21 | 414.07 | -1.49 |
| Masaka | 0.14 | | 1.08 | 487.73 | 6.62 | -0.18 | | -0.40 | 440.81 | -2.72 |
| Muganza | -0.04 | | -0.11 | 704.90 | -0.45 | -0.39 | | -2.62 | 689.09 | -11.40 |
| Mushubi | -0.32 | | -1.65 | 739.03 | -6.71 | -0.89 | | -2.91 | 704.65 | -12.41 |
| Ntaruka | -0.14 | | -0.62 | 520.66 | -3.56 | -0.07 | | -0.07 | 501.32 | -0.41 |
| Ntendezi | -0.11 | | -0.96 | 1051.26 | -2.74 | -0.96 | | -3.37 | 1020.75 | -9.90 |
| Nyagatare | 0.00 | | 0.19 | 432.55 | 1.35 | -0.14 | | -0.54 | 412.67 | -3.94 |
| Nyamata | 0.29 | | 0.82 | 473.17 | 5.22 | -0.36 | | -1.51 | 447.98 | -10.08 |
| Rubengera | -0.29 | | -1.67 | 512.77 | -9.79 | -1.03 | | -2.83 | 536.63 | -15.80 |
| Ruganda | -0.14 | | -0.62 | 523.23 | -3.53 | -0.54 | | -2.11 | 475.78 | -13.28 |
| Rugobagoba | 0.21 | | 0.47 | 522.10 | 2.72 | -0.82 | | -3.32 | 551.50 | -18.08 |
| Ruhengeri | 0.04 | | 0.09 | 627.47 | 0.44 | 0.07 | | 0.04 | 614.02 | 0.19 |
| Rutsiro | -0.36 | | -1.40 | 737.53 | -5.71 | -0.18 | | -0.94 | 683.38 | -4.14 |
| Rwamagana | 0.18 | | 0.54 | 410.32 | 3.98 | -0.25 | | -0.55 | 372.57 | -4.42 |
| Rwankeri | -0.18 | | -0.45 | 695.87 | -1.92 | -0.39 | | -1.06 | 656.29 | -4.85 |
| Save | 0.11 | | 0.68 | 538.47 | 3.76 | -0.32 | | -0.85 | 532.68 | -4.81 |

Table 4-23: Projected SOND precipitation trends for 2071 to 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| Stations | 2071-2100 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **RCP 4.5 w/m$^2$** | | | | | **RCP 8.5 w/m$^2$** | | | | |
| | Test Z | α level | Q | Annual | %Δ | Test Z | α level | Q | Annual | %Δ |
| Bukora | -1.43 | | -4.73 | 384.22 | -36.92 | 0.46 | | 2.60 | 437.45 | 17.83 |
| Busogo | -0.79 | | -2.22 | 686.67 | -9.71 | 0.79 | | 2.96 | 735.60 | 12.05 |
| Butare | -0.71 | | -1.55 | 530.86 | -8.76 | 1.43 | | 3.39 | 568.27 | 17.90 |
| Byimana | -1.28 | | -3.16 | 498.89 | -19.02 | 0.75 | | 2.78 | 619.58 | 13.46 |
| Byumba | -1.36 | | -2.98 | 404.83 | -22.11 | 0.75 | | 2.86 | 445.61 | 19.26 |
| Cyinzuzi | -1.25 | | -4.71 | 600.54 | -23.52 | 0.86 | | 4.85 | 665.96 | 21.86 |
| Gabiro | -1.21 | | -3.50 | 344.09 | -30.54 | 1.00 | | 4.12 | 391.09 | 31.59 |
| Gatumba | -0.71 | | -2.54 | 576.36 | -13.21 | 0.96 | | 3.55 | 638.36 | 16.68 |
| Gikongoro | -1.11 | | -2.60 | 522.07 | -14.97 | 0.86 | | 2.50 | 557.42 | 13.43 |
| Gisanga | -1.28 | | -3.16 | 498.89 | -19.02 | 0.75 | | 2.78 | 619.58 | 13.46 |
| Gisenyi | -0.57 | | -1.59 | 551.39 | -8.65 | 0.79 | | 2.53 | 594.34 | 12.75 |
| Gitarama | -1.28 | | -3.16 | 498.89 | -19.02 | 0.75 | | 2.78 | 619.58 | 13.46 |
| Gitega | -1.25 | | -4.71 | 600.54 | -23.52 | 0.86 | | 4.85 | 665.96 | 21.86 |
| Kamembe | -0.18 | | -1.44 | 688.97 | -6.28 | 0.14 | | 0.24 | 730.76 | 0.99 |
| Kanombe | -1.25 | | -4.71 | 600.54 | -23.52 | 0.86 | | 4.85 | 665.96 | 21.86 |
| Kansi | -0.68 | | -1.61 | 524.28 | -9.23 | 1.36 | | 3.12 | 557.15 | 16.78 |
| Kawangire | -1.25 | | -3.56 | 394.69 | -27.02 | 1.00 | | 3.75 | 448.45 | 25.07 |
| Kibungo | -1.50 | | -3.80 | 424.08 | -26.85 | 0.57 | | 2.14 | 463.20 | 13.85 |
| Masaka | -1.21 | | -4.44 | 467.90 | -28.45 | 1.07 | | 4.75 | 531.28 | 26.82 |
| Muganza | -0.61 | | -2.24 | 695.02 | -9.65 | 0.68 | | 2.79 | 703.53 | 11.89 |
| Mushubi | -0.21 | | -0.75 | 708.52 | -3.17 | 0.29 | | 0.98 | 714.97 | 4.10 |
| Ntaruka | -1.03 | | -2.67 | 527.28 | -15.18 | 0.54 | | 1.60 | 562.93 | 8.53 |
| Ntendezi | 0.00 | | 0.19 | 1016.82 | 0.55 | 0.14 | | 0.71 | 1002.44 | 2.12 |
| Nyagatare | -0.71 | | -2.06 | 437.26 | -14.16 | 0.43 | | 1.51 | 467.71 | 9.72 |
| Nyamata | -1.61 | | -4.51 | 450.86 | -30.00 | 1.07 | | 4.25 | 494.47 | 25.80 |
| Rubengera | 0.04 | | 0.18 | 486.83 | 1.09 | 0.25 | | 1.22 | 551.54 | 6.63 |
| Ruganda | -0.75 | | -2.65 | 506.14 | -15.72 | 0.93 | | 2.93 | 566.98 | 15.53 |
| Rugobagoba | -1.28 | | -3.16 | 498.89 | -19.02 | 0.75 | | 2.78 | 619.58 | 13.46 |
| Ruhengeri | -0.82 | | -1.88 | 641.66 | -8.81 | 0.54 | | 1.68 | 671.36 | 7.51 |
| Rutsiro | -0.64 | | -3.00 | 721.52 | -12.49 | 0.96 | | 2.82 | 763.26 | 11.10 |
| Rwamagana | -1.25 | | -3.56 | 394.69 | -27.02 | 1.00 | | 3.75 | 448.45 | 25.07 |
| Rwankeri | -0.79 | | -2.22 | 686.67 | -9.71 | 0.79 | | 2.96 | 735.60 | 12.05 |
| Save | -0.71 | | -1.55 | 530.86 | -8.76 | 1.43 | | 3.39 | 568.27 | 17.90 |

#### 4.6.1.5 Annual precipitation

Table 4-24 indicates that projected annual rainfall for the period 2021-2050 ranges from -7.74% or -4.31mm per year (not significant, $\alpha > 0.05$) in Busogo to -18.78% or -6.15mm per year (not significant, $\alpha > 0.05$) in Nyagatare under RCP 4.5 w/m$^2$ and ranges from -1.37% or -0.69mm per year (not significant, $\alpha > 0.05$) in Muganza to -20.8% or -11.45mm per year (not significant, $\alpha > 0.05$) in Rutsiro under RCP 8.5 w/m$^2$. Notably, projected annual precipitation for 2021-2050 under RCP 4.5 w/m$^2$ will decrease under RCP 8.5 w/m$^2$ over Rwanda except for parts of Kayonza which shows an increasing trend. Similarly, the study by Muhire et al. (2018) observed a steady decline in projected mean precipitation between 2015 and 2050, therefore, confirming the results of this study.

Table 4-25 shows that projected annual rainfall for the period 2041-2070 ranges from +5.7% or +2.22mm per year (not significant, $\alpha > 0.05$) in Ntaruka to -12.98% or -4.05mm per year (not significant, $\alpha > 0.05$) in Bukora under RCP 4.5 w/m$^2$ and ranges from -5.1% or -1.34mm per year (not significant, $\alpha > 0.05$) in Gabiro to -19.43% or -8.22mm per year (significant, $\alpha \leq 0.05$) in Byimana under RCP 8.5 w/m$^2$. In addition, projected annual precipitation for 2041-2070 under RCP 4.5 w/m$^2$ shows a decreasing trend around Kirehe and Karongi, whereas increasing trends are projected over central and northwards. Under RCP 8.5 w/m$^2$, a decreasing trend is projected from the northeast to the southwest.

Table 4-26 shows that projected annual rainfall for the period 2071-2100 ranges from -2.78% or -2.03mm per year (significant, $\alpha \leq 0.05$) in Ntendezi to -27.47% or -7.95mm per year (not significant, $\alpha > 0.05$) in Bukora under RCP 4.5 w/m$^2$ and ranges from +13.55% or +3.74mm per year (not significant, $\alpha > 0.05$) in Gabiro to –7.72% or -3.53mm per year (not significant, $\alpha > 0.05$) in Ruhengeri under RCP 8.5 w/m$^2$. Additionally, projected annual precipitation for 2071-2100 shows a decreasing trend over western toward eastern parts under RCP 4.5 w/m$^2$ and an increasing trend eastward under RCP 8.5 w/m$^2$, while the western, north-western, Nyamasheke district shows a decreasing trend.

Table 4-24: Projected annual precipitation trends for the period 2021 to 2050 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| **Timeframe** | **2021-2050** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **RCP 4.5 w/m$^2$** | | | | | **RCP 8.5 w/m$^2$** | | | | |
| Stations | Test Z | α level | Q | Annual | %Δ | Test Z | α level | Q | Annual | %Δ |
| Bukora | -0.64 | | -3.45 | 937.90 | -11.02 | -0.39 | | -2.50 | 884.66 | -8.49 |
| Busogo | -0.64 | | -4.31 | 1673.14 | -7.74 | -2.03 | * | -9.98 | 1686.08 | -17.77 |
| Butare | -1.75 | + | -6.41 | 1219.88 | -15.76 | -0.46 | | -1.79 | 1238.55 | -4.32 |
| Byimana | -1.18 | | -5.21 | 1180.14 | -13.24 | -0.71 | | -3.19 | 1350.39 | -7.09 |
| Byumba | -1.18 | | -4.69 | 1007.22 | -13.96 | -1.64 | | -4.89 | 1000.53 | -14.67 |
| Cyinzuzi | -1.14 | | -6.72 | 1489.32 | -13.54 | -1.32 | | -6.15 | 1468.30 | -12.56 |
| Gabiro | -0.79 | | -2.91 | 852.60 | -10.24 | -0.93 | | -2.43 | 805.17 | -9.06 |
| Gatumba | -0.82 | | -4.97 | 1401.40 | -10.64 | -1.71 | + | -7.13 | 1385.04 | -15.45 |
| Gikongoro | -1.43 | | -5.93 | 1242.95 | -14.31 | -1.18 | | -4.11 | 1262.78 | -9.76 |
| Gisanga | -1.18 | | -5.21 | 1180.14 | -13.24 | -0.71 | | -3.19 | 1350.39 | -7.09 |
| Gisenyi | -0.96 | | -4.31 | 1243.29 | -10.40 | -2.36 | * | -7.96 | 1268.02 | -18.84 |
| Gitarama | -1.18 | | -5.21 | 1180.14 | -13.24 | -0.71 | | -3.19 | 1350.39 | -7.09 |
| Gitega | -1.14 | | -6.72 | 1489.32 | -13.54 | -1.32 | | -6.15 | 1468.30 | -12.56 |
| Kamembe | -1.36 | | -5.67 | 1434.26 | -11.87 | -1.78 | + | -6.13 | 1463.10 | -12.56 |
| Kanombe | -1.14 | | -6.72 | 1489.32 | -13.54 | -1.32 | | -6.15 | 1468.30 | -12.56 |
| Kansi | -1.68 | + | -6.51 | 1208.94 | -16.16 | -0.46 | | -1.57 | 1216.81 | -3.88 |
| Kawangire | -0.93 | | -3.25 | 977.60 | -9.97 | -1.07 | | -3.26 | 954.86 | -10.24 |
| Kibungo | -1.07 | | -5.33 | 1049.28 | -15.23 | -0.89 | | -3.41 | 1008.32 | -10.13 |
| Masaka | -0.93 | | -3.71 | 1155.89 | -9.64 | -0.93 | | -3.69 | 1122.60 | -9.86 |
| Muganza | -1.21 | | -4.23 | 1476.83 | -8.58 | -0.07 | | -0.69 | 1519.60 | -1.37 |
| Mushubi | -1.68 | + | -7.13 | 1587.97 | -13.48 | -2.00 | * | -7.70 | 1655.04 | -13.95 |
| Ntaruka | -1.11 | | -3.61 | 1174.98 | -9.22 | -1.93 | + | -7.98 | 1170.43 | -20.44 |
| Ntendezi | -1.78 | + | -10.89 | 2331.54 | -14.02 | -2.68 | ** | -10.77 | 2428.71 | -13.30 |
| Nyagatare | -1.28 | | -6.15 | 982.36 | -18.78 | -1.25 | | -4.70 | 969.94 | -14.52 |
| Nyamata | -1.14 | | -4.95 | 1117.52 | -13.29 | -0.57 | | -2.40 | 1096.81 | -6.56 |
| Rubengera | -1.32 | | -4.77 | 1080.71 | -13.23 | -1.86 | + | -6.10 | 1260.52 | -14.51 |
| Ruganda | -0.75 | | -4.17 | 1231.00 | -10.17 | -1.68 | + | -6.09 | 1216.01 | -15.03 |
| Rugobagoba | -1.18 | | -5.21 | 1180.14 | -13.24 | -0.71 | | -3.19 | 1350.39 | -7.09 |
| Ruhengeri | -0.86 | | -4.05 | 1447.65 | -8.40 | -2.32 | * | -8.86 | 1456.49 | -18.25 |
| Rutsiro | -0.96 | | -6.60 | 1629.47 | -12.16 | -2.39 | * | -11.45 | 1652.00 | -20.80 |
| Rwamagana | -0.93 | | -3.25 | 977.60 | -9.97 | -1.07 | | -3.26 | 954.86 | -10.24 |
| Rwankeri | -0.64 | | -4.31 | 1673.14 | -7.74 | -2.03 | * | -9.98 | 1686.08 | -17.77 |
| Save | -1.75 | + | -6.41 | 1219.88 | -15.76 | -0.46 | | -1.79 | 1238.55 | -4.32 |

Table 4-25: Projected annual precipitation trend for the period 2041 to 2070 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| **Timeframe** | **2041-2070** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **RCP 4.5 w/m$^2$** | | | | | **RCP 8.5 w/m$^2$** | | | | |
| Stations | Test Z | α level | Q | Annual | %Δ | Test Z | α level | Q | Annual | %Δ |
| Bukora | -0.57 | | -4.05 | 936.44 | -12.98 | -0.82 | | -4.09 | 876.16 | -14.01 |
| Busogo | 0.11 | | 0.44 | 1671.26 | 0.79 | -0.96 | | -6.06 | 1601.13 | -11.36 |
| Butare | -0.36 | | -1.03 | 1192.96 | -2.59 | -0.79 | | -4.02 | 1198.84 | -10.06 |
| Byimana | 0.00 | | 0.24 | 1175.07 | 0.61 | -1.78 | + | -8.22 | 1269.61 | -19.43 |
| Byumba | 0.00 | | -0.28 | 1003.01 | -0.85 | -0.71 | | -2.51 | 957.19 | -7.85 |
| Cyinzuzi | 0.04 | | 0.38 | 1483.45 | 0.78 | -0.64 | | -3.71 | 1410.42 | -7.89 |
| Gabiro | 0.00 | | 0.22 | 847.13 | 0.79 | -0.46 | | -1.34 | 788.01 | -5.10 |
| Gatumba | 0.00 | | -0.12 | 1414.73 | -0.26 | -1.07 | | -6.50 | 1320.81 | -14.76 |
| Gikongoro | 0.07 | | 0.40 | 1231.15 | 0.97 | -1.78 | + | -6.97 | 1181.94 | -17.69 |
| Gisanga | 0.00 | | 0.24 | 1175.07 | 0.61 | -1.78 | + | -8.22 | 1269.61 | -19.43 |
| Gisenyi | -0.36 | | -1.54 | 1229.96 | -3.76 | -1.43 | | -5.05 | 1172.23 | -12.91 |
| Gitarama | 0.00 | | 0.24 | 1175.07 | 0.61 | -1.78 | + | -8.22 | 1269.61 | -19.43 |
| Gitega | 0.04 | | 0.38 | 1483.45 | 0.78 | -0.64 | | -3.71 | 1410.42 | -7.89 |
| Kamembe | -0.82 | | -3.63 | 1402.69 | -7.77 | -0.93 | | -3.44 | 1379.66 | -7.49 |
| Kanombe | 0.04 | | 0.38 | 1483.45 | 0.78 | -0.64 | | -3.71 | 1410.42 | -7.89 |
| Kansi | -0.32 | | -0.89 | 1181.61 | -2.27 | -0.86 | | -3.70 | 1178.54 | -9.41 |
| Kawangire | 0.04 | | 0.38 | 972.82 | 1.17 | -0.50 | | -1.85 | 924.82 | -6.01 |
| Kibungo | -0.75 | | -3.38 | 1027.67 | -9.87 | -1.28 | | -4.68 | 977.90 | -14.37 |
| Masaka | 0.00 | | -0.86 | 1149.19 | -2.24 | -0.39 | | -2.04 | 1091.91 | -5.61 |
| Muganza | -0.50 | | -2.42 | 1442.89 | -5.03 | -1.28 | | -6.19 | 1452.38 | -12.80 |
| Mushubi | -0.86 | | -4.77 | 1541.01 | -9.28 | -1.53 | | -8.63 | 1501.03 | -17.25 |
| Ntaruka | 0.36 | | 2.22 | 1169.77 | 5.70 | -1.03 | | -2.79 | 1128.41 | -7.40 |
| Ntendezi | -0.89 | | -5.15 | 2262.32 | -6.82 | -1.71 | + | -9.92 | 2228.93 | -13.35 |
| Nyagatare | 0.43 | | 1.55 | 983.26 | 4.72 | -0.36 | | -2.11 | 965.74 | -6.57 |
| Nyamata | -0.04 | | -0.40 | 1096.90 | -1.09 | -1.18 | | -5.66 | 1052.74 | -16.12 |
| Rubengera | -0.79 | | -4.45 | 1052.98 | -12.67 | -1.61 | | -6.80 | 1133.76 | -17.99 |
| Ruganda | 0.04 | | 1.03 | 1245.00 | 2.49 | -1.14 | | -5.71 | 1162.03 | -14.75 |
| Rugobagoba | 0.00 | | 0.24 | 1175.07 | 0.61 | -1.78 | + | -8.22 | 1269.61 | -19.43 |
| Ruhengeri | 0.57 | | 2.49 | 1436.18 | 5.21 | -1.00 | | -4.36 | 1400.72 | -9.34 |
| Rutsiro | -0.29 | | -2.25 | 1597.46 | -4.22 | -1.32 | | -6.04 | 1503.08 | -12.06 |
| Rwamagana | 0.04 | | 0.38 | 972.82 | 1.17 | -0.50 | | -1.85 | 924.82 | -6.01 |
| Rwankeri | 0.11 | | 0.44 | 1671.26 | 0.79 | -0.96 | | -6.06 | 1601.13 | -11.36 |
| Save | -0.36 | | -1.03 | 1192.96 | -2.59 | -0.79 | | -4.02 | 1198.84 | -10.06 |

Table 4-26: o Projected annual precipitation trend for the period 2071 to 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| **Timeframe** | **2071-2100** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **RCP 4.5 w/m$^2$** | | | | | **RCP 8.5 w/m$^2$** | | | | |
| Stations | Test Z | α level | Q | Annual | %Δ | Test Z | α level | Q | Annual | %Δ |
| Bukora | -1.71 | + | -7.95 | 868.69 | -27.47 | 0.54 | | 2.62 | 900.08 | 8.73 |
| Busogo | -0.93 | | -7.56 | 1607.41 | -14.11 | -0.18 | | -0.89 | 1594.56 | -1.67 |
| Butare | -0.71 | | -3.84 | 1211.87 | -9.51 | 0.50 | | 1.45 | 1203.14 | 3.61 |
| Byimana | -1.86 | + | -7.93 | 1139.15 | -20.89 | 0.46 | | 2.33 | 1309.43 | 5.33 |
| Byumba | -1.25 | | -6.18 | 961.07 | -19.30 | 0.07 | | 0.37 | 966.90 | 1.14 |
| Cyinzuzi | -1.36 | | -10.23 | 1420.64 | -21.61 | 0.21 | | 1.45 | 1437.99 | 3.02 |
| Gabiro | -1.28 | | -6.21 | 806.48 | -23.12 | 1.11 | | 3.74 | 828.19 | 13.55 |
| Gatumba | -1.21 | | -7.09 | 1349.51 | -15.77 | 0.50 | | 2.44 | 1371.45 | 5.33 |
| Gikongoro | -1.53 | | -6.39 | 1197.89 | -16.02 | 0.39 | | 1.81 | 1187.24 | 4.57 |
| Gisanga | -1.86 | + | -7.93 | 1139.15 | -20.89 | 0.46 | | 2.33 | 1309.43 | 5.33 |
| Gisenyi | -0.57 | | -1.67 | 1180.88 | -4.25 | -0.36 | | -1.54 | 1146.76 | -4.04 |
| Gitarama | -1.86 | + | -7.93 | 1139.15 | -20.89 | 0.46 | | 2.33 | 1309.43 | 5.33 |
| Gitega | -1.36 | | -10.23 | 1420.64 | -21.61 | 0.21 | | 1.45 | 1437.99 | 3.02 |
| Kamembe | -0.79 | | -2.94 | 1355.72 | -6.51 | -1.11 | | -2.79 | 1303.87 | -6.42 |
| Kanombe | -1.36 | | -10.23 | 1420.64 | -21.61 | 0.21 | | 1.45 | 1437.99 | 3.02 |
| Kansi | -0.71 | | -3.71 | 1198.97 | -9.29 | 0.36 | | 1.35 | 1179.37 | 3.42 |
| Kawangire | -1.28 | | -7.57 | 927.62 | -24.48 | 0.86 | | 3.00 | 958.17 | 9.38 |
| Kibungo | -1.53 | | -7.34 | 969.66 | -22.71 | 0.04 | | 0.48 | 969.41 | 1.50 |
| Masaka | -1.39 | | -8.87 | 1098.00 | -24.24 | 0.86 | | 3.84 | 1133.31 | 10.16 |
| Muganza | -1.00 | | -6.53 | 1444.52 | -13.56 | 0.75 | | 2.91 | 1371.60 | 6.37 |
| Mushubi | -0.50 | | -3.79 | 1481.90 | -7.67 | -0.68 | | -2.51 | 1390.62 | -5.42 |
| Ntaruka | -0.71 | | -2.35 | 1145.21 | -6.17 | -0.61 | | -0.92 | 1126.40 | -2.46 |
| Ntendezi | -0.43 | | -2.03 | 2186.32 | -2.78 | -1.89 | + | -4.71 | 2013.93 | -7.02 |
| Nyagatare | -0.64 | | -3.18 | 971.51 | -9.82 | -0.07 | | -0.74 | 968.41 | -2.29 |
| Nyamata | -1.53 | | -8.74 | 1070.35 | -24.50 | 0.39 | | 2.26 | 1078.44 | 6.29 |
| Rubengera | -0.32 | | -1.75 | 1003.10 | -5.22 | -0.39 | | -1.23 | 1058.24 | -3.48 |
| Ruganda | -1.21 | | -6.85 | 1185.84 | -17.33 | 0.50 | | 2.47 | 1212.01 | 6.11 |
| Rugobagoba | -1.86 | + | -7.93 | 1139.15 | -20.89 | 0.46 | | 2.33 | 1309.43 | 5.33 |
| Ruhengeri | -0.71 | | -1.92 | 1414.57 | -4.07 | -0.89 | | -3.53 | 1371.91 | -7.72 |
| Rutsiro | -0.86 | | -4.29 | 1531.50 | -8.40 | -0.50 | | -2.32 | 1439.27 | -4.83 |
| Rwamagana | -1.28 | | -7.57 | 927.62 | -24.48 | 0.86 | | 3.00 | 958.17 | 9.38 |
| Rwankeri | -0.93 | | -7.56 | 1607.41 | -14.11 | -0.18 | | -0.89 | 1594.56 | -1.67 |
| Save | -0.71 | | -3.84 | 1211.87 | -9.51 | 0.50 | | 1.45 | 1203.14 | 3.61 |

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### 4.6.2 *Temporal analysis of projected extreme precipitation*

The subsequent sections show the trend analysis of the projected very heavy precipitation days (R20mm) and very wet days (R95pTOT) between 2021-2050, 2041-2070 and 2071-2100 under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$..

#### 4.6.2.1 Very heavy precipitation days (R20mm)

Table 4-27 shows that projected very heavy precipitation days for the period 2021-2050 ranges from +0% or 0.001 days per year (not significant, $\alpha > 0.05$) in Busogo to -36.22% or -0.14 days per year (significant, $\alpha \leq 0.05$) in Byimana under RCP 4.5 w/m$^2$ and ranges from +26.97% or 0.08mm per year (not significant, $\alpha > 0.05$) in Gabiro to -18.01% or -0.14 mm per year (not significant, $\alpha > 0.05$) in Ntendezi under RCP 8.5 w/m$^2$. Projected very heavy precipitation days show decreasing trends over most parts of the country with more decrease over Amayaga areas and the central plateau under RCP 4.5 w/m$^2$. In contrast, an increasing trend was indicated over the south-eastern Bugesera, Kayonza, central and eastern Gatsibo, reducing towards the central plateau and decreasing over the northern highland under RCP 8.5 w/m$^2$ for the period 2021-2050.

Table 4-28 shows that projected very heavy precipitation days for the period 2041-2070 ranges from +28.85% or 0.13 days per year (not significant, $\alpha > 0.05$) in Byimana to -36.14% or -0.10 mm per year (not significant, $\alpha > 0.05$) in Rubengera under RCP 4.5 w/m$^2$ and ranges from +17.86% or 0.81 mm per year (not significant, $\alpha > 0.05$) in Byumba to -45.87% or -0.17 mm per year (significant, $\alpha \leq 0.05$) in Rubengera under RCP 8.5 w/m$^2$. Overall, a general decreasing trendency for the period 2041-2070 is expected under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$, with the western, south-western, central part and the northern highland part indicating more decrease whereas the areas around Ruhango, Muhanga, and Gisagara indicated an increasing trend under RCP 8.5 w/m$^2$ for the period 2041-2070.

Table 4-29 indicates that projected very heavy precipitation days for the period 2071-2100 ranges from 0.0% or 0.0 mm per year (significant, $\alpha > 0.05$) in Rubengera to -50.33% or -0.17 mm per year (not significant, $\alpha > 0.05$) in Gabiro under RCP 4.5 w/m$^2$ and ranges from +23.31% or +0.08 mm per year (not significant, $\alpha > 0.05$) in Gisenyi to –9.17% or -0.06mm per year (not significant, $\alpha \leq 0.05$) in Byimana under RCP 8.5 w/m$^2$. The projected very heavy precipitation days for the period 2071-2100 showed a decreasing trend over Rwanda under RCP 4.5 w/m$^2$ and an increasing trend over the Rubavu, southern part (Huye, Gisagara) and Bugarama valley under RCP 8.5 w/m$^2$.

Table 4-27: Projected very heavy precipitation days (R20mm) trends for the period between 2021 and 2050 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| Stations | 2021-2050 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | Mean | %Δ | Test Z | α level | Q | Mean | %Δ |
| Bukora | -0.93 | | -0.12 | 13.27 | -27.14 | 0.43 | | 0.00 | 12.57 | 0.00 |
| Busogo | -0.20 | | 0.00 | 20.00 | 0.00 | -0.95 | | -0.10 | 20.60 | -14.56 |
| Butare | -1.15 | | -0.09 | 13.63 | -20.00 | 0.68 | | 0.05 | 13.27 | 11.90 |
| Byimana | -2.26 | * | -0.14 | 11.83 | -36.22 | 0.56 | | 0.04 | 17.10 | 6.75 |
| Byumba | -1.16 | | -0.14 | 12.17 | -33.62 | 0.20 | | 0.00 | 11.93 | 0.00 |
| Cyinzuzi | -1.59 | | -0.25 | 24.20 | -30.99 | -0.50 | | -0.06 | 23.93 | -7.37 |
| Gabiro | -0.93 | | -0.11 | 10.10 | -31.27 | 1.30 | | 0.08 | 8.90 | 26.97 |
| Gatumba | 0.00 | | 0.00 | 18.33 | 0.00 | -0.82 | | -0.10 | 18.77 | -15.99 |
| Gikongoro | -2.02 | * | -0.14 | 13.03 | -32.88 | 1.22 | | 0.10 | 13.03 | 23.81 |
| Gisanga | -2.26 | * | -0.14 | 11.83 | -36.22 | 0.56 | | 0.04 | 17.10 | 6.75 |
| Gisenyi | -0.65 | | -0.06 | 9.93 | -16.78 | 0.36 | | 0.00 | 8.23 | 0.00 |
| Gitarama | -2.26 | * | -0.14 | 11.83 | -36.22 | 0.56 | | 0.04 | 17.10 | 6.75 |
| Gitega | -1.59 | | -0.25 | 24.20 | -30.99 | -0.50 | | -0.06 | 23.93 | -7.37 |
| Kamembe | -0.09 | | 0.00 | 11.03 | 0.00 | 0.43 | | 0.00 | 9.47 | 0.00 |
| Kanombe | -1.59 | | -0.25 | 24.20 | -30.99 | -0.50 | | -0.06 | 23.93 | -7.37 |
| Kansi | -1.10 | | -0.10 | 13.23 | -22.67 | 0.90 | | 0.06 | 12.93 | 13.64 |
| Kawangire | -1.16 | | -0.11 | 12.40 | -26.88 | 0.09 | | 0.00 | 12.30 | 0.00 |
| Kibungo | -1.09 | | -0.13 | 15.60 | -24.04 | -0.34 | | 0.00 | 15.37 | 0.00 |
| Masaka | -0.90 | | -0.10 | 15.97 | -17.89 | -0.04 | | 0.00 | 15.87 | 0.00 |
| Muganza | -0.47 | | 0.00 | 18.20 | 0.00 | 0.56 | | 0.04 | 18.80 | 6.65 |
| Mushubi | -0.79 | | -0.07 | 16.23 | -12.32 | -1.01 | | -0.07 | 16.50 | -12.12 |
| Ntaruka | -0.22 | | 0.00 | 13.77 | 0.00 | 0.78 | | 0.00 | 13.67 | 0.00 |
| Ntendezi | -0.88 | | -0.09 | 23.40 | -11.66 | -1.78 | + | -0.14 | 23.80 | -18.01 |
| Nyagatare | -0.74 | | -0.05 | 12.53 | -11.40 | 0.31 | | 0.00 | 10.97 | 0.00 |
| Nyamata | -1.27 | | -0.11 | 14.17 | -23.53 | 1.31 | | 0.10 | 13.77 | 21.79 |
| Rubengera | -0.05 | | 0.00 | 8.40 | 0.00 | -0.36 | | 0.00 | 11.97 | 0.00 |
| Ruganda | -0.20 | | 0.00 | 15.33 | 0.00 | -0.31 | | 0.00 | 15.57 | 0.00 |
| Rugobagoba | -2.26 | * | -0.14 | 11.83 | -36.22 | 0.56 | | 0.04 | 17.10 | 6.75 |
| Ruhengeri | -0.34 | | 0.00 | 10.90 | 0.00 | 1.15 | | 0.07 | 10.50 | 21.16 |
| Rutsiro | -0.91 | | -0.08 | 10.60 | -21.77 | 0.96 | | 0.07 | 10.43 | 19.17 |
| Rwamagana | -1.59 | | -0.25 | 24.20 | -30.99 | -0.50 | | -0.06 | 23.93 | -7.37 |
| Rwankeri | -0.20 | | 0.00 | 25.33 | 0.00 | -1.38 | | -0.15 | 26.40 | -17.48 |
| Save | -1.15 | | -0.09 | 13.63 | -20.00 | 0.68 | | 0.05 | 13.27 | 11.90 |

Table 4-28: Projected very heavy precipitation days (R20mm) trends for the period between 2041-2070 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| Stations | 2041-2070 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **RCP 4.5 w/m$^2$** | | | | | **RCP 8.5 w/m$^2$** | | | | |
| | Test Z | α level | Q | Mean | %Δ | Test Z | α level | Q | Mean | %Δ |
| Bukora | -0.02 | | 0.00 | 13.60 | 0.00 | -0.84 | | -0.06 | 13.03 | -14.39 |
| Busogo | 0.38 | | 0.05 | 21.63 | 7.30 | -0.65 | | -0.06 | 19.70 | -8.96 |
| Butare | -0.05 | | 0.00 | 13.27 | 0.00 | -0.13 | | 0.00 | 13.47 | 0.00 |
| Byimana | 1.10 | | 0.13 | 13.00 | 28.85 | -0.68 | | -0.06 | 16.67 | -10.59 |
| Byumba | 0.36 | | 0.00 | 12.37 | 0.00 | 0.81 | | 0.07 | 12.00 | 17.86 |
| Cyinzuzi | 0.11 | | 0.00 | 24.40 | 0.00 | -0.43 | | -0.06 | 23.33 | -7.56 |
| Gabiro | 0.52 | | 0.00 | 10.37 | 0.00 | -0.20 | | 0.00 | 9.57 | 0.00 |
| Gatumba | 0.14 | | 0.00 | 19.77 | 0.00 | -0.41 | | -0.06 | 18.17 | -9.17 |
| Gikongoro | 0.93 | | 0.09 | 13.83 | 19.72 | -0.45 | | 0.00 | 13.07 | 0.00 |
| Gisanga | 1.10 | | 0.13 | 13.00 | 28.85 | -0.68 | | -0.06 | 16.67 | -10.59 |
| Gisenyi | -0.31 | | 0.00 | 10.23 | 0.00 | -0.67 | | 0.00 | 8.10 | 0.00 |
| Gitarama | 1.10 | | 0.13 | 13.00 | 28.85 | -0.68 | | -0.06 | 16.67 | -10.59 |
| Gitega | 0.11 | | 0.00 | 24.40 | 0.00 | -0.43 | | -0.06 | 23.33 | -7.56 |
| Kamembe | -0.32 | | 0.00 | 11.27 | 0.00 | -0.27 | | 0.00 | 10.13 | 0.00 |
| Kanombe | 0.11 | | 0.00 | 24.40 | 0.00 | -0.43 | | -0.06 | 23.33 | -7.56 |
| Kansi | 0.02 | | 0.00 | 12.93 | 0.00 | -0.07 | | 0.00 | 13.20 | 0.00 |
| Kawangire | 0.38 | | 0.00 | 12.77 | 0.00 | 0.63 | | 0.06 | 12.20 | 13.66 |
| Kibungo | -0.18 | | 0.00 | 15.87 | 0.00 | -0.43 | | 0.00 | 15.40 | 0.00 |
| Masaka | 0.02 | | 0.00 | 16.83 | 0.00 | -0.13 | | 0.00 | 15.27 | 0.00 |
| Muganza | -0.22 | | 0.00 | 17.37 | 0.00 | -0.99 | | -0.08 | 17.33 | -14.42 |
| Mushubi | -1.13 | | -0.11 | 15.73 | -21.19 | -2.05 | * | -0.15 | 14.50 | -31.83 |
| Ntaruka | 0.56 | | 0.05 | 14.40 | 9.47 | -1.04 | | -0.06 | 13.77 | -12.82 |
| Ntendezi | -0.39 | | -0.04 | 22.60 | -4.74 | -1.70 | + | -0.17 | 19.90 | -25.13 |
| Nyagatare | 0.13 | | 0.00 | 12.70 | 0.00 | 0.74 | | 0.05 | 11.87 | 11.49 |
| Nyamata | -0.25 | | 0.00 | 13.80 | 0.00 | -1.31 | | -0.12 | 13.37 | -26.40 |
| Rubengera | -1.46 | | -0.10 | 8.30 | -36.14 | -2.23 | * | -0.17 | 10.90 | -45.87 |
| Ruganda | 0.52 | | 0.08 | 16.63 | 13.87 | -0.50 | | 0.00 | 15.33 | 0.00 |
| Rugobagoba | 1.10 | | 0.13 | 13.00 | 28.85 | -0.68 | | -0.06 | 16.67 | -10.59 |
| Ruhengeri | 0.31 | | 0.00 | 11.67 | 0.00 | -1.26 | | -0.10 | 11.07 | -25.82 |
| Rutsiro | -0.07 | | 0.00 | 11.37 | 0.00 | -0.32 | | 0.00 | 10.93 | 0.00 |
| Rwamagana | 0.11 | | 0.00 | 24.40 | 0.00 | -0.43 | | -0.06 | 23.33 | -7.56 |
| Rwankeri | 0.43 | | 0.07 | 26.10 | 8.51 | -1.20 | | -0.20 | 24.80 | -24.19 |
| Save | -0.05 | | 0.00 | 13.27 | 0.00 | -0.13 | | 0.00 | 13.47 | 0.00 |

Table 4-29: Projected very heavy precipitation days (R20mm) trends for the period between 2071-2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| Stations | 2071-2100 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **RCP 4.5 w/m$^2$** | | | | | **RCP 8.5 w/m$^2$** | | | | |
| | Test Z | α level | Q | Mean | %Δ | Test Z | α level | Q | Mean | %Δ |
| Bukora | -1.38 | | -0.18 | 12.57 | -43.40 | 0.27 | | 0.00 | 13.93 | 0.00 |
| Busogo | -2.18 | * | -0.31 | 20.40 | -45.25 | 0.97 | | 0.10 | 21.93 | 13.68 |
| Butare | -0.65 | | -0.06 | 13.87 | -12.73 | 1.26 | | 0.11 | 15.43 | 21.60 |
| Byimana | -1.96 | + | -0.20 | 12.70 | -47.24 | -0.63 | | -0.06 | 18.17 | -9.17 |
| Byumba | -1.70 | + | -0.19 | 12.37 | -45.49 | 0.40 | | 0.00 | 13.73 | 0.00 |
| Cyinzuzi | -1.52 | | -0.18 | 23.50 | -23.21 | 0.18 | | 0.00 | 24.20 | 0.00 |
| Gabiro | -1.41 | | -0.17 | 10.37 | -50.33 | 1.34 | | 0.09 | 11.20 | 23.29 |
| Gatumba | -1.97 | * | -0.25 | 19.13 | -39.20 | 0.95 | | 0.09 | 21.00 | 12.99 |
| Gikongoro | -1.81 | + | -0.20 | 13.37 | -44.89 | -0.04 | | 0.00 | 15.73 | 0.00 |
| Gisanga | -1.96 | + | -0.20 | 12.70 | -47.24 | -0.63 | | -0.06 | 18.17 | -9.17 |
| Gisenyi | -0.23 | | 0.00 | 9.67 | 0.00 | 1.01 | | 0.08 | 9.90 | 23.31 |
| Gitarama | -1.96 | + | -0.20 | 12.70 | -47.24 | -0.63 | | -0.06 | 18.17 | -9.17 |
| Gitega | -1.52 | | -0.18 | 23.50 | -23.21 | 0.18 | | 0.00 | 24.20 | 0.00 |
| Kamembe | -1.80 | + | -0.15 | 10.90 | -42.34 | 0.43 | | 0.00 | 11.47 | 0.00 |
| Kanombe | -1.52 | | -0.18 | 23.50 | -23.21 | 0.18 | | 0.00 | 24.20 | 0.00 |
| Kansi | -0.77 | | -0.07 | 13.57 | -14.74 | 1.15 | | 0.11 | 15.10 | 22.08 |
| Kawangire | -1.54 | | -0.18 | 12.70 | -41.69 | 0.50 | | 0.00 | 14.13 | 0.00 |
| Kibungo | -1.40 | | -0.15 | 14.53 | -31.76 | -0.20 | | 0.00 | 16.03 | 0.00 |
| Masaka | -1.18 | | -0.13 | 15.93 | -23.54 | 0.54 | | 0.06 | 17.30 | 9.63 |
| Muganza | -2.37 | * | -0.24 | 18.03 | -39.61 | 0.56 | | 0.00 | 17.40 | 0.00 |
| Mushubi | -1.08 | | -0.10 | 14.77 | -20.32 | -0.79 | | -0.04 | 14.40 | -9.06 |
| Ntaruka | -0.94 | | -0.07 | 13.70 | -14.60 | -0.18 | | 0.00 | 15.20 | 0.00 |
| Ntendezi | -1.90 | + | -0.25 | 21.50 | -34.88 | -0.57 | | -0.05 | 19.93 | -7.92 |
| Nyagatare | -1.04 | | -0.10 | 12.17 | -23.48 | 0.54 | | 0.04 | 13.50 | 9.26 |
| Nyamata | -1.75 | + | -0.18 | 14.53 | -37.53 | 0.36 | | 0.00 | 15.50 | 0.00 |
| Rubengera | 0.27 | | 0.00 | 7.63 | 0.00 | 0.07 | | 0.00 | 10.37 | 0.00 |
| Ruganda | -1.32 | | -0.17 | 15.43 | -32.40 | 0.92 | | 0.09 | 18.43 | 14.15 |
| Rugobagoba | -1.96 | + | -0.20 | 12.70 | -47.24 | -0.63 | | -0.06 | 18.17 | -9.17 |
| Ruhengeri | -1.19 | | -0.07 | 11.27 | -19.02 | 0.18 | | 0.00 | 12.33 | 0.00 |
| Rutsiro | -1.33 | | -0.11 | 10.70 | -31.15 | 0.38 | | 0.00 | 13.87 | 0.00 |
| Rwamagana | -1.52 | | -0.18 | 23.50 | -23.21 | 0.18 | | 0.00 | 24.20 | 0.00 |
| Rwankeri | -1.60 | | -0.25 | 25.23 | -29.72 | 1.10 | | 0.10 | 26.67 | 11.25 |
| Save | -0.65 | | -0.06 | 13.87 | -12.73 | 1.26 | | 0.11 | 15.43 | 21.60 |

#### 4.6.2.2 Very wet days

Trend analysis (Table 4-30) shows that projected very wet days for the period 2021-2050 ranges from +71.02% or +6.76 days per year (significant, $\alpha \leq 0.05$) in Byimana to +0.40% or +0.04 days per year (not significant, $\alpha > 0.05$) in Rutsiro under RCP 4.5 w/m$^2$ and ranges from 80.6% or +5.47 days per year (significant, $\alpha \leq 0.05$) in Gikongoro to +0.93% or +0.08 days per year (not significant, $\alpha > 0.05$) in Rutsiro under RCP 8.5 w/m$^2$. In addition, The projected very wet days are expected to decrease under RCP 4.5 w/m$^2$ with more decrease over the northern highland (Musanze, Gakenke, Ngororero, Nyabihu and Rulindo) while the areas bordering Lake Kivu indicated a slight increase under RCP 4.5 w/m$^2$. A general increase in wet days over Nyanza and Ruhango reduces towards the Amayaga and south-eastern part. At the same time, the areas of Rubavu and north-western Rutsiro show a decreasing trend under RCP 8.5 w/m$^2$ for 2021-2050. There is a decreasing trend in wet days over the western, southern, northern and south-eastern (Bugesera, Ngoma and Kirehe) and an increasing trend over Kigali and northeastern parts (Kayonza, Gatsibo and Nyagatare).

Table 4-31 shows that projected very wet days for the period 2041-2070 ranges from +14.33% or +1.04 days per year (not significant, $\alpha > 0.05$) in Byumba to -60.54% or -4.78 days per year (significant, $\alpha \leq 0.05$) in Rubengera under RCP 4.5 w/m$^2$ and ranges from +9.92% or +0.7 days per year (not significant, $\alpha > 0.05$) in Kawangire to -53.56% or -6.49 days per year (significant, $\alpha \leq 0.05$) in Ntendezi under RCP 8.5 w/m$^2$.

Table 4-32 shows that projected very wet days for the period 2071-2100 ranges from +70.53% or +7.12 days per year (not significant, $\alpha > 0.05$) in Gabiro to +7.0% or +0.67 days per year (significant, $\alpha \leq 0.05$) in Rubengera under RCP 4.5 w/m$^2$ and ranges from +78.25% or +7.53 days per year (significant, $\alpha \leq 0.05$) in Kawangire to +8.58% or +7.53 days per year (not significant, $\alpha > 0.05$) in Rubengera under RCP 8.5 w/m$^2$. Notably, the annual percentage change of projected very wet days for the period 2071-2100 indicated a decreasing trend except for the areas of Nyamasheke and south-western Karongi, which shows an increasing trend under RCP 4.5 w/m$^2$. Additionally, an increasing trend was indicated under RCP 8.5 w/m$^2$ over the eastern reducing towards the central and a low increase over Nyamasheke and south-western Karongi Districts. In a related study, Mafuru and Tan (2020) reported an increase in heavy rainfall events over East Africa.

Table 4-30: Annual percentage change of projected very wet days (R95pTOT) for the period 2021 to 2050 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| Station | 2021 to 2050 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | Mean | %Δ | Test Z | α level | Q | Mean | %Δ |
| Bukora | 0.50 | | 1.76 | 216.47 | 24.34 | 0.59 | | 1.43 | 189.61 | 22.57 |
| Busogo | 1.64 | | 3.63 | 270.89 | 40.24 | 1.55 | | 3.55 | 234.30 | 45.42 |
| Butare | 2.60 | ** | 5.59 | 251.52 | 66.65 | 2.60 | ** | 4.99 | 231.52 | 64.61 |
| Byimana | 2.03 | * | 6.76 | 285.73 | 71.02 | 2.28 | * | 6.26 | 242.54 | 77.38 |
| Byumba | 1.25 | | 1.87 | 186.63 | 30.07 | 0.73 | | 0.85 | 159.98 | 15.94 |
| Cyinzuzi | 1.46 | | 3.70 | 321.17 | 34.56 | 0.86 | | 1.95 | 280.86 | 20.88 |
| Gabiro | 0.79 | | 1.50 | 189.83 | 23.71 | 1.28 | | 1.74 | 164.70 | 31.76 |
| Gatumba | 1.50 | | 3.91 | 283.84 | 41.28 | 1.39 | | 3.31 | 237.61 | 41.84 |
| Gikongoro | 1.93 | + | 4.82 | 236.17 | 61.18 | 2.25 | * | 5.47 | 203.70 | 80.60 |
| Gisanga | 2.03 | * | 6.76 | 285.73 | 71.02 | 2.28 | * | 6.26 | 242.54 | 77.38 |
| Gisenyi | 0.18 | | 0.18 | 266.37 | 2.00 | 0.46 | | 0.49 | 241.47 | 6.07 |
| Gitarama | 2.03 | * | 6.76 | 285.73 | 71.02 | 2.28 | * | 6.26 | 242.54 | 77.38 |
| Gitega | 1.46 | | 3.70 | 321.17 | 34.56 | 0.86 | | 1.95 | 280.86 | 20.88 |
| Kamembe | 0.57 | | 0.62 | 267.28 | 6.98 | 0.64 | | 1.46 | 230.61 | 18.99 |
| Kanombe | 1.46 | | 3.70 | 321.17 | 34.56 | 0.86 | | 1.95 | 280.86 | 20.88 |
| Kansi | 2.57 | * | 5.32 | 247.61 | 64.48 | 2.60 | ** | 5.01 | 227.85 | 65.95 |
| Kawangire | 0.64 | | 1.31 | 208.54 | 18.83 | 0.61 | | 1.06 | 180.54 | 17.68 |
| Kibungo | 0.70 | | 1.85 | 198.09 | 27.96 | 0.32 | | 0.46 | 173.48 | 7.88 |
| Masaka | 1.28 | | 2.94 | 270.20 | 32.64 | 0.86 | | 2.04 | 236.64 | 25.82 |
| Muganza | 2.46 | * | 5.84 | 357.44 | 48.98 | 2.46 | * | 5.84 | 357.44 | 48.98 |
| Mushubi | 1.82 | + | 3.47 | 328.37 | 31.73 | 1.61 | | 3.36 | 315.17 | 31.97 |
| Ntaruka | 1.39 | | 2.39 | 224.51 | 31.92 | 1.21 | | 1.93 | 182.36 | 31.67 |
| Ntendezi | 1.43 | | 3.31 | 382.29 | 25.94 | 1.43 | | 3.31 | 381.45 | 25.99 |
| Nyagatare | 1.25 | | 2.72 | 200.23 | 40.79 | 1.07 | | 2.67 | 180.50 | 44.42 |
| Nyamata | 2.00 | * | 4.76 | 251.04 | 56.86 | 1.50 | | 3.58 | 218.40 | 49.13 |
| Rubengera | 1.57 | | 2.78 | 247.22 | 33.78 | 1.21 | | 2.59 | 232.11 | 33.45 |
| Ruganda | 1.32 | | 3.29 | 240.01 | 41.08 | 1.48 | | 2.62 | 195.40 | 40.21 |
| Ruhengeri | 1.20 | | 1.87 | 229.97 | 24.45 | 0.77 | | 1.58 | 203.48 | 23.33 |
| Rutsiro | 0.07 | | 0.04 | 325.99 | 0.40 | 0.00 | | 0.08 | 271.26 | 0.93 |
| Rwamagana | 0.64 | | 1.31 | 208.54 | 18.83 | 0.61 | | 1.06 | 180.54 | 17.68 |
| Rwankeri | 1.64 | | 3.63 | 270.89 | 40.24 | 1.55 | | 3.55 | 234.30 | 45.42 |
| Save | 2.60 | ** | 5.59 | 251.52 | 66.65 | 2.60 | ** | 4.99 | 231.52 | 64.61 |

Table 4-31: Annual percentage change of projected very wet days (R95pTOT) for the period 2041 to 2070 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| Station | 2041 to 2070 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | Mean | %Δ | Test Z | α level | Q | Mean | %Δ |
| Bukora | -0.71 | | -2.36 | 239.61 | -29.55 | -0.84 | | -1.85 | 210.36 | -26.38 |
| Busogo | -0.89 | | -2.87 | 291.10 | -29.54 | -1.50 | | -3.20 | 253.75 | -37.88 |
| Butare | -1.71 | + | -3.27 | 268.70 | -36.47 | -1.32 | | -2.18 | 247.78 | -26.38 |
| Byimana | -1.86 | + | -4.81 | 308.05 | -46.89 | -1.46 | | -3.95 | 268.90 | -44.07 |
| Byumba | 0.36 | | 1.04 | 217.76 | 14.33 | 0.20 | | 0.40 | 185.20 | 6.55 |
| Cyinzuzi | 0.14 | | 0.44 | 364.49 | 3.66 | 0.07 | | 0.34 | 325.42 | 3.11 |
| Gabiro | 0.02 | | 0.11 | 224.81 | 1.44 | 0.20 | | 0.40 | 200.57 | 5.91 |
| Gatumba | -1.18 | | -3.98 | 312.89 | -38.21 | -1.14 | | -2.77 | 277.25 | -30.00 |
| Gikongoro | -2.18 | * | -3.65 | 248.11 | -44.19 | -1.71 | + | -3.10 | 221.24 | -42.04 |
| Gisanga | -1.86 | + | -4.81 | 308.05 | -46.89 | -1.46 | | -3.95 | 268.90 | -44.07 |
| Gisenyi | -1.03 | | -1.78 | 280.88 | -18.97 | -1.21 | | -2.19 | 251.94 | -26.07 |
| Gitarama | -1.86 | + | -4.81 | 308.05 | -46.89 | -1.46 | | -3.95 | 268.90 | -44.07 |
| Gitega | 0.14 | | 0.44 | 364.49 | 3.66 | 0.07 | | 0.34 | 325.42 | 3.11 |
| Kamembe | -0.07 | | -0.61 | 294.34 | -6.18 | -0.29 | | -0.89 | 261.75 | -10.15 |
| Kanombe | 0.14 | | 0.44 | 364.49 | 3.66 | 0.07 | | 0.34 | 325.42 | 3.11 |
| Kansi | -1.87 | + | -3.03 | 264.65 | -34.33 | -1.34 | | -2.44 | 243.98 | -30.04 |
| Kawangire | 0.16 | | 0.33 | 241.74 | 4.14 | 0.29 | | 0.70 | 211.61 | 9.92 |
| Kibungo | -0.93 | | -2.16 | 223.76 | -28.96 | -0.79 | | -1.94 | 188.43 | -30.81 |
| Masaka | 0.18 | | 0.34 | 317.80 | 3.18 | 0.21 | | 0.70 | 277.69 | 7.56 |
| Muganza | -1.86 | + | -5.70 | 356.88 | -47.92 | -1.86 | + | -5.94 | 355.66 | -50.10 |
| Mushubi | -2.18 | * | -5.43 | 317.49 | -51.26 | -1.98 | * | -5.27 | 306.78 | -51.55 |
| Ntaruka | -0.43 | | -1.45 | 255.06 | -17.11 | -0.04 | | -0.36 | 219.27 | -4.95 |
| Ntendezi | -2.28 | * | -6.49 | 365.09 | -53.31 | -2.28 | * | -6.49 | 363.40 | -53.56 |
| Nyagatare | 0.43 | | 0.52 | 226.66 | 6.93 | 0.21 | | 0.52 | 212.29 | 7.40 |
| Nyamata | -1.25 | | -3.02 | 287.56 | -31.56 | -0.91 | | -2.33 | 246.89 | -28.26 |
| Rubengera | -2.25 | * | -4.78 | 236.79 | -60.54 | -2.07 | * | -3.84 | 220.91 | -52.09 |
| Ruganda | -1.36 | | -3.39 | 268.41 | -37.88 | -1.21 | | -2.75 | 236.52 | -34.88 |
| Ruhengeri | -0.93 | | -1.66 | 254.00 | -19.59 | -0.64 | | -1.45 | 226.12 | -19.21 |
| Rutsiro | -0.95 | | -2.89 | 331.91 | -26.13 | -2.21 | * | -4.51 | 278.31 | -48.57 |
| Rwamagana | 0.16 | | 0.33 | 241.74 | 4.14 | 0.29 | | 0.70 | 211.61 | 9.92 |
| Rwankeri | -0.89 | | -2.87 | 291.10 | -29.54 | -1.50 | | -3.20 | 253.75 | -37.88 |
| Save | -1.71 | + | -3.27 | 268.70 | -36.47 | -1.32 | | -2.18 | 247.78 | -26.38 |

Table 4-32: Annual percentage change of projected very wet days (R95pTOT) for the period 2071 to 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| Station | 2071-2100 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | Mean | %Δ | Test Z | α level | Q | Mean | %Δ |
| Bukora | 1.21 | | 3.98 | 321.98 | 37.06 | 1.09 | | 3.68 | 295.23 | 37.34 |
| Busogo | 0.80 | | 2.41 | 404.13 | 17.92 | 0.86 | | 2.57 | 376.88 | 20.49 |
| Butare | 1.68 | + | 4.63 | 363.86 | 38.20 | 1.64 | | 5.62 | 333.49 | 50.59 |
| Byimana | 1.43 | | 4.53 | 458.41 | 29.64 | 1.75 | + | 4.86 | 407.37 | 35.79 |
| Byumba | 1.68 | + | 3.98 | 268.04 | 44.49 | 1.89 | + | 5.14 | 244.88 | 62.98 |
| Cyinzuzi | 1.71 | + | 6.45 | 457.88 | 42.26 | 1.66 | + | 7.53 | 417.67 | 54.09 |
| Gabiro | 1.93 | + | 7.12 | 302.69 | 70.53 | 1.96 | * | 6.40 | 269.09 | 71.30 |
| Gatumba | 0.93 | | 3.32 | 460.01 | 21.63 | 1.14 | | 3.82 | 404.01 | 28.37 |
| Gikongoro | 1.18 | | 3.42 | 361.68 | 28.34 | 1.39 | | 3.87 | 324.88 | 35.75 |
| Gisanga | 1.43 | | 4.53 | 458.41 | 29.64 | 1.75 | + | 4.86 | 407.37 | 35.79 |
| Gisenyi | 0.50 | | 1.80 | 392.83 | 13.75 | 0.59 | | 3.09 | 364.06 | 25.47 |
| Gitarama | 1.43 | | 4.53 | 458.41 | 29.64 | 1.75 | + | 4.86 | 407.37 | 35.79 |
| Gitega | 1.71 | + | 6.45 | 457.88 | 42.26 | 1.66 | + | 7.53 | 417.67 | 54.09 |
| Kamembe | 0.54 | | 1.44 | 361.78 | 11.94 | 0.39 | | 1.23 | 335.27 | 11.05 |
| Kanombe | 1.71 | + | 6.45 | 457.88 | 42.26 | 1.66 | + | 7.53 | 417.67 | 54.09 |
| Kansi | 1.57 | | 4.48 | 353.75 | 37.98 | 1.71 | + | 5.21 | 327.19 | 47.80 |
| Kawangire | 1.64 | | 6.64 | 316.01 | 63.04 | 2.07 | * | 7.53 | 288.86 | 78.25 |
| Kibungo | 1.14 | | 3.13 | 284.33 | 32.97 | 0.86 | | 2.77 | 253.24 | 32.78 |
| Masaka | 1.89 | + | 7.99 | 400.44 | 59.89 | 1.93 | + | 8.52 | 371.42 | 68.80 |
| Muganza | 1.28 | | 4.93 | 383.09 | 38.63 | 1.32 | | 5.12 | 381.88 | 40.22 |
| Mushubi | 0.68 | | 1.28 | 365.02 | 10.48 | 0.68 | | 1.37 | 361.71 | 11.36 |
| Ntaruka | 0.64 | | 2.41 | 321.05 | 22.49 | 0.57 | | 1.97 | 289.79 | 20.36 |
| Ntendezi | 0.82 | | 1.53 | 398.39 | 11.55 | 0.82 | | 1.53 | 398.39 | 11.55 |
| Nyagatare | 1.07 | | 2.56 | 256.84 | 29.84 | 1.07 | | 2.75 | 242.53 | 33.98 |
| Nyamata | 1.14 | | 5.14 | 365.49 | 42.18 | 1.68 | + | 5.84 | 329.97 | 53.10 |
| Rubengera | 0.32 | | 0.67 | 289.16 | 7.00 | 0.43 | | 0.80 | 279.65 | 8.58 |
| Ruganda | 0.86 | | 2.58 | 392.37 | 19.75 | 0.43 | | 1.66 | 345.59 | 14.41 |
| Ruhengeri | 0.43 | | 1.60 | 312.89 | 15.34 | 0.61 | | 1.91 | 287.19 | 19.92 |
| Rutsiro | 0.75 | | 3.62 | 459.82 | 23.64 | 1.00 | | 3.48 | 421.80 | 24.75 |
| Rwamagana | 1.64 | | 6.64 | 316.01 | 63.04 | 2.07 | * | 7.53 | 288.86 | 78.25 |
| Rwankeri | 0.80 | | 2.41 | 404.13 | 17.92 | 0.86 | | 2.57 | 376.88 | 20.49 |
| Save | 1.68 | + | 4.63 | 363.86 | 38.20 | 1.64 | | 5.62 | 333.49 | 50.59 |

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#### 4.6.2.3 Consecutive dry days (CDD)

Table 4-32 indicates that the trend of projected consecutive dry days for the period 2021-2050 ranges from +36.55% or +0.57 days per year (significant, $\alpha \leq 0.05$) in Rutsiro to -6.9% or -0.17 days per year (not significant, $\alpha > 0.05$) in Kawangire under RCP 4.5 w/m$^2$ and ranges from +91.82% or +2.22 days per year (significant, $\alpha \leq 0.05$) in Kibungo to -7.78% or -0.07 days per year (not significant, $\alpha > 0.05$) in Ruhengeri under RCP 8.5 w/m$^2$. Notably, projected consecutive dry days are expected to increase under RCP 4.5 w/m$^2$ (Table 4-32) in many parts of Rwanda and highest around parts of Ngoma, Bugesera, Kayonza and Musanze and Nyamagabe, while the areas of Rwamagana and Kamonyi Gatsibo and Nyagatare which indicated a decreasing trend in number of consecutive dry days under RCP 4.5. A projected increase in most parts of the country extending from eastern to central, southern, and south-western while the northern highland extending to north-eastern indicated a decreasing trend in consecutive dry days under RCP 8.5 w/m$^2$ for the period 2021-2050.

In addition, Table 4-33 indicates that projected consecutive dry days for the period 2041-2070 ranged from +17.97% or +0.22 days per year (not significant, $\alpha > 0.05$) in Nyagatare to -37.9% or -0.71 days per year (significant, $\alpha \leq 0.05$) in Ntendezi under RCP 4.5 w/m$^2$ and ranges from +29.88% or +0.58 days per year (not significant, $\alpha > 0.05$) in Gikongoro to -28.8% or -0.52 days per year (significant, $\alpha \leq 0.05$) in Ruganda under RCP 8.5 w/m$^2$. Notably, a decreasing trend over the southern, south-western, and south-eastern while Kigali city, northern and north-eastern show an increasing trend under RCP 4.5. A decreasing trend was also indicated in the areas of the northern highland (Musanze, Ngororero, Gakenke, Burera and Nyabihu), areas of the eastern part (Kayonza and eastern of Gatsibo), while the rest of the country shows an increasing trend under RCP 8.5 w/m$^2$ for the period of 2041-2070.

Projected consecutive dry days for the period 2071-2100 ranges from +49.39% or +0.46 days per year (not significant, $\alpha > 0.05$) in Cyinzuzi to -41.5% or -1.13 days per year (significant, $\alpha \leq 0.05$) in Muganza under RCP 4.5 w/m$^2$ and ranged from +87.98% or +1.27 days per year (significant, $\alpha \leq 0.05$) in Ntaruka to 21.42% or +0.61 days per year (not significant, $\alpha > 0.05$) in Save under RCP 8.5 w/m$^2$ (Table 4-35) Furthermore, the projected consecutive dry days for the period 2071-2100 showed an increasing trend over the western, northern highland and some parts of the central with an increasing magnitude of 5% to 60%, while the eastern (Kayonza and Kirehe), Nyaruguru, Kamonyi and Nyagatare areas show a decreasing trend under RCP 4.5 w/m$^2$ whereas a projected increase is expected under RCP 8.5 w/m$^2$ for the period 2071-2100. Overall, the annual percentage change shows highly variable changes in projected very wet days under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

Table 4-33: Annual percentage change of projected consecutive dry days (CDD) for the period 2021 to 2050 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| | 2021-2050 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | Mean | %Δ | Test Z | Signific. | Q | Mean | %Δ |
| Bukora | 1.73 | + | 0.90 | 80.13 | 33.69 | 3.66 | *** | 2.25 | 79.20 | 85.23 |
| Busogo | 0.39 | | 0.17 | 47.33 | 10.56 | 1.43 | | 0.30 | 31.10 | 28.94 |
| Butare | 0.18 | | 0.07 | 56.10 | 3.82 | 2.84 | ** | 1.33 | 69.40 | 57.64 |
| Byimana | 0.96 | | 0.38 | 61.23 | 18.84 | 1.77 | + | 0.69 | 59.03 | 34.94 |
| Byumba | -0.05 | | 0.00 | 31.83 | 0.00 | 1.65 | + | 0.56 | 50.63 | 32.92 |
| Cyinzuzi | 0.29 | | 0.07 | 27.97 | 7.15 | 1.59 | | 0.60 | 45.30 | 39.74 |
| Gabiro | -0.21 | | -0.08 | 44.93 | -5.14 | 2.47 | * | 1.26 | 62.23 | 60.70 |
| Gatumba | 1.50 | | 0.25 | 29.20 | 25.68 | 1.38 | | 0.45 | 40.23 | 33.55 |
| Gikongoro | -0.16 | | 0.00 | 72.70 | 0.00 | 1.62 | | 0.52 | 50.23 | 31.16 |
| Gisanga | -0.04 | | 0.00 | 66.57 | 0.00 | 1.77 | + | 0.69 | 59.03 | 34.94 |
| Gisenyi | -0.07 | | 0.00 | 50.60 | 0.00 | 1.29 | | 0.30 | 27.23 | 33.05 |
| Gitarama | -0.04 | | 0.00 | 66.57 | 0.00 | 1.77 | + | 0.69 | 59.03 | 34.94 |
| Gitega | 0.39 | | 0.17 | 47.33 | 10.56 | 1.59 | | 0.60 | 45.30 | 39.74 |
| Kamembe | 0.20 | | 0.05 | 43.40 | 3.29 | 1.82 | + | 0.60 | 40.03 | 44.96 |
| Kanombe | 0.39 | | 0.17 | 47.33 | 10.56 | 1.59 | | 0.60 | 45.30 | 39.74 |
| Kansi | -0.14 | | -0.05 | 75.17 | -2.10 | 2.34 | * | 1.13 | 67.73 | 49.83 |
| Kawangire | -0.23 | | -0.17 | 72.47 | -6.90 | 2.27 | * | 1.16 | 59.37 | 58.51 |
| Kibungo | 1.04 | | 0.67 | 84.33 | 23.72 | 3.62 | *** | 2.22 | 72.53 | 91.91 |
| Masaka | 0.29 | | 0.17 | 56.40 | 9.25 | 1.39 | | 0.50 | 52.57 | 28.54 |
| Muganza | 0.07 | | 0.00 | 85.60 | 0.00 | 0.46 | | 0.23 | 75.97 | 9.11 |
| Mushubi | -0.05 | | 0.00 | 58.90 | 0.00 | 1.91 | + | 0.59 | 41.73 | 42.48 |
| Ntaruka | 1.97 | * | 0.29 | 24.70 | 34.70 | 0.00 | | 0.00 | 35.07 | 0.00 |
| Ntendezi | 1.11 | | 0.52 | 62.03 | 25.33 | 0.43 | | 0.14 | 29.83 | 13.87 |
| Nyagatare | 0.80 | | 0.27 | 36.33 | 22.02 | 0.27 | | 0.10 | 42.83 | 7.00 |
| Nyamata | 1.34 | | 0.79 | 82.43 | 28.59 | 1.43 | | 0.50 | 57.07 | 26.29 |
| Rubengera | 0.16 | | 0.12 | 60.00 | 5.88 | 2.41 | * | 0.84 | 53.10 | 47.58 |
| Ruganda | 0.84 | | 0.11 | 25.67 | 12.99 | 2.45 | * | 1.00 | 47.67 | 62.94 |
| Rugobagoba | -0.04 | | 0.00 | 66.57 | 0.00 | 1.77 | + | 0.69 | 59.03 | 34.94 |
| Ruhengeri | 0.48 | | 0.17 | 40.60 | 12.32 | -0.45 | | -0.07 | 27.53 | -7.78 |
| Rutsiro | 1.59 | | 0.57 | 46.90 | 36.55 | 1.70 | + | 0.63 | 44.00 | 42.93 |
| Rwamagana | -0.12 | | -0.08 | 57.83 | -4.32 | 1.59 | | 0.60 | 45.30 | 39.74 |
| Rwankeri | 1.50 | | 0.25 | 29.20 | 25.68 | 1.59 | | 0.35 | 36.73 | 28.82 |
| Save | -0.21 | | -0.08 | 76.47 | -3.02 | 2.84 | ** | 1.33 | 69.40 | 57.64 |

Table 4-34: Annual percentage change of projected consecutive dry (CDD) days for the period 2041 to 2070 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| | 2041 to 2070 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | Mean | %Δ | Test Z | α level | Q | Mean | %Δ |
| Bukora | -0.70 | | -0.43 | 80.87 | -16.13 | 0.87 | | 0.52 | 92.60 | 16.90 |
| Busogo | 0.46 | | 0.13 | 45.03 | 8.33 | -0.86 | | -0.25 | 32.53 | -23.05 |
| Butare | -0.29 | | -0.13 | 53.37 | -7.03 | -0.37 | | -0.31 | 73.93 | -12.68 |
| Byimana | -1.20 | | -0.48 | 54.57 | -26.39 | 0.52 | | 0.16 | 64.83 | 7.31 |
| Byumba | 0.52 | | 0.14 | 35.57 | 12.05 | -0.21 | | -0.11 | 55.33 | -6.02 |
| Cyinzuzi | 0.46 | | 0.15 | 30.00 | 15.38 | 0.36 | | 0.12 | 50.87 | 6.81 |
| Gabiro | 0.82 | | 0.19 | 42.53 | 13.56 | -0.09 | | -0.04 | 71.87 | -1.49 |
| Gatumba | 0.00 | | 0.00 | 34.07 | 0.00 | -0.23 | | -0.09 | 42.67 | -6.39 |
| Gikongoro | -1.09 | | -0.48 | 67.43 | -21.28 | 1.29 | | 0.58 | 57.93 | 29.88 |
| Gisanga | -0.48 | | -0.23 | 62.30 | -10.94 | 0.52 | | 0.16 | 64.83 | 7.31 |
| Gisenyi | 0.29 | | 0.09 | 48.60 | 5.61 | -0.18 | | 0.00 | 26.00 | 0.00 |
| Gitarama | -0.48 | | -0.23 | 62.30 | -10.94 | 0.52 | | 0.16 | 64.83 | 7.31 |
| Gitega | 0.46 | | 0.13 | 45.03 | 8.33 | 0.36 | | 0.12 | 50.87 | 6.81 |
| Kamembe | -0.32 | | -0.06 | 40.90 | -4.58 | 0.52 | | 0.18 | 44.67 | 11.85 |
| Kanombe | 0.46 | | 0.13 | 45.03 | 8.33 | 0.36 | | 0.12 | 50.87 | 6.81 |
| Kansi | -1.43 | | -0.61 | 70.67 | -25.94 | -0.05 | | 0.00 | 72.20 | 0.00 |
| Kawangire | -0.32 | | -0.13 | 66.97 | -5.60 | 0.00 | | 0.00 | 68.80 | 0.00 |
| Kibungo | -1.54 | | -0.67 | 80.87 | -24.73 | 0.46 | | 0.31 | 81.77 | 11.29 |
| Masaka | 0.00 | | 0.00 | 52.50 | 0.00 | 0.34 | | 0.12 | 56.17 | 6.16 |
| Muganza | -1.53 | | -1.00 | 80.93 | -37.07 | 0.62 | | 0.33 | 77.87 | 12.84 |
| Mushubi | -0.34 | | -0.14 | 54.20 | -7.91 | 0.55 | | 0.26 | 47.07 | 16.77 |
| Ntaruka | 0.38 | | 0.11 | 28.37 | 11.13 | -0.13 | | 0.00 | 37.37 | 0.00 |
| Ntendezi | -1.34 | | -0.71 | 56.53 | -37.90 | 0.68 | | 0.17 | 30.97 | 16.15 |
| Nyagatare | 1.00 | | 0.22 | 37.10 | 17.97 | 0.63 | | 0.20 | 46.33 | 12.95 |
| Nyamata | -1.36 | | -0.77 | 76.93 | -30.00 | 1.82 | + | 0.55 | 65.37 | 25.03 |
| Rubengera | -0.29 | | -0.10 | 54.90 | -5.20 | 0.66 | | 0.27 | 62.67 | 12.77 |
| Ruganda | 0.05 | | 0.00 | 29.07 | 0.00 | -1.05 | | -0.52 | 54.57 | -28.80 |
| Rugobagoba | -0.48 | | -0.23 | 62.30 | -10.94 | 0.52 | | 0.16 | 64.83 | 7.31 |
| Ruhengeri | -0.13 | | 0.00 | 39.90 | 0.00 | -0.38 | | -0.09 | 26.57 | -10.27 |
| Rutsiro | -0.43 | | -0.18 | 46.33 | -11.77 | -0.73 | | -0.31 | 49.13 | -18.79 |
| Rwamagana | -0.04 | | 0.00 | 52.77 | 0.00 | 0.36 | | 0.12 | 50.87 | 6.81 |
| Rwankeri | 0.00 | | 0.00 | 34.07 | 0.00 | -0.55 | | -0.19 | 38.90 | -14.69 |
| Save | -1.32 | | -0.61 | 71.03 | -25.81 | -0.37 | | -0.31 | 73.93 | -12.68 |

Table 4-35: Annual percentage change of projected consecutive dry days (CDD) for the period 2071 to 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| Station | 2071-2100 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | Mean | %Δ | Test Z | α level | Q | Mean | %Δ |
| Bukora | -0.48 | | -0.36 | 75.50 | -14.45 | 2.20 | * | 1.48 | 94.73 | 46.87 |
| Busogo | 0.00 | | 0.00 | 44.17 | 0.00 | 2.20 | * | 0.67 | 41.43 | 48.27 |
| Butare | 0.68 | | 0.30 | 52.03 | 17.55 | 1.20 | | 0.61 | 85.60 | 21.42 |
| Byimana | 0.45 | | 0.15 | 49.57 | 9.08 | 2.45 | * | 1.05 | 73.83 | 42.77 |
| Byumba | 1.77 | + | 0.32 | 28.97 | 33.14 | 2.07 | * | 1.22 | 65.27 | 55.96 |
| Cyinzuzi | 1.81 | + | 0.46 | 28.03 | 49.39 | 2.73 | ** | 1.33 | 57.77 | 69.24 |
| Gabiro | -0.57 | | -0.12 | 42.70 | -8.27 | 1.04 | | 0.67 | 74.40 | 26.88 |
| Gatumba | 0.41 | | 0.05 | 28.67 | 4.76 | 2.27 | * | 1.14 | 54.23 | 62.86 |
| Gikongoro | 0.04 | | 0.00 | 66.70 | 0.00 | 1.95 | + | 0.86 | 68.10 | 37.76 |
| Gisanga | -0.12 | | -0.08 | 61.70 | -3.74 | 2.45 | * | 1.05 | 73.83 | 42.77 |
| Gisenyi | -0.30 | | -0.08 | 41.67 | -6.00 | 2.16 | * | 0.69 | 33.70 | 61.63 |
| Gitarama | -0.12 | | -0.08 | 61.70 | -3.74 | 2.45 | * | 1.05 | 73.83 | 42.77 |
| Gitega | 0.00 | | 0.00 | 44.17 | 0.00 | 2.73 | ** | 1.33 | 57.77 | 69.24 |
| Kamembe | -0.05 | | 0.00 | 38.07 | 0.00 | 1.41 | | 0.71 | 53.93 | 39.73 |
| Kanombe | 0.00 | | 0.00 | 44.17 | 0.00 | 2.73 | ** | 1.33 | 57.77 | 69.24 |
| Kansi | -0.18 | | -0.08 | 70.37 | -3.55 | 1.29 | | 0.62 | 84.33 | 21.89 |
| Kawangire | 0.23 | | 0.17 | 67.33 | 7.43 | 1.41 | | 1.00 | 71.07 | 42.21 |
| Kibungo | -0.88 | | -0.40 | 81.20 | -14.78 | 1.84 | + | 1.26 | 76.07 | 49.73 |
| Masaka | 0.00 | | 0.00 | 50.80 | 0.00 | 2.07 | * | 1.22 | 65.27 | 55.96 |
| Muganza | -1.70 | + | -1.13 | 81.33 | -41.50 | 2.29 | * | 1.40 | 100.13 | 41.94 |
| Mushubi | 0.68 | | 0.30 | 52.03 | 17.55 | 0.79 | | 0.45 | 57.03 | 23.91 |
| Ntaruka | 0.61 | | 0.07 | 21.73 | 9.86 | 2.91 | ** | 1.27 | 43.40 | 87.98 |
| Ntendezi | 0.91 | | 0.35 | 49.70 | 21.13 | 1.52 | | 0.70 | 42.30 | 49.65 |
| Nyagatare | -0.68 | | -0.24 | 37.23 | -19.34 | 2.11 | * | 0.88 | 52.33 | 50.16 |
| Nyamata | -0.25 | | -0.17 | 74.97 | -6.67 | 1.95 | + | 1.14 | 75.37 | 45.49 |
| Rubengera | 0.48 | | 0.25 | 52.03 | 14.41 | 2.00 | * | 1.11 | 70.30 | 47.17 |
| Ruganda | 1.40 | | 0.20 | 23.90 | 25.10 | 1.98 | * | 1.06 | 67.43 | 47.27 |
| Rugobagoba | -0.12 | | -0.08 | 61.70 | -3.74 | 2.45 | * | 1.05 | 73.83 | 42.77 |
| Ruhengeri | 0.48 | | 0.14 | 35.53 | 12.06 | 2.36 | * | 0.64 | 32.80 | 58.80 |
| Rutsiro | 1.48 | | 0.46 | 37.30 | 36.86 | 2.43 | * | 1.40 | 62.93 | 66.74 |
| Rwamagana | -0.05 | | 0.00 | 51.27 | 0.00 | 2.73 | ** | 1.33 | 57.77 | 69.24 |
| Rwankeri | 0.41 | | 0.05 | 28.67 | 4.76 | 2.09 | * | 1.05 | 49.73 | 63.50 |
| Save | -0.20 | | -0.11 | 70.40 | -4.73 | 1.20 | | 0.61 | 85.60 | 21.42 |

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### 4.6.3 *Spatial analysis of projected precipitation*

Spatial analysis of seasonal (JF, MAM, JJA and SOND) and annual precipitation for the period 2021-2100 under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda is presented in the subsequent sections.

#### 4.6.3.1 January-February (JF) Season

Figure 4-7 (a) shows a projected JF precipitation under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$, which is decreasing from the southwest (Nyaruguru, Nyamagabe and Rusizi) to northeast for the period 2021-2050 with highest amounts between 300 and 600mm in Nyaruguru and Nyamasheke district and lowest quantities between 50 to 150mm around Nyagatare, Kayonza and Burera district. Similar projected precipitation distribution patterns are observed f for the period 2041-2070 (Figure 4-7b) and 2071-2100 (Figure 4-7c) under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$. Overall, the projected JF precipitation is expected to decrease from the southwest (300-450mm) to the northeast (50-150mm).

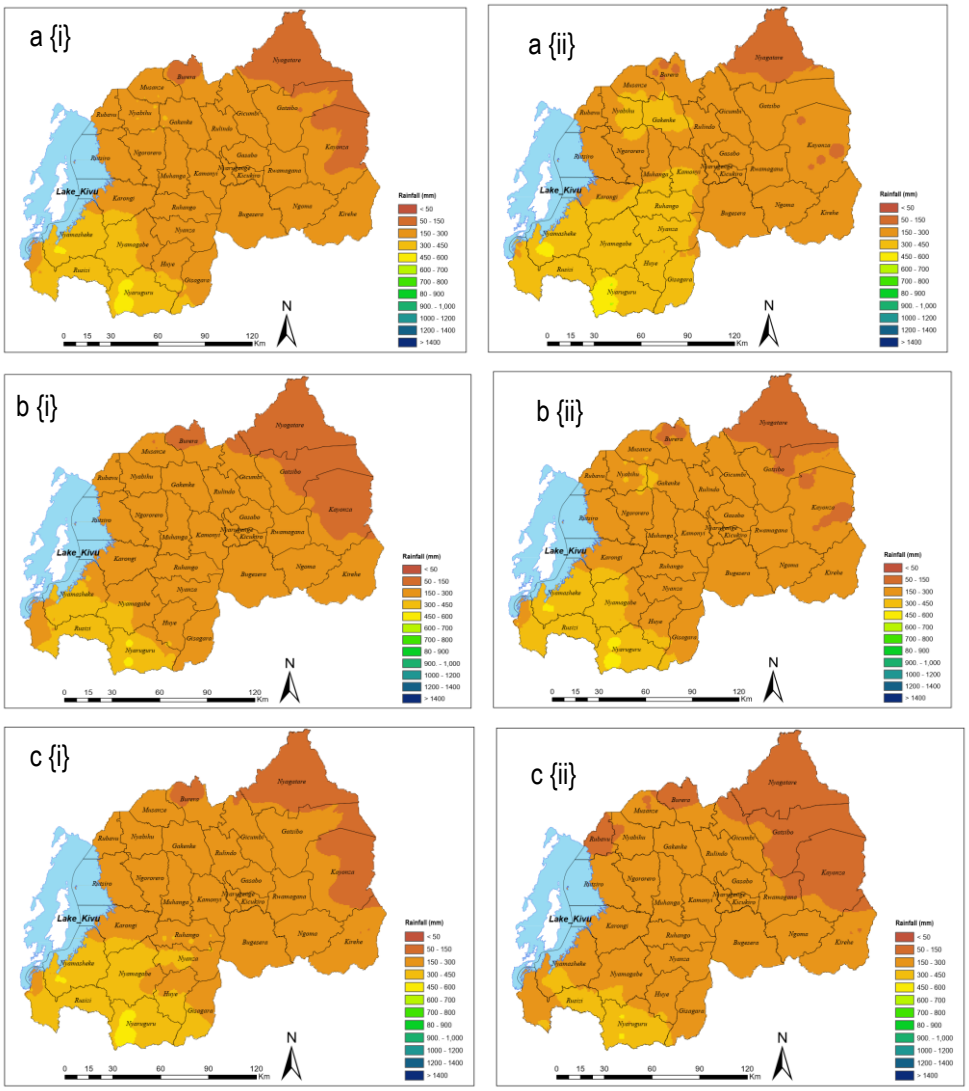


Figure 4-7: Projected JF precipitation for the period a) 2021-2050, b) 2041-2070, and c) 2071-2100 under i) RCP 4.5 w/m$^2$ and ii) RCP 8.5 w/m$^2$ over Rwanda.

### 4.6.3.2 March-April-May (MAM) Season

Projected MAM precipitation for the period 2021-2050 (Figure 4-8a), 2041-2070 (Figure 4-8b) and 2071-2100 (Figure 4-8c) ranges between 300 and 700mm for both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$. However, the MAM seasonal totals are expected to decrease in most regions towards 2100, especially most parts of Eastern parts, Rubavu, Rusizi, Karongi and the southern region more reduction is expected in the areas of Kayonza, and Kirehe, both under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ The central parts toward the North-western parts maintain the rainfall ranging between 450 to 600mm, under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$

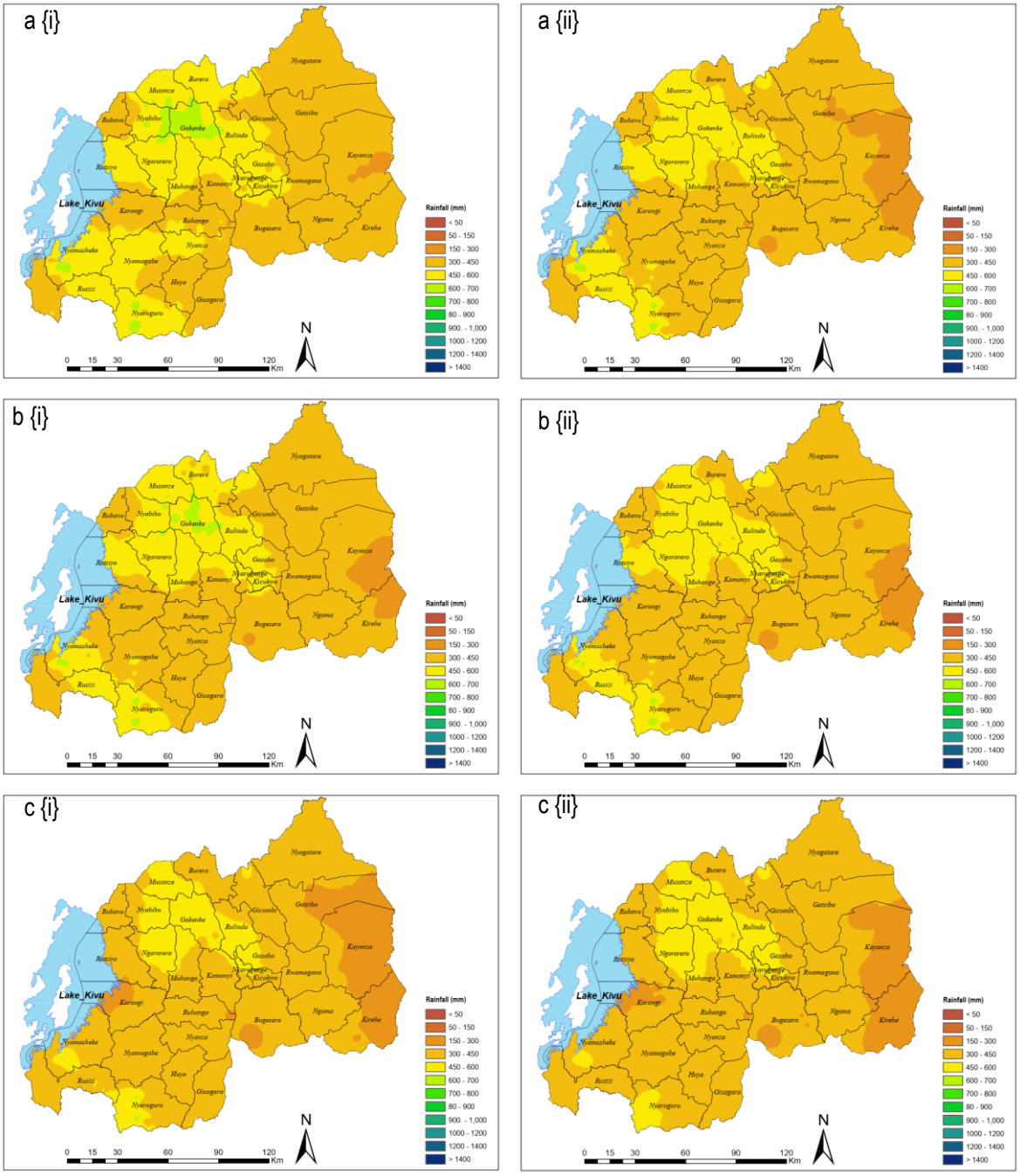


Figure 4-8: Projected MAM precipitation for the period a) 2021-2050, b) 2041-2070 and c) 2071-2100 under i) RCP 4.5 w/m$^2$ and ii) RCP 8.5 w/m$^2$ over Rwanda

#### 4.6.3.3 June, July August (JJA) Season

A general projected decrease in rainfall during the JJA season for the period 2021-2050 (Figure 4-9a), 2041-2070 (Figure 4-9b) and 2071-2100 (Figure 4-9c) from northwest to southeast.and range between <50mm and 150mm for both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ and decreased

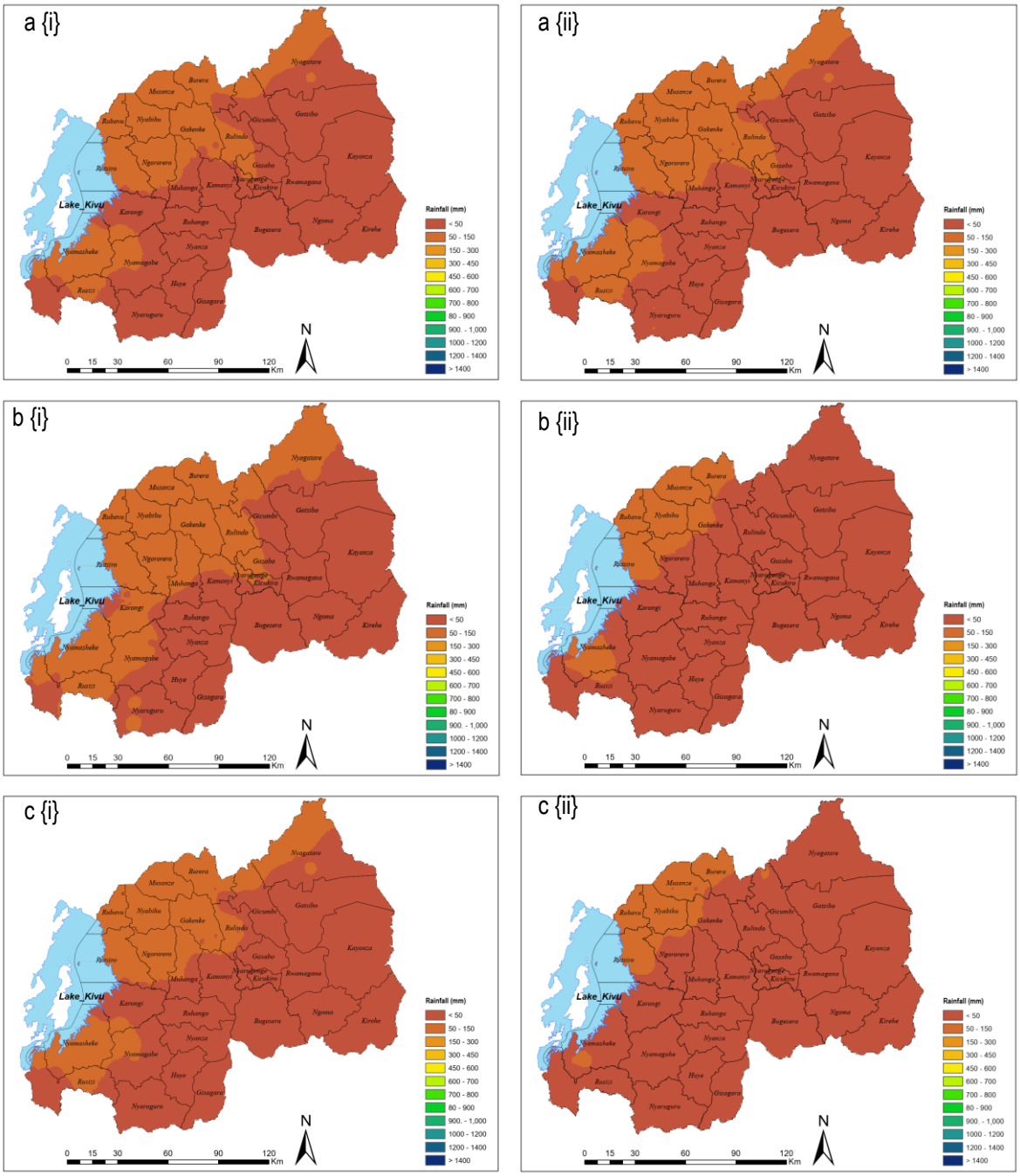


Figure 4-9: Projected JJA precipitation for the period a) 2021-2050, b) 2041-2070 and c) 2071-2100 under i) RCP 4.5 w/m$^2$ and ii) RCP 8.5 w/m$^2$ over Rwanda

#### 4.6.3.4 September-October-November-December (SOND) Season

Projected SOND precipitation for the period 2021-2050 (Figure 4-10a), 2041-2070 (Figure 4-10b) and 2071-2100 (Figure 4-10c) ranges between 300mm and 1000mm for both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ and expected to decrease from the southwest (areas around Nyungwe National park, Nyaruguru, Nyamagabe, Nyamasheke, Rusizi) extending to the northern highland and increasing towards the central plateau and the east, where most parts of the east are projected to have rainfall ranging from 300 to 600mm.

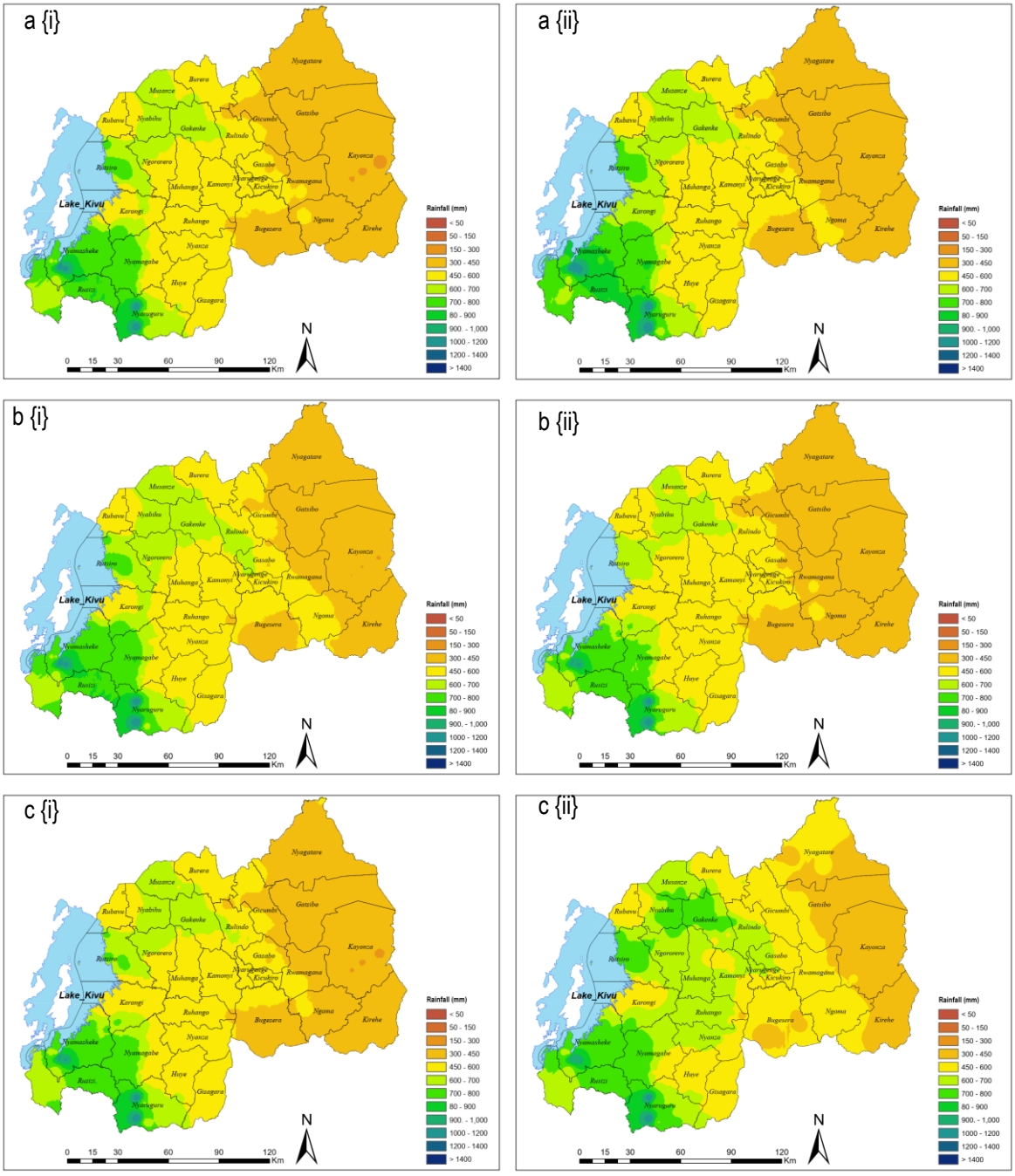


Figure 4-10: Projected SOND precipitation for the period a) 2021-2050, b) 2041-2070, and c) 2071-2100 under i) RCP 4.5 w/m$^2$ and ii) RCP 8.5 w/m$^2$ over Rwanda.

#### 4.6.3.5 Annual precipitation

Projected annual precipitation for the period 2021-2050 (Figure 4-11a), 2041-2070 (Figure 4-11b) and 2071-2100 (Figure 4-11c) ranges between 700mm and >1400mm for both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ and expected to decrease from southwest towards the east. For both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$, rainfall of more than 1400mm is projected mainly in mountain areas of southwest parts closer to Nyungwe National Park, northern and North-western parts, including Rulindo and Gakenke. The western part is also expected to receive rainfall ranging between 1200 to 1400mm. A lower amount of rain is expected in the eastern areas of Gatsibo, Kayonza and Kirehe Districts

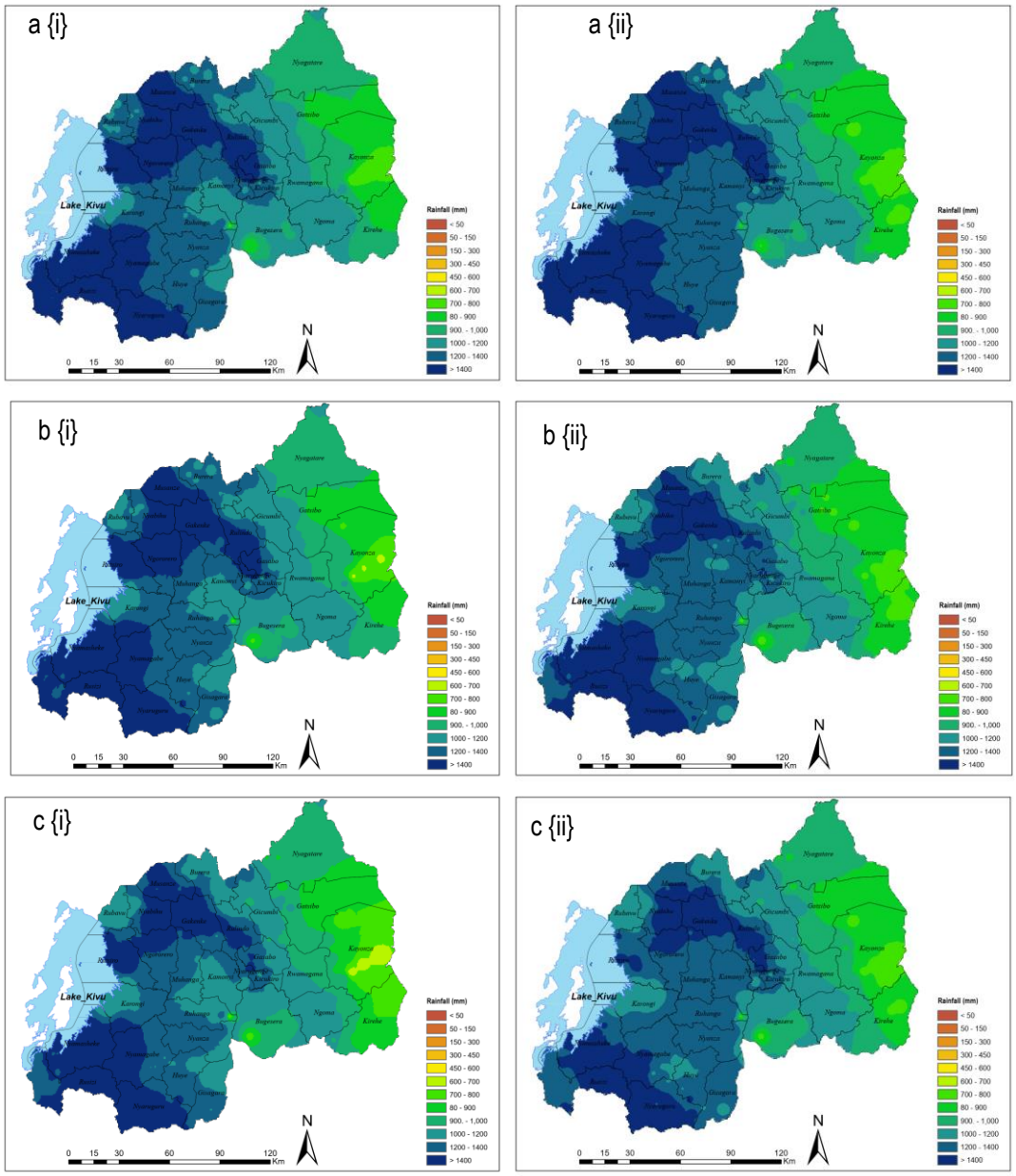


Figure 4-11: Projected annual precipitation for the period a) 2021-2050, b) 2041-2070 and c) 2071-2100 under i) RCP 4.5 w/m$^2$ and ii) RCP 8.5 w/m$^2$ over Rwanda.

### 4.6.4 *Spatial analysis of projected changes in precipitation*

The subsequent sections present the seasonal (JF, MAM, JJA and SOND) and annual changes of projected climate (2021-2100) against baseline (1981-2010) under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

#### 4.6.4.1 January February (JF) Season

Figure 4-12 indicates thats the JF during 2021-2050 is projected to receive more rainfall, increasing by 5 to 60% relative to the reference period over western, southwestern, south-eastern, and highland areas over northern parts of Rwanda and reducing eastwards by 5 to 30% and 10 to 30% under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ respectively In addition, Figure 4-12 shows that more areas will experience negative changes in precipitation for the period 2041-2070 under RCP 4.5 w/m$^2$ compared to RCP 8.5 w/m$^2$. Reduced rainfall is expected in the central plateau, southern areas, northern areas surrounding Volcano National Park and eastern region RCP 4.5 w/m$^2$. However, the south-eastern part (eastern Ngoma and western Kirehe), northern highland (Gakenke, Nyabihu, Ngororero, Rutsiro), and south-western part around Nyungwe National Park indicates 0 to 60% increase rainfall. Precipitation is expected to increase approximately 0 to 90% in most parts of the country with substantial changes in the southern, western, northern highland and regions of the eastern (Ngoma, Kayonza and Kirehe) compared to the central and north-eastern parts that are expected to receive a reduction in rainfall of ~ 5 to 30% under RCP 8.5 w/m$^2$.

The changes in projected precipitation will be more positive under RCP 4.5 w/m$^2$ for the period 2071-2100, whereas more negative changes are expected under RCP 8.5 w/m$^2$. More rainfall will be expected in the eastern and central parts with a reduced rainfall with a percentage change as a magnitude of the mean of 5 to 30%. In contrast, the southern, western, and northern areas are projected t to receive an increase in rainfall of ~0 to 60% of the mean of under RCP 4.5 w/m$^2$. The increasing trend in rainfall is expected over a few parts of the country (Gakenke, Nyaruguru and central Nyamagabe) with reduced rain with a percentage change as a magnitude of the mean of 10 to 30%. In contrast, the rest of the country is expected to receive a reduced rainfall amount of – 5 to -60%. Under RCP 4.5 w/m$^2$ for 2021 to 2050, 2041 to 2070 and 2071 to 2100, most eastern parts are projected to have a negative change, especially Kayonza, Kirehe and regions Nyagatare and Gatsibo bordering Akagera National Park.

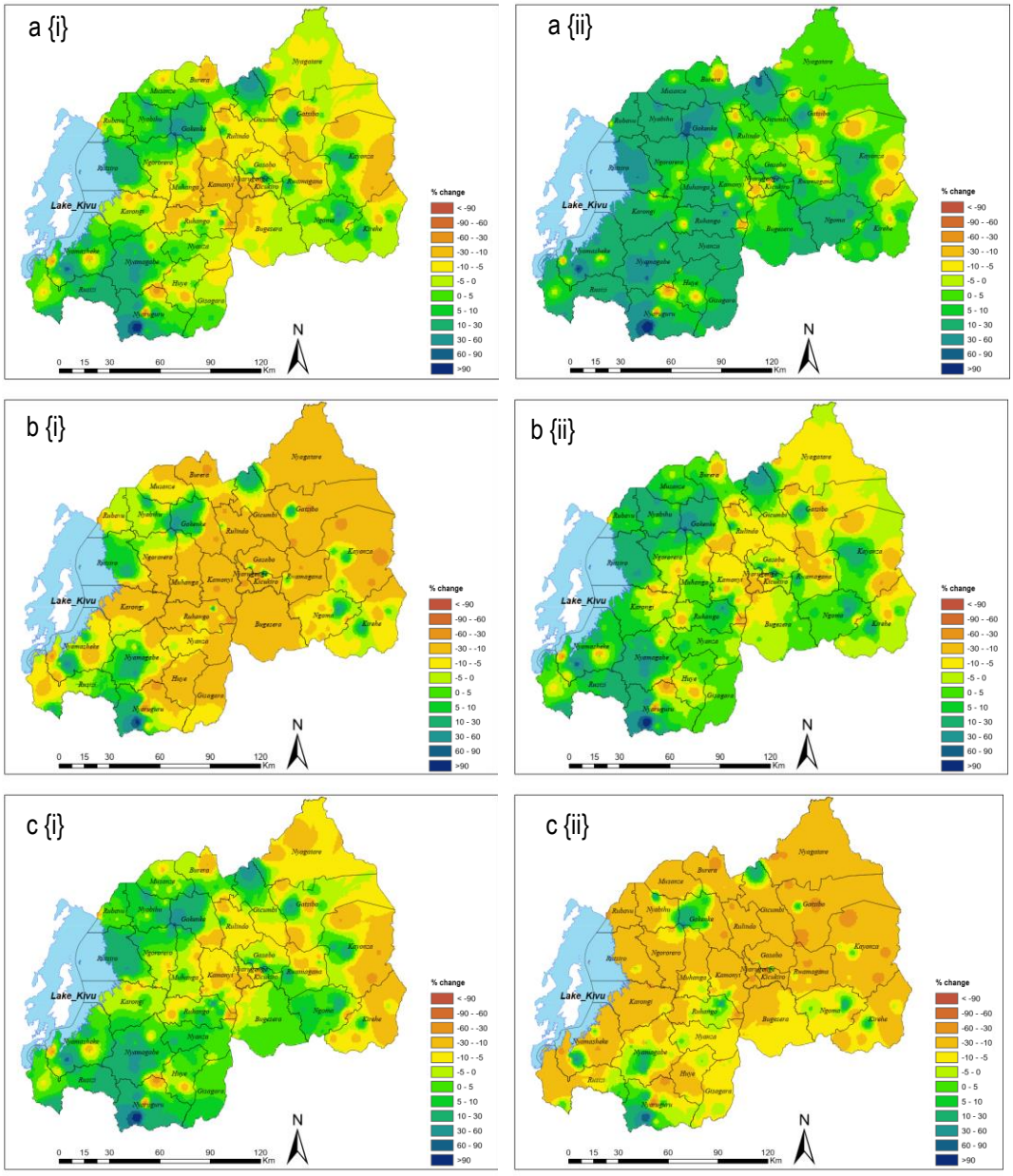


Figure 4-12: Projected precipitation changes (a) 2021-2050, b) 2041-2070 and c) 2071-2100 ) relative to the reference period (1981-2010) during JF season under (i)) RCP 4.5 w/m$^2$ and (ii)) RCP 8.5 w/m$^2$ over Rwanda.

#### 4.6.4.2 March-April-May (MAM) Season

Figure 4-13 (a) shows that 2021-2050 is expected to experience a more positive rainfall trend in projected MAM under RCP 4.5 w/m$^2$ with an increasing slope ranging between 0 to 60%. However, a few parts of the central and north-eastern areas will experience reduced rainfall with a percentage change as a magnitude of the mean of 0 to 30% (Figure 4-13a (i). compared to RCP 8.5 w/m$^2$ (Figure 4-13a (ii), which will exhibit more negative rainfall change over most parts of the East, central toward the west and south with a decreasing rainfall of -5 to -90%. At the same time, the areas of the northern highland (Gakenke, Nyabihu, Ngororero, Rutsiro) areas near Nyungwe National Park and areas of the south-eastern (western Kayonza, north-eastern Ngoma and Kirehe) are expected to receive increased rainfall with a rainfall change of 5 to 60% (Figure 4-13a (ii). Projected MAM precipitation for the period 2041-2170 (Figure 4-13b) and from 2071 through 2100 (Figure 4-13 c) indicates a reduced rainfall amount in most parts of the country with a reduction ranging between -5 to -60% except the areas around Gakenke, Nyaruguru, Nyamagabe and Kirehe which will exhibit an increasing rainfall change of 0 to 30% under RCP 4.5 w/m$^2$. Further, under RCP 8.5 w/m$^2$, the south-western part, the northern highland and the south-eastern are expected to receive an increased rainfall with a magnitude of 0 to 60%. In comparison, the rest of the country will receive a reduced rainfall ranging between -5 to -60%.

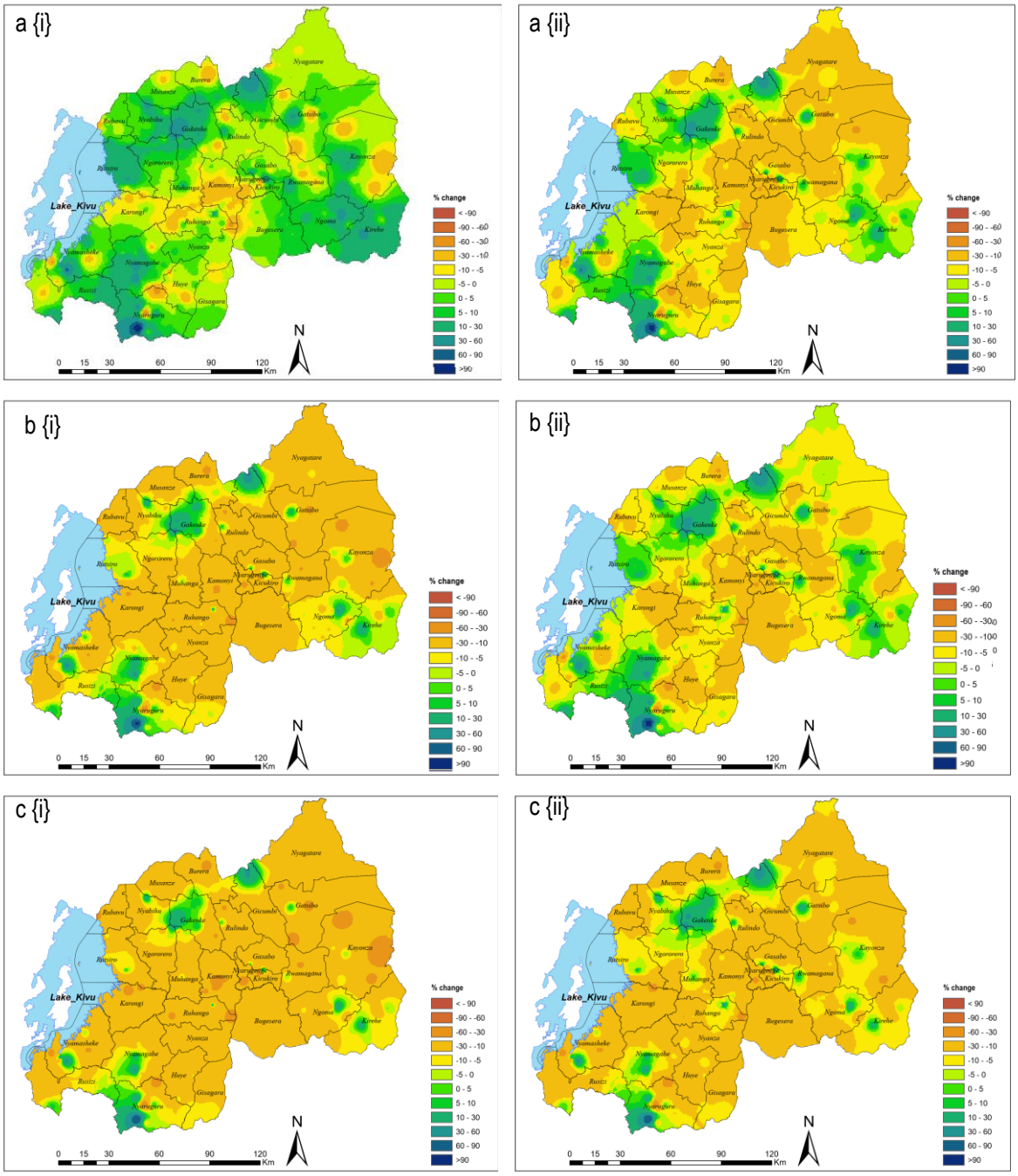


Figure 4-13: Projected precipitation changes ( (a) 2021-2050, b) 2041-2070 and c) 2071-2100 ) relative to the reference period (1981-2010) during MAM season under (i) RCP 4.5 w/m$^2$ and (ii) RCP 8.5 w/m$^2$ over Rwanda.

#### 4.6.4.3 June-July-August (JJA) Season

Figure 4-14 (a) shows that the period 2021-2050 is expected to experience positive rainfall changes in projected JJA precipitation in the north, Northeast, central-eastern and Southwestern parts with an increase of between 5 to 30% and a reduced rainfall change over the rest of the country with a change of -10 to 30% is expected under RCP 4.5 w/$m^2$ (Figure 4-14a (i)). A similar pattern is under RCP 8.5 w/$m^2$ with more increased rainfall over the western and the areas around Nyungwe national park (Figure 4-14a (ii)). During 2041-2070, a greater negative change is expected under RCP 8.5 w/$m^2$ than RCP 4.5 w/$m^2$. Towards 2100, the projected negative change in JJA precipitation is expected to be gretea under RCP 8.5 w/$m^2$ Figure 14c (ii) compared to RCP 4.5 w/$m^2$ (Figure 14c (i)). The only few parts expected to have positive change under RCP 4.5 w/$m^2$ are the Northern parts and a few parts of the Southwest. Overall, southern province, Kigali city and the south of eastern provinces are expected to have a negative change that is less than the baseline and increase from 2021 towards 2100 under all scenarios and pronounced under RCP 8.5 w/$m^2$ of up to -30% to -60% change compared to its 1981-2021 baseline.

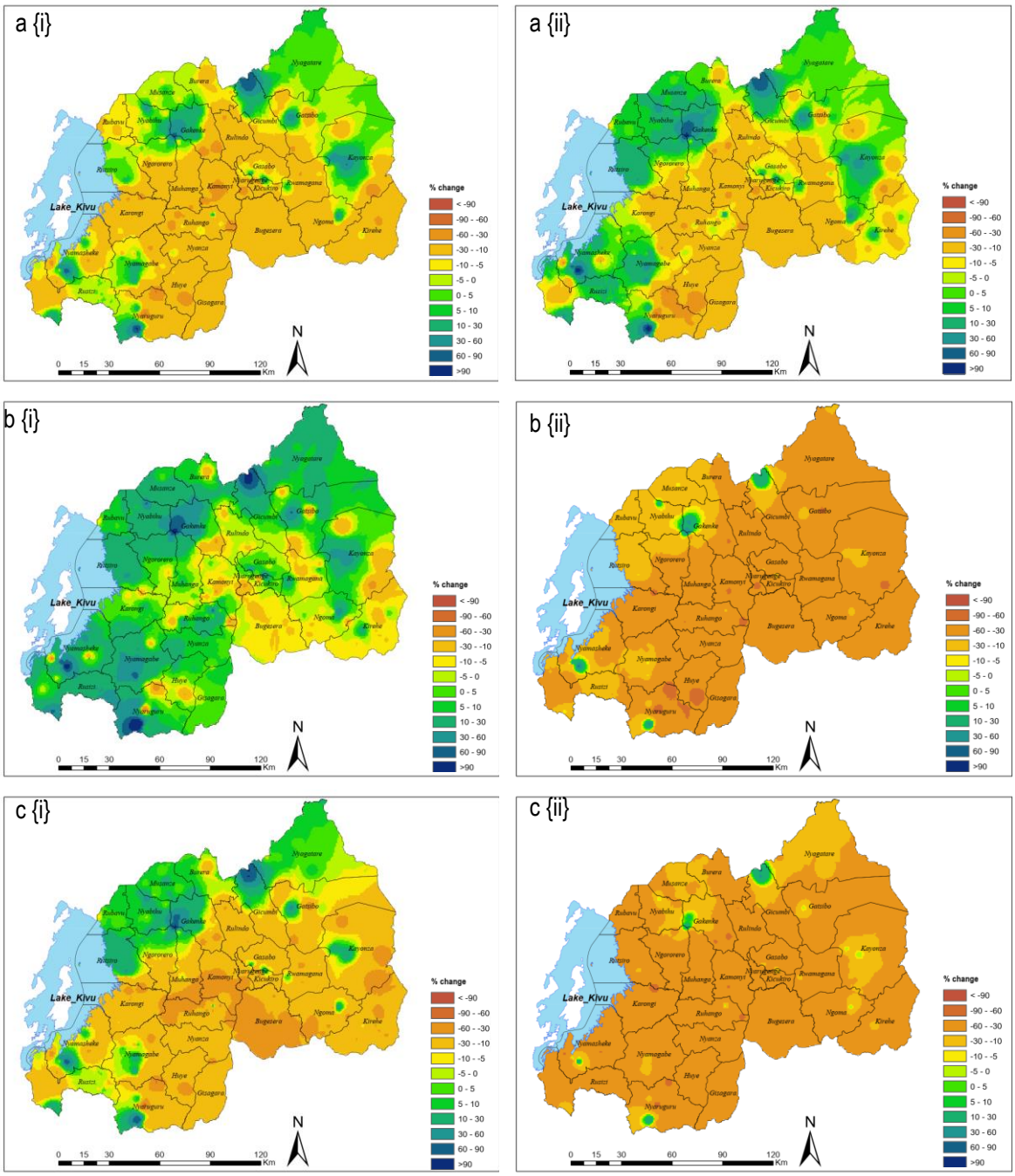


Figure 4-14: Projected precipitation changes (a) 2021-2050, b) 2041-2070 and c) 2071-2100 (relative to the reference period (1981-2010) during JJA season under (i) RCP 4.5 w/m$^2$ and (ii) RCP 8.5 w/m$^2$ over Rwanda.

#### 4.6.4.4 September-October-November-December (SOND) Season

Figure 4-15 (a) shows that the projected changes in SOND precipitation for the period 2021-2050 is expected to increase over many areas under both RCP 4.5 w/m$^2$ (Figure 4-15a (i) and RCP 8.5 w/m$^2$ (Figure 4-15a (ii) with an increased amount of 5 to 60% except few parts of the central areas expected to receive reduced rainfall under RCP 4.5 w/m$^2$. Similarly, 2041-2070 (Figure 4-15b) and 2071-2100 (Figure 4-15c) are expected to experience positive changes in projected SOND precipitation in both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$. The central parts such as Kamonyi, western Bugesera, western Kigali, Karongi and eastern Kayonza are projected to have negative change under both RCPs for 2021 to 2100. The SOND rainfall shows highly variable seasonal totals with most areas expected to receive above the 1981-2010 baseline rainfall.

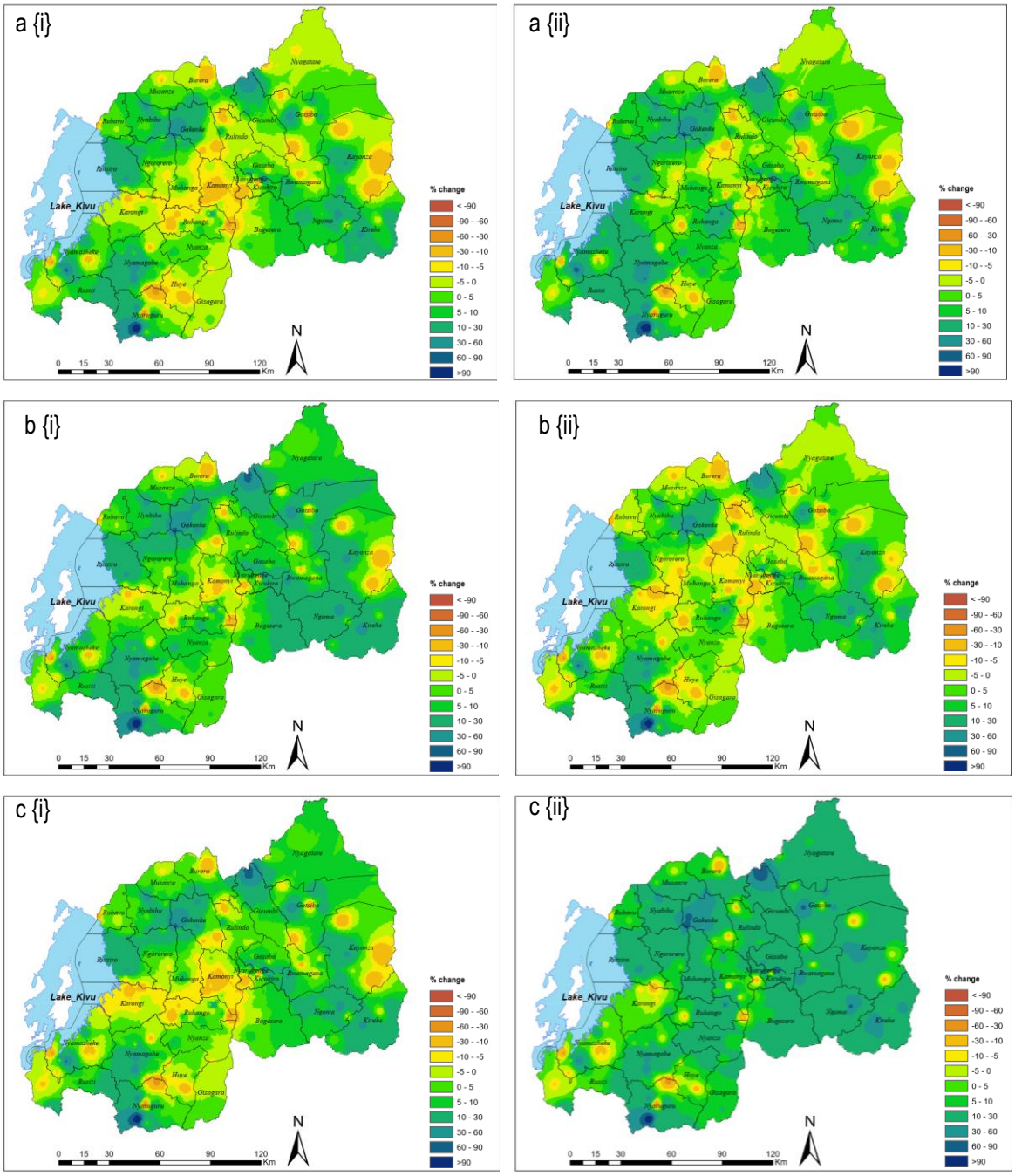


Figure 4-15: Projected precipitation changes (a) 2021-2050, b) 2041-2070 and c) 2071-2100 ( relative to the reference period (1981-2010) during the SOND season under (i) RCP 4.5 w/m$^2$ and (ii) RCP 8.5 w/m$^2$ over Rwanda

### 4.6.4.5 Annual precipitation

Figure 4-16 (a) shows that during the period 2021-2050 under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$, southwestern, North-western, and parts of South-eastern are expected to have positive change ranging from 30 to 90%, while parts of central and north-eastern are expected to receive slightly negative change. A similar pattern of either increasing or decreasing projected annual precipitation is shown for 2041-2070 (Figure 4-16b) and 2071-2100 (Figure 4-16c) and decreases towards 2100. Mukhala et al. (2017) observed that all stations in Rwanda showed a decreasing trend in precipitation for RCP 4.5 w/m$^2$ (2016-2045) scenario except Gabiro and Ruhuha. On the contrary, the precipitation trend for RCP 4.5 w/m$^2$ (2016 -2045) was noted to increase in selected stations except Gisenyi, Save and Ruhuha. For RCP 4.5 w/m$^2$ (2071-2100), the trend in precipitation was all decreasing except in Ruhuha.

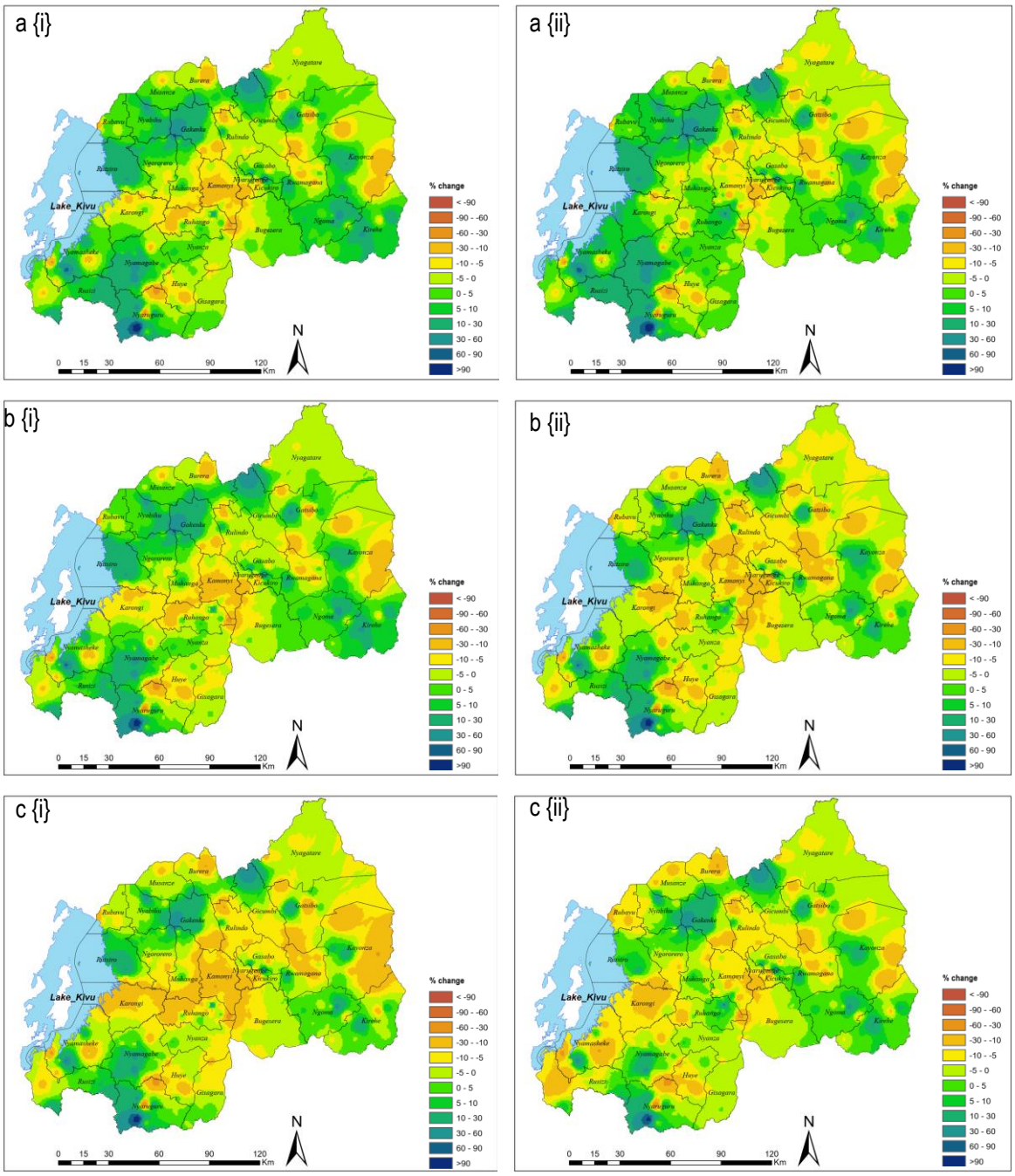

Figure 4-16: Projected precipitation changes (a) 2021-2050, b) 2041-2070 and c) 2071-2100 (relative to the reference period (1981-2010) during annual under (i) RCP 4.5 w/$m^2$ and (ii) RCP 8.5 w/$m^2$ over Rwanda

## 4.7 Analysis of Bias corrected climate projections – maximum temperature

This section analyses the trend of JF, MAM, JJA, SOND and Annual projected maximum temperature during the 30 years between 2021 and 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$.

### 4.7.1 *Temporal analysis of projected maximum temperature*

This subsection presents the trend of JF, MAM, JJA, SOND and Annual projected maximum temperature between 2021 and 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$.

#### 4.7.1.1 January-February Season

Table 4-36 shows that the projected JF season mean maximum temperature for the period 2021-2050 ranged from +6.09% or +0.04$^O$C per year (significant, $\alpha \leq 0.05$) in Ruhengeri to +2.48% or +0.02$^O$C per year (significant, $\alpha \leq 0.05$) in Kamembe under RCP 4.5 w/m$^2$ and ranged from 5.9% or +0.04$^O$C per year (significant, $\alpha \leq 0.05$) in Ruhengeri to +2.9% or 0.02$^O$C per year (significant, $\alpha \leq 0.05$) in Kamembe under RCP 8.5 w/m$^2$. Overall, the projected JF maximum temperature during the 2021-2050 period indicates an increasing trend in Ngoma, the eastern part of Bugesera, most parts of the northern highland (Rubavu, Ngororero, Nyabihu, Rutsiro, Musanze and western part of Gakenke) and the areas of Kagitumba in north-eastern part under RCP 4.5 w/m$^2$. Under RCP 8.5 w/m$^2$, an increasing trend at a higher rate is indicated over the north-western part of the country, reducing towards the western, central, northern and north-eastern parts, and an increasing trend at a lower rate is indicated over parts of the eastern around Kayonza, Kirehe and Amayaga region.

Table 4-37 shows that the projected JF season mean maximum temperature for the period 2041-2070 ranged from +2.0% or +0.02$^O$C per year (significant, $\alpha \leq 0.05$) in Gisenyi to +0.81% or +0.01$^O$C per year (not significant, $\alpha > 0.05$) in Kansi under RCP 4.5 w/m$^2$ and ranged from +9.2% or +0.06$^O$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +4.42% or 0.04$^O$C per year (significant, $\alpha \leq 0.05$) in Kamembe under RCP 8.5 w/m$^2$. Notably, the projected JF maximum temperature under RCP 4.5 w/m$^2$ indicates a high, increasing trend in most Nyamasheke and north-western parts of Rusizi Districts, south-eastern (Bugesera, Ngoma and southern Kayonza). Similarly, RCP 8.5 w/m$^2$ indicates an increasing trend in most Ngoma parts towards the eastern part of Bugesera and extreme southwestern parts of Rubavu Districts.

Table 4-38 shows that the projected JF season mean maximum temperature for the period 2071-2100 ranged from +0.37% or +0.001$^O$C per year (significant, $\alpha \leq 0.05$) in Bukora to -1.69% or -0.01$^O$C per year (not significant, $\alpha > 0.05$) in Gatumba under RCP 4.5 w/m$^2$ and ranged from +9.43% or +0.07$^O$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +4.94% or 0.04$^O$C per year (significant, $\alpha \leq 0.05$) in Kamembe under RCP 8.5 w/m$^2$. Notably, the projected JF maximum temperature during the 2071-2100 period under RCP 4.5 w/m$^2$ indicates a slightly decreasing trend in most of Nyamasheke and extreme Rusizi Districts, northern highland and Nyagatare district, with the rest of the country showing an increasing trend. Under the RCP 8.5 w/m$^2$, a slightly increasing trend was indicated in most parts of the Amayaga region, the eastern part of Huye, towards the south-eastern part of Nyaruguru, south-western part (Rusizi and Nyamasheke), Kigali city extending to northern areas and north-eastern part. At the same time, the rest of the country registered an increasing trend.

The projected JF maximum temperature during the 2021-2050 period indicates an increasing trend with a more considerable increase under RCP 8.5w/m$^2$ than RCP 4.5 w/m$^2$. Similarly, a rising trend for 2041-2070 and 2071-2100 with RCP 8.5 w/m$^2$ is expected to increase higher than RCP 4.5 w/m$^2$.

Table 4-36: The trend of projected JF maximum temperature for the period 2021 to 2050 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| Stations | **2021-2050** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | 2.57 | * | 0.04 | 24.10 | 4.95 | 2.21 | * | 0.03 | 23.57 | 3.51 |
| Busogo | 2.68 | ** | 0.03 | 20.56 | 4.59 | 3.71 | *** | 0.03 | 20.07 | 4.78 |
| Butare | 2.36 | * | 0.03 | 20.43 | 4.03 | 3.46 | *** | 0.03 | 20.02 | 3.89 |
| Byimana | 2.21 | * | 0.02 | 23.69 | 2.76 | 3.03 | ** | 0.03 | 23.30 | 3.33 |
| Byumba | 2.46 | * | 0.03 | 26.65 | 3.50 | 3.32 | *** | 0.03 | 26.20 | 3.82 |
| Cyinzuzi | 2.46 | * | 0.03 | 24.60 | 3.56 | 3.32 | *** | 0.03 | 24.17 | 3.89 |
| Gabiro | 2.46 | * | 0.03 | 27.36 | 3.36 | 2.68 | ** | 0.03 | 26.90 | 3.20 |
| Gatumba | 2.68 | ** | 0.04 | 20.38 | 5.58 | 3.71 | *** | 0.04 | 19.79 | 5.83 |
| Gikongoro | 2.28 | * | 0.02 | 23.64 | 3.03 | 3.46 | *** | 0.03 | 23.23 | 3.37 |
| Gisanga | 2.21 | * | 0.02 | 24.39 | 2.97 | 3.03 | ** | 0.03 | 23.96 | 3.60 |
| Gisenyi | 3.75 | *** | 0.05 | 24.00 | 5.79 | 4.39 | *** | 0.04 | 23.58 | 4.51 |
| Gitarama | 2.21 | * | 0.02 | 24.39 | 2.97 | 3.03 | ** | 0.03 | 23.96 | 3.60 |
| Gitega | 2.46 | * | 0.03 | 24.60 | 3.56 | 3.32 | *** | 0.03 | 24.17 | 3.89 |
| Kamembe | 2.53 | * | 0.02 | 24.61 | 2.48 | 3.39 | *** | 0.02 | 24.26 | 2.90 |
| Kanombe | 2.46 | * | 0.03 | 26.17 | 3.56 | 3.32 | *** | 0.03 | 25.72 | 3.88 |
| Kansi | 2.36 | * | 0.03 | 27.93 | 3.49 | 3.46 | *** | 0.03 | 27.44 | 3.36 |
| Kawangire | 2.46 | * | 0.03 | 26.70 | 3.40 | 2.68 | ** | 0.03 | 26.25 | 3.25 |
| Kibungo | 3.18 | ** | 0.05 | 25.68 | 5.92 | 3.53 | *** | 0.04 | 25.12 | 4.84 |
| Masaka | 3.18 | ** | 0.05 | 26.56 | 5.19 | 3.53 | *** | 0.04 | 26.04 | 4.25 |
| Muganza | 2.28 | * | 0.02 | 22.62 | 3.18 | 3.46 | *** | 0.03 | 22.21 | 3.53 |
| Mushubi | 2.18 | * | 0.02 | 21.57 | 2.99 | 3.25 | ** | 0.03 | 21.17 | 3.71 |
| Ntaruka | 3.00 | ** | 0.03 | 23.54 | 3.63 | 3.78 | *** | 0.03 | 23.14 | 4.34 |
| Ntendezi | 2.53 | * | 0.02 | 23.46 | 2.69 | 3.39 | *** | 0.02 | 23.05 | 3.18 |
| Nyagatare | 2.85 | ** | 0.03 | 28.43 | 3.21 | 3.53 | *** | 0.04 | 27.96 | 3.82 |
| Nyamata | 2.21 | * | 0.02 | 26.69 | 2.68 | 3.03 | ** | 0.03 | 26.26 | 3.24 |
| Rubengera | 2.18 | * | 0.02 | 23.52 | 2.77 | 3.25 | ** | 0.03 | 23.11 | 3.43 |
| Ruganda | 2.46 | * | 0.03 | 20.56 | 4.70 | 3.32 | *** | 0.03 | 20.09 | 5.16 |
| Rugobagoba | 2.21 | * | 0.03 | 20.61 | 3.78 | 3.03 | ** | 0.03 | 20.14 | 4.60 |
| Ruhengeri | 2.85 | ** | 0.04 | 20.02 | 6.09 | 3.53 | *** | 0.04 | 19.56 | 5.90 |
| Rutsiro | 2.68 | ** | 0.03 | 20.59 | 4.66 | 3.71 | *** | 0.03 | 20.09 | 4.86 |
| Rwamagana | 2.46 | * | 0.03 | 26.70 | 3.40 | 2.68 | ** | 0.03 | 26.25 | 3.25 |
| Rwankeri | 2.68 | ** | 0.03 | 21.40 | 4.16 | 3.71 | *** | 0.03 | 20.94 | 4.32 |
| Save | 2.36 | * | 0.03 | 26.03 | 3.56 | 3.46 | *** | 0.03 | 25.58 | 3.42 |

Table 4-37: The trend of projected JF maximum temperature for the period 2041 to 2070 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| Stations | **2041-2070** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | **Test Z** | **α level** | **Q** | **mean** | **%Δ** | **Test Z** | **α level** | **Q** | **mean** | **%Δ** |
| Bukora | 0.93 | | 0.01 | 24.63 | 1.26 | 4.25 | *** | 0.06 | 24.45 | 7.44 |
| Busogo | 1.50 | | 0.01 | 21.09 | 1.25 | 4.82 | *** | 0.05 | 20.97 | 7.61 |
| Butare | 0.79 | | 0.01 | 20.83 | 0.94 | 4.39 | *** | 0.04 | 20.71 | 5.99 |
| Byimana | 0.86 | | 0.01 | 24.08 | 0.93 | 4.46 | *** | 0.04 | 23.98 | 5.30 |
| Byumba | 1.50 | | 0.01 | 27.18 | 1.18 | 4.50 | *** | 0.05 | 27.06 | 5.73 |
| Cyinzuzi | 1.50 | | 0.01 | 25.10 | 1.20 | 4.50 | *** | 0.05 | 24.99 | 5.83 |
| Gabiro | 0.89 | | 0.01 | 27.85 | 0.90 | 4.17 | *** | 0.05 | 27.73 | 5.37 |
| Gatumba | 1.50 | | 0.01 | 21.01 | 1.51 | 4.82 | *** | 0.06 | 20.87 | 9.20 |
| Gikongoro | 0.96 | | 0.01 | 24.03 | 0.87 | 4.32 | *** | 0.04 | 23.92 | 5.12 |
| Gisanga | 0.86 | | 0.01 | 24.83 | 1.00 | 4.46 | *** | 0.05 | 24.72 | 5.70 |
| Gisenyi | 2.43 | * | 0.02 | 24.68 | 2.00 | 5.57 | *** | 0.06 | 24.49 | 6.84 |
| Gitarama | 0.86 | | 0.01 | 24.83 | 1.00 | 4.46 | *** | 0.05 | 24.72 | 5.70 |
| Gitega | 1.50 | | 0.01 | 25.10 | 1.20 | 4.50 | *** | 0.05 | 24.99 | 5.83 |
| Kamembe | 1.46 | | 0.01 | 24.97 | 0.95 | 4.71 | *** | 0.04 | 24.87 | 4.42 |
| Kanombe | 1.50 | | 0.01 | 26.70 | 1.20 | 4.50 | *** | 0.05 | 26.58 | 5.82 |
| Kansi | 0.79 | | 0.01 | 28.39 | 0.81 | 4.39 | *** | 0.05 | 28.26 | 5.20 |
| Kawangire | 0.89 | | 0.01 | 27.19 | 0.91 | 4.17 | *** | 0.05 | 27.06 | 5.45 |
| Kibungo | 1.39 | | 0.01 | 26.41 | 1.63 | 4.96 | *** | 0.07 | 26.18 | 7.61 |
| Masaka | 1.39 | | 0.01 | 27.22 | 1.43 | 4.96 | *** | 0.06 | 27.02 | 6.71 |
| Muganza | 0.96 | | 0.01 | 23.01 | 0.91 | 4.32 | *** | 0.04 | 22.90 | 5.37 |
| Mushubi | 0.82 | | 0.01 | 21.96 | 0.91 | 4.50 | *** | 0.04 | 21.87 | 5.60 |
| Ntaruka | 1.64 | | 0.01 | 24.04 | 1.17 | 4.28 | *** | 0.04 | 23.94 | 5.45 |
| Ntendezi | 1.46 | | 0.01 | 23.82 | 1.06 | 4.71 | *** | 0.04 | 23.69 | 4.83 |
| Nyagatare | 1.14 | | 0.01 | 28.98 | 1.08 | 4.25 | *** | 0.05 | 28.85 | 5.45 |
| Nyamata | 0.86 | | 0.01 | 27.12 | 0.91 | 4.46 | *** | 0.05 | 27.01 | 5.15 |
| Rubengera | 0.82 | | 0.01 | 23.91 | 0.85 | 4.50 | *** | 0.04 | 23.83 | 5.20 |
| Ruganda | 1.50 | | 0.01 | 21.11 | 1.58 | 4.50 | *** | 0.05 | 20.99 | 7.66 |
| Rugobagoba | 0.86 | | 0.01 | 21.07 | 1.27 | 4.46 | *** | 0.05 | 20.96 | 7.23 |
| Ruhengeri | 1.36 | | 0.01 | 20.72 | 1.46 | 4.21 | *** | 0.06 | 20.53 | 8.37 |
| Rutsiro | 1.50 | | 0.01 | 21.12 | 1.27 | 4.82 | *** | 0.05 | 21.00 | 7.73 |
| Rwamagana | 0.89 | | 0.01 | 27.19 | 0.91 | 4.17 | *** | 0.05 | 27.06 | 5.45 |
| Rwankeri | 1.50 | | 0.01 | 21.89 | 1.13 | 4.82 | *** | 0.05 | 21.78 | 6.91 |
| Save | 0.79 | | 0.01 | 26.48 | 0.83 | 4.39 | *** | 0.05 | 26.35 | 5.29 |

Table 4-38: The trend of projected JF maximum temperature for the period 2071 to 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| Stations | **2071-2100** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | **Test Z** | **α level** | **Q** | **mean** | **%Δ** | **Test Z** | **α level** | **Q** | **mean** | **%Δ** |
| Bukora | 0.14 | | 0.00 | 24.94 | 0.37 | 3.85 | *** | 0.07 | 25.75 | 7.71 |
| Busogo | -0.73 | | -0.01 | 21.55 | -1.41 | 4.48 | *** | 0.06 | 22.28 | 7.89 |
| Butare | 0.22 | | 0.00 | 21.20 | 0.20 | 4.13 | *** | 0.05 | 21.86 | 7.51 |
| Byimana | -0.22 | | 0.00 | 24.45 | -0.32 | 3.93 | *** | 0.05 | 25.06 | 6.19 |
| Byumba | -0.41 | | -0.01 | 27.60 | -0.67 | 4.13 | *** | 0.06 | 28.33 | 6.12 |
| Cyinzuzi | -0.41 | | -0.01 | 25.49 | -0.68 | 4.13 | *** | 0.05 | 26.18 | 6.21 |
| Gabiro | -0.14 | | 0.00 | 28.20 | -0.27 | 3.73 | *** | 0.06 | 28.91 | 6.06 |
| Gatumba | -0.73 | | -0.01 | 21.57 | -1.69 | 4.48 | *** | 0.07 | 22.44 | 9.43 |
| Gikongoro | -0.02 | | 0.00 | 24.42 | -0.05 | 4.37 | *** | 0.05 | 25.06 | 6.19 |
| Gisanga | -0.22 | | 0.00 | 25.23 | -0.34 | 3.93 | *** | 0.06 | 25.92 | 6.64 |
| Gisenyi | -0.26 | | 0.00 | 25.27 | -0.25 | 4.92 | *** | 0.06 | 26.03 | 6.38 |
| Gitarama | -0.22 | | 0.00 | 25.23 | -0.34 | 3.93 | *** | 0.06 | 25.92 | 6.64 |
| Gitega | -0.41 | | -0.01 | 25.49 | -0.68 | 4.13 | *** | 0.05 | 26.18 | 6.21 |
| Kamembe | -0.45 | | -0.01 | 25.31 | -0.63 | 4.45 | *** | 0.04 | 25.85 | 4.94 |
| Kanombe | -0.41 | | -0.01 | 27.12 | -0.68 | 4.13 | *** | 0.06 | 27.85 | 6.21 |
| Kansi | 0.22 | | 0.00 | 28.84 | 0.17 | 4.13 | *** | 0.06 | 29.62 | 6.57 |
| Kawangire | -0.14 | | 0.00 | 27.53 | -0.28 | 3.73 | *** | 0.06 | 28.24 | 6.15 |
| Kibungo | 0.18 | | 0.00 | 26.99 | 0.09 | 4.45 | *** | 0.08 | 27.91 | 8.13 |
| Masaka | 0.18 | | 0.00 | 27.74 | 0.08 | 4.45 | *** | 0.07 | 28.59 | 7.22 |
| Muganza | -0.02 | | 0.00 | 23.40 | -0.05 | 4.37 | *** | 0.05 | 24.04 | 6.48 |
| Mushubi | -0.45 | | -0.01 | 22.36 | -0.92 | 4.25 | *** | 0.05 | 22.98 | 6.47 |
| Ntaruka | -0.30 | | 0.00 | 24.29 | -0.40 | 3.22 | ** | 0.04 | 24.90 | 4.95 |
| Ntendezi | -0.45 | | -0.01 | 24.17 | -0.69 | 4.45 | *** | 0.04 | 24.70 | 5.38 |
| Nyagatare | -0.38 | | 0.00 | 29.31 | -0.43 | 3.34 | *** | 0.05 | 30.04 | 5.27 |
| Nyamata | -0.22 | | 0.00 | 27.51 | -0.31 | 3.93 | *** | 0.06 | 28.19 | 6.02 |
| Rubengera | -0.45 | | -0.01 | 24.32 | -0.85 | 4.25 | *** | 0.05 | 24.94 | 6.03 |
| Ruganda | -0.41 | | -0.01 | 21.54 | -0.89 | 4.13 | *** | 0.06 | 22.30 | 8.05 |
| Rugobagoba | -0.22 | | 0.00 | 21.51 | -0.43 | 3.93 | *** | 0.06 | 22.24 | 8.32 |
| Ruhengeri | -0.06 | | 0.00 | 20.97 | -0.33 | 3.38 | *** | 0.05 | 21.73 | 7.39 |
| Rutsiro | -0.73 | | -0.01 | 21.60 | -1.43 | 4.48 | *** | 0.06 | 22.33 | 8.02 |
| Rwamagana | -0.14 | | 0.00 | 27.53 | -0.28 | 3.73 | *** | 0.06 | 28.24 | 6.15 |
| Rwankeri | -0.73 | | -0.01 | 22.33 | -1.28 | 4.48 | *** | 0.06 | 23.02 | 7.21 |
| Save | 0.22 | | 0.00 | 26.90 | 0.18 | 4.13 | *** | 0.06 | 27.64 | 6.68 |

#### 4.7.1.2 March-April-May Season

Table 4-39 shows that projected MAM season mean maximum temperature for the period 2021-2050 ranged from +6.87% or +0.05$^{O}$C per year (significant, $\alpha \leq 0.05$) in Ruhengeri to +3.15% or +0.03$^{o}$C per year (not significant, $\alpha > 0.05$) in Kamembe under RCP 4.5 w/m$^2$ and ranged from 4.41% or +0.03$^{o}$C per year (significant, $\alpha \leq 0.05$) in Ntaruka to +1.67% or 0.01$^{o}$C per year (not significant, $\alpha > 0.05$) in Kamembe under RCP 8.5 w/m$^2$. The projected MAM maximum temperature in the 2021-2050 period for both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ indicates an increase over the south-east (eastern Bugesera, Ngoma and southern Kirehe) and Musanze in Northern.

Table 4-40 shows that projected MAM season mean maximum temperature for the period 2041-2070 ranged from +1.08% or +0.01$^{o}$C per year (not significant, $\alpha > 0.05$) in Gisenyi to -1.64% or -0.01$^{o}$C per year (not significant, $\alpha > 0.05$) in Rugobagoba under RCP 4.5 w/m$^2$ and ranged from +9.97% or +0.07$^{o}$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +4.46% or 0.05$^{o}$C per year (significant, $\alpha \leq 0.05$) in Nyagatare under RCP 8.5 w/m$^2$. Analysis shows that projected MAM maximum temperature during 2041-2070 indicated a general increasing trend with northern highland, northern extending to north-eastern, eastern part (Kayonza and Kirehe). The rest of the country indicated a negative trend under RCP 4.5 w/m$^2$, while more areas showed an increased maximum temperature under RCP 8.5 w/m$^2$.

Table 4-41 shows that the projected MAM season mean maximum temperature for the period 2071-2100 ranged from +0.04% or +0.001$^{o}$C per year (not significant, $\alpha > 0.05$) in Masaka to -2.62% or -0.02$^{o}$C per year (not significant, $\alpha > 0.05$) in Gatumba under RCP 4.5 w/m$^2$ and ranged from +9.79% or +0.07$^{o}$C per year (significant, $\alpha \leq 0.05$) in Rugobagoba to +4.73% or 0.04$^{o}$C per year (not significant, $\alpha > 0.05$) in Ntaruka under RCP 8.5 w/m$^2$. From 2071 through 2100, most parts of the country reported a negative maximum temperature trend except over eastern Bugesera and western Ngoma under RCP 4.5 w/m$^2$. Most areas of the country showed increasing maximum temperatures under RCP 8.5 w/m$^2$

The projected MAM maximum temperature indicates an increasing trend for both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ for 2021-2050. However, 2041-2070 is marked by a negative trend under RCP 4.5 w/m$^2$ compared to increasing trends under RCP 8.5 w/m$^2$. Similarly, the period 2071-2100 is characterized by a decreasing trend under RCP 4.5 w/m$^2$ compared to growing trends under RCP 8.5 w/m$^2$

Table 4-39: Trend of projected MAM maximum temperature for the period 2021 to 2050 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| Timeframe | 2021-2050 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Scenario | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| Stations | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | 1.46 | | 0.05 | 24.31 | 6.36 | 1.14 | | 0.02 | 24.01 | 2.71 |
| Busogo | 1.68 | + | 0.04 | 20.26 | 5.32 | 1.89 | + | 0.02 | 20.02 | 2.82 |
| Butare | 1.57 | | 0.04 | 20.23 | 5.29 | 1.93 | + | 0.03 | 20.05 | 4.07 |
| Byimana | 1.57 | | 0.03 | 23.39 | 3.87 | 1.68 | + | 0.02 | 23.21 | 2.97 |
| Byumba | 1.68 | + | 0.04 | 26.56 | 4.32 | 1.75 | + | 0.02 | 26.35 | 2.61 |
| Cyinzuzi | 1.68 | + | 0.04 | 24.51 | 4.40 | 1.75 | + | 0.02 | 24.31 | 2.66 |
| Gabiro | 1.61 | | 0.04 | 27.42 | 4.39 | 1.39 | | 0.02 | 27.21 | 2.32 |
| Gatumba | 1.68 | + | 0.04 | 20.01 | 6.49 | 1.89 | + | 0.02 | 19.73 | 3.44 |
| Gikongoro | 1.32 | | 0.03 | 23.37 | 4.00 | 1.61 | | 0.02 | 23.19 | 2.77 |
| Gisanga | 1.57 | | 0.03 | 24.07 | 4.17 | 1.68 | + | 0.03 | 23.86 | 3.21 |
| Gisenyi | 2.75 | ** | 0.05 | 24.63 | 5.80 | 2.50 | * | 0.03 | 24.29 | 3.70 |
| Gitarama | 1.57 | | 0.03 | 24.07 | 4.17 | 1.68 | + | 0.03 | 23.86 | 3.21 |
| Gitega | 1.68 | + | 0.04 | 24.51 | 4.40 | 1.75 | + | 0.02 | 24.31 | 2.66 |
| Kamembe | 1.53 | | 0.03 | 24.51 | 3.15 | 1.53 | | 0.01 | 24.32 | 1.67 |
| Kanombe | 1.68 | + | 0.04 | 26.08 | 4.39 | 1.75 | + | 0.02 | 25.87 | 2.66 |
| Kansi | 1.57 | | 0.04 | 27.69 | 4.57 | 1.93 | + | 0.03 | 27.48 | 3.52 |
| Kawangire | 1.61 | | 0.04 | 26.76 | 4.45 | 1.39 | | 0.02 | 26.55 | 2.36 |
| Kibungo | 1.78 | + | 0.06 | 26.04 | 6.81 | 1.75 | + | 0.03 | 25.64 | 4.00 |
| Masaka | 1.78 | + | 0.05 | 26.88 | 5.98 | 1.75 | + | 0.03 | 26.52 | 3.52 |
| Muganza | 1.32 | | 0.03 | 22.35 | 4.20 | 1.61 | | 0.02 | 22.17 | 2.91 |
| Mushubi | 1.32 | | 0.03 | 21.26 | 3.83 | 1.61 | | 0.02 | 21.07 | 2.53 |
| Ntaruka | 2.21 | * | 0.04 | 23.82 | 5.42 | 2.60 | ** | 0.03 | 23.52 | 4.41 |
| Ntendezi | 1.53 | | 0.03 | 23.35 | 3.37 | 1.53 | | 0.01 | 23.11 | 1.82 |
| Nyagatare | 2.03 | * | 0.05 | 28.67 | 5.03 | 2.46 | * | 0.03 | 28.37 | 3.11 |
| Nyamata | 1.57 | | 0.03 | 26.36 | 3.75 | 1.68 | + | 0.03 | 26.16 | 2.88 |
| Rubengera | 1.32 | | 0.03 | 23.21 | 3.55 | 1.61 | | 0.02 | 23.01 | 2.34 |
| Ruganda | 1.68 | + | 0.04 | 20.46 | 5.82 | 1.75 | + | 0.02 | 20.25 | 3.52 |
| Rugobagoba | 1.57 | | 0.04 | 20.25 | 5.34 | 1.68 | + | 0.03 | 20.03 | 4.11 |
| Ruhengeri | 2.14 | * | 0.05 | 20.42 | 6.87 | 2.39 | * | 0.03 | 20.05 | 4.04 |
| Rutsiro | 1.68 | + | 0.04 | 20.28 | 5.41 | 1.89 | + | 0.02 | 20.04 | 2.87 |
| Rwamagana | 1.61 | | 0.04 | 26.76 | 4.45 | 1.39 | | 0.02 | 26.55 | 2.36 |
| Rwankeri | 1.68 | + | 0.03 | 21.11 | 4.81 | 1.89 | + | 0.02 | 20.89 | 2.55 |
| Save | 1.57 | | 0.04 | 25.81 | 4.66 | 1.93 | + | 0.03 | 25.61 | 3.58 |

Table 4-40: Trend of projected MAM maximum temperature for the period 2041 to 2070 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| Timeframe | 2041-2070 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Scenario | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| Stations | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | 0.00 | | 0.00 | 25.07 | 0.11 | 2.93 | ** | 0.07 | 24.89 | 7.94 |
| Busogo | 0.04 | | 0.00 | 20.87 | 0.38 | 3.75 | *** | 0.06 | 20.87 | 8.24 |
| Butare | -0.29 | | -0.01 | 20.75 | -0.80 | 3.53 | *** | 0.05 | 20.73 | 6.65 |
| Byimana | -0.39 | | -0.01 | 23.91 | -1.20 | 3.07 | ** | 0.05 | 23.90 | 5.78 |
| Byumba | 0.00 | | 0.00 | 27.27 | -0.05 | 3.64 | *** | 0.06 | 27.21 | 6.58 |
| Cyinzuzi | 0.00 | | 0.00 | 25.18 | -0.05 | 3.64 | *** | 0.06 | 25.12 | 6.69 |
| Gabiro | -0.11 | | 0.00 | 28.15 | -0.32 | 3.18 | ** | 0.05 | 28.04 | 5.79 |
| Gatumba | 0.04 | | 0.00 | 20.74 | 0.46 | 3.75 | *** | 0.07 | 20.75 | 9.97 |
| Gikongoro | -0.18 | | 0.00 | 23.88 | -0.58 | 3.57 | *** | 0.05 | 23.88 | 6.05 |
| Gisanga | -0.39 | | -0.01 | 24.63 | -1.29 | 3.07 | ** | 0.05 | 24.62 | 6.22 |
| Gisenyi | 0.50 | | 0.01 | 25.38 | 1.08 | 4.53 | *** | 0.06 | 25.18 | 7.23 |
| Gitarama | -0.39 | | -0.01 | 24.63 | -1.29 | 3.07 | ** | 0.05 | 24.62 | 6.22 |
| Gitega | 0.00 | | 0.00 | 25.18 | -0.05 | 3.64 | *** | 0.06 | 25.12 | 6.69 |
| Kamembe | -0.29 | | -0.01 | 24.93 | -0.73 | 3.93 | *** | 0.04 | 24.92 | 4.96 |
| Kanombe | 0.00 | | 0.00 | 26.79 | -0.05 | 3.64 | *** | 0.06 | 26.72 | 6.69 |
| Kansi | -0.29 | | -0.01 | 28.30 | -0.70 | 3.53 | *** | 0.05 | 28.28 | 5.78 |
| Kawangire | -0.11 | | 0.00 | 27.48 | -0.32 | 3.18 | ** | 0.05 | 27.37 | 5.88 |
| Kibungo | -0.07 | | 0.00 | 26.92 | -0.07 | 3.71 | *** | 0.07 | 26.68 | 8.29 |
| Masaka | -0.07 | | 0.00 | 27.69 | -0.06 | 3.71 | *** | 0.07 | 27.47 | 7.33 |
| Muganza | -0.18 | | 0.00 | 22.86 | -0.61 | 3.57 | *** | 0.05 | 22.86 | 6.34 |
| Mushubi | 0.04 | | 0.00 | 21.72 | 0.04 | 3.60 | *** | 0.05 | 21.76 | 6.46 |
| Ntaruka | 0.14 | | 0.00 | 24.57 | 0.46 | 3.00 | ** | 0.04 | 24.36 | 5.14 |
| Ntendezi | -0.29 | | -0.01 | 23.78 | -0.79 | 3.93 | *** | 0.04 | 23.73 | 5.42 |
| Nyagatare | 0.25 | | 0.00 | 29.48 | 0.40 | 3.39 | *** | 0.05 | 29.30 | 4.66 |
| Nyamata | -0.39 | | -0.01 | 26.92 | -1.17 | 3.07 | ** | 0.05 | 26.91 | 5.62 |
| Rubengera | 0.04 | | 0.00 | 23.67 | 0.04 | 3.60 | *** | 0.05 | 23.71 | 5.99 |
| Ruganda | 0.00 | | 0.00 | 21.20 | -0.07 | 3.64 | *** | 0.06 | 21.13 | 8.78 |
| Rugobagoba | -0.39 | | -0.01 | 20.86 | -1.64 | 3.07 | ** | 0.05 | 20.86 | 7.90 |
| Ruhengeri | -0.18 | | 0.00 | 21.26 | -0.26 | 3.71 | *** | 0.06 | 21.05 | 8.50 |
| Rutsiro | 0.04 | | 0.00 | 20.90 | 0.39 | 3.75 | *** | 0.06 | 20.90 | 8.37 |
| Rwamagana | -0.11 | | 0.00 | 27.48 | -0.32 | 3.18 | ** | 0.05 | 27.37 | 5.88 |
| Rwankeri | 0.04 | | 0.00 | 21.68 | 0.35 | 3.75 | *** | 0.05 | 21.69 | 7.48 |
| Save | -0.29 | | -0.01 | 26.39 | -0.71 | 3.53 | *** | 0.05 | 26.37 | 5.88 |

Table 4-41: Trend of projected MAM maximum temperature for the period 2071 to 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| Timeframe | 2071-2100 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Scenario | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| Stations | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | -0.54 | | -0.01 | 25.20 | -1.70 | 2.46 | * | 0.08 | 25.97 | 8.85 |
| Busogo | -0.84 | | -0.02 | 21.31 | -2.17 | 3.32 | *** | 0.06 | 22.05 | 7.83 |
| Butare | -0.13 | | 0.00 | 21.13 | -0.40 | 2.79 | ** | 0.07 | 21.83 | 9.26 |
| Byimana | -0.47 | | -0.01 | 24.24 | -0.75 | 2.68 | ** | 0.06 | 24.88 | 7.27 |
| Byumba | -0.54 | | -0.01 | 27.63 | -1.04 | 2.64 | ** | 0.06 | 28.34 | 6.00 |
| Cyinzuzi | -0.54 | | -0.01 | 25.52 | -1.06 | 2.64 | ** | 0.05 | 26.19 | 6.09 |
| Gabiro | -0.36 | | -0.01 | 28.41 | -0.91 | 2.27 | * | 0.07 | 29.05 | 6.95 |
| Gatumba | -0.84 | | -0.02 | 21.28 | -2.62 | 3.32 | *** | 0.07 | 22.16 | 9.38 |
| Gikongoro | -0.43 | | -0.01 | 24.27 | -0.97 | 2.98 | ** | 0.07 | 24.95 | 8.11 |
| Gisanga | -0.47 | | -0.01 | 25.00 | -0.80 | 2.68 | ** | 0.07 | 25.71 | 7.80 |
| Gisenyi | -0.13 | | 0.00 | 25.92 | -0.28 | 3.43 | *** | 0.05 | 26.60 | 6.20 |
| Gitarama | -0.47 | | -0.01 | 25.00 | -0.80 | 2.68 | ** | 0.07 | 25.71 | 7.80 |
| Gitega | -0.54 | | -0.01 | 25.52 | -1.06 | 2.64 | ** | 0.05 | 26.19 | 6.09 |
| Kamembe | -0.66 | | -0.01 | 25.24 | -0.72 | 2.57 | * | 0.04 | 25.76 | 5.18 |
| Kanombe | -0.54 | | -0.01 | 27.14 | -1.06 | 2.64 | ** | 0.06 | 27.86 | 6.09 |
| Kansi | -0.13 | | 0.00 | 28.76 | -0.35 | 2.79 | ** | 0.08 | 29.58 | 8.09 |
| Kawangire | -0.36 | | -0.01 | 27.74 | -0.92 | 2.27 | * | 0.07 | 28.37 | 7.05 |
| Kibungo | 0.00 | | 0.00 | 27.38 | 0.04 | 2.79 | ** | 0.09 | 28.24 | 9.11 |
| Masaka | 0.00 | | 0.00 | 28.10 | 0.04 | 2.79 | ** | 0.08 | 28.89 | 8.11 |
| Muganza | -0.43 | | -0.01 | 23.25 | -1.01 | 2.98 | ** | 0.07 | 23.94 | 8.48 |
| Mushubi | -0.69 | | -0.01 | 22.12 | -1.81 | 2.87 | ** | 0.06 | 22.75 | 7.42 |
| Ntaruka | -0.62 | | -0.01 | 24.63 | -1.73 | 1.67 | + | 0.04 | 25.13 | 4.73 |
| Ntendezi | -0.66 | | -0.01 | 24.10 | -0.78 | 2.57 | * | 0.05 | 24.61 | 5.65 |
| Nyagatare | -0.54 | | -0.01 | 29.68 | -1.05 | 1.86 | + | 0.06 | 30.29 | 5.48 |
| Nyamata | -0.47 | | -0.01 | 27.29 | -0.73 | 2.68 | ** | 0.07 | 27.99 | 7.07 |
| Rubengera | -0.69 | | -0.01 | 24.07 | -1.68 | 2.87 | ** | 0.06 | 24.71 | 6.91 |
| Ruganda | -0.54 | | -0.01 | 21.57 | -1.38 | 2.64 | ** | 0.06 | 22.31 | 7.89 |
| Rugobagoba | -0.47 | | -0.01 | 21.26 | -1.02 | 2.68 | ** | 0.07 | 22.03 | 9.79 |
| Ruhengeri | -0.51 | | -0.01 | 21.41 | -1.49 | 2.27 | * | 0.05 | 22.05 | 6.94 |
| Rutsiro | -0.84 | | -0.02 | 21.35 | -2.21 | 3.32 | *** | 0.06 | 22.10 | 7.96 |
| Rwamagana | -0.36 | | -0.01 | 27.74 | -0.92 | 2.27 | * | 0.07 | 28.37 | 7.05 |
| Rwankeri | -0.84 | | -0.01 | 22.11 | -1.98 | 3.32 | *** | 0.05 | 22.80 | 7.15 |
| Save | -0.13 | | 0.00 | 26.82 | -0.35 | 2.79 | ** | 0.08 | 27.60 | 8.23 |

#### 4.7.1.3 June-July-August Season

Table 4-42 shows that the projected JJA season mean maximum temperature for the period 2021-2050 ranged from +8.5% or +0.06$^{O}$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +3.98% or +0.03$^{O}$C per year (significant, $\alpha \leq 0.05$) in Kamembe under RCP 4.5 w/m$^2$ and ranged from 4.6% or +0.03$^{O}$C per year (significant, $\alpha \leq 0.05$) in Ruhengeri to +2.23% or 0.02$^{O}$C per year (significant, $\alpha \leq 0.05$) in Kamembe under RCP 8.5 w/m$^2$. Notably, the projected JJA maximum temperature for the period 2021-2050 indicates an increasing trend for RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ with a high, increasing trend in most parts of the country, especially over south-eastern and northern highland areas under RCP 4.5 w/m$^2$ whereas Ngoma and Musanze district show a more increased trend compared to rest of the country under RCP 8.5 w/m$^2$

Table 4-43 shows that projected JJA season mean maximum temperature for the period 2041-2070 ranged from +2.92% or +0.03$^{O}$C per year (not significant, $\alpha > 0.05$) in Kibungo to +1.19% or +0.01$^{O}$C per year (not significant, $\alpha > 0.05$) in Gatumba under RCP 4.5 w/m$^2$ and ranged from +8.09% or +0.06$^{O}$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +4.48% or 0.04$^{O}$C per year (significant, $\alpha \leq 0.05$) in Kamembe under RCP 8.5 w/m$^2$. The period of 2041 to 2070 indicates an increasing trend countrywide under RCP 4.5 w/m$^{2,}$ the eastern region and Amayaga region indicate more increasing trend compared to the rest of the country while the areas of south-eastern (Bugesera, Ngoma south western Kirehe and Kayonza) and the northern highland (Ngororero, Nyabihu, Rutsiro, Musanze and Rubavu) extending to Muhanga and Ruhango indicate more increasing trend compared to the rest of the country under RCP 8.5 w/m$^2$

Table 4-43 shows that the projected JJA season mean maximum temperature for the period 2071-2100 ranged from +0.13% or +0.001$^{O}$C per year (not significant, $\alpha > 0.05$) in Kibungo to -3.91% or -0.03$^{O}$C per year (not significant, $\alpha > 0.05$) in Gatumba under RCP 4.5 w/m$^2$ and ranged from +8.66% or +0.07$^{O}$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +4.62% or 0.05$^{O}$C per year (significant, $\alpha \leq 0.05$) in Nyagatare under RCP 8.5 w/m$^2$. However, from 2071 to 2100, most areas indicate a decreasing trend except over eastern Bugesera, Ngoma and southwestern Kayonza under RCP 4.5 w/m$^2$ while the areas of south-eastern (Bugesera, Ngoma, Kirehe, southwestern Kayonza) and the northern highland (Ngororero, Nyabihu, Rutsiro, Musanze and Rubavu) extending to Karongi, Muhanga, Kamonyi and Ruhango indicated more increased trend under RCP 8.5 w/m$^2$

Table 4-42: Analysis of the trend of projected JJA maximum temperature for the period 2021 to 2050 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| Stations | 2021-2050 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | 3.53 | *** | 0.05 | 25.22 | 6.38 | 3.10 | ** | 0.03 | 24.82 | 3.42 |
| Busogo | 2.60 | ** | 0.05 | 21.98 | 7.09 | 1.96 | * | 0.02 | 21.44 | 3.31 |
| Butare | 3.71 | *** | 0.04 | 20.98 | 5.91 | 3.43 | *** | 0.03 | 20.68 | 3.86 |
| Byimana | 3.32 | *** | 0.04 | 24.55 | 4.98 | 2.85 | ** | 0.02 | 24.24 | 2.71 |
| Byumba | 3.07 | ** | 0.05 | 27.61 | 5.23 | 2.75 | ** | 0.03 | 27.19 | 2.97 |
| Cyinzuzi | 3.07 | ** | 0.05 | 25.50 | 5.32 | 2.75 | ** | 0.03 | 25.11 | 3.02 |
| Gabiro | 3.78 | *** | 0.05 | 28.15 | 5.24 | 3.10 | ** | 0.03 | 27.82 | 2.90 |
| Gatumba | 2.60 | ** | 0.06 | 22.08 | 8.50 | 1.96 | * | 0.03 | 21.43 | 3.99 |
| Gikongoro | 3.10 | ** | 0.04 | 24.63 | 4.91 | 3.21 | ** | 0.02 | 24.30 | 2.93 |
| Gisanga | 3.32 | *** | 0.05 | 25.35 | 5.34 | 2.85 | ** | 0.02 | 25.00 | 2.91 |
| Gisenyi | 3.64 | *** | 0.06 | 24.84 | 6.68 | 3.43 | *** | 0.03 | 24.32 | 3.70 |
| Gitarama | 3.32 | *** | 0.05 | 25.35 | 5.34 | 2.85 | ** | 0.02 | 25.00 | 2.91 |
| Gitega | 3.07 | ** | 0.05 | 25.50 | 5.32 | 2.75 | ** | 0.03 | 25.11 | 3.02 |
| Kamembe | 2.75 | ** | 0.03 | 25.85 | 3.98 | 2.68 | ** | 0.02 | 25.50 | 2.23 |
| Kanombe | 3.07 | ** | 0.05 | 27.13 | 5.32 | 2.75 | ** | 0.03 | 26.71 | 3.02 |
| Kansi | 3.71 | *** | 0.05 | 28.58 | 5.13 | 3.43 | *** | 0.03 | 28.23 | 3.35 |
| Kawangire | 3.78 | *** | 0.05 | 27.49 | 5.31 | 3.10 | ** | 0.03 | 27.15 | 2.95 |
| Kibungo | 3.85 | *** | 0.07 | 26.11 | 7.52 | 3.60 | *** | 0.04 | 25.63 | 4.45 |
| Masaka | 3.85 | *** | 0.06 | 26.95 | 6.61 | 3.60 | *** | 0.03 | 26.52 | 3.91 |
| Muganza | 3.10 | ** | 0.04 | 23.61 | 5.14 | 3.21 | ** | 0.02 | 23.28 | 3.06 |
| Mushubi | 2.53 | * | 0.04 | 22.75 | 5.30 | 2.25 | * | 0.02 | 22.37 | 2.95 |
| Ntaruka | 2.93 | ** | 0.04 | 24.61 | 4.41 | 2.46 | * | 0.02 | 24.32 | 2.59 |
| Ntendezi | 2.75 | ** | 0.04 | 24.72 | 4.30 | 2.68 | ** | 0.02 | 24.34 | 2.43 |
| Nyagatare | 3.68 | *** | 0.04 | 29.35 | 4.45 | 3.00 | ** | 0.03 | 29.01 | 2.81 |
| Nyamata | 3.32 | *** | 0.04 | 27.63 | 4.83 | 2.85 | ** | 0.02 | 27.29 | 2.63 |
| Rubengera | 2.53 | * | 0.04 | 24.71 | 4.94 | 2.25 | * | 0.02 | 24.33 | 2.75 |
| Ruganda | 3.07 | ** | 0.05 | 21.56 | 6.95 | 2.75 | ** | 0.03 | 21.12 | 3.96 |
| Rugobagoba | 3.32 | *** | 0.05 | 21.64 | 6.74 | 2.85 | ** | 0.03 | 21.26 | 3.69 |
| Ruhengeri | 2.46 | * | 0.05 | 21.13 | 7.68 | 2.43 | * | 0.03 | 20.65 | 4.60 |
| Rutsiro | 2.60 | ** | 0.05 | 22.03 | 7.20 | 1.96 | * | 0.02 | 21.48 | 3.37 |
| Rwamagana | 3.78 | *** | 0.05 | 27.49 | 5.31 | 3.10 | ** | 0.03 | 27.15 | 2.95 |
| Rwankeri | 2.60 | ** | 0.05 | 22.73 | 6.47 | 1.96 | * | 0.02 | 22.22 | 3.02 |
| Save | 3.71 | *** | 0.05 | 26.65 | 5.23 | 3.43 | *** | 0.03 | 26.32 | 3.41 |

Table 4-43: Analysis of trend of projected JJA maximum temperature for the period 2041 to 2070 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| Stations | 2041-2070 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | 2.14 | * | 0.02 | 25.92 | 2.62 | 4.46 | *** | 0.05 | 25.70 | 6.19 |
| Busogo | 0.89 | | 0.01 | 22.61 | 1.30 | 3.25 | ** | 0.05 | 22.36 | 6.78 |
| Butare | 2.07 | * | 0.02 | 21.54 | 2.63 | 4.53 | *** | 0.04 | 21.41 | 6.12 |
| Byimana | 1.96 | * | 0.02 | 25.12 | 1.80 | 4.17 | *** | 0.05 | 24.96 | 5.47 |
| Byumba | 1.68 | + | 0.02 | 28.28 | 1.71 | 4.07 | *** | 0.05 | 28.07 | 5.71 |
| Cyinzuzi | 1.68 | + | 0.02 | 26.13 | 1.74 | 4.07 | *** | 0.05 | 25.93 | 5.81 |
| Gabiro | 2.32 | * | 0.02 | 28.79 | 2.14 | 4.57 | *** | 0.05 | 28.64 | 5.28 |
| Gatumba | 0.89 | | 0.01 | 22.85 | 1.55 | 3.25 | ** | 0.06 | 22.54 | 8.09 |
| Gikongoro | 1.96 | * | 0.02 | 25.17 | 2.00 | 4.32 | *** | 0.04 | 25.01 | 5.21 |
| Gisanga | 1.96 | * | 0.02 | 25.98 | 1.93 | 4.17 | *** | 0.05 | 25.80 | 5.86 |
| Gisenyi | 1.82 | + | 0.02 | 25.56 | 1.97 | 5.00 | *** | 0.05 | 25.25 | 6.31 |
| Gitarama | 1.96 | * | 0.02 | 25.98 | 1.93 | 4.17 | *** | 0.05 | 25.80 | 5.86 |
| Gitega | 1.68 | + | 0.02 | 26.13 | 1.74 | 4.07 | *** | 0.05 | 25.93 | 5.81 |
| Kamembe | 1.64 | | 0.01 | 26.30 | 1.24 | 3.78 | *** | 0.04 | 26.13 | 4.48 |
| Kanombe | 1.68 | + | 0.02 | 27.80 | 1.74 | 4.07 | *** | 0.05 | 27.58 | 5.80 |
| Kansi | 2.07 | * | 0.02 | 29.24 | 2.29 | 4.53 | *** | 0.05 | 29.08 | 5.34 |
| Kawangire | 2.32 | * | 0.02 | 28.11 | 2.17 | 4.57 | *** | 0.05 | 27.97 | 5.35 |
| Kibungo | 1.94 | + | 0.03 | 27.02 | 2.92 | 4.92 | *** | 0.07 | 26.76 | 7.46 |
| Masaka | 1.94 | + | 0.02 | 27.78 | 2.57 | 4.92 | *** | 0.06 | 27.54 | 6.59 |
| Muganza | 1.96 | * | 0.02 | 24.16 | 2.08 | 4.32 | *** | 0.04 | 24.00 | 5.45 |
| Mushubi | 1.43 | | 0.01 | 23.29 | 1.54 | 3.75 | *** | 0.05 | 23.10 | 5.96 |
| Ntaruka | 2.11 | * | 0.02 | 25.20 | 2.37 | 3.93 | *** | 0.04 | 25.06 | 4.94 |
| Ntendezi | 1.64 | | 0.01 | 25.19 | 1.34 | 3.78 | *** | 0.04 | 25.00 | 4.88 |
| Nyagatare | 2.64 | ** | 0.02 | 30.02 | 2.41 | 4.39 | *** | 0.05 | 29.88 | 5.15 |
| Nyamata | 1.96 | * | 0.02 | 28.25 | 1.75 | 4.17 | *** | 0.05 | 28.07 | 5.32 |
| Rubengera | 1.43 | | 0.01 | 25.26 | 1.43 | 3.75 | *** | 0.05 | 25.06 | 5.55 |
| Ruganda | 1.68 | + | 0.02 | 22.25 | 2.25 | 4.07 | *** | 0.06 | 22.03 | 7.54 |
| Rugobagoba | 1.96 | * | 0.02 | 22.31 | 2.41 | 4.17 | *** | 0.05 | 22.12 | 7.36 |
| Ruhengeri | 1.03 | | 0.01 | 21.97 | 1.66 | 3.32 | *** | 0.05 | 21.60 | 6.34 |
| Rutsiro | 0.89 | | 0.01 | 22.68 | 1.32 | 3.25 | ** | 0.05 | 22.42 | 6.88 |
| Rwamagana | 2.32 | * | 0.02 | 28.11 | 2.17 | 4.57 | *** | 0.05 | 27.97 | 5.35 |
| Rwankeri | 0.89 | | 0.01 | 23.33 | 1.19 | 3.25 | ** | 0.05 | 23.09 | 6.19 |
| Save | 2.07 | * | 0.02 | 27.28 | 2.33 | 4.53 | *** | 0.05 | 27.13 | 5.43 |

Table 4-44: Analysis of trend of projected JJA maximum temperature for the period 2071 to 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| Stations | 2071-2100 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | -0.06 | | 0.00 | 26.32 | -0.14 | 3.40 | *** | 0.06 | 27.28 | 6.86 |
| Busogo | -1.41 | | -0.03 | 23.02 | -3.29 | 3.36 | *** | 0.06 | 23.80 | 7.34 |
| Butare | -0.36 | | 0.00 | 21.96 | -0.39 | 3.73 | *** | 0.05 | 22.74 | 6.37 |
| Byimana | -0.36 | | 0.00 | 25.52 | -0.52 | 3.36 | *** | 0.05 | 26.25 | 5.58 |
| Byumba | -0.39 | | -0.01 | 28.74 | -0.83 | 3.28 | ** | 0.06 | 29.59 | 5.83 |
| Cyinzuzi | -0.39 | | -0.01 | 26.56 | -0.84 | 3.28 | ** | 0.05 | 27.36 | 5.92 |
| Gabiro | -0.06 | | 0.00 | 29.22 | -0.01 | 3.47 | *** | 0.05 | 30.08 | 5.30 |
| Gatumba | -1.41 | | -0.03 | 23.34 | -3.91 | 3.36 | *** | 0.07 | 24.28 | 8.66 |
| Gikongoro | -0.62 | | -0.01 | 25.61 | -0.79 | 3.51 | *** | 0.05 | 26.35 | 5.27 |
| Gisanga | -0.36 | | 0.00 | 26.42 | -0.55 | 3.36 | *** | 0.05 | 27.24 | 5.96 |
| Gisenyi | -0.62 | | -0.01 | 26.14 | -0.80 | 4.15 | *** | 0.05 | 26.93 | 5.53 |
| Gitarama | -0.36 | | 0.00 | 26.42 | -0.55 | 3.36 | *** | 0.05 | 27.24 | 5.96 |
| Gitega | -0.39 | | -0.01 | 26.56 | -0.84 | 3.28 | ** | 0.05 | 27.36 | 5.92 |
| Kamembe | -0.84 | | -0.01 | 26.63 | -0.95 | 3.55 | *** | 0.04 | 27.26 | 4.66 |
| Kanombe | -0.39 | | -0.01 | 28.25 | -0.84 | 3.28 | ** | 0.06 | 29.10 | 5.91 |
| Kansi | -0.36 | | 0.00 | 29.74 | -0.34 | 3.73 | *** | 0.06 | 30.66 | 5.60 |
| Kawangire | -0.06 | | 0.00 | 28.54 | -0.01 | 3.47 | *** | 0.05 | 29.40 | 5.37 |
| Kibungo | 0.02 | | 0.00 | 27.65 | 0.13 | 3.96 | *** | 0.08 | 28.74 | 7.99 |
| Masaka | 0.02 | | 0.00 | 28.35 | 0.12 | 3.96 | *** | 0.07 | 29.34 | 7.12 |
| Muganza | -0.62 | | -0.01 | 24.59 | -0.83 | 3.51 | *** | 0.05 | 25.34 | 5.50 |
| Mushubi | -0.81 | | -0.01 | 23.69 | -1.85 | 3.32 | *** | 0.05 | 24.39 | 6.38 |
| Ntaruka | -0.77 | | -0.01 | 25.54 | -0.91 | 2.98 | ** | 0.04 | 26.27 | 4.97 |
| Ntendezi | -0.84 | | -0.01 | 25.53 | -1.03 | 3.55 | *** | 0.04 | 26.17 | 5.06 |
| Nyagatare | -0.17 | | 0.00 | 30.47 | -0.23 | 3.28 | ** | 0.05 | 31.35 | 4.62 |
| Nyamata | -0.36 | | 0.00 | 28.69 | -0.50 | 3.36 | *** | 0.05 | 29.49 | 5.43 |
| Rubengera | -0.81 | | -0.01 | 25.66 | -1.73 | 3.32 | *** | 0.05 | 26.37 | 5.97 |
| Ruganda | -0.39 | | -0.01 | 22.72 | -1.09 | 3.28 | ** | 0.06 | 23.60 | 7.57 |
| Rugobagoba | -0.36 | | -0.01 | 22.79 | -0.69 | 3.36 | *** | 0.06 | 23.66 | 7.38 |
| Ruhengeri | -0.62 | | -0.02 | 22.09 | -2.13 | 2.01 | * | 0.05 | 22.92 | 6.27 |
| Rutsiro | -1.41 | | -0.03 | 23.09 | -3.34 | 3.36 | *** | 0.06 | 23.89 | 7.44 |
| Rwamagana | -0.06 | | 0.00 | 28.54 | -0.01 | 3.47 | *** | 0.05 | 29.40 | 5.37 |
| Rwankeri | -1.41 | | -0.02 | 23.72 | -3.01 | 3.36 | *** | 0.05 | 24.46 | 6.74 |
| Save | -0.36 | | 0.00 | 27.76 | -0.35 | 3.73 | *** | 0.05 | 28.63 | 5.69 |

#### 4.7.1.4 September-October-November-December Season

Table 4-45 shows that projected SOND season mean maximum temperature for the period 2021-2050 ranged from +4.89% or +0.04$^{O}$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +0.92% or +0.01$^{O}$C per year (not significant, $\alpha > 0.05$) in Gabiro under RCP 4.5 w/m$^2$ and ranged from +8.05% or +0.05$^{O}$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +3.64% or 0.03$^{O}$C per year (significant, $\alpha \leq 0.05$) in Bukora under RCP 8.5 w/m$^2$ Notably, the projected SOND maximum temperature for the period 2021-2050 for RCP 4.5 w/m$^2$ indicates a high, increasing trend, especially in north-western parts of the country, southwestern (Rusizi, Nyamasheke, Nyamagabe, Nyaruguru), most of southeastern (Ngoma towards eastern parts of Bugesera and southwestern part of Rwamagana Districts). Similarly, RCP 8.5 w/m$^2$ indicates a very high increasing trend in Musanze, Nyabihu, Ngororero and Rutsiro, and a slight increase over the eastern part (Kayonza and Kirehe) and in Nyamasheke district.

Table 4-46 shows that projected SOND season mean maximum temperature for the period 2041-2070 ranged from +3.9% or +0.02$^{O}$C per year (significant, $\alpha \leq 0.05$) in Ruhengeri to +2.04% or +0.02$^{O}$C per year (not significant, $\alpha > 0.05$) in Bukora under RCP 4.5 w/m$^2$ and ranged from +9.81% or +0.07$^{O}$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +4.94% or 0.04$^{O}$C per year (significant, $\alpha \leq 0.05$) in Kamembe under RCP 8.5 w/m$^2$. In addition, the projected SOND maximum temperature for the period 2041-2070 for RCP 4.5 w/m$^2$ ( (indicates a positive increasing trend from East to West, while for RCP 8.5 w/m$^2$ shows high increasing trend in north-western part of the country, central part, eastern part and Bugarama valley.

Table 4-47 shows that the projected SOND season mean maximum temperature for the period 2071-2100 ranged from +1.5% or +0.01$^{O}$C per year (not significant, $\alpha > 0.05$) in Butare to +0.13% or 0.001$^{O}$C per year (not significant, $\alpha > 0.05$) in Gisenyi under RCP 4.5 w/m$^2$ and ranged from +8.38% or +0.06$^{O}$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +4.27% or 0.04$^{O}$C per year (significant, $\alpha \leq 0.05$) in Kamembe under RCP 8.5 w/m$^2$. The projected SOND maximum temperature for the period 2071-2100 for RCP 4.5 w/m$^2$ indicates a slightly increasing trend countrywide, while for RCP 8.5 w/m$^2$ shows a high, increasing trend in most southern states Kirehe and the northern highland.

In general, the projected SOND maximum temperature trend shows an increase under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ for the period 2021-2050. In addition, a more increasing trend of projected maximum temperature is expected under RCP 8.5 w/m$^2$compared to RCP 4.5 w/m$^2$ for the period 2041-2070. Similarly, a rising trend is noted for the period 2071-2100, whereby the RCP 8.5 w/m$^2$ i is indicating an increase at a more considerable magnitude than RCP 4.5w/m$^2$.

Table 4-45: Analysis of the trend of projected SOND maximum temperature for the period 2021-2050, under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| Stations | 2021-2050 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | 0.82 | | 0.01 | 22.13 | 2.03 | 2.50 | * | 0.03 | 22.68 | 3.64 |
| Busogo | 2.21 | * | 0.02 | 19.16 | 3.55 | 3.68 | *** | 0.04 | 19.61 | 6.56 |
| Butare | 1.71 | + | 0.01 | 19.47 | 2.09 | 4.21 | *** | 0.03 | 19.72 | 4.72 |
| Byimana | 1.14 | | 0.01 | 22.55 | 1.03 | 4.17 | *** | 0.03 | 22.89 | 3.95 |
| Byumba | 1.28 | | 0.01 | 25.14 | 1.68 | 4.35 | *** | 0.04 | 25.48 | 4.95 |
| Cyinzuzi | 1.28 | | 0.01 | 23.18 | 1.71 | 4.35 | *** | 0.04 | 23.50 | 5.04 |
| Gabiro | 1.14 | | 0.01 | 25.73 | 0.92 | 3.60 | *** | 0.03 | 26.13 | 3.85 |
| Gatumba | 2.21 | * | 0.03 | 18.69 | 4.38 | 3.68 | *** | 0.05 | 19.24 | 8.05 |
| Gikongoro | 1.89 | + | 0.02 | 22.56 | 2.58 | 4.85 | *** | 0.03 | 22.89 | 4.53 |
| Gisanga | 1.14 | | 0.01 | 23.13 | 1.11 | 4.17 | *** | 0.03 | 23.51 | 4.26 |
| Gisenyi | 3.78 | *** | 0.04 | 22.71 | 4.89 | 4.17 | *** | 0.04 | 22.98 | 5.38 |
| Gitarama | 1.14 | | 0.01 | 23.13 | 1.11 | 4.17 | *** | 0.03 | 23.51 | 4.26 |
| Gitega | 1.28 | | 0.01 | 23.18 | 1.71 | 4.35 | *** | 0.04 | 23.50 | 5.04 |
| Kamembe | 2.03 | * | 0.02 | 23.48 | 2.04 | 4.17 | *** | 0.03 | 23.89 | 3.83 |
| Kanombe | 1.28 | | 0.01 | 24.66 | 1.71 | 4.35 | *** | 0.04 | 25.00 | 5.03 |
| Kansi | 1.71 | + | 0.02 | 26.79 | 1.79 | 4.21 | *** | 0.04 | 27.08 | 4.07 |
| Kawangire | 1.14 | | 0.01 | 25.08 | 0.94 | 3.60 | *** | 0.03 | 25.48 | 3.91 |
| Kibungo | 2.50 | * | 0.03 | 24.17 | 3.23 | 4.71 | *** | 0.04 | 24.48 | 4.77 |
| Masaka | 2.50 | * | 0.02 | 25.19 | 2.81 | 4.71 | *** | 0.04 | 25.47 | 4.17 |
| Muganza | 1.89 | + | 0.02 | 21.54 | 2.71 | 4.85 | *** | 0.03 | 21.87 | 4.76 |
| Mushubi | 1.71 | + | 0.01 | 20.41 | 1.63 | 4.21 | *** | 0.04 | 20.79 | 5.07 |
| Ntaruka | 0.82 | | 0.01 | 21.81 | 1.59 | 4.07 | *** | 0.04 | 22.24 | 5.70 |
| Ntendezi | 2.07 | * | 0.02 | 22.29 | 2.21 | 4.17 | *** | 0.03 | 22.67 | 4.19 |
| Nyagatare | 1.14 | | 0.01 | 26.44 | 1.64 | 3.75 | *** | 0.05 | 26.88 | 5.07 |
| Nyamata | 1.14 | | 0.01 | 25.44 | 1.00 | 4.17 | *** | 0.03 | 25.81 | 3.83 |
| Rubengera | 1.71 | + | 0.01 | 22.35 | 1.50 | 4.21 | *** | 0.04 | 22.73 | 4.69 |
| Ruganda | 1.28 | | 0.01 | 18.99 | 2.30 | 4.35 | *** | 0.04 | 19.34 | 6.76 |
| Rugobagoba | 1.14 | | 0.01 | 19.24 | 1.44 | 4.17 | *** | 0.04 | 19.65 | 5.49 |
| Ruhengeri | 2.03 | * | 0.03 | 18.19 | 4.26 | 3.35 | *** | 0.05 | 18.64 | 7.80 |
| Rutsiro | 2.21 | * | 0.02 | 19.16 | 3.61 | 3.68 | *** | 0.04 | 19.62 | 6.67 |
| Rwamagana | 1.14 | | 0.01 | 25.08 | 0.94 | 3.60 | *** | 0.03 | 25.48 | 3.91 |
| Rwankeri | 2.21 | * | 0.02 | 20.08 | 3.19 | 3.68 | *** | 0.04 | 20.50 | 5.92 |
| Save | 1.71 | + | 0.02 | 24.95 | 1.83 | 4.21 | *** | 0.03 | 25.23 | 4.15 |

Table 4-46: Analysis of trend of projected SOND maximum temperature for the period a) 2041-2070 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| Stations | 2041-2070 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | 1.11 | | 0.02 | 22.46 | 2.04 | 4.10 | *** | 0.06 | 23.56 | 7.58 |
| Busogo | 2.00 | * | 0.02 | 19.56 | 3.04 | 4.85 | *** | 0.06 | 20.58 | 8.08 |
| Butare | 1.89 | + | 0.02 | 19.73 | 2.42 | 3.96 | *** | 0.04 | 20.43 | 6.10 |
| Byimana | 2.11 | * | 0.02 | 22.80 | 2.16 | 4.25 | *** | 0.04 | 23.60 | 5.53 |
| Byumba | 2.00 | * | 0.02 | 25.47 | 2.43 | 4.25 | *** | 0.05 | 26.39 | 6.04 |
| Cyinzuzi | 2.00 | * | 0.02 | 23.49 | 2.48 | 4.25 | *** | 0.05 | 24.35 | 6.14 |
| Gabiro | 1.32 | | 0.02 | 26.00 | 2.04 | 4.00 | *** | 0.05 | 26.96 | 5.76 |
| Gatumba | 2.00 | * | 0.02 | 19.17 | 3.74 | 4.85 | *** | 0.07 | 20.40 | 9.81 |
| Gikongoro | 2.00 | * | 0.02 | 22.84 | 2.63 | 4.50 | *** | 0.04 | 23.63 | 5.56 |
| Gisanga | 2.11 | * | 0.02 | 23.41 | 2.33 | 4.25 | *** | 0.05 | 24.29 | 5.95 |
| Gisenyi | 2.25 | * | 0.02 | 23.26 | 3.21 | 5.50 | *** | 0.05 | 23.91 | 6.89 |
| Gitarama | 2.11 | * | 0.02 | 23.41 | 2.33 | 4.25 | *** | 0.05 | 24.29 | 5.95 |
| Gitega | 2.00 | * | 0.02 | 23.49 | 2.48 | 4.25 | *** | 0.05 | 24.35 | 6.14 |
| Kamembe | 2.18 | * | 0.02 | 23.76 | 2.26 | 4.96 | *** | 0.04 | 24.53 | 4.94 |
| Kanombe | 2.00 | * | 0.02 | 24.99 | 2.47 | 4.25 | *** | 0.05 | 25.91 | 6.13 |
| Kansi | 1.89 | + | 0.02 | 27.10 | 2.08 | 3.96 | *** | 0.05 | 27.92 | 5.28 |
| Kawangire | 1.32 | | 0.02 | 25.35 | 2.07 | 4.00 | *** | 0.05 | 26.31 | 5.84 |
| Kibungo | 2.21 | * | 0.03 | 24.72 | 3.09 | 5.14 | *** | 0.07 | 25.55 | 7.81 |
| Masaka | 2.21 | * | 0.02 | 25.69 | 2.70 | 5.14 | *** | 0.06 | 26.44 | 6.87 |
| Muganza | 2.00 | * | 0.02 | 21.82 | 2.76 | 4.50 | *** | 0.04 | 22.60 | 5.84 |
| Mushubi | 2.32 | * | 0.02 | 20.68 | 2.91 | 4.64 | *** | 0.04 | 21.54 | 6.25 |
| Ntaruka | 1.57 | | 0.02 | 22.08 | 2.43 | 3.53 | *** | 0.05 | 23.05 | 5.86 |
| Ntendezi | 2.25 | * | 0.02 | 22.59 | 2.43 | 4.96 | *** | 0.04 | 23.34 | 5.40 |
| Nyagatare | 1.28 | | 0.02 | 26.73 | 2.15 | 3.46 | *** | 0.05 | 27.80 | 5.88 |
| Nyamata | 2.11 | * | 0.02 | 25.71 | 2.09 | 4.25 | *** | 0.05 | 26.58 | 5.37 |
| Rubengera | 2.32 | * | 0.02 | 22.62 | 2.69 | 4.64 | *** | 0.05 | 23.49 | 5.80 |
| Ruganda | 2.00 | * | 0.02 | 19.33 | 3.32 | 4.25 | *** | 0.06 | 20.29 | 8.14 |
| Rugobagoba | 2.11 | * | 0.02 | 19.54 | 3.01 | 4.25 | *** | 0.05 | 20.49 | 7.59 |
| Ruhengeri | 2.07 | * | 0.02 | 18.64 | 3.90 | 3.89 | *** | 0.05 | 19.61 | 8.34 |
| Rutsiro | 2.00 | * | 0.02 | 19.57 | 3.10 | 4.85 | *** | 0.06 | 20.60 | 8.22 |
| Rwamagana | 1.32 | | 0.02 | 25.35 | 2.07 | 4.00 | *** | 0.05 | 26.31 | 5.84 |
| Rwankeri | 2.00 | * | 0.02 | 20.45 | 2.75 | 4.85 | *** | 0.05 | 21.41 | 7.33 |
| Save | 1.89 | + | 0.02 | 25.25 | 2.13 | 3.96 | *** | 0.05 | 26.03 | 5.38 |

Table 4-47: Analysis of trend of projected SOND maximum temperature for the period 2071-2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| Stations | 2071-2100 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | 0.34 | | 0.01 | 22.77 | 0.71 | 3.77 | *** | 0.05 | 24.91 | 6.37 |
| Busogo | 0.22 | | 0.00 | 20.11 | 0.55 | 4.33 | *** | 0.05 | 21.89 | 6.98 |
| Butare | 0.57 | | 0.01 | 20.00 | 1.50 | 4.05 | *** | 0.04 | 21.54 | 5.82 |
| Byimana | 0.57 | | 0.00 | 23.12 | 0.63 | 4.01 | *** | 0.04 | 24.65 | 4.83 |
| Byumba | 0.61 | | 0.01 | 25.88 | 0.67 | 4.33 | *** | 0.05 | 27.60 | 5.08 |
| Cyinzuzi | 0.61 | | 0.01 | 23.88 | 0.68 | 4.33 | *** | 0.04 | 25.49 | 5.16 |
| Gabiro | 0.30 | | 0.00 | 26.31 | 0.35 | 4.01 | *** | 0.04 | 28.17 | 4.76 |
| Gatumba | 0.22 | | 0.00 | 19.83 | 0.67 | 4.33 | *** | 0.06 | 21.97 | 8.38 |
| Gikongoro | 0.85 | | 0.01 | 23.16 | 1.29 | 4.17 | *** | 0.04 | 24.71 | 5.13 |
| Gisanga | 0.57 | | 0.01 | 23.76 | 0.68 | 4.01 | *** | 0.04 | 25.46 | 5.18 |
| Gisenyi | 0.06 | | 0.00 | 23.95 | 0.13 | 4.72 | *** | 0.05 | 25.36 | 6.13 |
| Gitarama | 0.57 | | 0.01 | 23.76 | 0.68 | 4.01 | *** | 0.04 | 25.46 | 5.18 |
| Gitega | 0.61 | | 0.01 | 23.88 | 0.68 | 4.33 | *** | 0.04 | 25.49 | 5.16 |
| Kamembe | 0.34 | | 0.01 | 24.12 | 0.71 | 4.05 | *** | 0.04 | 25.49 | 4.27 |
| Kanombe | 0.61 | | 0.01 | 25.40 | 0.68 | 4.33 | *** | 0.05 | 27.11 | 5.16 |
| Kansi | 0.57 | | 0.01 | 27.42 | 1.30 | 4.05 | *** | 0.05 | 29.24 | 5.08 |
| Kawangire | 0.30 | | 0.00 | 25.66 | 0.36 | 4.01 | *** | 0.04 | 27.50 | 4.83 |
| Kibungo | 0.22 | | 0.00 | 25.28 | 0.45 | 4.76 | *** | 0.06 | 27.25 | 6.43 |
| Masaka | 0.22 | | 0.00 | 26.20 | 0.40 | 4.76 | *** | 0.05 | 27.98 | 5.70 |
| Muganza | 0.85 | | 0.01 | 22.13 | 1.36 | 4.17 | *** | 0.04 | 23.69 | 5.37 |
| Mushubi | 0.53 | | 0.01 | 21.07 | 1.12 | 4.21 | *** | 0.04 | 22.62 | 5.29 |
| Ntaruka | 0.49 | | 0.00 | 22.42 | 0.65 | 3.69 | *** | 0.04 | 24.01 | 4.79 |
| Ntendezi | 0.30 | | 0.01 | 22.96 | 0.76 | 4.05 | *** | 0.04 | 24.34 | 4.66 |
| Nyagatare | 0.38 | | 0.00 | 27.06 | 0.28 | 3.34 | *** | 0.05 | 28.96 | 4.80 |
| Nyamata | 0.57 | | 0.01 | 26.07 | 0.61 | 4.01 | *** | 0.04 | 27.74 | 4.69 |
| Rubengera | 0.53 | | 0.01 | 23.02 | 1.04 | 4.21 | *** | 0.04 | 24.58 | 4.92 |
| Ruganda | 0.61 | | 0.01 | 19.76 | 0.91 | 4.33 | *** | 0.05 | 21.54 | 6.75 |
| Rugobagoba | 0.57 | | 0.01 | 19.93 | 0.87 | 4.01 | *** | 0.05 | 21.76 | 6.52 |
| Ruhengeri | 0.30 | | 0.00 | 19.17 | 0.71 | 3.73 | *** | 0.05 | 20.82 | 7.75 |
| Rutsiro | 0.22 | | 0.00 | 20.13 | 0.56 | 4.33 | *** | 0.05 | 21.94 | 7.10 |
| Rwamagana | 0.30 | | 0.00 | 25.66 | 0.36 | 4.01 | *** | 0.04 | 27.50 | 4.83 |
| Rwankeri | 0.22 | | 0.00 | 20.97 | 0.49 | 4.33 | *** | 0.05 | 22.65 | 6.37 |
| Save | 0.57 | | 0.01 | 25.55 | 1.33 | 4.05 | *** | 0.05 | 27.28 | 5.17 |

#### 4.7.1.5 Annual maximum temperature

Table 4-48 shows that the projected mean annual maximum temperature for the period 2021-2050 ranged from +6.09% or +0.04$^{O}$C per year (significant, $\alpha \leq 0.05$) in Ruhengeri to +2.48% or +0.02$^{O}$C per year (significant, $\alpha \leq 0.05$) in Kamembe under RCP 4.5 w/m$^2$ and ranged from 5.9% or +0.04$^{O}$C per year (significant, $\alpha \leq 0.05$) in Ruhengeri to +2.9% or 0.02$^{O}$C per year (significant, $\alpha \leq 0.05$) in Kamembe under RCP 8.5 w/m$^2$. Notably, the projected annual maximum temperature trend for 2021-2050 under RCP 4.5 w/m$^2$ will highly increase over most of the eastern part of Bugesera, Ngoma, Kirehe and south part of Kayonza northern highland. At the same time, other areas indicate an increasing trend Under RCP 8.5 w/m$^2$, a higher increasing trend is indicated over eastern Bugesera, Ngoma and southwestern part of Rwamagana, a small part of eastern Kicukiro and northern tips of Nyagatare Districts, the northern highland extending to Muhanga and Bugarama valley.

Table 4-49 shows that the projected mean annual maximum temperature for the period 2041-2070 ranged from +2.0% or +0.02$^{O}$C per year (significant, $\alpha \leq 0.05$) in Gisenyi to +0.81% or +0.01$^{O}$C per year (not significant, $\alpha > 0.05$) in Kansi under RCP 4.5 w/m$^2$ and ranged from +9.2% or +0.06$^{O}$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +4.42% or 0.04$^{O}$C per year (significant, $\alpha \leq 0.05$) in Kamembe under RCP 8.5 w/m$^2$. Notably, the trend of projected annual maximum temperature for the period 2041-2070 for RCP 4.5 w/m$^2$ shows an increasing trend countrywide, especially over the south-eastern (eastern Bugesera, Ngoma, Kirehe and southern Kayonza) northern highland extending to Muhanga, Kamonyi) reducing towards the southern, southwestern, central and the rest of the eastern parts of the country under RCP 8.5 w/m$^2$

Table 4-50 shows that the Projected mean annual maximum temperature for the period 2071-2100 ranged from +0.37% or +0.001$^{O}$C per year (significant, $\alpha \leq 0.05$) in Bukora to -1.69% or -0.01$^{O}$C per year (not significant, $\alpha > 0.05$) in Gatumba under RCP 4.5 w/m$^2$ and ranged from +9.43% or +0.07$^{O}$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +4.94% or 0.04$^{O}$C per year (significant, $\alpha \leq 0.05$) in Kamembe under RCP 8.5 w/m$^2$ . The projected annual maximum temperature trend for 2071-2100 under RCP 4.5 indicates a slight increase over south-eastern (western Bugarama, Kirehe and Ngoma) and Amayaga areas. The rest of the country indicated a decreasing trend.w/m$^2$. The projected annual maximum temperature indicates a slight increase over the north-eastern, Burera, northern Gicumbi and southwestern areas. In contrast, the remaining areas indicate an enhanced increasing trend ranging between 10 and 20% under RCP 8.5 w/m$^2$. These findings agree with Umugwaneza et al. (2021) study that the projected maximum temperature will increase for 2020-2050 and 2050–2100.

Overall, the projected annual maximum temperature trend shows an increase under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ for the period 2021-2050. An increasing trend of projected maximum temperature with more growth is expected under RCP 8.5 w/m$^2$ compared to RCP 4.5. However, a decreasing trend is noted for the period 2071-2100 over most parts of Rwanda under RCP 4.5 w/m$^2$, whereas a significant increase marks RCP 8.5 w/m$^2$.

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Table 4-48: Analysis of trend of projected annual maximum temperature for the period 2021 to 2050 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| **Stations** | **2021-2050** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **RCP 4.5** w/m$^2$ | | | | | **RCP 8.5** w/m$^2$ | | | | |
| | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | 2.57 | * | 0.04 | 24.10 | 4.95 | 2.21 | * | 0.03 | 23.57 | 3.51 |
| Busogo | 2.68 | ** | 0.03 | 20.56 | 4.59 | 3.71 | *** | 0.03 | 20.07 | 4.78 |
| Butare | 2.36 | * | 0.03 | 20.43 | 4.03 | 3.46 | *** | 0.03 | 20.02 | 3.89 |
| Byimana | 2.21 | * | 0.02 | 23.69 | 2.76 | 3.03 | ** | 0.03 | 23.30 | 3.33 |
| Byumba | 2.46 | * | 0.03 | 26.65 | 3.50 | 3.32 | *** | 0.03 | 26.20 | 3.82 |
| Cyinzuzi | 2.46 | * | 0.03 | 24.60 | 3.56 | 3.32 | *** | 0.03 | 24.17 | 3.89 |
| Gabiro | 2.46 | * | 0.03 | 27.36 | 3.36 | 2.68 | ** | 0.03 | 26.90 | 3.20 |
| Gatumba | 2.68 | ** | 0.04 | 20.38 | 5.58 | 3.71 | *** | 0.04 | 19.79 | 5.83 |
| Gikongoro | 2.28 | * | 0.02 | 23.64 | 3.03 | 3.46 | *** | 0.03 | 23.23 | 3.37 |
| Gisanga | 2.21 | * | 0.02 | 24.39 | 2.97 | 3.03 | ** | 0.03 | 23.96 | 3.60 |
| Gisenyi | 3.75 | *** | 0.05 | 24.00 | 5.79 | 4.39 | *** | 0.04 | 23.58 | 4.51 |
| Gitarama | 2.21 | * | 0.02 | 24.39 | 2.97 | 3.03 | ** | 0.03 | 23.96 | 3.60 |
| Gitega | 2.46 | * | 0.03 | 24.60 | 3.56 | 3.32 | *** | 0.03 | 24.17 | 3.89 |
| Kamembe | 2.53 | * | 0.02 | 24.61 | 2.48 | 3.39 | *** | 0.02 | 24.26 | 2.90 |
| Kanombe | 2.46 | * | 0.03 | 26.17 | 3.56 | 3.32 | *** | 0.03 | 25.72 | 3.88 |
| Kansi | 2.36 | * | 0.03 | 27.93 | 3.49 | 3.46 | *** | 0.03 | 27.44 | 3.36 |
| Kawangire | 2.46 | * | 0.03 | 26.70 | 3.40 | 2.68 | ** | 0.03 | 26.25 | 3.25 |
| Kibungo | 3.18 | ** | 0.05 | 25.68 | 5.92 | 3.53 | *** | 0.04 | 25.12 | 4.84 |
| Masaka | 3.18 | ** | 0.05 | 26.56 | 5.19 | 3.53 | *** | 0.04 | 26.04 | 4.25 |
| Muganza | 2.28 | * | 0.02 | 22.62 | 3.18 | 3.46 | *** | 0.03 | 22.21 | 3.53 |
| Mushubi | 2.18 | * | 0.02 | 21.57 | 2.99 | 3.25 | ** | 0.03 | 21.17 | 3.71 |
| Ntaruka | 3.00 | ** | 0.03 | 23.54 | 3.63 | 3.78 | *** | 0.03 | 23.14 | 4.34 |
| Ntendezi | 2.53 | * | 0.02 | 23.46 | 2.69 | 3.39 | *** | 0.02 | 23.05 | 3.18 |
| Nyagatare | 2.85 | ** | 0.03 | 28.43 | 3.21 | 3.53 | *** | 0.04 | 27.96 | 3.82 |
| Nyamata | 2.21 | * | 0.02 | 26.69 | 2.68 | 3.03 | ** | 0.03 | 26.26 | 3.24 |
| Rubengera | 2.18 | * | 0.02 | 23.52 | 2.77 | 3.25 | ** | 0.03 | 23.11 | 3.43 |
| Ruganda | 2.46 | * | 0.03 | 20.56 | 4.70 | 3.32 | *** | 0.03 | 20.09 | 5.16 |
| Rugobagoba | 2.21 | * | 0.03 | 20.61 | 3.78 | 3.03 | ** | 0.03 | 20.14 | 4.60 |
| Ruhengeri | 2.85 | ** | 0.04 | 20.02 | 6.09 | 3.53 | *** | 0.04 | 19.56 | 5.90 |
| Rutsiro | 2.68 | ** | 0.03 | 20.59 | 4.66 | 3.71 | *** | 0.03 | 20.09 | 4.86 |
| Rwamagana | 2.46 | * | 0.03 | 26.70 | 3.40 | 2.68 | ** | 0.03 | 26.25 | 3.25 |
| Rwankeri | 2.68 | ** | 0.03 | 21.40 | 4.16 | 3.71 | *** | 0.03 | 20.94 | 4.32 |
| Save | 2.36 | * | 0.03 | 26.03 | 3.56 | 3.46 | *** | 0.03 | 25.58 | 3.42 |

Table 4-49: Analysis of trend of projected annual maximum temperature for the period 2041 to 2070 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| **Stations** | **2041-2070** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **RCP 4.5** w/m$^2$ | | | | | **RCP 8.5** w/m$^2$ | | | | |
| | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | 0.93 | | 0.01 | 24.63 | 1.26 | 4.25 | *** | 0.06 | 24.45 | 7.44 |
| Busogo | 1.50 | | 0.01 | 21.09 | 1.25 | 4.82 | *** | 0.05 | 20.97 | 7.61 |
| Butare | 0.79 | | 0.01 | 20.83 | 0.94 | 4.39 | *** | 0.04 | 20.71 | 5.99 |
| Byimana | 0.86 | | 0.01 | 24.08 | 0.93 | 4.46 | *** | 0.04 | 23.98 | 5.30 |
| Byumba | 1.50 | | 0.01 | 27.18 | 1.18 | 4.50 | *** | 0.05 | 27.06 | 5.73 |
| Cyinzuzi | 1.50 | | 0.01 | 25.10 | 1.20 | 4.50 | *** | 0.05 | 24.99 | 5.83 |
| Gabiro | 0.89 | | 0.01 | 27.85 | 0.90 | 4.17 | *** | 0.05 | 27.73 | 5.37 |
| Gatumba | 1.50 | | 0.01 | 21.01 | 1.51 | 4.82 | *** | 0.06 | 20.87 | 9.20 |
| Gikongoro | 0.96 | | 0.01 | 24.03 | 0.87 | 4.32 | *** | 0.04 | 23.92 | 5.12 |
| Gisanga | 0.86 | | 0.01 | 24.83 | 1.00 | 4.46 | *** | 0.05 | 24.72 | 5.70 |
| Gisenyi | 2.43 | * | 0.02 | 24.68 | 2.00 | 5.57 | *** | 0.06 | 24.49 | 6.84 |
| Gitarama | 0.86 | | 0.01 | 24.83 | 1.00 | 4.46 | *** | 0.05 | 24.72 | 5.70 |
| Gitega | 1.50 | | 0.01 | 25.10 | 1.20 | 4.50 | *** | 0.05 | 24.99 | 5.83 |
| Kamembe | 1.46 | | 0.01 | 24.97 | 0.95 | 4.71 | *** | 0.04 | 24.87 | 4.42 |
| Kanombe | 1.50 | | 0.01 | 26.70 | 1.20 | 4.50 | *** | 0.05 | 26.58 | 5.82 |
| Kansi | 0.79 | | 0.01 | 28.39 | 0.81 | 4.39 | *** | 0.05 | 28.26 | 5.20 |
| Kawangire | 0.89 | | 0.01 | 27.19 | 0.91 | 4.17 | *** | 0.05 | 27.06 | 5.45 |
| Kibungo | 1.39 | | 0.01 | 26.41 | 1.63 | 4.96 | *** | 0.07 | 26.18 | 7.61 |
| Masaka | 1.39 | | 0.01 | 27.22 | 1.43 | 4.96 | *** | 0.06 | 27.02 | 6.71 |
| Muganza | 0.96 | | 0.01 | 23.01 | 0.91 | 4.32 | *** | 0.04 | 22.90 | 5.37 |
| Mushubi | 0.82 | | 0.01 | 21.96 | 0.91 | 4.50 | *** | 0.04 | 21.87 | 5.60 |
| Ntaruka | 1.64 | | 0.01 | 24.04 | 1.17 | 4.28 | *** | 0.04 | 23.94 | 5.45 |
| Ntendezi | 1.46 | | 0.01 | 23.82 | 1.06 | 4.71 | *** | 0.04 | 23.69 | 4.83 |
| Nyagatare | 1.14 | | 0.01 | 28.98 | 1.08 | 4.25 | *** | 0.05 | 28.85 | 5.45 |
| Nyamata | 0.86 | | 0.01 | 27.12 | 0.91 | 4.46 | *** | 0.05 | 27.01 | 5.15 |
| Rubengera | 0.82 | | 0.01 | 23.91 | 0.85 | 4.50 | *** | 0.04 | 23.83 | 5.20 |
| Ruganda | 1.50 | | 0.01 | 21.11 | 1.58 | 4.50 | *** | 0.05 | 20.99 | 7.66 |
| Rugobagoba | 0.86 | | 0.01 | 21.07 | 1.27 | 4.46 | *** | 0.05 | 20.96 | 7.23 |
| Ruhengeri | 1.36 | | 0.01 | 20.72 | 1.46 | 4.21 | *** | 0.06 | 20.53 | 8.37 |
| Rutsiro | 1.50 | | 0.01 | 21.12 | 1.27 | 4.82 | *** | 0.05 | 21.00 | 7.73 |
| Rwamagana | 0.89 | | 0.01 | 27.19 | 0.91 | 4.17 | *** | 0.05 | 27.06 | 5.45 |
| Rwankeri | 1.50 | | 0.01 | 21.89 | 1.13 | 4.82 | *** | 0.05 | 21.78 | 6.91 |
| Save | 0.79 | | 0.01 | 26.48 | 0.83 | 4.39 | *** | 0.05 | 26.35 | 5.29 |

Table 4-50: Analysis of trend of projected annual maximum temperature for the period 2071 to 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| **Stations** | **2071-2100** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **RCP 4.5** w/m$^2$ | | | | | **RCP 8.5** w/m$^2$ | | | | |
| | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | 0.14 | | 0.00 | 24.94 | 0.37 | 3.85 | *** | 0.07 | 25.75 | 7.71 |
| Busogo | -0.73 | | -0.01 | 21.55 | -1.41 | 4.48 | *** | 0.06 | 22.28 | 7.89 |
| Butare | 0.22 | | 0.00 | 21.20 | 0.20 | 4.13 | *** | 0.05 | 21.86 | 7.51 |
| Byimana | -0.22 | | 0.00 | 24.45 | -0.32 | 3.93 | *** | 0.05 | 25.06 | 6.19 |
| Byumba | -0.41 | | -0.01 | 27.60 | -0.67 | 4.13 | *** | 0.06 | 28.33 | 6.12 |
| Cyinzuzi | -0.41 | | -0.01 | 25.49 | -0.68 | 4.13 | *** | 0.05 | 26.18 | 6.21 |
| Gabiro | -0.14 | | 0.00 | 28.20 | -0.27 | 3.73 | *** | 0.06 | 28.91 | 6.06 |
| Gatumba | -0.73 | | -0.01 | 21.57 | -1.69 | 4.48 | *** | 0.07 | 22.44 | 9.43 |
| Gikongoro | -0.02 | | 0.00 | 24.42 | -0.05 | 4.37 | *** | 0.05 | 25.06 | 6.19 |
| Gisanga | -0.22 | | 0.00 | 25.23 | -0.34 | 3.93 | *** | 0.06 | 25.92 | 6.64 |
| Gisenyi | -0.26 | | 0.00 | 25.27 | -0.25 | 4.92 | *** | 0.06 | 26.03 | 6.38 |
| Gitarama | -0.22 | | 0.00 | 25.23 | -0.34 | 3.93 | *** | 0.06 | 25.92 | 6.64 |
| Gitega | -0.41 | | -0.01 | 25.49 | -0.68 | 4.13 | *** | 0.05 | 26.18 | 6.21 |
| Kamembe | -0.45 | | -0.01 | 25.31 | -0.63 | 4.45 | *** | 0.04 | 25.85 | 4.94 |
| Kanombe | -0.41 | | -0.01 | 27.12 | -0.68 | 4.13 | *** | 0.06 | 27.85 | 6.21 |
| Kansi | 0.22 | | 0.00 | 28.84 | 0.17 | 4.13 | *** | 0.06 | 29.62 | 6.57 |
| Kawangire | -0.14 | | 0.00 | 27.53 | -0.28 | 3.73 | *** | 0.06 | 28.24 | 6.15 |
| Kibungo | 0.18 | | 0.00 | 26.99 | 0.09 | 4.45 | *** | 0.08 | 27.91 | 8.13 |
| Masaka | 0.18 | | 0.00 | 27.74 | 0.08 | 4.45 | *** | 0.07 | 28.59 | 7.22 |
| Muganza | -0.02 | | 0.00 | 23.40 | -0.05 | 4.37 | *** | 0.05 | 24.04 | 6.48 |
| Mushubi | -0.45 | | -0.01 | 22.36 | -0.92 | 4.25 | *** | 0.05 | 22.98 | 6.47 |
| Ntaruka | -0.30 | | 0.00 | 24.29 | -0.40 | 3.22 | ** | 0.04 | 24.90 | 4.95 |
| Ntendezi | -0.45 | | -0.01 | 24.17 | -0.69 | 4.45 | *** | 0.04 | 24.70 | 5.38 |
| Nyagatare | -0.38 | | 0.00 | 29.31 | -0.43 | 3.34 | *** | 0.05 | 30.04 | 5.27 |
| Nyamata | -0.22 | | 0.00 | 27.51 | -0.31 | 3.93 | *** | 0.06 | 28.19 | 6.02 |
| Rubengera | -0.45 | | -0.01 | 24.32 | -0.85 | 4.25 | *** | 0.05 | 24.94 | 6.03 |
| Ruganda | -0.41 | | -0.01 | 21.54 | -0.89 | 4.13 | *** | 0.06 | 22.30 | 8.05 |
| Rugobagoba | -0.22 | | 0.00 | 21.51 | -0.43 | 3.93 | *** | 0.06 | 22.24 | 8.32 |
| Ruhengeri | -0.06 | | 0.00 | 20.97 | -0.33 | 3.38 | *** | 0.05 | 21.73 | 7.39 |
| Rutsiro | -0.73 | | -0.01 | 21.60 | -1.43 | 4.48 | *** | 0.06 | 22.33 | 8.02 |
| Rwamagana | -0.14 | | 0.00 | 27.53 | -0.28 | 3.73 | *** | 0.06 | 28.24 | 6.15 |
| Rwankeri | -0.73 | | -0.01 | 22.33 | -1.28 | 4.48 | *** | 0.06 | 23.02 | 7.21 |
| Save | 0.22 | | 0.00 | 26.90 | 0.18 | 4.13 | *** | 0.06 | 27.64 | 6.68 |

### 4.7.2 *Temporal analysis of projected Number of cold days (TX10p)*

Table 4-51 shows that projected annual number of cold days for the period 2021-2050 ranged from -54.52% or -0.18 days per year (significant, $\alpha \leq 0.05$) in Bukora to -173.73% or -0.57 days per year (significant, $\alpha \leq 0.05$) in Gisenyi under RCP 4.5 w/m$^2$ and ranged from -55.98% or -0.18 days per year (significant, $\alpha \leq 0.05$) in Gatumba to -124.67% or -0.4 days per year (significant, $\alpha \leq 0.05$) in Kibungo under RCP 8.5 w/m$^2$. Notably, the trend of projected number of cold days during the period 2021-2050 under RCP 4.5 w/m$^2$ highly decreases in most parts of Nyamasheke, Rusizi, Rubavu, Nyagatare and Ngoma Districts, small parts of Rutsiro, eastern Bugesera and Kicukiro Districts, southern part of Rwamagana and small part of southwestern Kirehe Districts, the rest parts of the country indicates a decrease trend while for RCP 8.5 w/m$^2$ indicates an increasing trend country wide.

Table 4-52 shows that projected annual number of cold days for the period 2041-2070 ranged from -25.3% or -0.05 days per year (not significant, $\alpha > 0.05$) in Byumba to -76.12% or -0.1 days per year (significant, $\alpha \leq 0.05$) in Kibungo under RCP 4.5 w/m$^2$ and ranged from 0.0% or +0.001days per year (not significant, $\alpha > 0.05$) in Nyamata to -228.29% or 0.18 days per year (significant, $\alpha \leq 0.05$) in Kibungo under RCP 8.5 w/m$^2$. The trend of projected number of cold days during the period 2041-2070 for RCP 4.5 w/m$^2$ shows a slight decrease trend in most part of Rulindo towards eastern part of Gakenke, northwestern part of Gasabo, northern part of Kamonyi, southern part of Burera and small part of northwestern Gicumbi Districts, while the rest part of the country shows a decrease trend whereas RCP 8.5 w/m$^2$ indicates a decreasing trend over most parts of the country.

Table 4-53 shows that Projected annual number of cold days for the period 2071-2100 ranged from +33.83% or +0.05 days per year (not significant, $\alpha > 0.05$) in Gabiro to -53.59% or -0.03 days per year (not significant, $\alpha > 0.05$) in Kibungo under RCP 4.5 w/m$^2$ and ranged from +0.0% or +0.001 days per year (not significant, $\alpha > 0.05$) in Kibungo to +0.0% or 0.001 days per year (significant, $\alpha \leq 0.05$) in Byimana under RCP 8.5 w/m$^2$. The trend of projected number of cold days during the period 2071-2100 for RCP 4.5 w/m$^2$ shows a slight increasing trend in most part of Northern, Central, southwestern and Eastern regions while the rest parts of southeastern including Ngoma, Bugesera, eastern Kicukiro and southern part of Rwamagana indicates a decrease trend. In addition, RCP 8.5 w/m$^2$ indicates a slight increasing trend over parts of Gicumbi, Nyagatare, Gatsibo and south eastern (western Bugesera, Ngoma and Kirehe) while the rest of the country show a high decreasing trend of number of cold days.

Generally, the trend of projected number of cold days shows a decrease during the period 2021-2050 with more areas expected to experience a greater number of cold days under RCP 8.5 w/m$^2$ compared to RCP 4.5 w/m$^2$. In addition, the period 2041-2070 shows the decreasing trend of projected number of cold days with more decrease expected under RCP 8.5 w/m$^2$ compared to RCP 4.5 w/m$^2$. However, most parts in the Eastern Rwanda shows increasing trends of number of cold days for the period 2071-2100 whereas parts of Western Rwanda showed decreasing trend of number of cold days and thus a decreasing trend of projected number of cold days with more decrease expected under RCP 8.5 w/m$^2$ compared to RCP 4.5 w/m$^2$.

Table 4-51: Analysis of trend of projected number of cold days (TX10p) for the period 2021 to 2050 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| Station | 2021-2050 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | Mean | %Δ | Test Z | α level | Q | Mean | %Δ |
| Bukora | -2.36 | * | -0.18 | 9.63 | -54.52 | -2.21 | * | -0.18 | 9.61 | -55.98 |
| Busogo | -2.93 | ** | -0.27 | 9.61 | -85.14 | -3.36 | *** | -0.24 | 9.86 | -73.02 |
| Butare | -2.71 | ** | -0.20 | 9.85 | -60.91 | -3.32 | *** | -0.30 | 9.86 | -91.25 |
| Byimana | -2.41 | * | -0.20 | 9.72 | -61.75 | -3.27 | ** | -0.27 | 9.74 | -84.40 |
| Byumba | -2.86 | ** | -0.22 | 9.53 | -69.25 | -4.27 | *** | -0.40 | 9.73 | -124.67 |
| Cyinzuzi | -2.86 | ** | -0.22 | 9.53 | -69.25 | -3.74 | *** | -0.30 | 9.80 | -91.87 |
| Gabiro | -2.54 | * | -0.21 | 9.70 | -65.31 | -2.77 | ** | -0.20 | 9.77 | -61.39 |
| Gatumba | -2.93 | ** | -0.27 | 9.61 | -85.14 | -3.90 | *** | -0.30 | 9.80 | -91.84 |
| Gikongoro | -2.96 | ** | -0.21 | 9.70 | -63.79 | -3.70 | *** | -0.28 | 9.90 | -83.36 |
| Gisanga | -2.41 | * | -0.20 | 9.72 | -61.75 | -3.27 | ** | -0.27 | 9.74 | -84.40 |
| Gisenyi | -4.89 | *** | -0.57 | 9.76 | -173.73 | -3.36 | *** | -0.24 | 9.86 | -73.02 |
| Gitarama | -2.41 | * | -0.20 | 9.72 | -61.75 | -3.27 | ** | -0.27 | 9.74 | -84.40 |
| Gitega | -2.86 | ** | -0.22 | 9.53 | -69.25 | -3.36 | *** | -0.24 | 9.86 | -73.02 |
| Kamembe | -3.18 | ** | -0.24 | 9.69 | -74.96 | -3.90 | *** | -0.30 | 9.80 | -91.84 |
| Kanombe | -2.86 | ** | -0.22 | 9.53 | -69.25 | -3.36 | *** | -0.24 | 9.86 | -73.02 |
| Kansi | -2.71 | ** | -0.20 | 9.85 | -60.91 | -3.32 | *** | -0.30 | 9.86 | -91.25 |
| Kawangire | -2.54 | * | -0.21 | 9.70 | -65.31 | -2.21 | * | -0.18 | 9.61 | -55.98 |
| Kibungo | -3.73 | *** | -0.42 | 9.78 | -128.16 | -4.27 | *** | -0.40 | 9.73 | -124.67 |
| Masaka | -3.73 | *** | -0.42 | 9.78 | -128.16 | -4.27 | *** | -0.40 | 9.73 | -124.67 |
| Muganza | -2.96 | ** | -0.21 | 9.70 | -63.79 | -3.70 | *** | -0.28 | 9.90 | -83.36 |
| Mushubi | -2.82 | ** | -0.22 | 9.64 | -68.49 | -3.45 | *** | -0.25 | 9.73 | -77.05 |
| Ntaruka | -2.54 | * | -0.18 | 9.67 | -55.13 | -2.77 | ** | -0.20 | 9.77 | -61.39 |
| Ntendezi | -3.18 | ** | -0.24 | 9.69 | -74.96 | -2.99 | ** | -0.25 | 9.81 | -77.04 |
| Nyagatare | -3.15 | ** | -0.18 | 9.65 | -55.94 | -2.77 | ** | -0.20 | 9.77 | -61.39 |
| Nyamata | -2.41 | * | -0.20 | 9.72 | -61.75 | -2.41 | * | -0.20 | 9.72 | -61.75 |
| Rubengera | -2.82 | ** | -0.22 | 9.64 | -68.49 | -3.45 | *** | -0.25 | 9.73 | -77.05 |
| Rugunga | -2.86 | ** | -0.22 | 9.53 | -69.25 | -3.54 | *** | -0.24 | 9.88 | -71.55 |
| Ruhengeri | -2.39 | * | -0.21 | 9.76 | -64.53 | -3.54 | *** | -0.24 | 9.88 | -71.55 |
| Rutsiro | -2.93 | ** | -0.27 | 9.61 | -85.14 | -3.74 | *** | -0.30 | 9.80 | -91.87 |
| Rwamagana | -2.54 | * | -0.21 | 9.70 | -65.31 | -3.12 | ** | -0.20 | 9.80 | -61.20 |
| Rwesero | -2.93 | ** | -0.27 | 9.61 | -85.14 | -3.74 | *** | -0.30 | 9.80 | -91.87 |
| Zaza | -2.71 | ** | -0.20 | 9.85 | -60.91 | -3.32 | *** | -0.30 | 9.86 | -91.25 |

Table 4-52: Analysis of trend of projected number of cold days (TX10p) for the period 2041 to 2070 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| Station | 2041-2070 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | Mean | %Δ | Test Z | α level | Q | Mean | %Δ |
| Bukora | -1.39 | | -0.08 | 6.07 | -41.82 | -4.01 | *** | -0.19 | 4.74 | -121.71 |
| Busogo | -1.79 | + | -0.09 | 5.45 | -47.15 | -4.72 | *** | -0.20 | 4.40 | -139.43 |
| Butare | -2.33 | * | -0.09 | 6.19 | -44.40 | -4.09 | *** | -0.20 | 4.64 | -129.22 |
| Byimana | -1.91 | + | -0.08 | 5.88 | -42.20 | -4.38 | *** | -0.19 | 4.35 | -132.18 |
| Byumba | -0.91 | | -0.05 | 5.93 | -25.30 | -5.05 | *** | -0.18 | 2.35 | -228.29 |
| Cyinzuzi | -0.91 | | -0.05 | 5.93 | -25.30 | -4.53 | *** | -0.19 | 3.87 | -146.55 |
| Gabiro | -2.06 | * | -0.09 | 6.08 | -45.26 | -4.60 | *** | -0.20 | 4.64 | -129.31 |
| Gatumba | -1.79 | + | -0.09 | 5.45 | -47.15 | -4.41 | *** | -0.20 | 4.28 | -140.19 |
| Gikongoro | -1.15 | | -0.06 | 6.31 | -28.53 | -4.16 | *** | -0.18 | 4.71 | -116.86 |
| Gisanga | -1.91 | + | -0.08 | 5.88 | -42.20 | -4.38 | *** | -0.19 | 4.35 | -132.18 |
| Gisenyi | -2.10 | * | -0.07 | 3.12 | -68.75 | -4.72 | *** | -0.20 | 4.40 | -139.43 |
| Gitarama | -1.91 | + | -0.08 | 5.88 | -42.20 | -4.38 | *** | -0.19 | 4.35 | -132.18 |
| Gitega | -0.91 | | -0.05 | 5.93 | -25.30 | -4.72 | *** | -0.20 | 4.40 | -139.43 |
| Kamembe | -1.91 | + | -0.10 | 5.94 | -50.48 | -4.41 | *** | -0.20 | 4.28 | -140.19 |
| Kanombe | -0.91 | | -0.05 | 5.93 | -25.30 | -4.72 | *** | -0.20 | 4.40 | -139.43 |
| Kansi | -2.33 | * | -0.09 | 6.19 | -44.40 | -4.09 | *** | -0.20 | 4.64 | -129.22 |
| Kawangire | -2.06 | * | -0.09 | 6.08 | -45.26 | -4.01 | *** | -0.19 | 4.74 | -121.71 |
| Kibungo | -2.02 | * | -0.10 | 3.77 | -76.12 | -5.05 | *** | -0.18 | 2.35 | -228.29 |
| Masaka | -2.02 | * | -0.10 | 3.77 | -76.12 | -5.05 | *** | -0.18 | 2.35 | -228.29 |
| Muganza | -1.15 | | -0.06 | 6.31 | -28.53 | -4.16 | *** | -0.18 | 4.71 | -116.86 |
| Mushubi | -1.47 | | -0.07 | 5.92 | -34.65 | -4.81 | *** | -0.20 | 4.36 | -137.51 |
| Ntaruka | -1.07 | | -0.06 | 6.10 | -27.15 | -4.60 | *** | -0.20 | 4.64 | -129.31 |
| Ntendezi | -1.91 | + | -0.10 | 5.94 | -50.48 | -4.14 | *** | -0.18 | 4.57 | -118.16 |
| Nyagatare | -1.00 | | -0.06 | 6.45 | -28.41 | -4.60 | *** | -0.20 | 4.64 | -129.31 |
| Nyamata | -1.91 | + | -0.08 | 5.88 | -42.20 | 0.04 | | 0.00 | 3.90 | 0.00 |
| Rubengera | -1.47 | | -0.07 | 5.92 | -34.65 | -4.81 | *** | -0.20 | 4.36 | -137.51 |
| Rugunga | -0.91 | | -0.05 | 5.93 | -25.30 | -4.40 | *** | -0.19 | 4.62 | -124.79 |
| Ruhengeri | -1.52 | | -0.05 | 4.98 | -31.58 | -4.40 | *** | -0.19 | 4.62 | -124.79 |
| Rutsiro | -1.79 | + | -0.09 | 5.45 | -47.15 | -4.53 | *** | -0.19 | 3.87 | -146.55 |
| Rwamagana | -2.06 | * | -0.09 | 6.08 | -45.26 | -4.58 | *** | -0.19 | 4.67 | -124.70 |
| Rwesero | -1.79 | + | -0.09 | 5.45 | -47.15 | -4.53 | *** | -0.19 | 3.87 | -146.55 |
| Zaza | -2.33 | * | -0.09 | 6.19 | -44.40 | -4.09 | *** | -0.20 | 4.64 | -129.22 |

Table 4-53: Analysis of trend of projected number of cold days (TX10p) for the period 2071 to 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| Station | 2071-2100 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | Mean | %Δ | Test Z | α level | Q | Mean | %Δ |
| Bukora | 0.43 | | 0.03 | 4.51 | 18.82 | -2.02 | * | -0.04 | 1.10 | -100.13 |
| Busogo | -0.49 | | -0.01 | 2.93 | -13.80 | -2.17 | * | -0.03 | 0.77 | -105.78 |
| Butare | 0.15 | | 0.00 | 4.13 | 0.00 | -2.60 | ** | -0.03 | 0.94 | -102.31 |
| Byimana | 0.04 | | 0.00 | 3.90 | 0.00 | -3.14 | ** | -0.04 | 0.83 | -142.67 |
| Byumba | 0.45 | | 0.02 | 3.88 | 14.07 | -1.62 | | 0.00 | 0.14 | 0.00 |
| Cyinzuzi | 0.45 | | 0.02 | 3.88 | 14.07 | -2.16 | * | -0.01 | 0.55 | -66.12 |
| Gabiro | 1.04 | | 0.05 | 4.29 | 33.83 | -2.73 | ** | -0.05 | 1.20 | -126.33 |
| Gatumba | -0.49 | | -0.01 | 2.93 | -13.80 | -2.92 | ** | -0.04 | 0.78 | -131.17 |
| Gikongoro | -1.30 | | -0.05 | 4.19 | -32.26 | -2.67 | ** | -0.03 | 0.80 | -95.39 |
| Gisanga | 0.04 | | 0.00 | 3.90 | 0.00 | -3.14 | ** | -0.04 | 0.83 | -142.67 |
| Gisenyi | -0.47 | | 0.00 | 1.06 | 0.00 | -2.17 | * | -0.03 | 0.77 | -105.78 |
| Gitarama | 0.04 | | 0.00 | 3.90 | 0.00 | -3.14 | ** | -0.04 | 0.83 | -142.67 |
| Gitega | 0.45 | | 0.02 | 3.88 | 14.07 | -2.17 | * | -0.03 | 0.77 | -105.78 |
| Kamembe | 0.23 | | 0.00 | 3.71 | 0.00 | -2.92 | ** | -0.04 | 0.78 | -131.17 |
| Kanombe | 0.45 | | 0.02 | 3.88 | 14.07 | -2.17 | * | -0.03 | 0.77 | -105.78 |
| Kansi | 0.15 | | 0.00 | 4.13 | 0.00 | -2.60 | ** | -0.03 | 0.94 | -102.31 |
| Kawangire | 1.04 | | 0.05 | 4.29 | 33.83 | -2.02 | * | -0.04 | 1.10 | -100.13 |
| Kibungo | -1.00 | | -0.03 | 1.48 | -53.59 | -1.62 | | 0.00 | 0.14 | 0.00 |
| Masaka | -1.00 | | -0.03 | 1.48 | -53.59 | -1.62 | | 0.00 | 0.14 | 0.00 |
| Muganza | -1.30 | | -0.05 | 4.19 | -32.26 | -2.67 | ** | -0.03 | 0.80 | -95.39 |
| Mushubi | -0.58 | | -0.03 | 3.64 | -23.64 | -2.69 | ** | -0.03 | 0.68 | -115.84 |
| Ntaruka | 0.26 | | 0.01 | 4.34 | 9.74 | -2.73 | ** | -0.05 | 1.20 | -126.33 |
| Ntendezi | 0.23 | | 0.00 | 3.71 | 0.00 | -1.94 | + | -0.03 | 1.02 | -74.77 |
| Nyagatare | 0.64 | | 0.03 | 4.78 | 20.21 | -2.73 | ** | -0.05 | 1.20 | -126.33 |
| Nyamata | 0.04 | | 0.00 | 3.90 | 0.00 | 0.04 | | 0.00 | 3.90 | 0.00 |
| Rubengera | -0.58 | | -0.03 | 3.64 | -23.64 | -2.69 | ** | -0.03 | 0.68 | -115.84 |
| Rugunga | 0.45 | | 0.02 | 3.88 | 14.07 | -1.27 | | -0.02 | 1.21 | -50.86 |
| Ruhengeri | 0.36 | | 0.02 | 3.49 | 14.13 | -1.27 | | -0.02 | 1.21 | -50.86 |
| Rutsiro | -0.49 | | -0.01 | 2.93 | -13.80 | -2.16 | * | -0.01 | 0.55 | -66.12 |
| Rwamagana | 1.04 | | 0.05 | 4.29 | 33.83 | -1.89 | + | -0.04 | 1.32 | -92.56 |
| Rwesero | -0.49 | | -0.01 | 2.93 | -13.80 | -2.16 | * | -0.01 | 0.55 | -66.12 |
| Zaza | 0.15 | | 0.00 | 4.13 | 0.00 | -2.60 | ** | -0.03 | 0.94 | -102.31 |

### 4.7.3 *Temporal analysis of projected number of warm days (TX90p-)*

Trend analysis of projected number of warm days (TX90p) over Rwanda with the range of 30-year period between 2021 and 2100 under RCP 4.5 w/m$^2$and RCP 8.5 w/m$^2$ - are presented in Table 4-54 to Table 4-56.

Table 4-54 shows that projected annual number of warm days for the period 2021-2050 ranged from +145.11% or +0.48 days per year (significant, $\alpha \leq 0.05$) in Gisenyi to +75.03% or +0.24 days per year (not significant, $\alpha > 0.05$) in Mushubi under RCP 4.5 w/m$^2$ and ranged from +179.45% or +0.58 days per year (significant, $\alpha \leq 0.05$) in Ruganda to +89.5% or +0.38 days per year (significant, $\alpha \leq 0.05$) in Ntendezi under RCP 8.5 w/m$^2$. The trend of projected number of warm days for the period 2021-2050 for RCP 4.5 w/m$^2$ (shows a high positive trend in the northern tip of Nyagatare district and positive trend from Western to Eastern parts of the country. The increasing trend is indicated over Rwanda except parts of Karongi, northern part of Nyamagabe, eastern part of Nyamasheke and western parts of Ruhango and Nyanza district Table 4-55 shows that projected annual number of warm days for the period 2041-2070 ranged from +59.16% or +0.38 days per year (significant, $\alpha \leq 0.05$) in Gisenyi to 18.47% or +0.11 days per year (not significant, $\alpha > 0.05$) in Ruhengeri under RCP 4.5 w/m$^2$ and ranged from 147.69% or +15 w/m$^2$ days per year (significant, $\alpha \leq 0.05$) in Byumba to +32.19% or +0.17 days per year (not significant, $\alpha > 0.05$) in Nyamata under RCP 8.5 w/m$^2$ The trend of projected number of warm days for the period 2041-2070 for RCP 4.5 w/m$^2$ (shows an increase trend countrywide expect a small tip of Nyagatare district which indicates a positive trend while for RCP 8.5 w/m$^2$ (a high increase trend in most parts of Gisagara, Kirehe and Kayonza, southern part of Gatsibo, eastern parts of Huye and Nyaruguru, central part of Gicumbi towards northern Rulindo and southwestern part of Nyaruguru while the rest of the country indicates an increasing trend except for most parts of Bugesera and isolated parts of Ngoma Districts which indicates a positive trend.

Table 4-56 shows that projected annual number of warm days for the period 2071-2100 ranged from +184.87% or +1.51 days per year (significant, $\alpha \leq 0.05$) in Byumba to +19.21% or +0.16 days per year (not significant, $\alpha > 0.05$) in Nyamata under RCP 4.5 w/m$^2$and ranged from +70.76% or +1.26 days per year (significant, $\alpha \leq 0.05$) in Kawangire to +19.21% or +0.16 days per year (not significant, $\alpha > 0.05$) in Nyamata under RCP 8.5 w/m$^2$2. The trend of projected number of warm days for the period 2071-2100 for RCP 4.5 w/m$^2$ (shows a high increase especially in parts of Kirehe and Kayonza, parts of Bugesera and Ngoma Districts. Similarly, under RCP 8.5 w/m$^2$ (indicates an increasing trend countrywide especially in parts of Bugesera, Ngoma and Rwamagana Districts. While RCP 8.5 w/m$^2$ (shows an increasing trend in the northern, Northwestern, and southern parts of the country except Karongi and in the Districts of Bugesera, Ngoma, southeastern parts of Kirehe and most parts of Rwamagana.

Generally, the trend of projected number of warm days shows an increase during the period 2021-2050 under RCP 4.5 w/m$^2$ and with more areas expected to experience increased number of warm days under RCP 8.5 w/m$^2$ compared to RCP 4.5. During the period 2041-2070, an increasing trend of projected number of warm days is expected for both RCP 4.5 w/m$^2$and RCP 8.5 w/m$^2$ with more increase under RCP 8.5 w/m$^2$ compared to RCP 4.5. During the period 2071-2100, both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ mark an increase in the trend of projected number of warm days.

Table 4-54: Trend analysis of projected number of warm days (TX90p) for the period 2021 to 2050 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| Station | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Test Z | α level | Q | Mean | %Δ | Test Z | α level | Q | Mean | %Δ |
| Bukora | 2.25 | * | 0.32 | 9.73 | 97.40 | 2.68 | ** | 0.34 | 9.71 | 105.56 |
| Busogo | 2.03 | * | 0.38 | 9.71 | 115.82 | 3.57 | *** | 0.47 | 9.75 | 145.35 |
| Butare | 2.29 | * | 0.40 | 9.54 | 125.83 | 3.32 | *** | 0.44 | 9.80 | 133.54 |
| Byimana | 2.16 | * | 0.33 | 9.64 | 103.73 | 3.23 | ** | 0.38 | 9.80 | 115.42 |
| Byumba | 2.43 | * | 0.36 | 9.72 | 109.99 | 3.52 | *** | 0.51 | 9.73 | 156.48 |
| Cyinzuzi | 2.43 | * | 0.36 | 9.72 | 109.99 | 3.14 | ** | 0.46 | 9.72 | 140.56 |
| Gabiro | 2.14 | * | 0.32 | 9.70 | 97.94 | 3.34 | *** | 0.42 | 9.68 | 129.18 |
| Gatumba | 2.03 | * | 0.38 | 9.71 | 115.82 | 3.04 | ** | 0.40 | 9.78 | 123.92 |
| Gikongoro | 1.88 | + | 0.33 | 9.73 | 100.24 | 3.43 | *** | 0.43 | 9.71 | 132.01 |
| Gisanga | 2.16 | * | 0.33 | 9.64 | 103.73 | 3.23 | ** | 0.38 | 9.80 | 115.42 |
| Gisenyi | 2.98 | ** | 0.48 | 9.82 | 145.11 | 3.57 | *** | 0.47 | 9.75 | 145.35 |
| Gitarama | 2.16 | * | 0.33 | 9.64 | 103.73 | 3.23 | ** | 0.38 | 9.80 | 115.42 |
| Gitega | 2.43 | * | 0.36 | 9.72 | 109.99 | 3.57 | *** | 0.47 | 9.75 | 145.35 |
| Kamembe | 1.82 | + | 0.31 | 9.81 | 93.62 | 3.04 | ** | 0.40 | 9.78 | 123.92 |
| Kanombe | 2.43 | * | 0.36 | 9.72 | 109.99 | 3.57 | *** | 0.47 | 9.75 | 145.35 |
| Kansi | 2.29 | * | 0.40 | 9.54 | 125.83 | 3.32 | *** | 0.44 | 9.80 | 133.54 |
| Kawangire | 2.14 | * | 0.32 | 9.70 | 97.94 | 2.68 | ** | 0.34 | 9.71 | 105.56 |
| Kibungo | 2.56 | * | 0.38 | 9.72 | 118.54 | 3.52 | *** | 0.51 | 9.73 | 156.48 |
| Masaka | 2.56 | * | 0.38 | 9.72 | 118.54 | 3.52 | *** | 0.51 | 9.73 | 156.48 |
| Muganza | 1.88 | + | 0.33 | 9.73 | 100.24 | 3.43 | *** | 0.43 | 9.71 | 132.01 |
| Mushubi | 1.39 | | 0.24 | 9.77 | 75.03 | 3.09 | ** | 0.40 | 9.72 | 123.46 |
| Ntaruka | 2.59 | ** | 0.39 | 9.80 | 120.30 | 3.34 | *** | 0.42 | 9.68 | 129.18 |
| Ntendezi | 1.82 | + | 0.31 | 9.81 | 93.62 | 2.57 | * | 0.29 | 9.78 | 89.50 |
| Nyagatare | 2.59 | ** | 0.36 | 9.84 | 108.36 | 3.34 | *** | 0.42 | 9.68 | 129.18 |
| Nyamata | 2.16 | * | 0.33 | 9.64 | 103.73 | 2.16 | * | 0.33 | 9.64 | 103.73 |
| Rubengera | 1.39 | | 0.24 | 9.77 | 75.03 | 3.09 | ** | 0.40 | 9.72 | 123.46 |
| Ruganda | 2.43 | * | 0.36 | 9.72 | 109.99 | 4.11 | *** | 0.58 | 9.74 | 179.45 |
| Ruhengeri | 2.68 | ** | 0.44 | 9.83 | 135.43 | 4.11 | *** | 0.58 | 9.74 | 179.45 |
| Rutsiro | 2.03 | * | 0.38 | 9.71 | 115.82 | 3.14 | ** | 0.46 | 9.72 | 140.56 |
| Rwamagana | 2.14 | * | 0.32 | 9.70 | 97.94 | 3.93 | *** | 0.51 | 9.65 | 157.89 |
| Rwankeri | 2.03 | * | 0.38 | 9.71 | 115.82 | 3.14 | ** | 0.46 | 9.72 | 140.56 |
| Save | 2.29 | * | 0.40 | 9.54 | 125.83 | 3.32 | *** | 0.44 | 9.80 | 133.54 |

Table 4-55: Trend analysis of projected number of warm days (TX90p) for the period 2041 to 2070 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| Station | 2041-2070 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | Mean | %Δ | Test Z | α level | Q | Mean | %Δ |
| Bukora | 1.25 | | 0.21 | 15.26 | 40.97 | 4.46 | *** | 1.30 | 26.56 | 146.33 |
| Busogo | 1.57 | | 0.19 | 16.12 | 35.35 | 4.30 | *** | 1.11 | 26.37 | 126.21 |
| Butare | 1.61 | | 0.21 | 15.89 | 40.47 | 4.71 | *** | 1.18 | 26.08 | 135.74 |
| Byimana | 1.21 | | 0.17 | 15.53 | 32.19 | 4.21 | *** | 1.03 | 25.94 | 118.89 |
| Byumba | 1.48 | | 0.20 | 16.32 | 36.77 | 5.01 | *** | 1.50 | 30.55 | 147.69 |
| Cyinzuzi | 1.48 | | 0.20 | 16.32 | 36.77 | 4.16 | *** | 1.26 | 28.30 | 133.10 |
| Gabiro | 1.66 | + | 0.21 | 15.61 | 40.58 | 4.21 | *** | 1.13 | 26.40 | 128.23 |
| Gatumba | 1.57 | | 0.19 | 16.12 | 35.35 | 4.48 | *** | 1.23 | 26.35 | 140.40 |
| Gikongoro | 1.43 | | 0.21 | 16.00 | 40.18 | 4.42 | *** | 1.08 | 26.43 | 123.08 |
| Gisanga | 1.21 | | 0.17 | 15.53 | 32.19 | 4.21 | *** | 1.03 | 25.94 | 118.89 |
| Gisenyi | 2.34 | * | 0.38 | 19.02 | 59.16 | 4.30 | *** | 1.11 | 26.37 | 126.21 |
| Gitarama | 1.21 | | 0.17 | 15.53 | 32.19 | 4.21 | *** | 1.03 | 25.94 | 118.89 |
| Gitega | 1.48 | | 0.20 | 16.32 | 36.77 | 4.30 | *** | 1.11 | 26.37 | 126.21 |
| Kamembe | 1.84 | + | 0.29 | 16.23 | 54.09 | 4.48 | *** | 1.23 | 26.35 | 140.40 |
| Kanombe | 1.48 | | 0.20 | 16.32 | 36.77 | 4.30 | *** | 1.11 | 26.37 | 126.21 |
| Kansi | 1.61 | | 0.21 | 15.89 | 40.47 | 4.71 | *** | 1.18 | 26.08 | 135.74 |
| Kawangire | 1.66 | + | 0.21 | 15.61 | 40.58 | 4.46 | *** | 1.30 | 26.56 | 146.33 |
| Kibungo | 1.68 | + | 0.31 | 17.64 | 52.92 | 5.01 | *** | 1.50 | 30.55 | 147.69 |
| Masaka | 1.68 | + | 0.31 | 17.64 | 52.92 | 5.01 | *** | 1.50 | 30.55 | 147.69 |
| Muganza | 1.43 | | 0.21 | 16.00 | 40.18 | 4.42 | *** | 1.08 | 26.43 | 123.08 |
| Mushubi | 1.32 | | 0.18 | 15.25 | 36.07 | 4.14 | *** | 1.10 | 26.43 | 124.87 |
| Ntaruka | 1.71 | + | 0.25 | 17.16 | 42.92 | 4.21 | *** | 1.13 | 26.40 | 128.23 |
| Ntendezi | 1.84 | + | 0.29 | 16.23 | 54.09 | 4.10 | *** | 1.21 | 25.38 | 142.42 |
| Nyagatare | 1.64 | | 0.21 | 16.55 | 38.44 | 4.21 | *** | 1.13 | 26.40 | 128.23 |
| Nyamata | 1.21 | | 0.17 | 15.53 | 32.19 | 1.21 | | 0.17 | 15.53 | 32.19 |
| Rubengera | 1.32 | | 0.18 | 15.25 | 36.07 | 4.14 | *** | 1.10 | 26.43 | 124.87 |
| Ruganda | 1.48 | | 0.20 | 16.32 | 36.77 | 4.46 | *** | 1.19 | 27.27 | 130.93 |
| Ruhengeri | 1.14 | | 0.11 | 18.27 | 18.47 | 4.46 | *** | 1.19 | 27.27 | 130.93 |
| Rutsiro | 1.57 | | 0.19 | 16.12 | 35.35 | 4.16 | *** | 1.26 | 28.30 | 133.10 |
| Rwamagana | 1.66 | + | 0.21 | 15.61 | 40.58 | 4.24 | *** | 1.11 | 26.90 | 124.06 |
| Rwankeri | 1.57 | | 0.19 | 16.12 | 35.35 | 4.16 | *** | 1.26 | 28.30 | 133.10 |
| Save | 1.61 | | 0.21 | 15.89 | 40.47 | 4.71 | *** | 1.18 | 26.08 | 135.74 |

Table 4-56: Trend analysis of projected number of warm days (TX90p) for the period 2071 to 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| Station | 2071-2100 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | Mean | %Δ | Test Z | α level | Q | Mean | %Δ |
| Bukora | 4.24 | *** | 1.29 | 21.42 | 174.46 | 3.08 | ** | 1.26 | 51.78 | 70.76 |
| Busogo | 4.01 | *** | 1.07 | 25.39 | 121.86 | 3.51 | *** | 1.16 | 54.58 | 61.72 |
| Butare | 4.45 | *** | 1.15 | 24.42 | 136.28 | 3.73 | *** | 1.20 | 56.49 | 61.39 |
| Byimana | 3.96 | *** | 1.00 | 23.81 | 121.42 | 3.51 | *** | 1.27 | 54.16 | 67.90 |
| Byumba | 4.80 | *** | 1.51 | 23.75 | 184.87 | 4.05 | *** | 1.40 | 66.93 | 60.86 |
| Cyinzuzi | 3.86 | *** | 1.22 | 23.75 | 149.10 | 4.30 | *** | 1.21 | 62.17 | 56.56 |
| Gabiro | 3.92 | *** | 1.05 | 22.36 | 136.33 | 3.17 | ** | 1.15 | 52.47 | 63.29 |
| Gatumba | 4.20 | *** | 1.20 | 25.39 | 136.59 | 4.09 | *** | 1.16 | 57.20 | 58.77 |
| Gikongoro | 4.15 | *** | 1.04 | 25.40 | 118.54 | 3.71 | *** | 1.33 | 56.20 | 68.85 |
| Gisanga | 3.96 | *** | 1.00 | 23.81 | 121.42 | 3.51 | *** | 1.27 | 54.16 | 67.90 |
| Gisenyi | 4.01 | *** | 1.07 | 31.49 | 98.24 | 3.51 | *** | 1.16 | 54.58 | 61.72 |
| Gitarama | 3.96 | *** | 1.00 | 23.81 | 121.42 | 3.51 | *** | 1.27 | 54.16 | 67.90 |
| Gitega | 4.01 | *** | 1.07 | 23.75 | 130.24 | 3.51 | *** | 1.16 | 54.58 | 61.72 |
| Kamembe | 4.20 | *** | 1.20 | 25.41 | 136.47 | 4.09 | *** | 1.16 | 57.20 | 58.77 |
| Kanombe | 4.01 | *** | 1.07 | 23.75 | 130.24 | 3.51 | *** | 1.16 | 54.58 | 61.72 |
| Kansi | 4.45 | *** | 1.15 | 24.42 | 136.28 | 3.73 | *** | 1.20 | 56.49 | 61.39 |
| Kawangire | 4.24 | *** | 1.29 | 22.36 | 167.12 | 3.08 | ** | 1.26 | 51.78 | 70.76 |
| Kibungo | 4.80 | *** | 1.51 | 27.48 | 159.77 | 4.05 | *** | 1.40 | 66.93 | 60.86 |
| Masaka | 4.80 | *** | 1.51 | 27.48 | 159.77 | 4.05 | *** | 1.40 | 66.93 | 60.86 |
| Muganza | 4.15 | *** | 1.04 | 25.40 | 118.54 | 3.71 | *** | 1.33 | 56.20 | 68.85 |
| Mushubi | 3.85 | *** | 1.07 | 23.87 | 130.45 | 3.81 | *** | 1.27 | 56.41 | 65.17 |
| Ntaruka | 3.92 | *** | 1.05 | 22.30 | 136.69 | 3.17 | ** | 1.15 | 52.47 | 63.29 |
| Ntendezi | 3.81 | *** | 1.13 | 25.41 | 129.53 | 4.28 | *** | 1.12 | 58.00 | 56.17 |
| Nyagatare | 3.92 | *** | 1.05 | 22.79 | 133.75 | 3.17 | ** | 1.15 | 52.47 | 63.29 |
| Nyamata | 1.07 | | 0.16 | 23.81 | 19.21 | 1.07 | | 0.16 | 23.81 | 19.21 |
| Rubengera | 3.85 | *** | 1.07 | 23.87 | 130.45 | 3.81 | *** | 1.27 | 56.41 | 65.17 |
| Ruganda | 4.18 | *** | 1.15 | 23.75 | 140.41 | 2.83 | ** | 0.86 | 51.49 | 48.54 |
| Ruhengeri | 4.18 | *** | 1.15 | 22.10 | 150.90 | 2.83 | ** | 0.86 | 51.49 | 48.54 |
| Rutsiro | 3.86 | *** | 1.22 | 25.39 | 139.50 | 4.30 | *** | 1.21 | 62.17 | 56.56 |
| Rwamagana | 3.95 | *** | 1.05 | 22.36 | 136.40 | 2.72 | ** | 0.92 | 52.37 | 51.17 |
| Rwankeri | 3.86 | *** | 1.22 | 25.39 | 139.50 | 4.30 | *** | 1.21 | 62.17 | 56.56 |
| Save | 4.45 | *** | 1.15 | 24.42 | 136.28 | 3.73 | *** | 1.20 | 56.49 | 61.39 |

### 4.7.4 *Spatial analysis of projected maximum temperature*

Spatial analysis of seasonal (JF, MAM, JJA and SOND) and annual maximum temperature for the period a) 2021-2050, b) 2041-2070 and c) 2071-2100 under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda is presented in the subsequent sections.

#### 4.7.4.1 January-February (JF) Season

Analysis of the spatial distribution of JF maximum temperature for the period between 2021 and 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ are presented in Figure 4-17.

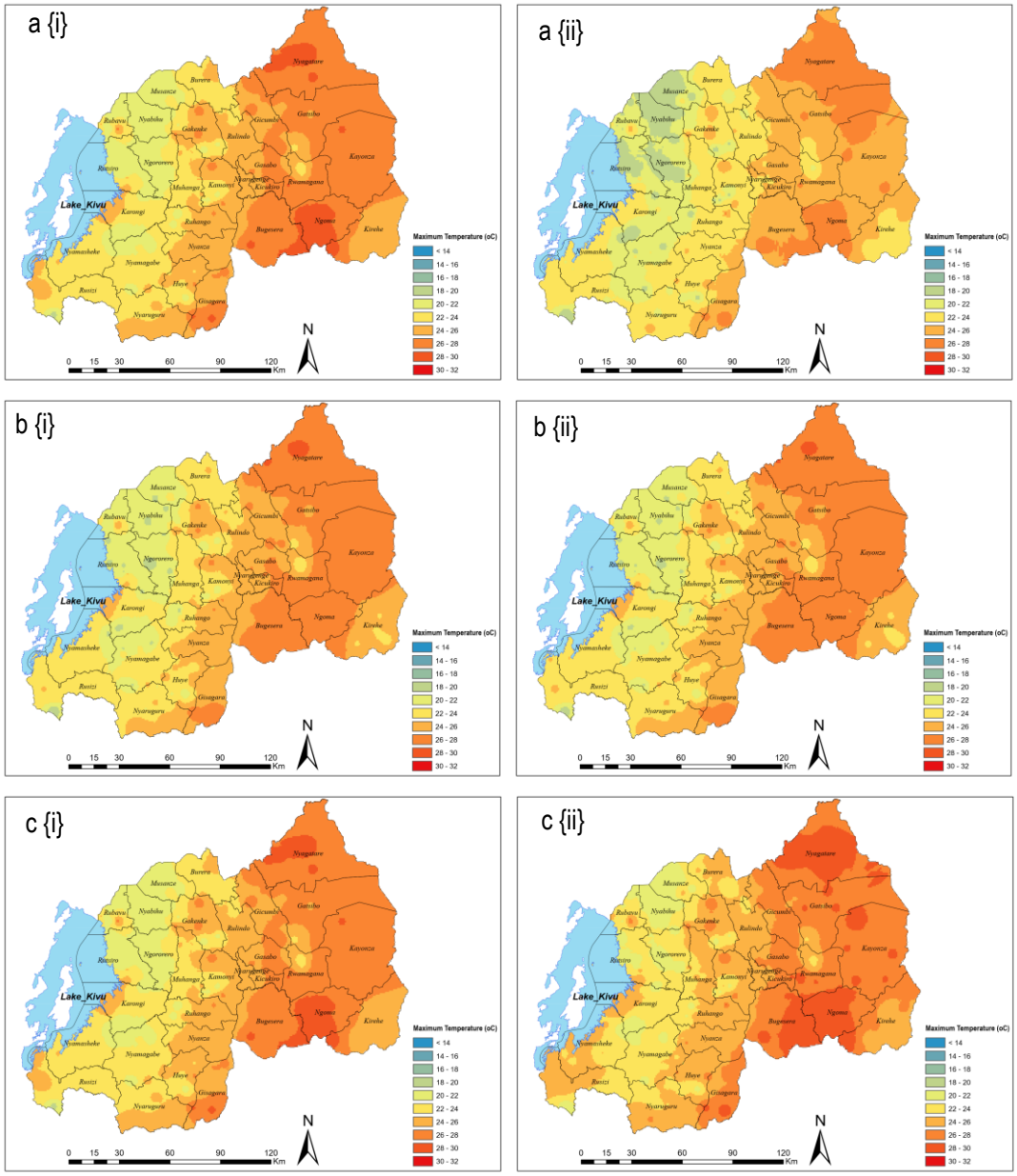


Figure 4-17: Analysis of projected JF seasonal maximum temperature for the period a) 2021-2050, b) 2041-2070 and c) 2071-2100 under i) RCP 4.5 w/m$^2$ and ii) RCP 8.5 w/m$^2$ over Rwanda.

Figure 4-17 (a) shows that Eastern parts except most part of Kirehe district, isolated parts of Northern, few part of central of Rwanda and southern part of Gisagara Districts are expected to experience higher maximum temperature ranging between 26$^{o}$C to 30$^{o}$C during the JF season compared to Western and Northern parts of Rwanda with a maximum temperature ranging between 20$^{o}$C to 24$^{o}$C for the period 2021-2050 under both RCP 4.5 w/m$^{2}$ (Figure 4-17a (i)) and RCP 8.5 w/m$^{2}$ (Figure 4-17a (ii)).

From (Figure 4-17b) shows that Eastern parts, isolated parts of Northern, few part of central of Rwanda and southern part of Gisagara Districts are expected to experience higher maximum temperature ranging between 28$^{o}$C to 30$^{o}$C during the JF season compared to Western and Northern parts of Rwanda that ranging between 20$^{o}$C to 24$^{o}$C for the period 2041-2070 under both RCP 4.5 w/m$^{2}$ (Figure 4-17b (i)) and RCP 8.5 w/m$^{2}$ (Figure 4-17b (ii)).

From Figure 4-17 (c) shows that Eastern parts except most part of Kirehe district, isolated parts of Northern, few part of central of Rwanda and most part of Gisagara Districts are expected to experience higher maximum temperature ranging between 26$^{o}$C to 30$^{o}$C during the JF season compared to Western and Northern parts of Rwanda most part of Kirehe district and northern part of Rwamagana towards southern part of Gatsibo that ranging between 20$^{o}$C to 24$^{o}$C for the period 2071-2100 under both RCP 4.5 w/m$^{2}$ (Figure 4-17c (i)).and RCP 8.5 w/m$^{2}$ (Figure 4-17c (ii)).

Generally, Figure 4-17 (a) shows that Eastern parts of Rwanda is expected to experience higher maximum temperature during the JF season of up to 30$^{o}$C compared to western parts of Rwanda for the period 2021-2050 under both RCP 4.5 w/m$^{2}$ and RCP 8.5 w/m$^{2}$ In addition, RCP 4.5 w/m$^{2}$ are expected to have higher temperatures compared to RCP 8.5 w/m$^{2}$ Similar patterns of higher temperatures during the JF season over Eastern parts of Rwanda compared to Western parts of Rwanda are expected for the period 2041-2070 (Figure 4-17b) and for the period 2071-2100 (Figure 4-17c) under both RCP 4.5 w/m$^{2}$ and RCP 8.5 w/m$^{2}$

### 4.7.4.2 March-April-May (MAM) Season

Analysis of the spatial distribution of MAM maximum temperature for the period between 2021 and 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ are presented in Figure 4-18.

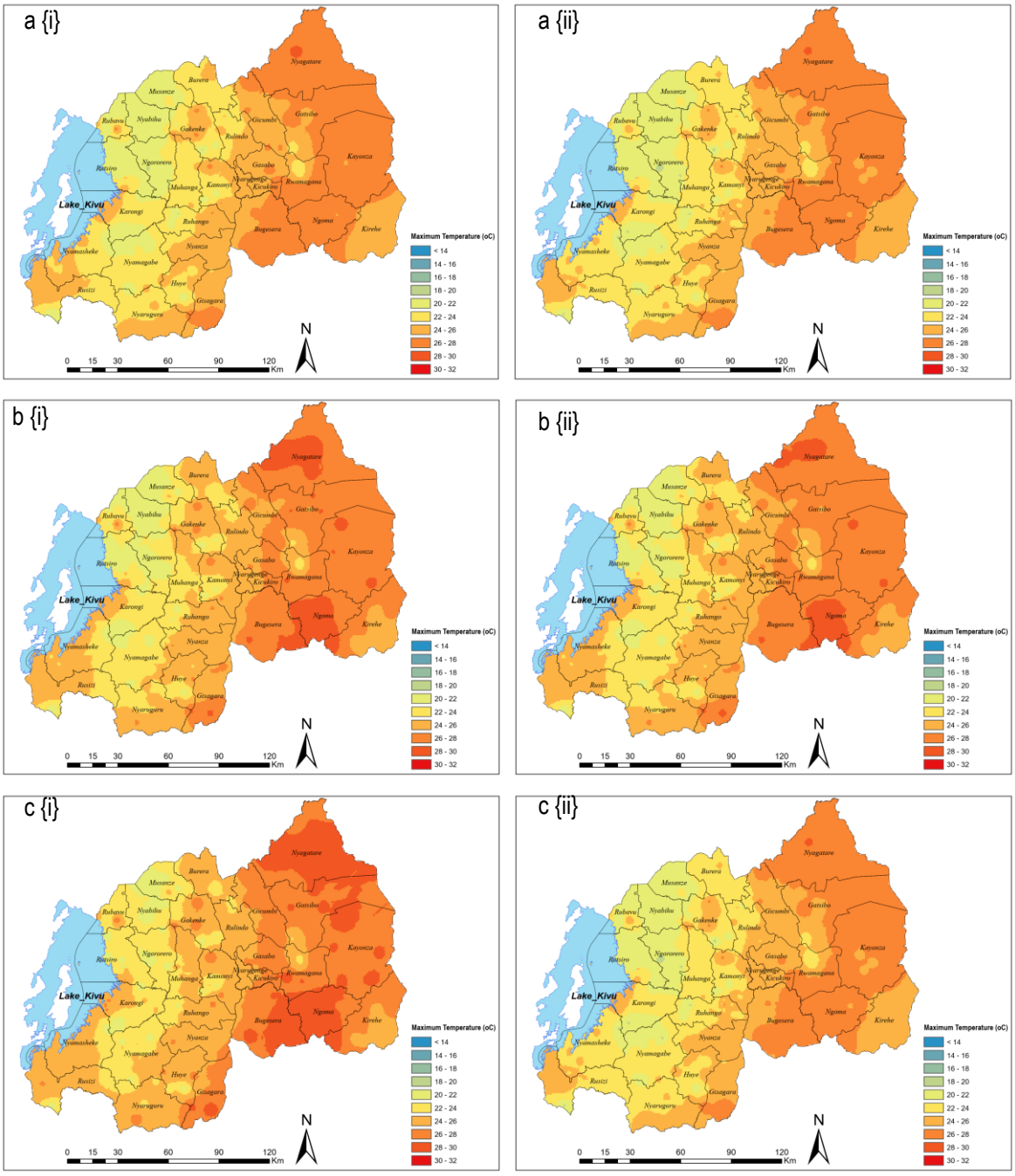


Figure 4-18: Analysis of projected MAM seasonal maximum temperature for the period a) 2021-2050, b) 2041-2070 and c) 2071-2100 under i) RCP 4.5 w/m$^2$ and ii) RCP 8.5 w/m$^2$ over Rwanda

Figure 4-18 (a) shows that Eastern parts of Rwanda and southern part of Gisagara Districts are expected to experience higher maximum temperature ranging between 26$^o$C to 28$^o$C reducing towards the central parts and southern parts of the country, southern part of Nyamasheke towards northern parts of Rusizi, western part of Karongi and northern parts

of Gakenke are expected to range between 24°C to 26°C during the MAM season compared to Western, most parts of Northern of Rwanda are expected to receive maximum temperature ranging between 20°C to 24°C for the period 2021-2050 under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$

Figure 4-18 (b) shows that most parts of Ngoma towards southeastern part of Bugesera and central part of Nyagatare are expected to experience higher temperature ranging between 28°C to 30°C whereas the rest of parts of Eastern Rwanda towards central parts and southern part of Gicumbi including most part of Gisagara small parts of Kirehe Districts are expected to experience maximum temperature ranging between 26°C to 28°C while most parts of northern towards southern parts of the country and Kivu belt region are expected to experience maximum temperature ranging between 24°C to 26°C during MAM season compared to the rest parts of Western, most parts of Northern of Rwanda that ranging between 20°C to 22°C for the period 2041-2070 under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$

The Figure 4-18 (c) shows that most parts of Ngoma towards eastern part of Bugesera, northern Kayonza and most part of Nyagatare towards northern Gatsibo are expected to experience higher temperature ranging between 28°C to 30°C while the rest of parts of Eastern Rwanda towards central parts and most part of Gicumbi and Gisagara Districts are expected to experience maximum temperature ranging between 26°C to 28°C whereas northern parts towards southern parts of the country, small part of Kirehe, most part of Rusizi, Nyamasheke and Karongi are expected to range between 24°C to 26°C during MAM season compared to the rest parts of Western region and Musanze district that ranging between 20°C to 22°C for the period 2071-2100 under RCP 4.5 w/m$^2$ while under RCP 8.5 w/m$^2$ projected maximum temperature show that most parts Eastern and small parts of Gisagara are expected to experience maximum temperature ranging between 26°C to 28°C while the rest parts of the country are expected to experience maximum temperature varying between 22°C to 26°C except most parts of northwestern parts of the country that are expected to experience between 20°C to 22°C.

Generally, the Eastern part of Rwanda is expected to experience higher maximum temperature during MAM season compared to western parts of Rwanda for the period 2021-2050 under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ In addition, RCP 4.5 w/m$^2$ is expected to have higher temperatures compared to RCP 8.5 w/m$^2$ Similar patterns of higher temperatures over Eastern parts of Rwanda compared to Western parts of Rwanda are expected for the period 2041-2070 and for the period 2071-2100 under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$

### 4.7.4.3 June-July-August (JJA) Season

Analysis of the spatial distribution of JJA maximum temperature for the period between 2021 and 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ are presented in Figure 4-19.

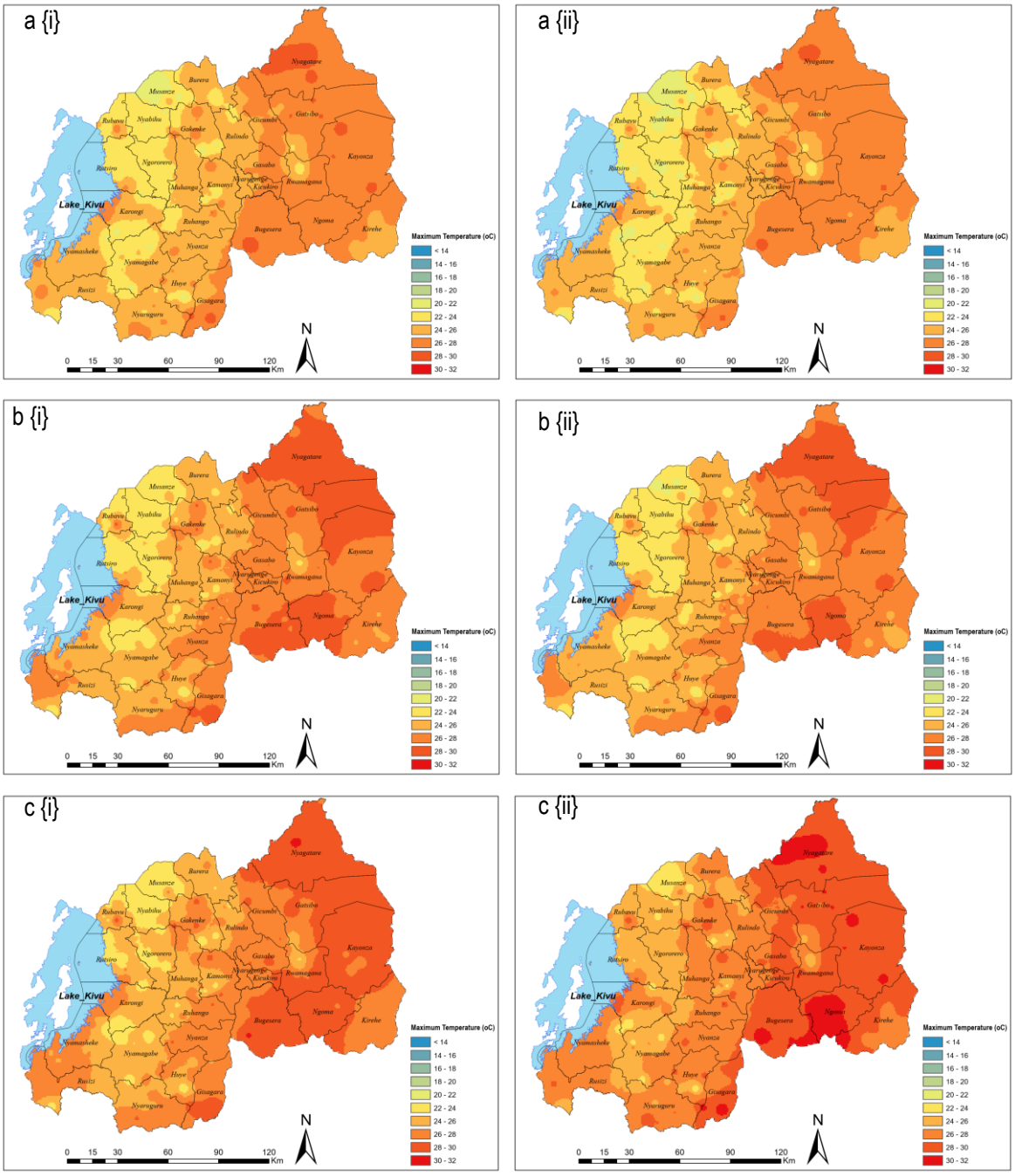


Figure 4-19: Analysis of projected JJA seasonal maximum temperature for the period a) 2021-2050, b) 2041-2070 and c) 2071-2100 under i) RCP 4.5 w/m$^2$ and ii) RCP 8.5 w/m$^2$ over Rwanda.

Figure 4-19 (a) shows that central part of Nyagatare is expected to experience higher maximum temperature ranging between 28$^o$C to 30$^o$C while most Eastern parts of Rwanda is expected to experience maximum temperature ranging between 26$^o$C to 28$^o$C whereas northern parts towards southern parts of the country including most part of Rusizi,

Nyamasheke and small part of Karongi are expected to range between 24°C to 26°C during the JJA season compared to the rest part of Northwestern highland of Rwanda and most part of Nyamagabe district that ranging between 22°C to 24°C expect Musanze district that ranging between 18°C to 20°C for the period 2021-2050 under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$

Figure 4-19 (b) shows that most part northeastern (Nyagatare, western Gatsibo and Northern Kayonza), and southeastern parts of the country (southern Bugesera and Ngoma) are expected to experience higher maximum temperature ranging between 28°C to 30°C while the rest of the Eastern parts towards central part and eastern part of Southern province extending to Amayaga region are expected to experience maximum temperature ranging between 26°C to 28°C whereas northern parts towards southern parts of the country including most part of Nyamasheke, Karongi and small part of Rubavu, Rutsiro and Rusizi are expected to range between 24°C to 26°C during JJA season compared to the rest of northwestern part of the country that ranging between 22°C to 24°C for the period 2041-2070 under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$

The Figure 4-19 (c) shows that most part of Eastern province and southern part of Gisagara district are expected to experience higher maximum temperature ranging between 28°C to 30°C while few parts of Northern province towards central part, eastern part of Southern province, southern part of Kivu belt region and most part of Kirehe district are expected to experience maximum temperature ranging between 26°C to 28°C whereas western parts of Southern province towards northwestern parts of the country are expected to range between 24°C to 26°C expect Musanze and Nyabihu are expected to experience lower maximum temperature ranging between 20°C to 22°C during JJA season for the period 2071-2100 under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ except under RCP 8.5 w/m$^2$ where small parts of Nyagatare and most parts of Ngoma including isolated parts of Bugesera, Kayonza and Gisagara are expected to experience high maximum temperature ranging between 30°C to 32°C.

Generally, the Eastern part of Rwanda is expected to experience higher maximum temperature during the JJA season compared to western parts of Rwanda for the period 2021-2050 under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ In addition, RCP 4.5 w/m$^2$ is expected to have higher maximum temperatures during the JJA season compared to RCP 8.5 w/m$^2$ Similar patterns of higher temperatures over Eastern parts of Rwanda compared to Western parts of Rwanda are expected for the period 2041-2070 and for the period 2071-2100 under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$

#### 4.7.4.4 September-October-November-December (SOND) Season

Analysis of the spatial distribution of SOND maximum temperature for the period between 2021 and 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ are presented in Figure 4-20.

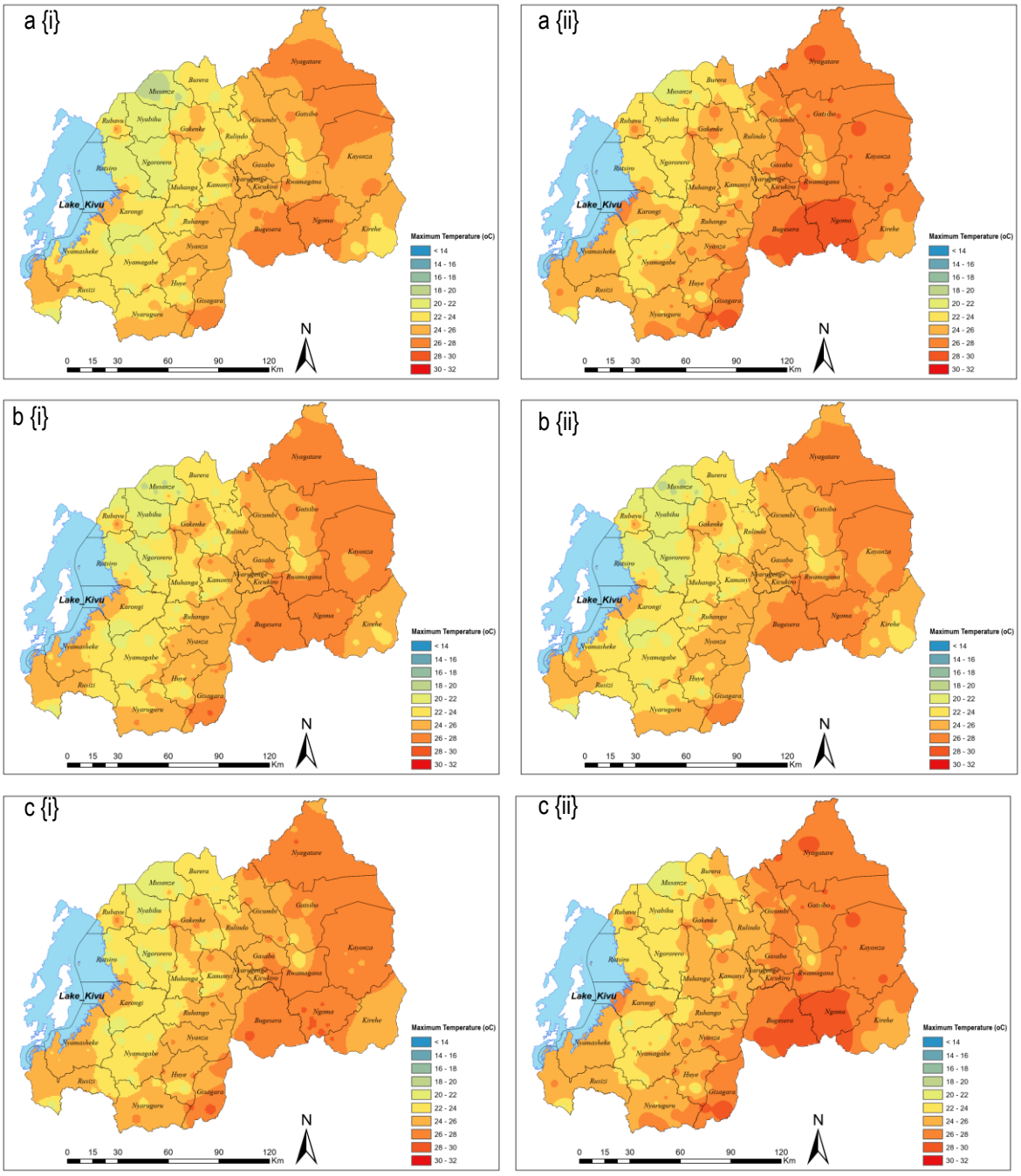


Figure 4-20: Analysis of projected SOND seasonal maximum temperature for the period a) 2021-2050, b) 2041-2070 and c) 2071-2100 under i) RCP 4.5 w/m$^2$ and ii) RCP 8.5 w/m$^2$ over Rwanda.

Figure 4-20 (a) shows that most part north-eastern and south-eastern parts of the country except most parts of Kirehe district are expected to experience higher maximum temperature ranging between 26$^o$C to 28$^o$C under RCP 4.5 w/m$^2$ (Figure 4-20a (i)) while under RCP 8.5 w/m$^2$ (Figure 4-20a (ii)) most parts of Ngoma, Bugesera, isolated parts of

Nyagatare, Kayonza and Gisagara districts are expected to experience high maximum temperature ranging between 28$^{o}$C to 30$^{o}$C the rest part of Eastern parts towards central part and eastern part of Southern province are expected to experience maximum temperature ranging between 24$^{o}$C to 28$^{o}$C whereas northern parts towards southern parts of the country including most part of Nyamasheke, Karongi and small part of Rusizi are expected to range between 22$^{o}$C to 24$^{o}$C the rest parts of northwestern that ranging between 16$^{o}$C to 20$^{o}$C during SOND season for the period 2021-2050 under both RCP 4.5 w/m$^{2}$ (Figure 4-20a (i)) and RCP 8.5 w/m$^{2}$ (Figure 4-20a (ii)

Figure 4-20 (b) shows that under RCP 8.5 w/m$^{2}$ most parts of Ngoma and Bugesera are expected to experience high maximum temperature ranging between 26$^{o}$C to 28$^{o}$C while most Eastern province towards central parts,few part of Southern province towards most parts of Northern province, Kirehe and some parts of Rusizi, Nyamasheke, Karongi and small parts of Rubavu are expected to experience maximum temperature ranging between 24$^{o}$C to 26$^{o}$C while the rest parts of northwestern of the country including few part of Musanze and Nyabihu are expected to range between 18$^{o}$C to 20$^{o}$C during SOND season for the period 2041-2070 under both RCP 4.5 w/m$^{2}$ (Figure 4-20b (i)) and RCP 8.5 w/m$^{2}$ (Figure 4-20b (ii)).

Figure 4-20 (c) shows that under RCP 8.5 w/m$^{2}$ most parts of Ngoma, Bugesera and small parts of Nyagatare are expected to experience high maximum temperature ranging between 28$^{o}$C to 30$^{o}$C while most Eastern province towards southeastern of Southern province are expected to experience maximum temperature ranging between 26$^{o}$C to 28$^{o}$C whereas few part of Southern province towards most parts of Northern province, Kirehe and some parts of Rusizi, Nyamasheke and Karongi are expected to experience maximum temperature ranging between 24$^{o}$C to 26$^{o}$C while the rest parts of northwestern of the country including few part of Musanze and Nyabihu are expected to range between 20$^{o}$C to 24$^{o}$C during the SOND season for the period 2071-2100 under both RCP 4.5 w/m$^{2}$ (Figure 4-20c (i)) and RCP 8.5 w/m$^{2}$ (Figure 4-20c (ii)).

Generally, the Eastern part of Rwanda is expected to experience higher maximum temperature during SOND season compared to Western parts of Rwanda for the period 2021-2050 under both RCP 4.5 w/m$^{2}$ and RCP 8.5 w/m$^{2}$In addition, RCP 8.5 w/m$^{2}$ is expected to have higher temperatures compared to RCP 4.5 w/m$^{2}$ Similar patterns of higher temperatures over Eastern parts of Rwanda during SOND season compared to western parts of Rwanda are expected for the period 2041-2070 and for the period 2071-2100 under both RCP 4.5 w/m$^{2}$ and RCP 8.5 w/m$^{2}$

### 4.7.4.5 Annual maximum temperature

Analysis of the spatial distribution of annual maximum temperature for the period between 2021 and 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$are presented in Figure 4-21.

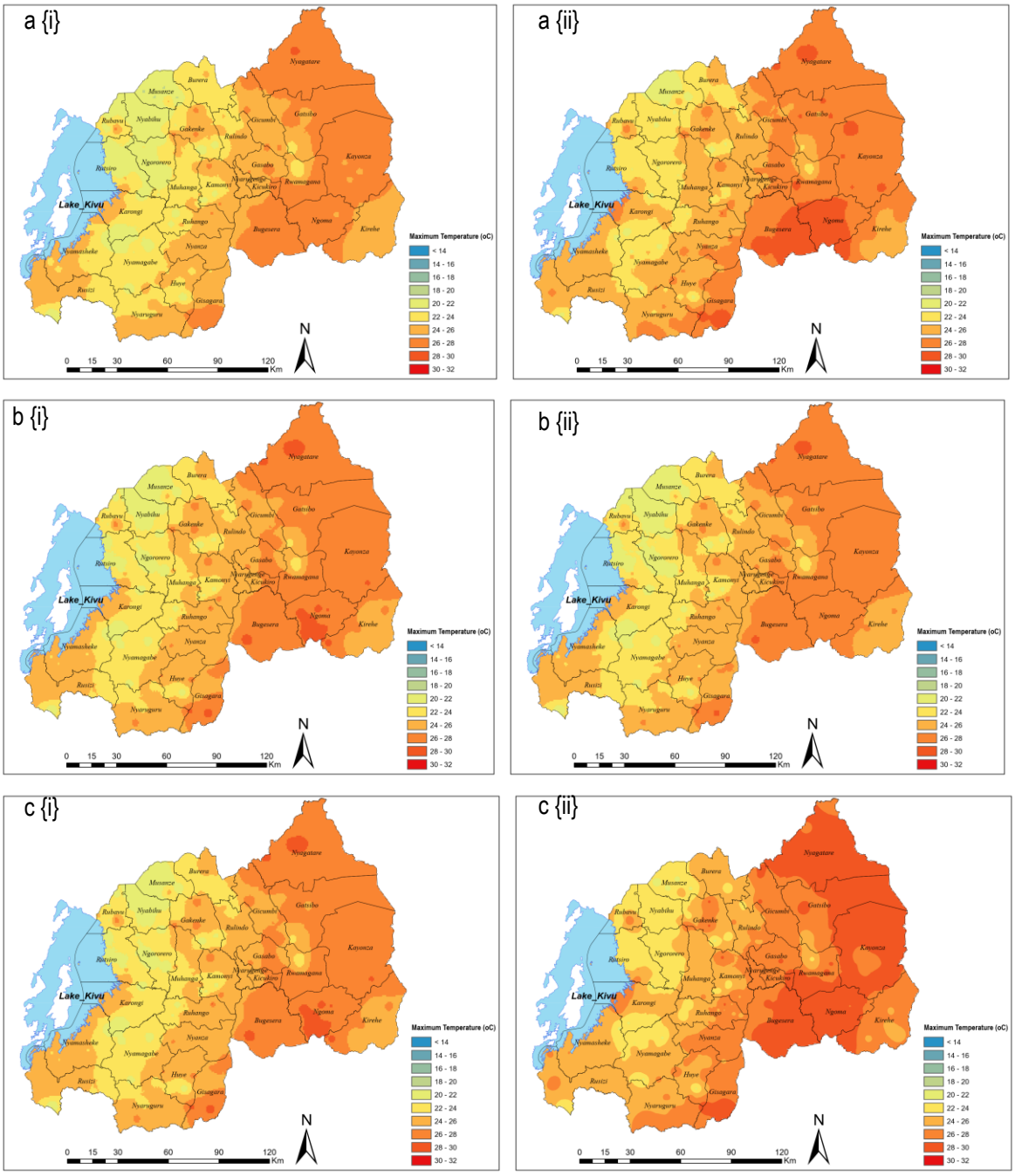


Figure 4-21: Analysis of projected annual maximum temperature for the period a) 2021-2050, b) 2041-2070 and c) 2071-2100 under i) RCP 4.5 w/m$^2$ and ii) RCP 8.5 w/m$^2$over Rwanda.

Figure 4-21 (a) shows that most part north-eastern, small parts of Gisagara, Nyaruguru and Huye districts are expected to experience higher maximum temperature ranging between 26$^o$C to 28$^o$C under RCP 4.5 w/m$^2$ (Figure 4-21a (i)) while under RCP 8.5 w/m$^2$ (Figure 4-21a (ii)) most parts of Ngoma and Bugesera are expected to experience high maximum

temperature ranging between 28°C to 30°C the rest part of Eastern parts towards central part and eastern part of Southern province are expected to experience maximum temperature ranging between 24°C to 28°C whereas northern parts towards southern parts of the country including most part of Nyamasheke, Karongi and small part of Rusizi are expected to range between 22°C to 26°C the rest parts of northwestern that ranging between 18°C to 24°C during SOND season for the period 2021-2050 under both RCP 4.5 w/m$^2$ (Figure 4-21a (i)) and RCP 8.5 w/m$^2$ (Figure 4-21a (ii)).

The Figure 4-21 (a,b) shows that under RCP 8.5 w/m$^2$ and RCP 4.5 w/m$^2$ most parts of Ngoma and Bugesera are expected to experience high maximum temperature ranging between 28°C to 30°C while most Eastern province towards central parts and eastern of Southern province are expected to experience maximum temperature ranging between 26°C to 28°C whereas few part of Southern province towards most parts of Northern province, Kirehe and some parts of Rusizi, Nyamasheke and Karongi are expected to experience maximum temperature ranging between 24°C to 26°C while the rest parts of northwestern of the country including few part of Musanze and Nyabihu are expected to range between 20°C to 24°C during SOND season for the period 2041-2070 under both RCP 4.5 w/m$^2$ (Figure 4-21b (i)) and RCP 8.5 w/m$^2$ (Figure 4-21b (ii)).

Figure 4-21 (c) shows that under RCP 8.5 w/m$^2$ most parts of Eastern province except Kirehe and small part of Gisagara are expected to experience high maximum temperature ranging between 28°C to 30°C.and 26°C to 30°C under RCP 4.5 w/m$^2$ while part of Eastern province towards central parts and east of Southern province are expected to experience maximum temperature ranging between 26°C to 28°C under RCP 8.5 w/m$^2$ and 24°C to 26°C under RCP 4.5 w/m$^2$ whereas few part of Southern province towards most parts of Northern province, some parts of Rusizi, Nyamasheke and Karongi are expected to experience maximum temperature ranging between 24°C to 26°C while the rest parts of northwestern of the country including few part of Musanze and Nyabihu are expected to range between 20°C to 24°C during the SOND season for the period 2071-2100 under both RCP 4.5 w/m$^2$ (Figure 4-21c (i)) and RCP 8.5 w/m$^2$ (Figure 4-21c (ii)).

Generally, the Eastern part of Rwanda is expected to experience higher maximum temperature during SOND season compared to Western parts of Rwanda for the period 2021-2050 under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ In addition, RCP 8.5 w/m$^2$ is expected to have higher temperatures compared to RCP 4.5 w/m$^2$ Similar patterns of higher temperatures over Eastern parts of Rwanda during SOND season compared to western parts of Rwanda are expected for the period 2041-2070 (Figure 4-21b) and for the period 2071-2100 (Figure 4-21c) under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$

### 4.7.5 *Spatial analysis of projected change of maximum temperature*

Spatial analysis of seasonal (JF, MAM, JJA and SOND) and annual changes of projected climate (2021-2100) against baseline (1981-2010) maximum temperature under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda is presented in the subsequent sections.

#### 4.7.5.1 January-February (JF) Season

Analysis of the changes of projected (2021-2100) maximum temperature against its baseline (1981-2010) during the JF season under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ are presented in Figure 4-22.

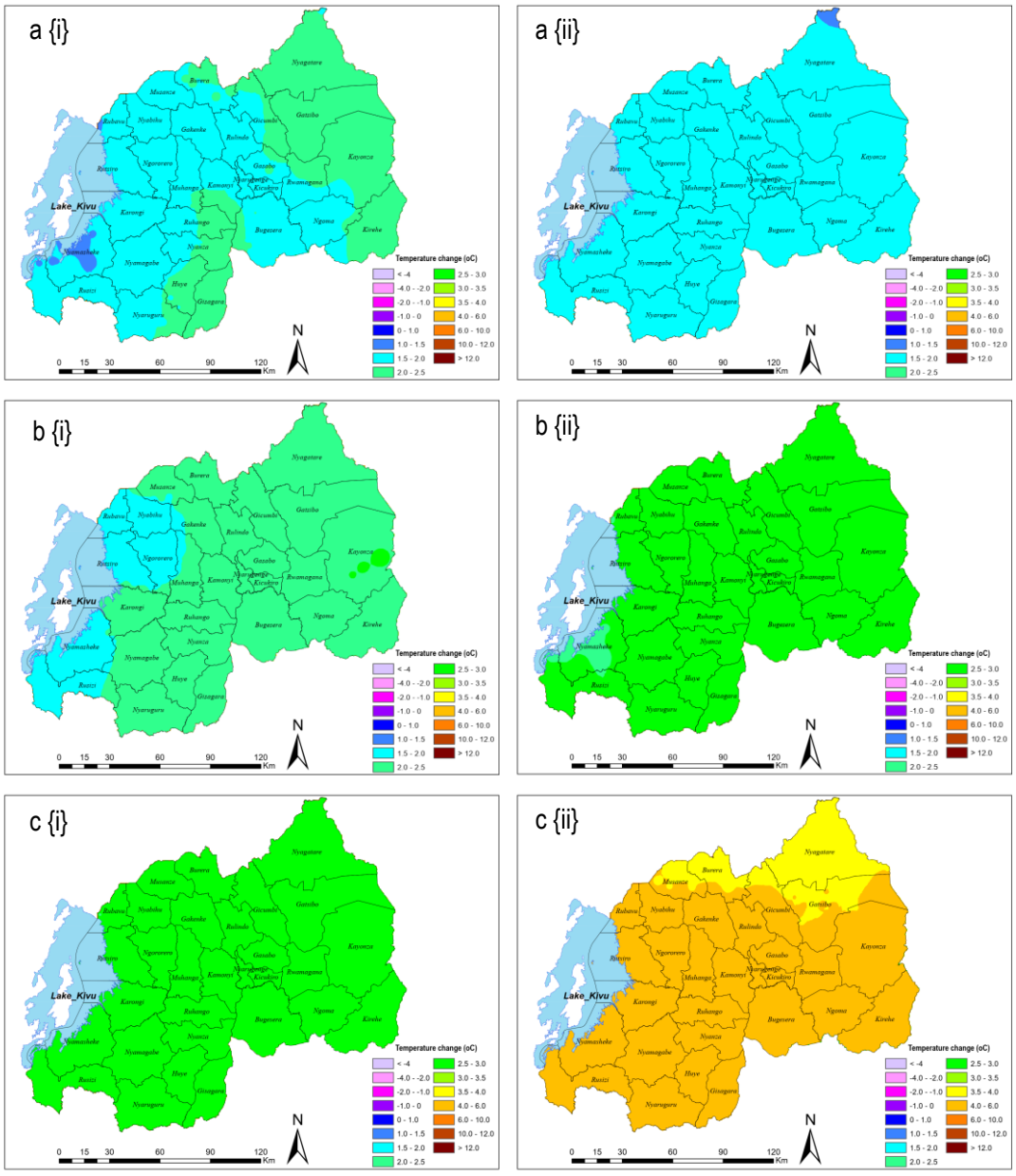


Figure 4-22: Analysis of changes of projected maximum temperature for the period a) 2021-2050, b) 2041-2070 and c) 2071-2100 against its baseline (1981-2010) during JF season under a) RCP 4.5 w/m$^2$ and b) RCP 8.5 w/m$^2$ over Rwanda.

Figure 4-22a (i) shows positive changes in maximum temperature are expected over Kigali city, western and Northern Province of between 1.5 $^{o}$C and 2.0 $^{o}$C and over parts of eastern province (Kirehe, Kayonza, Gatsibo, and Nyagatare) of between 2.0 $^{o}$C and 2.5 under RCP 4.5 w/m$^2$ whereas the rest of the country are expected to have a positive change of between 1.5 $^{o}$C and 2.0 $^{o}$C under RCP 8.5 w/m$^2$ during JF season for the period 2021-2050.

Figure 4-22 (b-i) shows that most parts of the country are expected to have positive changes of maximum temperature of 2.0 to 2.5 $^{o}$C under RCP 4.5 w/m$^2$ whereas most of the country are expected to have a positive change of between 2.5 to 3.0 $^{o}$C under RCP 8.5 w/m$^2$ (Figure 4-22 (b -ii)) during JF season for the period 2041-2070.

Figure 4-22 (c -i) shows that most parts of the country are expected to have positive changes of maximum temperature of between 2.5 to 3.0 $^{o}$C under RCP 4.5 w/m$^2$ and above 3.5 $^{o}$C under RCP 8.5 w/m$^2$ (Figure 4-22c (ii)) during JF season for the period 2071-2100. Overall, maximum temperature are expected to change from 1.5 $^{o}$C in 2021 to 3.0 $^{o}$C in 2100 under RCP 4.5 w/m$^2$ and from 1.5 $^{o}$C in 2021 to 6.0 $^{o}$C in 2100 under RCP 8.5 w/m$^2$. Overall, changes in maximum temperatures are expected to increase from 1.5 $^{o}$C in 2021 to 3.0 $^{o}$C in 2100 under RCP 4.5 w/m$^2$ and from 1.5 $^{o}$C in 2021 to 6.0 $^{o}$C in 2100 under RCP 8.5 w/m$^2$ during JF season.

### 4.7.5.2 March-April-May (MAM) Season

Analysis of the changes of projected (2021-2100) maximum temperature against its baseline (1981-2010) during MAM season under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ are presented in Figure 4-23.

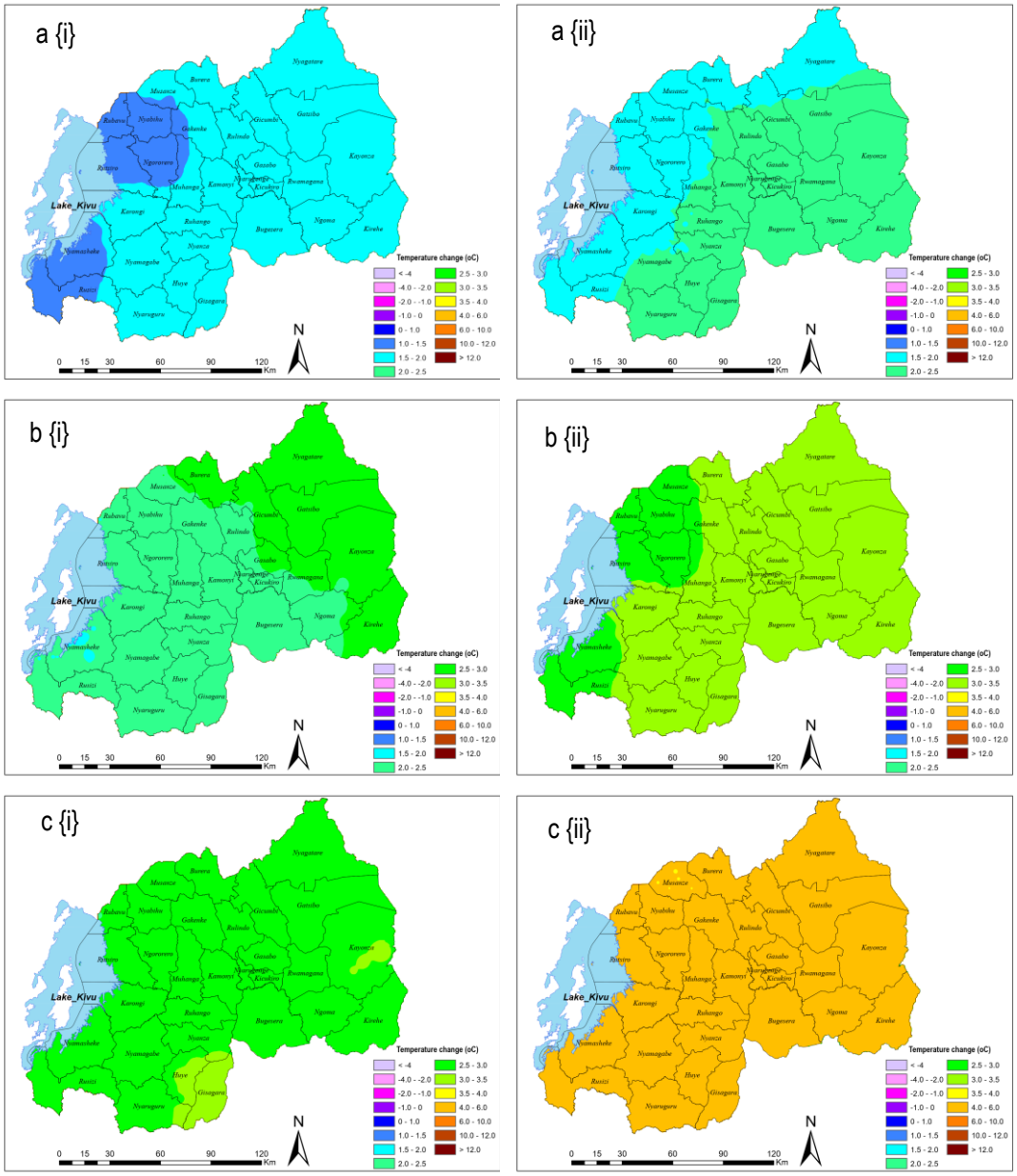


Figure 4-23: Analysis of changes of projected (2071-2100) maximum temperature against its baseline (1981-2010) during MAM season under a) RCP 4.5 w/m$^2$ and b) RCP 8.5 w/m$^2$ over Rwanda.

Figure 4-23 (a) shows that most parts of the country are projected to have positive changes of maximum temperature from Eastern (1.5$^o$C to 2.0$^o$C) towards the western (1.5$^o$C to 2.0$^o$C) especially in Nyabihu, Ngororero, Rutsiro, Rubavu, Nyamasheke and Rusizi) Districts under RCP 4.5 w/m$^2$ (Figure 4-23a (i)) while positive changes in maximum temperature are expected to increase from Northwest ((1.5$^o$C to 2.0$^o$C) towards south east (2.0$^o$C to 2.5$^o$C) districts under RCP 8.5 w/m$^2$ (Figure 4-23a (ii)) during MAM season for the period 2021-2050.

Figure 4-23 (b) shows that most parts of the country are expected to have positive changes of maximum temperature with North West (2.5$^{o}$C to 3.0$^{o}$C) areas of Nyagatare, Gatsibo, Kayonza, Gichumbi and Kirehe districts to south east (2.0$^{o}$C to 2.5$^{o}$C) progression under both RCP 4.5 w/m$^2$ (Figure 4-23c (i)) whereas most of areas under RCP 8.5 w/m$^2$ (Figure 4-23b (ii)) are expected to experience maximum temperature change of between 2.5$^{o}$C to 3.5$^{o}$C during MAM season for the period 2041-2070.

Figure 4-23 (c) shows that most parts of the country are expected to have positive changes of maximum temperature (2.5$^{o}$C to 3.0$^{o}$C) under RCP 4.5 w/m$^2$ (Figure 4-23c (i)) and range from 4.0$^{o}$C to 6.0$^{o}$C) under RCP 8.5 w/m$^2$ (Figure 4-23c (ii)).

Overall, changes in maximum temperatures are expected to increase from approximately 0 $^{o}$C mostly in Nyabihu, Ngororero, Rutsiro, Rubavu, Nyamasheke and Rusizi in 2021 to 3.0 $^{o}$C over most parts of Rwanda in 2100 under RCP 4.5 w/m$^2$ and from 1.0 $^{o}$C mostly in Rusizi, Nyamasheke, karongi, Rutsiro, Ngororero, Nyabihu, Rubavu, Musanze, Burera and Nyagatare in 2021 to 6.0 $^{o}$C over most parts of Rwanda in 2100 under RCP 8.5 w/m$^2$ during MAM season.

#### 4.7.5.3 June-July-August (JJA) Season

Analysis of the changes of projected (2021-2100) maximum temperature against its baseline (1981-2010) during the JJA season under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ are presented in Figure 4-24.

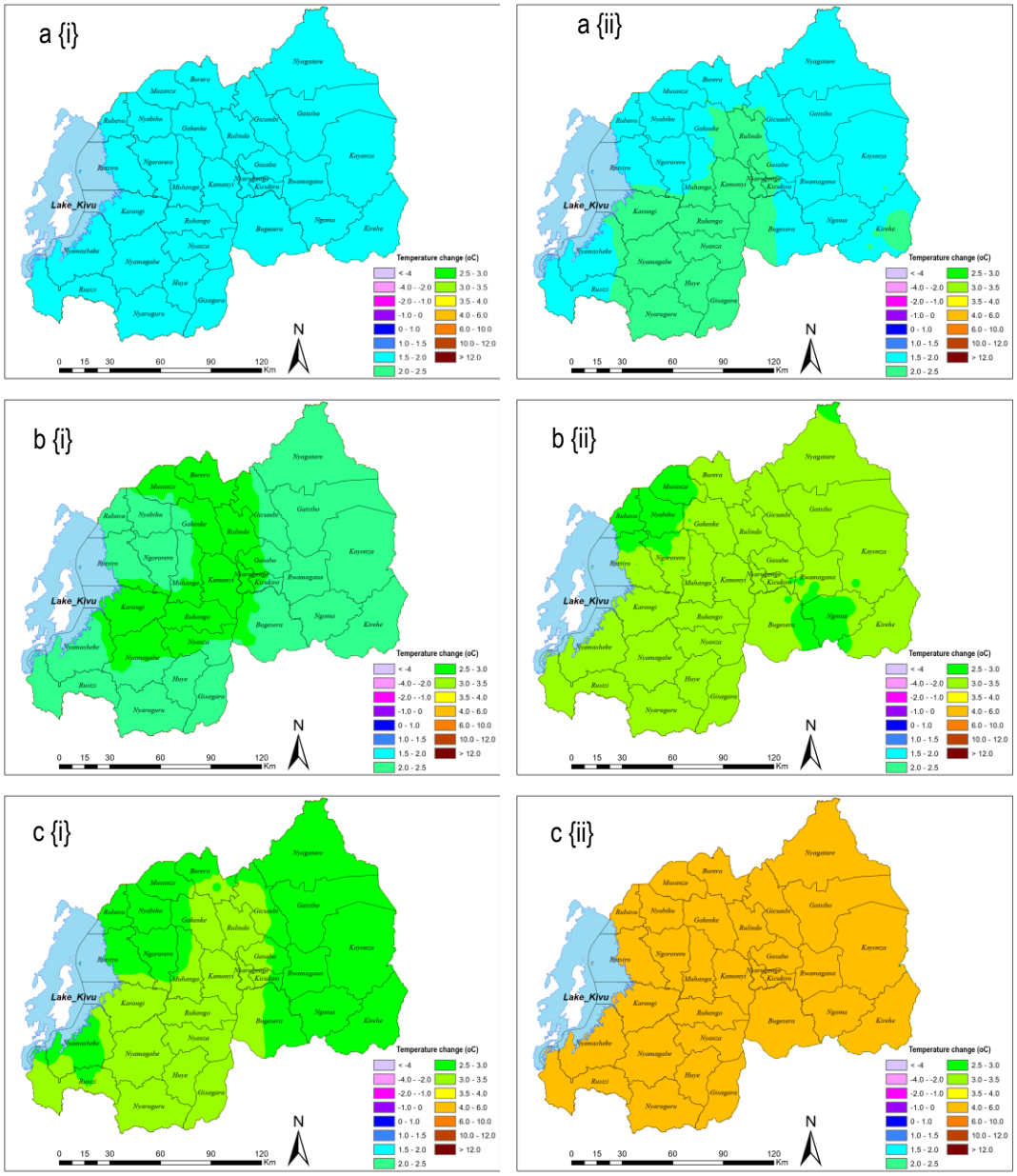


Figure 4-24: Analysis of changes of projected (2071-2100) maximum temperature against its baseline (1981-2010) during JJA season under a) RCP 4.5 w/m$^2$ and b) RCP 8.5 w/m$^2$ over Rwanda.

Figure 4-24 (a) shows that most parts of the country are expected to have positive changes of maximum temperature of between 1.5$^o$C to 2.0$^o$C under RCP 4.5 w/m$^2$ (Figure 4-24a (i)) whereas most districts in southern province and parts of western province (Karongi), Northern province (Rulindo and Gakenke), Kigali city (Nyarugenge) and southern province (Kirehe) are expected to have slightly higher change of between 2.0$^o$C to 2.5$^o$C than the rest of the country who's change are expected to range between 1.5$^o$C to 2.0$^o$C under RCP 8.5 w/m$^2$ (Figure 4-24a (ii)) during JJA season for the period 2021-2050.

Figure 4-24 (b) shows that most parts of the country are expected to have positive changes of maximum temperature of between 2.5°C and 3.0°C with slightly higher changes (2.5°C to 3.0°C) over parts of western province (Karongi), southern province (Nyamagabe, Nyanza, Ruhango, Kamonyi districts), northern province (Rulindo, Gakenke, Burera and Musanze districts) under RCP 4.5 w/m$^2$ (Figure 4-24b (i)) whereas most parts of the country are expected to have positive changes (3.0°C to 3.5°C) except parts of northern province (Musanze), western province (Nyabihu and Rubavu) and Southern province (Ngoma and Bugesera) which are expected to have a slightly lower values temperature change (2.5°C to 3.0°C) under RCP 8.5 w/m$^2$ (Figure 4-24b (ii)) during JJA season for the period 2041-2070.

Figure 4-24 (c) shows that most parts in the Eastern province, western (Rutsiro, Ngororero, Nyabihu, Rubavu and Nyamasheke) and northern (Burera and Musanze districts) province are expected to have positive changes in maximum temperature of between 2.5°C and 3.0°C with the rest of the country especially the southern province expected to have slightly higher temperature change of between 3.0°C and 3.5°C under RCP 4.5 w/m$^2$ (Figure 4-24c (i)) whereas a higher change in maximum temperature of 4.0°C and 6.0°C is project over Rwanda under RCP 8.5 w/m$^2$ during JJA season for the period 2071-2100.

Overall, changes in maximum temperatures are expected to increase from approximately 1.5 °C over many parts of Rwanda in 2021 to 3.5 °C over northern, southern and south of western provinces of Rwanda in 2100 under RCP 4.5 w/m$^2$ and from 1.5 °C over eastern, northern and south of western (Rusizi and Nyamasheke) provinces in 2021 to 6.0 °C over most parts of Rwanda in 2100 under RCP 8.5 w/m$^2$ during JJA season.

#### 4.7.5.4 September-October-November-December (SOND) Season

Analysis of the changes of projected (2021-2100) maximum temperature against its baseline (1981-2010) during SOND season under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ are presented in Figure 4-25.

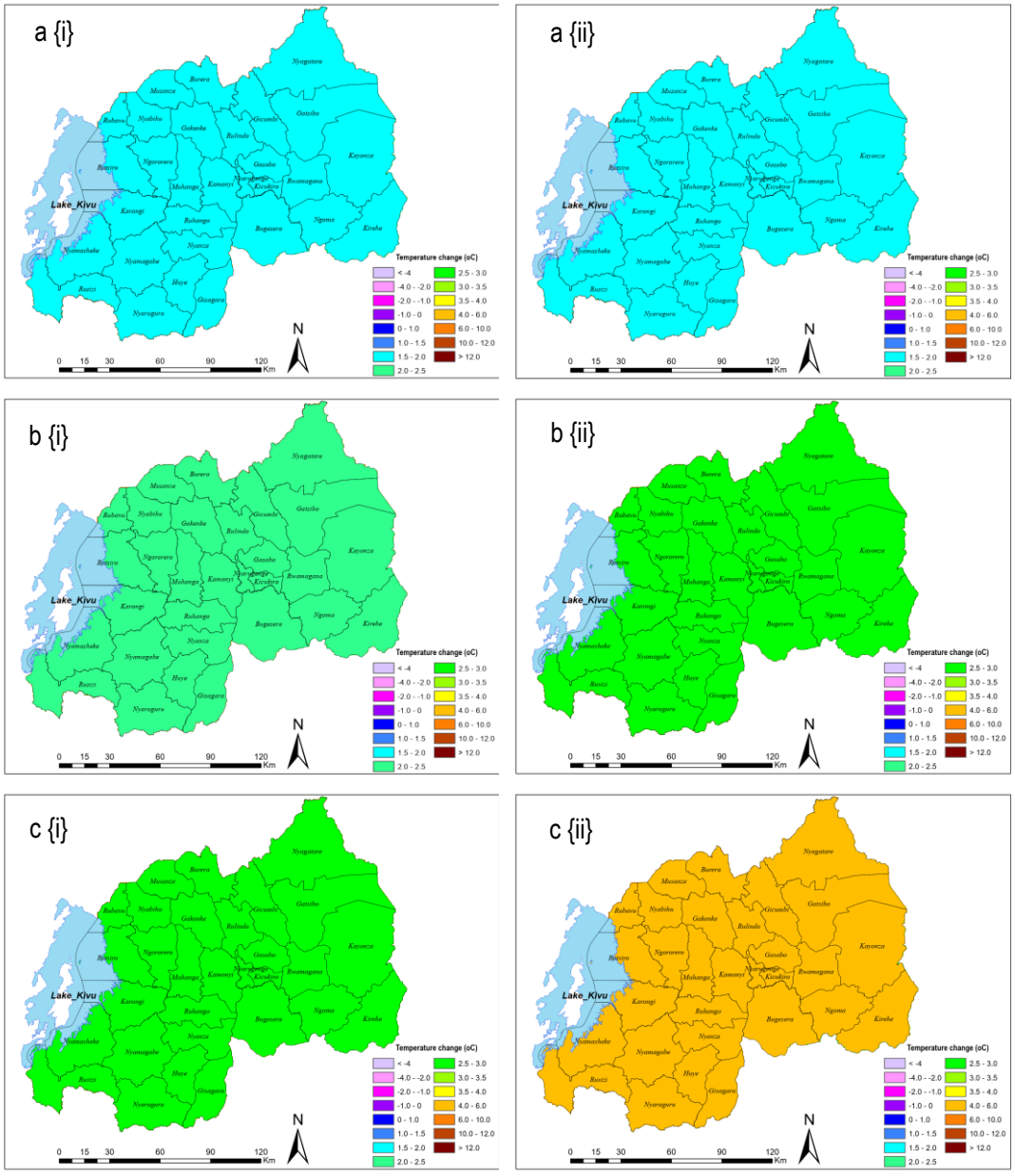


Figure 4-25: Analysis of changes of projected (2071-2100) maximum temperature against its baseline (1981-2010) during SOND season under a) RCP 4.5 w/m$^2$ and b) RCP 8.5 w/m$^2$ over Rwanda.

Figure 4-25 (a) shows that most parts of the country are expected to have positive changes of maximum temperature of between 1.5$^o$C and 2.0$^o$C under both RCP 4.5 w/m$^2$ (Figure 4-25a (i)) and RCP 8.5 w/m$^2$ (Figure 4-25a (ii)) during SOND season for the period 2021-2050.

Figure 4-25b shows that most parts of the country are expected to have positive changes of maximum temperature of between 2.0$^{o}$C and 2.5$^{o}$C under RCP 4.5 w/m$^{2}$ (Figure 4-25b (i)) and slightly higher (2.5$^{o}$C and 3.0$^{o}$C) under RCP 8.5 w/m$^{2}$ (Figure 4-25b (ii)) during SOND season for the period 2041-2070.

Figure 4-25c shows that most parts of the country are expected to have positive changes of maximum temperature of between 2.5$^{o}$C and 3.0$^{o}$C under RCP 4.5 w/m$^{2}$ (Figure 4-25c (i)) and significantly higher under RCP 8.5 w/m$^{2}$ (Figure 4-25c (ii)) of between 4.0$^{o}$C and 6.0$^{o}$C during SOND season for the period 2071-2100.

Generally, changes in maximum temperature are expected to under a faster increament under RCP 8.5 w/m$^{2}$ (1.5$^{o}$C - 2.0$^{o}$C in 2021-2050 to 4.0$^{o}$C-6.0$^{o}$C for 2071-2100 period) compared to RCP 4.5 w/m$^{2}$ (1.5$^{o}$C -2.0$^{o}$C in 2021-2050 to 3.0$^{o}$C-3.5$^{o}$C for 2071-2100 period).

Overall, changes in maximum temperatures are expected to increase from approximately 1.5 $^{o}$C over many parts of Rwanda in 2021 to 3.5 $^{o}$C over most parts of Rwanda in 2100 under RCP 4.5 w/m$^{2}$ and from 1.5 $^{o}$C over many parts of Rwanda in 2021 to 6.0 $^{o}$C over most parts of Rwanda in 2100 under RCP 8.5 w/m$^{2}$ during SOND season.

### 4.7.5.5 Annual maximum temperature

Analysis of the changes of projected (2021-2100) maximum temperature against its baseline (1981-2010) during annual under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ are presented in Figure 4-26.

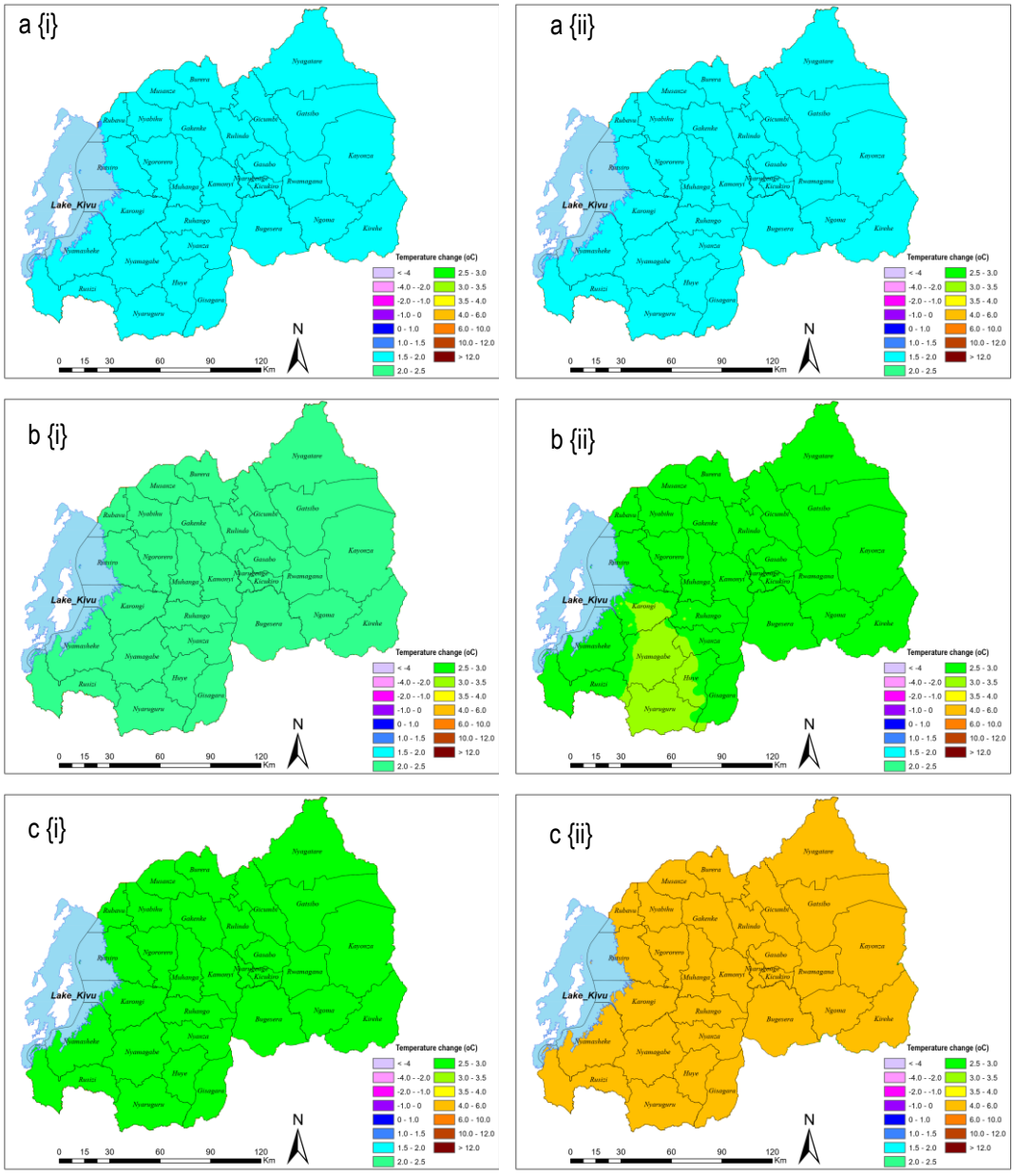


Figure 4-26: Analysis of changes of projected (2071-2100) maximum temperature against its baseline (1981-2010) during annual under a) RCP 4.5 w/m$^2$ and b) RCP 8.5 w/m$^2$ over Rwanda.

Figure 4-26 (a) shows that most parts of the country are expected to have positive changes of annual maximum temperature of between 1.5$^o$C and 2.0$^o$C under both RCP 4.5 w/m$^2$ (Figure 4-26a (i)) and RCP 8.5 w/m$^2$ (Figure 4-25a (ii)) during for the period 2021-2050.

Figure 4-26b shows that most parts of the country are expected to have positive changes of annual maximum temperature of between 2.0$^{o}$C and 2.5$^{o}$C under RCP 4.5 w/m$^{2}$ (Figure 4-26b (i)) and slightly higher between 2.5$^{o}$C and 3.5$^{o}$C under RCP 8.5 w/m$^{2}$ (Figure 4-26b (ii)) during the period 2041-2070.

Figure 4-26c shows that most parts of the country are expected to have positive changes of annual maximum temperature of between 2.5$^{o}$C and 3.0$^{o}$C under RCP 4.5 w/m$^{2}$ (Figure 4-26c (i)) and significantly higher under RCP 8.5 w/m$^{2}$ (Figure 4-26c (ii)) of between 4.0$^{o}$C and 6.0$^{o}$C during the period 2071-2100.

Changes in maximum temperature are expected to under a faster increament under RCP 8.5 w/m$^{2}$ (1.5$^{o}$C -2.0$^{o}$C in 2021-2050 to 4.0$^{o}$C-6.0$^{o}$C for 2071-2100 period) compared to RCP 4.5 w/m$^{2}$ (1.5$^{o}$C - 2.0$^{o}$C) in 2021-2050 to 3.0$^{o}$C - 3.5$^{o}$C for 2071-2100 period). Overall, changes in maximum temperatures are expected to increase from approximately 1.5 $^{o}$C over many parts of Rwanda in 2021 to 3.5 $^{o}$C over most parts of Rwanda in 2100 under RCP 4.5 w/m$^{2}$ and from 1.5 $^{o}$C over many parts of Rwanda in 2021 to 6.0 $^{o}$C over most parts of Rwanda in 2100 under RCP 8.5 w/m$^{2}$ during SOND season.

## 4.8 Analysis of Bias corrected climate projections –minimum temperature

### 4.8.1 *Temporal analysis of projected minimum temperature*

Analysis of the trend of JF, MAM, JJA, SOND and Annual projected minimum temperature during the 30-year period between 2021 and 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ are presented in the subsequent section.

#### 4.8.1.1 January-February (JF) Season

Table 4-57 shows that projected mean JF minimum temperature for the period 2021-2050 ranges from +7.3% or +0.03$^o$C per year (significant, α ≤ 0.05) in Gatumba to +3.6% or +0.02$^O$C per year (significant, α ≤ 0.05) in Masaka under RCP45w/m$^2$ and ranged from 8.45% or +0.03$^O$C per year (significant, α ≤ 0.05) in Gatumba to +2.48% or 0.01$^O$C per year (significant, α ≤ 0.05) in Gisenyi under RCP 8.5 w/m$^2$. In addition, projected minimum temperature is expected to increase during the period 2021-2050 under both RCP 4.5 w/m$^2$ over Musanze, Ngororero, and Northeastern parts (Nyagatare, and parts of Gatsibo and Gichumbi) and over, Nyabihu, Gakenke, Muhanga, Rutsiro and Nyamagabe under RCP 8.5 w/m$^2$ at 99.9% significance level with highest changes of between 6% and 10%.

Table 4-58 shows that projected mean JF minimum temperature for the period 2041-2070 ranged from +6.6% or +0.03$^O$C per year (significant, α ≤ 0.05) in Gatumba to +2.1% or +0.01$^O$C per year (significant, α ≤ 0.05) in Masaka under RCP 4.5 w/m$^2$ and ranged from +3.5% or +0.02$^O$C per year (not significant, α > 0.05) in Nyagatare to +0.5% or 0.001$^O$C per year (not significant, α > 0.05) in Gisenyi under RCP 8.5 w/m$^2$.The trend of projected minimum temperatures for the period 2041-2070 are also expected to increase by 6% to 10% for both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ especially over northern highland and northeastern parts of Rwanda while the rest of the country is expected to increase at a rate of 0 to 4% under RCP 4.5 w/m$^2$.

Table 4-59 shows that projected mean JF minimum temperature for the period 2071-2100 ranged from +11.8% or +0.05$^O$C per year (significant, α ≤ 0.05) in Gatumba to +6.1% or +0.03$^O$C per year (significant, α ≤ 0.05) in Kawangire under RCP 4.5 w/m$^2$ and ranged from +9.7% or +0.04$^O$C per year (significant, α ≤ 0.05) in Gatumba to +10.9% or 0.04$^O$C per year (significant, α ≤ 0.05) in Gisenyi under RCP 8.5 w/m$^2$. An increasing trend across the country of projected minimum temperature for the period between 2071 -2100 under both RCP 4.5 w/m$^2$ of2% to 4% over southeastern, central, western and northern parts and general increase of 4 to 8% in most part of the country except the areas of Ngororero and Musanze showing an increase of 10% to 20% under RCP 8.5 w/m$^2$ for the period of 2071-2100.

In general, projected minimum temperature during JF season is expected to increase under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$.More areas under RCP 8.5 w/m$^2$ are expected to experience higher minimum temperatures compared to RCP 4.5 w/m$^2$ for the period 2021-2050. Projected minimum temperature for the JF season under RCP 4.5 w/m$^2$ shows larger changes for the period 2021-2050 and decreases towards end of the century (2071-2100) whereas the smaller changes are expected under RCP 8.5 w/m$^2$ during the period 2021-2050 and increases towards 2100.

.

Table 4-57: Projected trends of minimum temperature during JF season for the period 2021 to 2050 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| Stations | 2021-2050 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | 3.82 | *** | 0.02 | 16.6 | 4.2 | 4.82 | *** | 0.03 | 16.18 | 5.44 |
| Busogo | 3.10 | ** | 0.02 | 10.6 | 5.9 | 3.53 | *** | 0.02 | 10.28 | 6.79 |
| Butare | 3.53 | *** | 0.02 | 14.3 | 3.8 | 4.35 | *** | 0.02 | 14.03 | 5.09 |
| Byimana | 3.60 | *** | 0.02 | 12.5 | 4.9 | 4.21 | *** | 0.02 | 12.21 | 5.69 |
| Byumba | 3.96 | *** | 0.02 | 12.5 | 4.6 | 3.78 | *** | 0.02 | 12.24 | 4.96 |
| Cyinzuzi | 3.96 | *** | 0.02 | 14.2 | 5.0 | 3.78 | *** | 0.03 | 13.82 | 5.46 |
| Gabiro | 3.89 | *** | 0.03 | 15.1 | 5.5 | 4.42 | *** | 0.03 | 14.69 | 6.05 |
| Gatumba | 3.10 | ** | 0.03 | 11.6 | 7.3 | 3.53 | *** | 0.03 | 11.19 | 8.45 |
| Gikongoro | 3.57 | *** | 0.02 | 12.6 | 4.1 | 4.17 | *** | 0.02 | 12.26 | 4.93 |
| Gisanga | 3.60 | *** | 0.02 | 12.5 | 4.9 | 4.21 | *** | 0.02 | 12.21 | 5.69 |
| Gisenyi | 3.64 | *** | 0.03 | 15.8 | 5.2 | 2.57 | * | 0.01 | 15.41 | 2.48 |
| Gitarama | 3.60 | *** | 0.02 | 12.5 | 4.9 | 4.21 | *** | 0.02 | 12.21 | 5.69 |
| Gitega | 3.96 | *** | 0.02 | 14.2 | 5.0 | 3.78 | *** | 0.03 | 13.82 | 5.46 |
| Kamembe | 3.93 | *** | 0.02 | 12.6 | 3.8 | 4.14 | *** | 0.02 | 12.27 | 3.83 |
| Kanombe | 3.96 | *** | 0.02 | 14.2 | 5.0 | 3.78 | *** | 0.03 | 13.82 | 5.46 |
| Kansi | 3.53 | *** | 0.02 | 13.7 | 4.2 | 4.35 | *** | 0.03 | 13.39 | 5.60 |
| Kawangire | 3.89 | *** | 0.02 | 15.7 | 4.6 | 4.42 | *** | 0.03 | 15.34 | 5.00 |
| Kibungo | 4.92 | *** | 0.02 | 15.6 | 3.8 | 4.92 | *** | 0.03 | 15.14 | 5.01 |
| Masaka | 4.92 | *** | 0.02 | 15.5 | 3.6 | 4.92 | *** | 0.02 | 15.11 | 4.78 |
| Muganza | 3.57 | *** | 0.02 | 13.2 | 3.8 | 4.17 | *** | 0.02 | 12.93 | 4.57 |
| Mushubi | 3.28 | ** | 0.02 | 10.7 | 5.7 | 3.89 | *** | 0.02 | 10.35 | 6.82 |
| Ntaruka | 3.75 | *** | 0.02 | 11.2 | 5.4 | 3.64 | *** | 0.02 | 10.87 | 4.67 |
| Ntendezi | 3.93 | *** | 0.02 | 11.5 | 4.8 | 4.14 | *** | 0.02 | 11.19 | 4.83 |
| Nyagatare | 3.78 | *** | 0.03 | 13.8 | 6.9 | 4.32 | *** | 0.03 | 13.32 | 6.20 |
| Nyamata | 3.60 | *** | 0.02 | 15.3 | 4.1 | 4.21 | *** | 0.02 | 14.99 | 4.73 |
| Rubengera | 3.28 | ** | 0.02 | 15.1 | 3.7 | 3.89 | *** | 0.02 | 14.77 | 4.37 |
| Ruganda | 3.96 | *** | 0.03 | 14.4 | 5.5 | 3.78 | *** | 0.03 | 13.94 | 5.94 |
| Rugobagoba | 3.60 | *** | 0.02 | 12.5 | 4.9 | 4.21 | *** | 0.02 | 12.21 | 5.69 |
| Ruhengeri | 3.43 | *** | 0.02 | 9.8 | 6.4 | 3.28 | ** | 0.02 | 9.48 | 6.54 |
| Rutsiro | 3.10 | ** | 0.03 | 12.9 | 6.2 | 3.53 | *** | 0.03 | 12.47 | 7.13 |
| Rwamagana | 3.89 | *** | 0.02 | 15.7 | 4.6 | 4.42 | *** | 0.03 | 15.34 | 5.00 |
| Rwankeri | 3.10 | ** | 0.02 | 10.6 | 5.9 | 3.53 | *** | 0.02 | 10.28 | 6.79 |
| Save | 3.53 | *** | 0.02 | 14.3 | 3.8 | 4.35 | *** | 0.02 | 14.03 | 5.09 |

Table 4-58: Projected trends of minimum temperature during JF season for the period 2041 to 2050 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| Stations | 2041-2070 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | 2.46 | * | 0.02 | 17.0 | 2.8 | 4.50 | *** | 0.03 | 16.82 | 4.87 |
| Busogo | 3.18 | ** | 0.02 | 11.1 | 5.4 | 4.50 | *** | 0.03 | 10.85 | 7.98 |
| Butare | 3.00 | ** | 0.01 | 14.7 | 2.5 | 4.67 | *** | 0.02 | 14.51 | 3.99 |
| Byimana | 3.21 | ** | 0.01 | 12.9 | 3.1 | 4.89 | *** | 0.02 | 12.71 | 4.94 |
| Byumba | 2.64 | ** | 0.01 | 12.9 | 3.3 | 4.17 | *** | 0.02 | 12.72 | 4.92 |
| Cyinzuzi | 2.64 | ** | 0.02 | 14.7 | 3.6 | 4.17 | *** | 0.03 | 14.43 | 5.39 |
| Gabiro | 2.50 | * | 0.02 | 15.6 | 3.7 | 4.03 | *** | 0.03 | 15.40 | 6.16 |
| Gatumba | 3.18 | ** | 0.03 | 12.2 | 6.6 | 4.50 | *** | 0.04 | 11.96 | 9.81 |
| Gikongoro | 3.14 | ** | 0.01 | 12.9 | 2.8 | 4.75 | *** | 0.02 | 12.71 | 4.68 |
| Gisanga | 3.21 | ** | 0.01 | 12.9 | 3.1 | 4.89 | *** | 0.02 | 12.71 | 4.94 |
| Gisenyi | 2.18 | * | 0.01 | 16.3 | 2.6 | 4.85 | *** | 0.04 | 16.00 | 7.02 |
| Gitarama | 3.21 | ** | 0.01 | 12.9 | 3.1 | 4.89 | *** | 0.02 | 12.71 | 4.94 |
| Gitega | 2.64 | ** | 0.02 | 14.7 | 3.6 | 4.17 | *** | 0.03 | 14.43 | 5.39 |
| Kamembe | 2.82 | ** | 0.01 | 12.8 | 2.5 | 4.67 | *** | 0.02 | 12.66 | 4.20 |
| Kanombe | 2.64 | ** | 0.02 | 14.7 | 3.6 | 4.17 | *** | 0.03 | 14.43 | 5.39 |
| Kansi | 3.00 | ** | 0.01 | 14.1 | 2.7 | 4.67 | *** | 0.02 | 13.89 | 4.38 |
| Kawangire | 2.50 | * | 0.02 | 16.2 | 3.1 | 4.03 | *** | 0.03 | 15.95 | 5.14 |
| Kibungo | 3.10 | ** | 0.01 | 15.9 | 2.2 | 5.25 | *** | 0.02 | 15.66 | 4.30 |
| Masaka | 3.10 | ** | 0.01 | 15.9 | 2.1 | 5.25 | *** | 0.02 | 15.61 | 4.12 |
| Muganza | 3.14 | ** | 0.01 | 13.6 | 2.6 | 4.75 | *** | 0.02 | 13.37 | 4.35 |
| Mushubi | 3.64 | *** | 0.02 | 11.1 | 4.5 | 4.50 | *** | 0.02 | 10.86 | 6.37 |
| Ntaruka | 2.36 | * | 0.01 | 11.5 | 3.7 | 4.32 | *** | 0.03 | 11.36 | 6.75 |
| Ntendezi | 2.82 | ** | 0.01 | 11.9 | 3.1 | 4.67 | *** | 0.02 | 11.64 | 5.25 |
| Nyagatare | 2.21 | * | 0.02 | 14.4 | 5.0 | 3.93 | *** | 0.04 | 14.10 | 7.88 |
| Nyamata | 3.21 | ** | 0.01 | 15.7 | 2.6 | 4.89 | *** | 0.02 | 15.50 | 4.14 |
| Rubengera | 3.64 | *** | 0.02 | 15.5 | 3.0 | 4.50 | *** | 0.02 | 15.24 | 4.15 |
| Ruganda | 2.64 | ** | 0.02 | 14.9 | 3.9 | 4.17 | *** | 0.03 | 14.60 | 5.85 |
| Rugobagoba | 3.21 | ** | 0.01 | 12.9 | 3.1 | 4.89 | *** | 0.02 | 12.71 | 4.94 |
| Ruhengeri | 2.57 | * | 0.02 | 10.2 | 5.7 | 4.53 | *** | 0.03 | 10.07 | 9.51 |
| Rutsiro | 3.18 | ** | 0.03 | 13.5 | 5.7 | 4.50 | *** | 0.04 | 13.20 | 8.37 |
| Rwamagana | 2.50 | * | 0.02 | 16.2 | 3.1 | 4.03 | *** | 0.03 | 15.95 | 5.14 |
| Rwankeri | 3.18 | ** | 0.02 | 11.1 | 5.4 | 4.50 | *** | 0.03 | 10.85 | 7.98 |
| Save | 3.00 | ** | 0.01 | 14.7 | 2.5 | 4.67 | *** | 0.02 | 14.51 | 3.99 |

Table 4-59: Projected trends of minimum temperature during JF season for the period 2071 to 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| Stations | 2071-2100 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | 1.96 | * | 0.01 | 17.3 | 2.2 | 4.96 | *** | 0.04 | 17.8 | 6.5 |
| Busogo | 0.93 | | 0.01 | 11.3 | 1.6 | 5.14 | *** | 0.04 | 11.8 | 9.7 |
| Butare | 1.50 | | 0.01 | 15.0 | 1.2 | 5.46 | *** | 0.03 | 15.3 | 6.7 |
| Byimana | 1.43 | | 0.01 | 13.2 | 1.7 | 5.17 | *** | 0.03 | 13.5 | 7.4 |
| Byumba | 1.57 | | 0.01 | 13.2 | 1.6 | 5.28 | *** | 0.03 | 13.5 | 6.8 |
| Cyinzuzi | 1.57 | | 0.01 | 15.0 | 1.8 | 5.28 | *** | 0.04 | 15.4 | 7.4 |
| Gabiro | 1.82 | + | 0.02 | 16.0 | 3.0 | 5.07 | *** | 0.04 | 16.5 | 7.3 |
| Gatumba | 0.93 | | 0.01 | 12.6 | 1.9 | 5.14 | *** | 0.05 | 13.2 | 11.8 |
| Gikongoro | 1.03 | | 0.00 | 13.1 | 1.1 | 5.53 | *** | 0.03 | 13.5 | 7.6 |
| Gisanga | 1.43 | | 0.01 | 13.2 | 1.7 | 5.17 | *** | 0.03 | 13.5 | 7.4 |
| Gisenyi | 0.25 | | 0.00 | 16.6 | 0.5 | 5.35 | *** | 0.05 | 17.1 | 8.1 |
| Gitarama | 1.43 | | 0.01 | 13.2 | 1.7 | 5.17 | *** | 0.03 | 13.5 | 7.4 |
| Gitega | 1.57 | | 0.01 | 15.0 | 1.8 | 5.28 | *** | 0.04 | 15.4 | 7.4 |
| Kamembe | 0.50 | | 0.00 | 13.0 | 0.5 | 5.50 | *** | 0.03 | 13.3 | 6.9 |
| Kanombe | 1.57 | | 0.01 | 15.0 | 1.8 | 5.28 | *** | 0.04 | 15.4 | 7.4 |
| Kansi | 1.50 | | 0.01 | 14.4 | 1.3 | 5.46 | *** | 0.04 | 14.7 | 7.3 |
| Kawangire | 1.82 | + | 0.01 | 16.5 | 2.5 | 5.07 | *** | 0.03 | 16.9 | 6.1 |
| Kibungo | 1.28 | | 0.01 | 16.2 | 1.0 | 5.67 | *** | 0.04 | 16.6 | 6.6 |
| Masaka | 1.28 | | 0.01 | 16.1 | 0.9 | 5.67 | *** | 0.03 | 16.5 | 6.3 |
| Muganza | 1.03 | | 0.00 | 13.8 | 1.0 | 5.53 | *** | 0.03 | 14.1 | 7.1 |
| Mushubi | 1.03 | | 0.01 | 11.3 | 1.6 | 5.25 | *** | 0.04 | 11.7 | 9.4 |
| Ntaruka | 0.96 | | 0.01 | 11.8 | 1.5 | 5.25 | *** | 0.03 | 12.2 | 7.4 |
| Ntendezi | 0.50 | | 0.00 | 12.0 | 0.6 | 5.50 | *** | 0.04 | 12.4 | 8.5 |
| Nyagatare | 1.68 | + | 0.02 | 14.8 | 3.5 | 5.00 | *** | 0.04 | 15.3 | 8.0 |
| Nyamata | 1.43 | | 0.01 | 16.0 | 1.4 | 5.17 | *** | 0.03 | 16.3 | 6.3 |
| Rubengera | 1.03 | | 0.01 | 15.7 | 1.1 | 5.25 | *** | 0.03 | 16.0 | 6.3 |
| Ruganda | 1.57 | | 0.01 | 15.2 | 1.9 | 5.28 | *** | 0.04 | 15.7 | 8.0 |
| Rugobagoba | 1.43 | | 0.01 | 13.2 | 1.7 | 5.17 | *** | 0.03 | 13.5 | 7.4 |
| Ruhengeri | 0.54 | | 0.00 | 10.6 | 1.1 | 5.25 | *** | 0.04 | 11.1 | 10.9 |
| Rutsiro | 0.93 | | 0.01 | 13.8 | 1.6 | 5.14 | *** | 0.05 | 14.4 | 10.2 |
| Rwamagana | 1.82 | + | 0.01 | 16.5 | 2.5 | 5.07 | *** | 0.03 | 16.9 | 6.1 |
| Rwankeri | 0.93 | | 0.01 | 11.3 | 1.6 | 5.14 | *** | 0.04 | 11.8 | 9.7 |
| Save | 1.50 | | 0.01 | 15.0 | 1.2 | 5.46 | *** | 0.03 | 15.3 | 6.7 |

#### 4.8.1.2 March-April-May Season

Analysis of the minimum temperature trends for the period between 2021 and 2100 under RCP 4.5 and RCP 8.5 w/m$^2$ are presented in Table 4-60 to Table 4-62

Table 4-60 shows that projected MAM mean minimum temperature for the period 2021-2050 ranges from +5.2% or +0.02$^O$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +2.1% or +0.01$^O$C per year (significant, $\alpha \leq 0.05$) in Save under RCP 4.5 w/m$^2$ and ranged from +6.2% or +0.03$^O$C per year (significant, $\alpha \leq 0.05$) in Gisenyi to +3.1% or 0.01$^O$C per year (significant, $\alpha \leq 0.05$) in Rubengera under RCP 8.5 w/m$^2$. Notably, projected MAM minimum temperature is expected to increase by up to 10% during the period 2021-2050 under both RCP 4.5 w/m$^2$ especially over Ngorero, Rutsiro, Nyabihu and Musanze and statistically significant at 95% significance level and RCP 8.5 w/m$^2$ with highest change of up to 10% along the Congo-Nile divide, the Southeastern and Northeastern parts of the country.

Table 4-61 shows that Projected mean MAM minimum temperature for the period 2041-2070 ranged from +3.9% or +0.02$^O$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +1.6% or +0.01$^O$C per year (significant, $\alpha \leq 0.05$) in Rubengera and ranges from +10.3% or +0.04$^O$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +5.1% or 0.03$^O$C per year (significant, $\alpha \leq 0.05$) in Rubengera under RCP 4.5 and RCP 8.5 w/m$^2$ respectiv. Notably for the period of 2041-2070, a general increasing trend was observed under both RCP 4.5 w/m$^2$ with a low increase over the south-eastern and Amayaga areas and a higher increase over the rest of the country. An increasing trend was indicated over the eastern part (Kayonza, Rwamagana, Kirehe, Ngoma and Bugesera), the areas of Amayaga, Rusizi, Karongi, Rulindo and western Gakenke while the rest of the country registered an increasing trend under RCP 8.5 w/m$^2$

Table 4-62 shows that projected mean MAM minimum temperature for the period 2071-2100 ranges from +2.2% or +0.01$^O$C per year (not significant, $\alpha > 0.05$) in Nyagatare to +0.6% or +0.001$^O$C per year (not significant, $\alpha > 0.05$) in Rubengera under RCP 4.5 w/m$^2$ and ranges from +10.9% or +0.05$^O$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +5.1% or 0.03$^O$C per year (significant, $\alpha \leq 0.05$) in Masaka under RCP 8.5 w/m$^2$. Increasing trend of projected minimum temperature was also noted during MAM season for the period 2071- 2100 under RCP 4.5 w/m$^2$ over Northeastern (Nyagatare) under RCP 4.5 w/m$^2$ while the RCP 8.5 w/m$^2$ indicated an increasing trend over the south-eastern ( Bugesera, Ngoma and Kirehe) and south-western part ( Rusizi and Nyamasheke) while the rest of the country show an increase especially around Ngororero.

In overall, projected changes in MAM minimum temperature under RCP 4.5 w/m$^2$ shows larger changes during 2021-2050 compared to 2071-2100. However, under RCP 8.5 w/m$^2$, larger changes are noted for the 2071-2100 compared to 2021-2050.

Table 4-60: Projected trends of minimum temperature during MAM season for the period 2021 to 2050 under RCP 4.5 w/m$^2$ and RCP 8.5w/m$^2$ over Rwanda

| Stations | 2021-2050 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | 2.82 | ** | 0.01 | 16.5 | 2.6 | 4.78 | *** | 0.02 | 16.1 | 4.0 |
| Busogo | 2.50 | * | 0.01 | 10.5 | 4.2 | 3.03 | ** | 0.02 | 10.1 | 4.9 |
| Butare | 2.50 | * | 0.01 | 14.1 | 2.1 | 3.75 | *** | 0.02 | 13.7 | 3.3 |
| Byimana | 2.46 | * | 0.01 | 12.3 | 2.8 | 3.46 | *** | 0.02 | 11.9 | 3.8 |
| Byumba | 2.60 | ** | 0.01 | 12.4 | 2.9 | 3.07 | ** | 0.01 | 12.1 | 3.3 |
| Cyinzuzi | 2.60 | ** | 0.01 | 14.0 | 3.2 | 3.07 | ** | 0.02 | 13.6 | 3.7 |
| Gabiro | 2.93 | ** | 0.02 | 15.0 | 3.3 | 4.53 | *** | 0.02 | 14.6 | 4.9 |
| Gatumba | 2.50 | * | 0.02 | 11.5 | 5.2 | 3.03 | ** | 0.02 | 11.0 | 6.1 |
| Gikongoro | 2.36 | * | 0.01 | 12.2 | 2.6 | 3.43 | *** | 0.01 | 11.9 | 3.7 |
| Gisanga | 2.46 | * | 0.01 | 12.3 | 2.8 | 3.46 | *** | 0.02 | 11.9 | 3.8 |
| Gisenyi | 3.07 | ** | 0.02 | 16.1 | 4.0 | 5.14 | *** | 0.03 | 15.6 | 6.2 |
| Gitarama | 2.46 | * | 0.01 | 12.3 | 2.8 | 3.46 | *** | 0.02 | 11.9 | 3.8 |
| Gitega | 2.60 | ** | 0.01 | 14.0 | 3.2 | 3.07 | ** | 0.02 | 13.6 | 3.7 |
| Kamembe | 2.64 | ** | 0.01 | 12.3 | 2.6 | 3.64 | *** | 0.01 | 12.0 | 3.3 |
| Kanombe | 2.60 | ** | 0.01 | 14.0 | 3.2 | 3.07 | ** | 0.02 | 13.6 | 3.7 |
| Kansi | 2.50 | * | 0.01 | 13.4 | 2.3 | 3.75 | *** | 0.02 | 13.0 | 3.7 |
| Kawangire | 2.93 | ** | 0.01 | 15.6 | 2.7 | 4.53 | *** | 0.02 | 15.3 | 4.0 |
| Kibungo | 3.43 | *** | 0.02 | 15.1 | 3.4 | 4.71 | *** | 0.02 | 14.8 | 4.9 |
| Masaka | 3.43 | *** | 0.02 | 15.1 | 3.2 | 4.71 | *** | 0.02 | 14.7 | 4.7 |
| Muganza | 2.36 | * | 0.01 | 12.9 | 2.4 | 3.43 | *** | 0.01 | 12.6 | 3.4 |
| Mushubi | 2.43 | * | 0.01 | 10.4 | 3.4 | 3.07 | ** | 0.02 | 10.0 | 4.8 |
| Ntaruka | 2.75 | ** | 0.01 | 11.2 | 3.2 | 3.57 | *** | 0.01 | 10.9 | 3.9 |
| Ntendezi | 2.64 | ** | 0.01 | 11.2 | 3.2 | 3.64 | *** | 0.02 | 10.9 | 4.2 |
| Nyagatare | 2.93 | ** | 0.02 | 13.8 | 3.8 | 4.03 | *** | 0.03 | 13.3 | 5.7 |
| Nyamata | 2.46 | * | 0.01 | 15.0 | 2.4 | 3.46 | *** | 0.02 | 14.7 | 3.2 |
| Rubengera | 2.43 | * | 0.01 | 14.8 | 2.2 | 3.07 | ** | 0.01 | 14.4 | 3.1 |
| Ruganda | 2.60 | ** | 0.02 | 14.1 | 3.4 | 3.07 | ** | 0.02 | 13.7 | 4.0 |
| Rugobagoba | 2.46 | * | 0.01 | 12.3 | 2.8 | 3.46 | *** | 0.02 | 11.9 | 3.8 |
| Ruhengeri | 2.82 | ** | 0.02 | 10.0 | 5.2 | 2.93 | ** | 0.02 | 9.7 | 5.0 |
| Rutsiro | 2.50 | * | 0.02 | 12.8 | 4.4 | 3.03 | ** | 0.02 | 12.3 | 5.2 |
| Rwamagana | 2.93 | ** | 0.01 | 15.6 | 2.7 | 4.53 | *** | 0.02 | 15.3 | 4.0 |
| Rwankeri | 2.50 | * | 0.01 | 10.5 | 4.2 | 3.03 | ** | 0.02 | 10.1 | 4.9 |
| Save | 2.50 | * | 0.01 | 14.1 | 2.1 | 3.75 | *** | 0.02 | 13.7 | 3.3 |

Table 4-61: Projected trends of minimum temperature during MAM season for the period 2041 to 2070 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| Stations | 2041-2070 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | 1.32 | | 0.01 | 16.8 | 1.7 | 4.42 | *** | 0.03 | 16.7 | 5.5 |
| Busogo | 2.21 | * | 0.01 | 10.8 | 3.2 | 4.28 | *** | 0.03 | 10.7 | 8.4 |
| Butare | 1.75 | + | 0.01 | 14.3 | 1.7 | 4.71 | *** | 0.03 | 14.2 | 5.5 |
| Byimana | 1.93 | + | 0.01 | 12.5 | 2.0 | 4.75 | *** | 0.03 | 12.4 | 6.7 |
| Byumba | 2.03 | * | 0.01 | 12.6 | 2.1 | 4.39 | *** | 0.02 | 12.5 | 5.5 |
| Cyinzuzi | 2.03 | * | 0.01 | 14.3 | 2.2 | 4.39 | *** | 0.03 | 14.2 | 6.0 |
| Gabiro | 1.71 | + | 0.01 | 15.4 | 2.4 | 4.46 | *** | 0.03 | 15.2 | 6.5 |
| Gatumba | 2.21 | * | 0.02 | 11.9 | 3.9 | 4.28 | *** | 0.04 | 11.7 | 10.3 |
| Gikongoro | 2.11 | * | 0.01 | 12.4 | 1.8 | 4.82 | *** | 0.03 | 12.4 | 6.3 |
| Gisanga | 1.93 | + | 0.01 | 12.5 | 2.0 | 4.75 | *** | 0.03 | 12.4 | 6.7 |
| Gisenyi | 2.25 | * | 0.02 | 16.5 | 2.9 | 5.14 | *** | 0.04 | 16.3 | 6.6 |
| Gitarama | 1.93 | + | 0.01 | 12.5 | 2.0 | 4.75 | *** | 0.03 | 12.4 | 6.7 |
| Gitega | 2.03 | * | 0.01 | 14.3 | 2.2 | 4.39 | *** | 0.03 | 14.2 | 6.0 |
| Kamembe | 2.03 | * | 0.01 | 12.5 | 2.0 | 4.78 | *** | 0.02 | 12.4 | 5.8 |
| Kanombe | 2.03 | * | 0.01 | 14.3 | 2.2 | 4.39 | *** | 0.03 | 14.2 | 6.0 |
| Kansi | 1.75 | + | 0.01 | 13.6 | 1.8 | 4.71 | *** | 0.03 | 13.6 | 6.1 |
| Kawangire | 1.71 | + | 0.01 | 15.9 | 2.0 | 4.46 | *** | 0.03 | 15.8 | 5.4 |
| Kibungo | 1.43 | | 0.01 | 15.5 | 1.9 | 4.75 | *** | 0.03 | 15.4 | 5.9 |
| Masaka | 1.43 | | 0.01 | 15.4 | 1.8 | 4.75 | *** | 0.03 | 15.3 | 5.6 |
| Muganza | 2.11 | * | 0.01 | 13.1 | 1.6 | 4.82 | *** | 0.03 | 13.0 | 5.8 |
| Mushubi | 1.96 | * | 0.01 | 10.6 | 2.4 | 4.50 | *** | 0.03 | 10.5 | 7.9 |
| Ntaruka | 2.14 | * | 0.01 | 11.5 | 2.6 | 4.67 | *** | 0.02 | 11.4 | 6.2 |
| Ntendezi | 2.03 | * | 0.01 | 11.5 | 2.5 | 4.78 | *** | 0.03 | 11.4 | 7.2 |
| Nyagatare | 1.71 | + | 0.01 | 14.2 | 3.1 | 4.46 | *** | 0.04 | 14.0 | 7.6 |
| Nyamata | 1.93 | + | 0.01 | 15.3 | 1.6 | 4.75 | *** | 0.03 | 15.2 | 5.6 |
| Rubengera | 1.96 | * | 0.01 | 15.0 | 1.6 | 4.50 | *** | 0.03 | 14.9 | 5.1 |
| Ruganda | 2.03 | * | 0.01 | 14.4 | 2.4 | 4.39 | *** | 0.03 | 14.3 | 6.5 |
| Rugobagoba | 1.93 | + | 0.01 | 12.5 | 2.0 | 4.75 | *** | 0.03 | 12.4 | 6.7 |
| Ruhengeri | 2.43 | * | 0.01 | 10.4 | 3.5 | 4.25 | *** | 0.03 | 10.2 | 8.8 |
| Rutsiro | 2.21 | * | 0.01 | 13.1 | 3.4 | 4.28 | *** | 0.04 | 13.0 | 8.8 |
| Rwamagana | 1.71 | + | 0.01 | 15.9 | 2.0 | 4.46 | *** | 0.03 | 15.8 | 5.4 |
| Rwankeri | 2.21 | * | 0.01 | 10.8 | 3.2 | 4.28 | *** | 0.03 | 10.7 | 8.4 |
| Save | 1.75 | + | 0.01 | 14.3 | 1.7 | 4.71 | *** | 0.03 | 14.2 | 5.5 |

Table 4-62: Projected trends of minimum temperature during MAM season for the period 2071 to 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| Stations | 2071-2100 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | 1.61 | | 0.01 | 17.1 | 1.8 | 4.57 | *** | 0.04 | 17.7 | 5.9 |
| Busogo | 0.82 | | 0.01 | 11.1 | 1.6 | 4.89 | *** | 0.04 | 11.7 | 9.0 |
| Butare | 1.07 | | 0.01 | 14.6 | 1.2 | 4.89 | *** | 0.03 | 15.1 | 5.9 |
| Byimana | 0.96 | | 0.01 | 12.8 | 1.4 | 4.75 | *** | 0.03 | 13.3 | 7.0 |
| Byumba | 0.96 | | 0.01 | 12.9 | 1.3 | 4.64 | *** | 0.03 | 13.4 | 6.8 |
| Cyinzuzi | 0.96 | | 0.01 | 14.6 | 1.4 | 4.64 | *** | 0.04 | 15.2 | 7.4 |
| Gabiro | 1.39 | | 0.01 | 15.7 | 2.1 | 4.60 | *** | 0.04 | 16.4 | 7.2 |
| Gatumba | 0.82 | | 0.01 | 12.3 | 2.0 | 4.89 | *** | 0.05 | 13.1 | 10.9 |
| Gikongoro | 0.54 | | 0.00 | 12.7 | 0.8 | 4.64 | *** | 0.03 | 13.2 | 6.5 |
| Gisanga | 0.96 | | 0.01 | 12.8 | 1.4 | 4.75 | *** | 0.03 | 13.3 | 7.0 |
| Gisenyi | 1.18 | | 0.01 | 16.8 | 1.8 | 4.35 | *** | 0.04 | 17.4 | 6.0 |
| Gitarama | 0.96 | | 0.01 | 12.8 | 1.4 | 4.75 | *** | 0.03 | 13.3 | 7.0 |
| Gitega | 0.96 | | 0.01 | 14.6 | 1.4 | 4.64 | *** | 0.04 | 15.2 | 7.4 |
| Kamembe | 0.50 | | 0.00 | 12.7 | 0.7 | 4.60 | *** | 0.02 | 13.2 | 5.4 |
| Kanombe | 0.96 | | 0.01 | 14.6 | 1.4 | 4.64 | *** | 0.04 | 15.2 | 7.4 |
| Kansi | 1.07 | | 0.01 | 13.9 | 1.3 | 4.89 | *** | 0.03 | 14.5 | 6.5 |
| Kawangire | 1.39 | | 0.01 | 16.2 | 1.8 | 4.60 | *** | 0.03 | 16.8 | 6.1 |
| Kibungo | 0.39 | | 0.00 | 15.7 | 0.8 | 4.21 | *** | 0.03 | 16.3 | 5.3 |
| Masaka | 0.39 | | 0.00 | 15.7 | 0.8 | 4.21 | *** | 0.03 | 16.2 | 5.1 |
| Muganza | 0.54 | | 0.00 | 13.4 | 0.8 | 4.64 | *** | 0.03 | 13.9 | 6.0 |
| Mushubi | 0.50 | | 0.00 | 10.9 | 0.9 | 4.78 | *** | 0.03 | 11.5 | 8.5 |
| Ntaruka | 1.07 | | 0.01 | 11.7 | 1.7 | 4.64 | *** | 0.03 | 12.3 | 7.1 |
| Ntendezi | 0.50 | | 0.00 | 11.7 | 0.9 | 4.60 | *** | 0.03 | 12.2 | 6.7 |
| Nyagatare | 1.78 | + | 0.01 | 14.6 | 2.2 | 4.46 | *** | 0.04 | 15.3 | 8.6 |
| Nyamata | 0.96 | | 0.01 | 15.6 | 1.2 | 4.75 | *** | 0.03 | 16.1 | 5.9 |
| Rubengera | 0.50 | | 0.00 | 15.3 | 0.6 | 4.78 | *** | 0.03 | 15.8 | 5.6 |
| Ruganda | 0.96 | | 0.01 | 14.8 | 1.5 | 4.64 | *** | 0.04 | 15.5 | 8.0 |
| Rugobagoba | 0.96 | | 0.01 | 12.8 | 1.4 | 4.75 | *** | 0.03 | 13.3 | 7.0 |
| Ruhengeri | 0.93 | | 0.01 | 10.7 | 2.1 | 4.50 | *** | 0.04 | 11.3 | 9.6 |
| Rutsiro | 0.82 | | 0.01 | 13.5 | 1.7 | 4.89 | *** | 0.04 | 14.3 | 9.5 |
| Rwamagana | 1.39 | | 0.01 | 16.2 | 1.8 | 4.60 | *** | 0.03 | 16.8 | 6.1 |
| Rwankeri | 0.82 | | 0.01 | 11.1 | 1.6 | 4.89 | *** | 0.04 | 11.7 | 9.0 |
| Save | 1.07 | | 0.01 | 14.6 | 1.2 | 4.89 | *** | 0.03 | 15.1 | 5.9 |

#### 4.8.1.3 June-July-August Season

Analysis of the JJA minimum temperature trends for the period between 2021 and 2100 under RCP 4.5 and RCP 8.5 w/m$^2$ are presented in Table 4-63 to Table 4-65.

Table 4-63 shows that projected mean JJA minimum temperature for the period 2021-2050 ranged from +6.4% or +0.02$^O$C per year (not significant, $\alpha > 0.05$) in Gatumba to +2.1% or +0.01$^O$C per year (not significant, $\alpha > 0.05$) in Gisenyi under RCP 4.5 w/m$^2$ and ranged from +19.0% or +0.06$^O$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +6.3% or 0.03$^O$C per year (significant, $\alpha \leq 0.05$) in Masaka under RCP 8.5 w/m$^2$. Projected JJA minimum temperature is expected to increase under RCP 4.5 w/m$^2$ countrywide with lower increase over the eastern, central plateau extending towards the south-western while the northern highland indicated higher increased trend with highest changes over parts of Nyagatare, A general increase was observed from southeast and Amayaga increasing towards the central, southern, northern, western and north-eastern parts under RCP 8.5 w/m$^2$ for the period 2021-2050.

Table 4-64 shows that projected mean JJA minimum temperature for the period 2041-2070 ranged from +5.1% or +0.02$^O$C per year (not significant, $\alpha > 0.05$) in Gatumba to +2.2% or +0.01$^O$C per year (not significant, $\alpha > 0.05$) in Muganza under RCP45w/m$^2$ and ranged from +6.61% or +0.02$^O$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +3.41% or 0.02$^O$C per year (significant, $\alpha \leq 0.05$) in Rubengera under RCP 8.5 w/m$^2$. During the period 2041-2070, increasing trends of minimum temperatures are expected with the highest increase of 0.03OC/year under RCP 8.5 w/m$^2$ over north-east (Nyagatare) and north-west (Gisenyi) compared to RCP 4.5 w/m$^2$.

Table 4-65 shows that projected mean JJA minimum temperature for the period 2071-2100 ranged from +8.4% or +0.04$^O$C per year (significant, $\alpha \leq 0.05$) in Nyagatare to +2.7% or +0.01$^O$C per year (not significant, $\alpha > 0.05$) in Gisenyi under RCP 4.5 w/m$^2$ and ranged from +12.08% or +0.05$^O$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +6.3% or 0.03$^O$C per year (significant, $\alpha \leq 0.05$) in Masaka under RCP 8.5 w/m$^2$. During 2071-2100, areas of Rusizi, Nyamasheke and Karongi are expected to exhibit a lower increasing trend under RCP 4.5 w/m$^2$ while a general increase under RCP 8.5 w/m$^2$ was observed.

In overall, projected JJA temperatures are expected to increase with changes expected to be highest under RCP 8.5 w/m$^2$ compared to RCP 4.5 w/m$^2$.

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Table 4-63: Projected trends of minimum temperature during JJA season for the period 2021 to 2050 under i) RCP 4.5 w/m$^2$ and ii) RCP 8.5 w/m$^2$ over Rwanda

| Stations | **2021-2050** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | 1.93 | + | 0.01 | 15.3 | 2.5 | 4.60 | *** | 0.05 | 15.2 | 9.0 |
| Busogo | 1.61 | | 0.02 | 9.5 | 5.0 | 5.17 | *** | 0.05 | 9.3 | 14.9 |
| Butare | 1.71 | + | 0.02 | 13.1 | 3.9 | 4.75 | *** | 0.04 | 13.0 | 8.2 |
| Byimana | 1.46 | | 0.02 | 11.4 | 4.1 | 4.71 | *** | 0.04 | 11.3 | 10.4 |
| Byumba | 1.43 | | 0.01 | 11.6 | 3.5 | 4.89 | *** | 0.04 | 11.5 | 10.6 |
| Cyinzuzi | 1.43 | | 0.02 | 13.0 | 3.8 | 4.89 | *** | 0.05 | 12.9 | 11.7 |
| Gabiro | 1.96 | * | 0.02 | 14.1 | 3.7 | 4.85 | *** | 0.05 | 14.0 | 10.9 |
| Gatumba | 1.61 | | 0.02 | 10.1 | 6.4 | 5.17 | *** | 0.06 | 9.9 | 19.0 |
| Gikongoro | 1.43 | | 0.01 | 11.4 | 3.1 | 4.75 | *** | 0.04 | 11.3 | 10.2 |
| Gisanga | 1.46 | | 0.02 | 11.4 | 4.1 | 4.71 | *** | 0.04 | 11.3 | 10.4 |
| Gisenyi | 1.32 | | 0.01 | 15.2 | 2.1 | 5.28 | *** | 0.04 | 15.0 | 8.2 |
| Gitarama | 1.46 | | 0.02 | 11.4 | 4.1 | 4.71 | *** | 0.04 | 11.3 | 10.4 |
| Gitega | 1.43 | | 0.02 | 13.0 | 3.8 | 4.89 | *** | 0.05 | 12.9 | 11.7 |
| Kamembe | 1.21 | | 0.01 | 11.5 | 2.4 | 4.89 | *** | 0.04 | 11.4 | 9.5 |
| Kanombe | 1.43 | | 0.02 | 13.0 | 3.8 | 4.89 | *** | 0.05 | 12.9 | 11.7 |
| Kansi | 1.71 | + | 0.02 | 12.4 | 4.3 | 4.75 | *** | 0.04 | 12.3 | 9.1 |
| Kawangire | 1.96 | * | 0.02 | 14.8 | 3.1 | 4.85 | *** | 0.04 | 14.7 | 8.9 |
| Kibungo | 1.61 | | 0.01 | 14.3 | 2.8 | 4.64 | *** | 0.03 | 14.3 | 6.6 |
| Masaka | 1.61 | | 0.01 | 14.3 | 2.7 | 4.64 | *** | 0.03 | 14.3 | 6.3 |
| Muganza | 1.43 | | 0.01 | 12.0 | 2.8 | 4.75 | *** | 0.04 | 11.9 | 9.4 |
| Mushubi | 1.53 | | 0.01 | 9.4 | 4.7 | 4.78 | *** | 0.05 | 9.3 | 14.9 |
| Ntaruka | 1.57 | | 0.01 | 10.5 | 4.1 | 4.85 | *** | 0.04 | 10.4 | 12.1 |
| Ntendezi | 1.21 | | 0.01 | 10.4 | 3.0 | 4.89 | *** | 0.04 | 10.2 | 12.3 |
| Nyagatare | 1.86 | + | 0.03 | 12.7 | 6.3 | 4.82 | *** | 0.06 | 12.5 | 14.8 |
| Nyamata | 1.46 | | 0.02 | 14.1 | 3.4 | 4.71 | *** | 0.04 | 14.1 | 8.5 |
| Rubengera | 1.53 | | 0.01 | 13.9 | 2.9 | 4.78 | *** | 0.04 | 13.8 | 9.2 |
| Ruganda | 1.43 | | 0.02 | 13.1 | 4.2 | 4.89 | *** | 0.06 | 13.0 | 12.9 |
| Rugobagoba | 1.46 | | 0.02 | 11.4 | 4.1 | 4.71 | *** | 0.04 | 11.3 | 10.4 |
| Ruhengeri | 1.61 | | 0.02 | 9.0 | 5.1 | 5.14 | *** | 0.05 | 8.9 | 15.7 |
| Rutsiro | 1.61 | | 0.02 | 11.4 | 5.4 | 5.17 | *** | 0.06 | 11.3 | 15.7 |
| Rwamagana | 1.96 | * | 0.02 | 14.8 | 3.1 | 4.85 | *** | 0.04 | 14.7 | 8.9 |
| Rwankeri | 1.61 | | 0.02 | 9.5 | 5.0 | 5.17 | *** | 0.05 | 9.3 | 14.9 |
| Save | 1.71 | + | 0.02 | 13.1 | 3.9 | 4.75 | *** | 0.04 | 13.0 | 8.2 |

Table 4-64: Projected trends of minimum temperature during JJA season for the period 2041 to 2070 under i) RCP 4.5w/m$^2$ and ii) RCP 8.5 w/m$^2$ over Rwanda

| Stations | **2041-2070** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | 1.89 | + | 0.02 | 15.8 | 3.9 | 2.64 | ** | 0.02 | 15.97 | 4.57 |
| Busogo | 1.71 | + | 0.01 | 9.9 | 4.1 | 2.28 | * | 0.02 | 10.00 | 5.27 |
| Butare | 1.28 | | 0.01 | 13.5 | 2.6 | 2.39 | * | 0.02 | 13.62 | 4.70 |
| Byimana | 1.61 | | 0.01 | 11.8 | 3.4 | 1.78 | + | 0.02 | 11.93 | 4.53 |
| Byumba | 1.43 | | 0.01 | 12.0 | 3.1 | 1.82 | + | 0.02 | 12.13 | 3.85 |
| Cyinzuzi | 1.43 | | 0.02 | 13.5 | 3.4 | 1.82 | + | 0.02 | 13.69 | 4.24 |
| Gabiro | 1.61 | | 0.02 | 14.7 | 4.3 | 2.25 | * | 0.02 | 14.85 | 4.96 |
| Gatumba | 1.71 | + | 0.02 | 10.6 | 5.1 | 2.28 | * | 0.02 | 10.81 | 6.61 |
| Gikongoro | 1.25 | | 0.01 | 11.7 | 2.3 | 2.39 | * | 0.02 | 11.85 | 4.89 |
| Gisanga | 1.61 | | 0.01 | 11.8 | 3.4 | 1.78 | + | 0.02 | 11.93 | 4.53 |
| Gisenyi | 1.96 | * | 0.02 | 15.6 | 3.5 | 4.21 | *** | 0.03 | 15.74 | 5.41 |
| Gitarama | 1.61 | | 0.01 | 11.8 | 3.4 | 1.78 | + | 0.02 | 11.93 | 4.53 |
| Gitega | 1.43 | | 0.02 | 13.5 | 3.4 | 1.82 | + | 0.02 | 13.69 | 4.24 |
| Kamembe | 1.53 | | 0.01 | 11.8 | 3.3 | 2.50 | * | 0.02 | 11.95 | 4.46 |
| Kanombe | 1.43 | | 0.02 | 13.5 | 3.4 | 1.82 | + | 0.02 | 13.69 | 4.24 |
| Kansi | 1.28 | | 0.01 | 12.8 | 2.9 | 2.39 | * | 0.02 | 12.96 | 5.19 |
| Kawangire | 1.61 | | 0.02 | 15.3 | 3.5 | 2.25 | * | 0.02 | 15.47 | 4.11 |
| Kibungo | 2.28 | * | 0.02 | 14.8 | 4.0 | 3.25 | ** | 0.02 | 14.91 | 4.57 |
| Masaka | 2.28 | * | 0.02 | 14.8 | 3.9 | 3.25 | ** | 0.02 | 14.89 | 4.36 |
| Muganza | 1.25 | | 0.01 | 12.4 | 2.2 | 2.39 | * | 0.02 | 12.53 | 4.52 |
| Mushubi | 1.21 | | 0.01 | 9.8 | 3.7 | 2.21 | * | 0.02 | 9.95 | 5.40 |
| Ntaruka | 1.28 | | 0.01 | 10.9 | 3.0 | 2.00 | * | 0.02 | 11.04 | 4.35 |
| Ntendezi | 1.53 | | 0.01 | 10.7 | 4.1 | 2.50 | * | 0.02 | 10.82 | 5.66 |
| Nyagatare | 1.32 | | 0.02 | 13.3 | 4.7 | 2.00 | * | 0.03 | 13.47 | 6.01 |
| Nyamata | 1.61 | | 0.01 | 14.5 | 2.8 | 1.78 | + | 0.02 | 14.70 | 3.75 |
| Rubengera | 1.21 | | 0.01 | 14.3 | 2.4 | 2.21 | * | 0.02 | 14.40 | 3.41 |
| Ruganda | 1.43 | | 0.02 | 13.6 | 3.7 | 1.82 | + | 0.02 | 13.80 | 4.62 |
| Rugobagoba | 1.61 | | 0.01 | 11.8 | 3.4 | 1.78 | + | 0.02 | 11.93 | 4.53 |
| Ruhengeri | 1.57 | | 0.01 | 9.5 | 4.1 | 2.39 | * | 0.02 | 9.57 | 5.79 |
| Rutsiro | 1.71 | + | 0.02 | 11.9 | 4.3 | 2.28 | * | 0.02 | 12.11 | 5.55 |
| Rwamagana | 1.61 | | 0.02 | 15.3 | 3.5 | 2.25 | * | 0.02 | 15.47 | 4.11 |
| Rwankeri | 1.71 | + | 0.01 | 9.9 | 4.1 | 2.28 | * | 0.02 | 10.00 | 5.27 |
| Save | 1.28 | | 0.01 | 13.5 | 2.6 | 2.39 | * | 0.02 | 13.62 | 4.70 |

Table 4-65: Projected trends of minimum temperature during JJA season for the period 2071 to 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| Stations | **2071-2100** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | 2.75 | ** | 0.03 | 16.2 | 5.8 | 3.35 | *** | 0.04 | 17.26 | 6.63 |
| Busogo | 2.39 | * | 0.02 | 10.2 | 5.1 | 3.10 | ** | 0.04 | 11.12 | 9.88 |
| Butare | 2.57 | * | 0.02 | 13.8 | 4.2 | 3.35 | *** | 0.04 | 14.67 | 7.14 |
| Byimana | 2.53 | * | 0.02 | 12.1 | 5.5 | 3.10 | ** | 0.04 | 13.02 | 8.04 |
| Byumba | 2.75 | ** | 0.02 | 12.3 | 5.1 | 3.03 | ** | 0.03 | 13.10 | 7.52 |
| Cyinzuzi | 2.75 | ** | 0.03 | 13.9 | 5.6 | 3.03 | ** | 0.04 | 14.89 | 8.22 |
| Gabiro | 2.75 | ** | 0.03 | 15.1 | 5.9 | 3.32 | *** | 0.04 | 16.21 | 8.02 |
| Gatumba | 2.39 | * | 0.02 | 11.1 | 6.3 | 3.10 | ** | 0.05 | 12.33 | 12.08 |
| Gikongoro | 2.32 | * | 0.02 | 12.0 | 4.4 | 3.14 | ** | 0.04 | 12.86 | 8.14 |
| Gisanga | 2.53 | * | 0.02 | 12.1 | 5.5 | 3.10 | ** | 0.04 | 13.02 | 8.04 |
| Gisenyi | 1.86 | + | 0.01 | 16.1 | 2.7 | 4.67 | *** | 0.04 | 16.95 | 7.01 |
| Gitarama | 2.53 | * | 0.02 | 12.1 | 5.5 | 3.10 | ** | 0.04 | 13.02 | 8.04 |
| Gitega | 2.75 | ** | 0.03 | 13.9 | 5.6 | 3.03 | ** | 0.04 | 14.89 | 8.22 |
| Kamembe | 2.14 | * | 0.01 | 12.1 | 3.2 | 3.10 | ** | 0.03 | 12.80 | 7.01 |
| Kanombe | 2.75 | ** | 0.03 | 13.9 | 5.6 | 3.03 | ** | 0.04 | 14.89 | 8.22 |
| Kansi | 2.57 | * | 0.02 | 13.1 | 4.6 | 3.35 | *** | 0.04 | 14.05 | 7.84 |
| Kawangire | 2.75 | ** | 0.03 | 15.7 | 4.9 | 3.32 | *** | 0.04 | 16.65 | 6.74 |
| Kibungo | 2.21 | * | 0.02 | 15.1 | 4.1 | 4.07 | *** | 0.04 | 16.08 | 6.58 |
| Masaka | 2.21 | * | 0.02 | 15.1 | 3.9 | 4.07 | *** | 0.03 | 16.00 | 6.30 |
| Muganza | 2.32 | * | 0.02 | 12.7 | 4.0 | 3.14 | ** | 0.04 | 13.52 | 7.57 |
| Mushubi | 2.64 | ** | 0.02 | 10.2 | 5.1 | 2.93 | ** | 0.04 | 11.07 | 10.42 |
| Ntaruka | 2.71 | ** | 0.02 | 11.3 | 5.9 | 3.14 | ** | 0.03 | 11.99 | 7.93 |
| Ntendezi | 2.14 | * | 0.01 | 11.0 | 4.0 | 3.10 | ** | 0.04 | 11.81 | 8.73 |
| Nyagatare | 2.96 | ** | 0.04 | 13.8 | 8.4 | 3.32 | *** | 0.05 | 14.91 | 9.14 |
| Nyamata | 2.53 | * | 0.02 | 14.9 | 4.6 | 3.10 | ** | 0.04 | 15.82 | 6.75 |
| Rubengera | 2.64 | ** | 0.02 | 14.6 | 3.3 | 2.93 | ** | 0.04 | 15.42 | 6.84 |
| Ruganda | 2.75 | ** | 0.03 | 14.1 | 6.1 | 3.03 | ** | 0.05 | 15.11 | 8.89 |
| Rugobagoba | 2.53 | * | 0.02 | 12.1 | 5.5 | 3.10 | ** | 0.04 | 13.02 | 8.04 |
| Ruhengeri | 2.43 | * | 0.02 | 9.8 | 5.6 | 3.25 | ** | 0.04 | 10.67 | 10.72 |
| Rutsiro | 2.39 | * | 0.02 | 12.4 | 5.4 | 3.10 | ** | 0.05 | 13.54 | 10.35 |
| Rwamagana | 2.75 | ** | 0.03 | 15.7 | 4.9 | 3.32 | *** | 0.04 | 16.65 | 6.74 |
| Rwankeri | 2.39 | * | 0.02 | 10.2 | 5.1 | 3.10 | ** | 0.04 | 11.12 | 9.88 |
| Save | 2.57 | * | 0.02 | 13.8 | 4.2 | 3.35 | *** | 0.04 | 14.67 | 7.14 |

#### 4.8.1.4 September-October-November-December Season

Analysis of SOND minimum temperature trends for the period between 2021 and 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ are presented in Table 4-66 to Table 4-68.

Table 4-66 shows that Projected mean SOND minimum temperature for the period 2021-2050 ranges from +5.4% or +0.02$^O$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +1.9% or +0.01$^O$C per year (significant, $\alpha \leq 0.05$) in Nyamata under RCP 4.5 w/m$^2$ and ranged from +9.29% or +0.04$^O$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +3.6% or 0.02$^O$C per year (significant, $\alpha \leq 0.05$) in Gisenyi under RCP 8.5 w/m$^2$. Projected minimum temperature during SOND for the period 2021-2050 is expected to increase under both RCP 4.5 w/m$^2$ over parts of Ngororero, Rutsiro, Nyabihu and Musanze by 4 to 6% and RCP 8.5 w/m$^2$ over parts of Nyamagabe, Muhanga, Kamonyi, Ngororero, Rutsiro, Rubavu, Nyabihu, Gakenke, Musanze, Burera, Gicumbi and Nyagatare by 4-9%.

The Table 4-67 shows that for the period 2041-2070, projected minimum temperatures under RCP 4.5 w/m$^2$ showed increasing trends with highest changes in Nyagatare and western of Gatsibo (4 to 6%) at 99% confidence level whereas RCP 8.5 w/m$^2$ showed projected minimum temperatures to be increasing and highest in Nyamagabe, western and northern highlands and northeastern parts of Rwanda (Nyagatare) with a magnitude of 5-8%. Projected mean SOND minimum temperature for the period 2041-2070 ranges from +4.1% or +0.02$^O$C per year (significant, $\alpha \leq 0.05$) in Nyagatare to +2.0% or +0.01$^O$C per year (significant, $\alpha \leq 0.05$) in Kamembe under RCP 4.5 w/m$^2$ and ranged from +7.99% or +0.03$^O$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +4.25% or 0.02$^O$C per year (significant, $\alpha \leq 0.05$) in Rubengera under RCP 8.5 w/m$^2$

Table 4-68 shows that projected mean SOND minimum temperature for the period 2071-2100 ranged from +2.0% or +0.01$^O$C per year (not significant, $\alpha > 0.05$) in Gisenyi to +0.9% or +0.01$^O$C per year (not significant, $\alpha > 0.05$) in Rubengera, Byumba and Ntaruka under RCP 4.5 w/m$^2$ and ranged from +10.7% or +0.05$^O$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +5.86% or 0.03$^O$C per year (significant, $\alpha \leq 0.05$) in Rubengera under RCP 8.5 w/m$^2$. During the period 2071-2100, projected changes in minimum temperatures showed an increase under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ with the highest in Ngororero.

Overall, projected minimum temperature for the SOND season is expected to increase with the highest changes expected under RCP 8.5 w/m$^2$ compared to RCP 4.5 w/m$^2$ .

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Table 4-66: Projected trends of minimum temperature during SOND season for the period 2021 to 2050 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| | 2021-2050 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| Stations | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | 3.00 | ** | 0.01 | 17.1 | 2.5 | 4.57 | *** | 0.02 | 16.60 | 4.48 |
| Busogo | 3.46 | *** | 0.02 | 11.2 | 4.4 | 4.92 | *** | 0.03 | 10.77 | 7.54 |
| Butare | 2.75 | ** | 0.01 | 14.8 | 2.3 | 4.25 | *** | 0.02 | 14.43 | 5.19 |
| Byimana | 2.82 | ** | 0.01 | 13.0 | 2.3 | 4.82 | *** | 0.03 | 12.57 | 6.12 |
| Byumba | 2.28 | * | 0.01 | 13.0 | 2.0 | 5.07 | *** | 0.02 | 12.56 | 5.38 |
| Cyinzuzi | 2.28 | * | 0.01 | 14.7 | 2.2 | 5.07 | *** | 0.03 | 14.22 | 5.90 |
| Gabiro | 2.60 | ** | 0.01 | 15.7 | 2.6 | 4.85 | *** | 0.03 | 15.15 | 6.07 |
| Gatumba | 3.46 | *** | 0.02 | 12.5 | 5.4 | 4.92 | *** | 0.04 | 11.85 | 9.29 |
| Gikongoro | 2.85 | ** | 0.01 | 13.0 | 2.8 | 4.32 | *** | 0.02 | 12.62 | 5.60 |
| Gisanga | 2.82 | ** | 0.01 | 13.0 | 2.3 | 4.82 | *** | 0.03 | 12.57 | 6.12 |
| Gisenyi | 2.21 | * | 0.02 | 16.0 | 3.4 | 3.71 | *** | 0.02 | 15.59 | 3.60 |
| Gitarama | 2.82 | ** | 0.01 | 13.0 | 2.3 | 4.82 | *** | 0.03 | 12.57 | 6.12 |
| Gitega | 2.28 | * | 0.01 | 14.7 | 2.2 | 5.07 | *** | 0.03 | 14.22 | 5.90 |
| Kamembe | 3.18 | ** | 0.01 | 12.9 | 2.9 | 4.39 | *** | 0.02 | 12.58 | 4.44 |
| Kanombe | 2.28 | * | 0.01 | 14.7 | 2.2 | 5.07 | *** | 0.03 | 14.22 | 5.90 |
| Kansi | 2.75 | ** | 0.01 | 14.2 | 2.6 | 4.25 | *** | 0.03 | 13.80 | 5.70 |
| Kawangire | 2.60 | ** | 0.01 | 16.2 | 2.2 | 4.85 | *** | 0.03 | 15.73 | 5.05 |
| Kibungo | 3.25 | ** | 0.01 | 15.8 | 2.7 | 4.82 | *** | 0.03 | 15.36 | 5.05 |
| Masaka | 3.25 | ** | 0.01 | 15.7 | 2.6 | 4.82 | *** | 0.02 | 15.32 | 4.82 |
| Muganza | 2.85 | ** | 0.01 | 13.7 | 2.6 | 4.32 | *** | 0.02 | 13.28 | 5.20 |
| Mushubi | 3.10 | ** | 0.01 | 11.2 | 3.3 | 4.71 | *** | 0.03 | 10.73 | 7.35 |
| Ntaruka | 2.60 | ** | 0.01 | 11.7 | 2.4 | 5.21 | *** | 0.02 | 11.31 | 5.91 |
| Ntendezi | 3.18 | ** | 0.01 | 11.9 | 3.6 | 4.39 | *** | 0.02 | 11.55 | 5.56 |
| Nyagatare | 2.60 | ** | 0.02 | 14.4 | 3.4 | 4.60 | *** | 0.03 | 13.77 | 7.12 |
| Nyamata | 2.82 | ** | 0.01 | 15.8 | 1.9 | 4.82 | *** | 0.03 | 15.36 | 5.11 |
| Rubengera | 3.10 | ** | 0.01 | 15.5 | 2.2 | 4.71 | *** | 0.02 | 15.12 | 4.77 |
| Ruganda | 2.28 | * | 0.01 | 14.9 | 2.3 | 5.07 | *** | 0.03 | 14.38 | 6.40 |
| Rugobagoba | 2.82 | ** | 0.01 | 13.0 | 2.3 | 4.82 | *** | 0.03 | 12.57 | 6.12 |
| Ruhengeri | 3.32 | *** | 0.01 | 10.6 | 4.2 | 5.03 | *** | 0.03 | 10.16 | 8.17 |
| Rutsiro | 3.46 | *** | 0.02 | 13.7 | 4.7 | 4.92 | *** | 0.03 | 13.09 | 7.91 |
| Rwamagana | 2.60 | ** | 0.01 | 16.2 | 2.2 | 4.85 | *** | 0.03 | 15.73 | 5.05 |
| Rwankeri | 3.46 | *** | 0.02 | 11.2 | 4.4 | 4.92 | *** | 0.03 | 10.77 | 7.54 |
| Save | 2.75 | ** | 0.01 | 14.8 | 2.3 | 4.25 | *** | 0.02 | 14.43 | 5.19 |

Table 4-67: Projected trends of minimum temperature during SOND season for the period 2041 to 2070 under RCP 4.5w/m$^2$ and RCP 8.5 w/m$^2$over Rwanda

| | 2041-2070 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| Stations | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | 2.78 | ** | 0.02 | 17.5 | 2.9 | 4.96 | *** | 0.03 | 17.18 | 5.44 |
| Busogo | 2.96 | ** | 0.01 | 11.6 | 3.2 | 4.89 | *** | 0.02 | 11.30 | 6.56 |
| Butare | 3.07 | ** | 0.01 | 15.2 | 2.7 | 4.25 | *** | 0.02 | 14.92 | 4.43 |
| Byimana | 3.10 | ** | 0.01 | 13.4 | 3.1 | 4.75 | *** | 0.02 | 13.08 | 5.35 |
| Byumba | 2.85 | ** | 0.01 | 13.3 | 2.8 | 4.82 | *** | 0.02 | 13.03 | 5.09 |
| Cyinzuzi | 2.85 | ** | 0.02 | 15.1 | 3.0 | 4.82 | *** | 0.03 | 14.82 | 5.56 |
| Gabiro | 2.89 | ** | 0.02 | 16.2 | 3.8 | 5.17 | *** | 0.03 | 15.83 | 6.49 |
| Gatumba | 2.96 | ** | 0.02 | 12.9 | 3.9 | 4.89 | *** | 0.03 | 12.58 | 7.99 |
| Gikongoro | 3.07 | ** | 0.01 | 13.3 | 2.2 | 4.17 | *** | 0.02 | 13.08 | 5.07 |
| Gisanga | 3.10 | ** | 0.01 | 13.4 | 3.1 | 4.75 | *** | 0.02 | 13.08 | 5.35 |
| Gisenyi | 2.11 | * | 0.02 | 16.4 | 2.8 | 4.53 | *** | 0.03 | 16.15 | 5.81 |
| Gitarama | 3.10 | ** | 0.01 | 13.4 | 3.1 | 4.75 | *** | 0.02 | 13.08 | 5.35 |
| Gitega | 2.85 | ** | 0.02 | 15.1 | 3.0 | 4.82 | *** | 0.03 | 14.82 | 5.56 |
| Kamembe | 2.50 | * | 0.01 | 13.2 | 2.0 | 4.32 | *** | 0.02 | 12.96 | 4.68 |
| Kanombe | 2.85 | ** | 0.02 | 15.1 | 3.0 | 4.82 | *** | 0.03 | 14.82 | 5.56 |
| Kansi | 3.07 | ** | 0.01 | 14.6 | 3.0 | 4.25 | *** | 0.02 | 14.32 | 4.85 |
| Kawangire | 2.89 | ** | 0.02 | 16.6 | 3.2 | 5.17 | *** | 0.03 | 16.32 | 5.44 |
| Kibungo | 2.71 | ** | 0.02 | 16.2 | 2.9 | 5.25 | *** | 0.03 | 15.90 | 5.12 |
| Masaka | 2.71 | ** | 0.01 | 16.1 | 2.8 | 5.25 | *** | 0.03 | 15.83 | 4.90 |
| Muganza | 3.07 | ** | 0.01 | 14.0 | 2.1 | 4.17 | *** | 0.02 | 13.74 | 4.72 |
| Mushubi | 3.07 | ** | 0.01 | 11.5 | 3.1 | 4.67 | *** | 0.02 | 11.26 | 6.43 |
| Ntaruka | 2.75 | ** | 0.01 | 12.0 | 2.9 | 5.28 | *** | 0.02 | 11.79 | 5.85 |
| Ntendezi | 2.50 | * | 0.01 | 12.2 | 2.4 | 4.32 | *** | 0.02 | 11.99 | 5.82 |
| Nyagatare | 2.85 | ** | 0.02 | 14.9 | 4.1 | 4.96 | *** | 0.04 | 14.52 | 7.85 |
| Nyamata | 3.10 | ** | 0.01 | 16.2 | 2.6 | 4.75 | *** | 0.02 | 15.88 | 4.50 |
| Rubengera | 3.07 | ** | 0.01 | 15.9 | 2.1 | 4.67 | *** | 0.02 | 15.60 | 4.25 |
| Ruganda | 2.85 | ** | 0.02 | 15.3 | 3.2 | 4.82 | *** | 0.03 | 15.03 | 6.02 |
| Rugobagoba | 3.10 | ** | 0.01 | 13.4 | 3.1 | 4.75 | *** | 0.02 | 13.08 | 5.35 |
| Ruhengeri | 3.00 | ** | 0.01 | 11.0 | 3.9 | 5.21 | *** | 0.03 | 10.71 | 7.55 |
| Rutsiro | 2.96 | ** | 0.02 | 14.1 | 3.4 | 4.89 | *** | 0.03 | 13.77 | 6.86 |
| Rwamagana | 2.89 | ** | 0.02 | 16.6 | 3.2 | 5.17 | *** | 0.03 | 16.32 | 5.44 |
| Rwankeri | 2.96 | ** | 0.01 | 11.6 | 3.2 | 4.89 | *** | 0.02 | 11.30 | 6.56 |
| Save | 3.07 | ** | 0.01 | 15.2 | 2.7 | 4.25 | *** | 0.02 | 14.92 | 4.43 |

Table 4-68: Projected trends of minimum temperature during SOND season for the period 2071 to 2100 under RCP 4.5w/m$^2$ and RCP 8.5w/m$^2$ over Rwanda

| | 2071-2100 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| Stations | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | 1.43 | | 0.01 | 17.9 | 1.3 | 5.57 | *** | 0.04 | 18.21 | 6.18 |
| Busogo | 1.32 | | 0.01 | 11.9 | 1.5 | 6.28 | *** | 0.04 | 12.25 | 8.93 |
| Butare | 1.61 | | 0.01 | 15.5 | 1.1 | 5.42 | *** | 0.03 | 15.82 | 6.17 |
| Byimana | 1.39 | | 0.01 | 13.7 | 1.2 | 5.96 | *** | 0.03 | 13.98 | 7.26 |
| Byumba | 0.96 | | 0.00 | 13.5 | 0.9 | 6.10 | *** | 0.03 | 13.82 | 6.49 |
| Cyinzuzi | 0.96 | | 0.01 | 15.4 | 1.0 | 6.10 | *** | 0.04 | 15.80 | 7.06 |
| Gabiro | 1.18 | | 0.01 | 16.6 | 1.5 | 5.60 | *** | 0.04 | 16.94 | 7.59 |
| Gatumba | 1.32 | | 0.01 | 13.3 | 1.8 | 6.28 | *** | 0.05 | 13.86 | 10.70 |
| Gikongoro | 1.43 | | 0.01 | 13.6 | 1.2 | 5.74 | *** | 0.03 | 13.96 | 6.95 |
| Gisanga | 1.39 | | 0.01 | 13.7 | 1.2 | 5.96 | *** | 0.03 | 13.98 | 7.26 |
| Gisenyi | 1.61 | | 0.01 | 16.9 | 2.0 | 5.39 | *** | 0.04 | 17.23 | 6.84 |
| Gitarama | 1.39 | | 0.01 | 13.7 | 1.2 | 5.96 | *** | 0.03 | 13.98 | 7.26 |
| Gitega | 0.96 | | 0.01 | 15.4 | 1.0 | 6.10 | *** | 0.04 | 15.80 | 7.06 |
| Kamembe | 1.61 | | 0.01 | 13.4 | 1.2 | 5.99 | *** | 0.03 | 13.71 | 6.17 |
| Kanombe | 0.96 | | 0.01 | 15.4 | 1.0 | 6.10 | *** | 0.04 | 15.80 | 7.06 |
| Kansi | 1.61 | | 0.01 | 14.9 | 1.2 | 5.42 | *** | 0.03 | 15.27 | 6.72 |
| Kawangire | 1.18 | | 0.01 | 17.0 | 1.2 | 5.60 | *** | 0.04 | 17.28 | 6.43 |
| Kibungo | 2.50 | * | 0.01 | 16.5 | 1.7 | 5.78 | *** | 0.04 | 16.86 | 6.63 |
| Masaka | 2.50 | * | 0.01 | 16.4 | 1.6 | 5.78 | *** | 0.04 | 16.74 | 6.36 |
| Muganza | 1.43 | | 0.01 | 14.3 | 1.2 | 5.74 | *** | 0.03 | 14.59 | 6.50 |
| Mushubi | 1.39 | | 0.01 | 11.8 | 1.3 | 6.03 | *** | 0.04 | 12.21 | 8.64 |
| Ntaruka | 0.86 | | 0.00 | 12.3 | 0.9 | 6.10 | *** | 0.03 | 12.56 | 7.09 |
| Ntendezi | 1.61 | | 0.01 | 12.5 | 1.5 | 5.99 | *** | 0.03 | 12.85 | 7.57 |
| Nyagatare | 0.93 | | 0.01 | 15.3 | 1.4 | 5.85 | *** | 0.05 | 15.69 | 8.75 |
| Nyamata | 1.39 | | 0.01 | 16.5 | 1.0 | 5.96 | *** | 0.03 | 16.80 | 6.17 |
| Rubengera | 1.39 | | 0.00 | 16.1 | 0.9 | 6.03 | *** | 0.03 | 16.47 | 5.86 |
| Ruganda | 0.96 | | 0.01 | 15.7 | 1.1 | 6.10 | *** | 0.04 | 16.10 | 7.60 |
| Rugobagoba | 1.39 | | 0.01 | 13.7 | 1.2 | 5.96 | *** | 0.03 | 13.98 | 7.26 |
| Ruhengeri | 1.25 | | 0.00 | 11.3 | 1.0 | 6.35 | *** | 0.04 | 11.64 | 9.42 |
| Rutsiro | 1.32 | | 0.01 | 14.5 | 1.5 | 6.28 | *** | 0.05 | 14.98 | 9.31 |
| Rwamagana | 1.18 | | 0.01 | 17.0 | 1.2 | 5.60 | *** | 0.04 | 17.28 | 6.43 |
| Rwankeri | 1.32 | | 0.01 | 11.9 | 1.5 | 6.28 | *** | 0.04 | 12.25 | 8.93 |
| Save | 1.61 | | 0.01 | 15.5 | 1.1 | 5.42 | *** | 0.03 | 15.82 | 6.17 |

#### 4.8.1.5 Annual minimum temperature

Analysis of the annual minimum temperature trend for the period between 2021 and 2100 under RCP 4.5 w/m$^2$ and RCP85w/m$^2$ are presented in Table 4-69 to Table 4-71.

Table 4-69 shows that projected mean annual minimum temperature for the period 2021-2050 ranges from +5.5% or +0.02$^O$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +2.6% or +0.01$^O$C per year (significant, $\alpha \leq 0.05$) in Nyamata under RCP 4.5 w/m$^2$ and ranged from 10.1% or +0.04$^O$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +5.2% or 0.03$^O$C per year (significant, $\alpha \leq 0.05$) in Rubengera, Masaka and Kamembe under RCP 8.5 w/m$^2$. Additionally, the projected annual minimum temperature is expected to increase during the period 2021-2050 under RCP 4.5 w/m$^2$ with higher increase over north-eastern, northern highland and Ngororero while under RCP 8.5 w/m$^2$ , areas of Rusizi, , Amayaga and south-eastern parts indicated lower increasing trend.

Table 4-70 shows that projected mean annual minimum temperature for the period 2041-2070 ranges from +5.0% or +0.02$^O$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +2.2% or +0.01$^O$C per year (significant, $\alpha \leq 0.05$) in Kamembe under RCP 4.5 w/m$^2$ and ranges from +9.45% or +0.04$^O$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +4.57% or 0.02$^O$C per year (significant, $\alpha \leq 0.05$) in Rubengera under RCP 8.5 w/m$^2$. The trend of projected minimum temperatures for the period 2041-2070 are also expected to increase across the country under both RCP 4.5 w/m$^2$ with more increase over Gatumba, Rutsiro, Ruhengeri, Nyagatare and Rwankeri while the areas of Gatumba and northern highland parts of the country show higher increase under RCP 8.5 w/m$^2$ Table 4-71 shows that projected mean annual minimum temperature for the period 2071-2100 ranges from +3.7% or +0.02$^O$C per year (significant, $\alpha \leq 0.05$) in Nyagatare to +1.7% or +0.01$^O$C per year (significant, $\alpha \leq 0.05$) in Rubengera under RCP 4.5 w/m$^2$ and ranged from +11.3% or +0.05$^O$C per year (significant, $\alpha \leq 0.05$) in Gatumba to +5.9% or 0.03$^O$C per year (significant, $\alpha \leq 0.05$) in Masaka under RCP 8.5 w/m$^2$. In addition, an increasing trend of projected annual minimum temperature for the period between 2071 and 2100 was observed with higher increase (6-11%) under RCP 8.5 w/m$^2$ compared to RCP 4.5 (2 to 4%).

In overall, the trend of projected annual minimum temperature under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$are increasing. However, larger changes in magnitude as percentage of mean are expected for the period 2021-2050 and decrease towards 2100 under RCP 4.5 w/m$^2$ whereas smaller changes in magnitude as percentage of mean are expected from 2041-2070 under RCP 8.5 w/m$^2$.

Table 4-69: Projected trends of annual minimum temperature for the period 2021 to 2050 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| Stations | 2021-2050 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | 3.50 | *** | 0.02 | 16.4 | 3.1 | 5.25 | *** | 0.03 | 16.1 | 5.6 |
| Busogo | 3.93 | *** | 0.02 | 10.5 | 4.4 | 5.74 | *** | 0.03 | 10.2 | 8.1 |
| Butare | 3.14 | ** | 0.01 | 14.1 | 2.8 | 5.42 | *** | 0.02 | 13.8 | 5.4 |
| Byimana | 3.25 | ** | 0.01 | 12.3 | 3.2 | 5.57 | *** | 0.03 | 12.0 | 6.5 |
| Byumba | 3.39 | *** | 0.01 | 12.4 | 3.1 | 5.46 | *** | 0.02 | 12.1 | 6.0 |
| Cyinzuzi | 3.39 | *** | 0.02 | 14.0 | 3.4 | 5.46 | *** | 0.03 | 13.7 | 6.6 |
| Gabiro | 3.43 | *** | 0.02 | 15.0 | 3.9 | 5.42 | *** | 0.04 | 14.6 | 7.2 |
| Gatumba | 3.93 | *** | 0.02 | 11.5 | 5.5 | 5.74 | *** | 0.04 | 11.0 | 10.1 |
| Gikongoro | 3.46 | *** | 0.01 | 12.3 | 3.4 | 5.57 | *** | 0.02 | 12.0 | 5.9 |
| Gisanga | 3.25 | ** | 0.01 | 12.3 | 3.2 | 5.57 | *** | 0.03 | 12.0 | 6.5 |
| Gisenyi | 3.21 | ** | 0.02 | 15.8 | 3.8 | 5.53 | *** | 0.03 | 15.4 | 5.3 |
| Gitarama | 3.25 | ** | 0.01 | 12.3 | 3.2 | 5.57 | *** | 0.03 | 12.0 | 6.5 |
| Gitega | 3.39 | *** | 0.02 | 14.0 | 3.4 | 5.46 | *** | 0.03 | 13.7 | 6.6 |
| Kamembe | 3.68 | *** | 0.01 | 12.4 | 2.9 | 5.46 | *** | 0.02 | 12.1 | 5.2 |
| Kanombe | 3.39 | *** | 0.02 | 14.0 | 3.4 | 5.46 | *** | 0.03 | 13.7 | 6.6 |
| Kansi | 3.14 | ** | 0.01 | 13.5 | 3.0 | 5.42 | *** | 0.03 | 13.2 | 5.9 |
| Kawangire | 3.43 | *** | 0.02 | 15.6 | 3.3 | 5.42 | *** | 0.03 | 15.3 | 6.0 |
| Kibungo | 3.71 | *** | 0.02 | 15.2 | 3.0 | 5.92 | *** | 0.03 | 14.9 | 5.4 |
| Masaka | 3.71 | *** | 0.01 | 15.2 | 2.9 | 5.92 | *** | 0.03 | 14.9 | 5.2 |
| Muganza | 3.46 | *** | 0.01 | 13.0 | 3.2 | 5.57 | *** | 0.02 | 12.7 | 5.4 |
| Mushubi | 3.53 | *** | 0.01 | 10.5 | 4.2 | 5.64 | *** | 0.03 | 10.1 | 8.1 |
| Ntaruka | 3.53 | *** | 0.01 | 11.2 | 3.5 | 5.46 | *** | 0.02 | 10.9 | 6.6 |
| Ntendezi | 3.68 | *** | 0.01 | 11.3 | 3.6 | 5.46 | *** | 0.02 | 11.0 | 6.6 |
| Nyagatare | 3.39 | *** | 0.02 | 13.7 | 4.8 | 5.28 | *** | 0.04 | 13.3 | 8.7 |
| Nyamata | 3.25 | ** | 0.01 | 15.1 | 2.6 | 5.57 | *** | 0.03 | 14.8 | 5.4 |
| Rubengera | 3.53 | *** | 0.01 | 14.9 | 2.7 | 5.64 | *** | 0.03 | 14.6 | 5.2 |
| Ruganda | 3.39 | *** | 0.02 | 14.2 | 3.7 | 5.46 | *** | 0.03 | 13.8 | 7.1 |
| Rugobagoba | 3.25 | ** | 0.01 | 12.3 | 3.2 | 5.57 | *** | 0.03 | 12.0 | 6.5 |
| Ruhengeri | 3.96 | *** | 0.02 | 9.9 | 4.6 | 5.78 | *** | 0.03 | 9.6 | 8.6 |
| Rutsiro | 3.93 | *** | 0.02 | 12.8 | 4.7 | 5.74 | *** | 0.03 | 12.3 | 8.5 |
| Rwamagana | 3.43 | *** | 0.02 | 15.6 | 3.3 | 5.42 | *** | 0.03 | 15.3 | 6.0 |
| Rwankeri | 3.93 | *** | 0.02 | 10.5 | 4.4 | 5.74 | *** | 0.03 | 10.2 | 8.1 |
| Save | 3.14 | ** | 0.01 | 14.1 | 2.8 | 5.42 | *** | 0.02 | 13.8 | 5.4 |

Table 4-70: Projected trends of annual minimum temperature for the period 2041 to 2070 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| Stations | 2041-2070 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | 2.71 | ** | 0.02 | 16.8 | 3.2 | 4.71 | *** | 0.03 | 16.69 | 5.38 |
| Busogo | 2.78 | ** | 0.01 | 10.9 | 4.0 | 5.67 | *** | 0.03 | 10.746 | 7.67 |
| Butare | 2.18 | * | 0.01 | 14.5 | 2.4 | 5.00 | *** | 0.02 | 14.347 | 5.02 |
| Byimana | 2.43 | * | 0.01 | 12.7 | 2.9 | 4.82 | *** | 0.02 | 12.558 | 5.69 |
| Byumba | 2.21 | * | 0.01 | 12.7 | 2.7 | 5.00 | *** | 0.02 | 12.625 | 5.19 |
| Cyinzuzi | 2.21 | * | 0.01 | 14.4 | 3.0 | 5.00 | *** | 0.03 | 14.309 | 5.69 |
| Gabiro | 2.60 | ** | 0.02 | 15.5 | 3.8 | 4.71 | *** | 0.03 | 15.368 | 6.13 |
| Gatumba | 2.78 | ** | 0.02 | 12.0 | 5.0 | 5.67 | *** | 0.04 | 11.82 | 9.45 |
| Gikongoro | 2.36 | * | 0.01 | 12.6 | 2.6 | 5.03 | *** | 0.02 | 12.53 | 5.54 |
| Gisanga | 2.43 | * | 0.01 | 12.7 | 2.9 | 4.82 | *** | 0.02 | 12.558 | 5.69 |
| Gisenyi | 2.50 | * | 0.02 | 16.2 | 2.8 | 5.39 | *** | 0.03 | 16.064 | 6.10 |
| Gitarama | 2.43 | * | 0.01 | 12.7 | 2.9 | 4.82 | *** | 0.02 | 12.558 | 5.69 |
| Gitega | 2.21 | * | 0.01 | 14.4 | 3.0 | 5.00 | *** | 0.027 | 14.309 | 5.69 |
| Kamembe | 2.71 | ** | 0.01 | 12.6 | 2.2 | 5.25 | *** | 0.02 | 12.527 | 5.08 |
| Kanombe | 2.21 | * | 0.01 | 14.4 | 3.0 | 5.00 | *** | 0.027 | 14.309 | 5.69 |
| Kansi | 2.18 | * | 0.01 | 13.8 | 2.6 | 5.00 | *** | 0.025 | 13.716 | 5.52 |
| Kawangire | 2.60 | ** | 0.02 | 16.0 | 3.2 | 4.71 | *** | 0.03 | 15.921 | 5.11 |
| Kibungo | 2.82 | ** | 0.01 | 15.6 | 2.7 | 5.17 | *** | 0.03 | 15.474 | 5.09 |
| Masaka | 2.82 | ** | 0.01 | 15.6 | 2.6 | 5.17 | *** | 0.025 | 15.426 | 4.87 |
| Muganza | 2.36 | * | 0.01 | 13.3 | 2.4 | 5.03 | *** | 0.02 | 13.196 | 5.14 |
| Mushubi | 2.39 | * | 0.01 | 10.8 | 3.4 | 5.32 | *** | 0.03 | 10.677 | 7.05 |
| Ntaruka | 2.28 | * | 0.01 | 11.5 | 3.1 | 5.14 | *** | 0.02 | 11.432 | 5.91 |
| Ntendezi | 2.71 | ** | 0.01 | 11.6 | 2.7 | 5.25 | *** | 0.02 | 11.491 | 6.37 |
| Nyagatare | 2.53 | * | 0.02 | 14.2 | 4.4 | 4.39 | *** | 0.04 | 14.07 | 7.47 |
| Nyamata | 2.43 | * | 0.01 | 15.5 | 2.4 | 4.82 | *** | 0.02 | 15.348 | 4.75 |
| Rubengera | 2.39 | * | 0.01 | 15.2 | 2.3 | 5.32 | *** | 0.02 | 15.065 | 4.57 |
| Ruganda | 2.21 | * | 0.02 | 14.6 | 3.2 | 5.00 | *** | 0.03 | 14.471 | 6.18 |
| Rugobagoba | 2.43 | * | 0.01 | 12.7 | 2.9 | 4.82 | *** | 0.02 | 12.558 | 5.69 |
| Ruhengeri | 2.71 | ** | 0.01 | 10.3 | 4.1 | 5.67 | *** | 0.03 | 10.199 | 8.53 |
| Rutsiro | 2.78 | ** | 0.02 | 13.2 | 4.3 | 5.67 | *** | 0.04 | 13.064 | 8.04 |
| Rwamagana | 2.60 | ** | 0.02 | 16.0 | 3.2 | 4.71 | *** | 0.03 | 15.921 | 5.11 |
| Rwankeri | 2.78 | ** | 0.01 | 10.9 | 4.0 | 5.67 | *** | 0.03 | 10.746 | 7.67 |
| Save | 2.18 | * | 0.01 | 14.5 | 2.4 | 5.00 | *** | 0.024 | 14.347 | 5.02 |

Table 4-71: Projected trends of annual minimum temperature for the period 2071 to 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| Stations | 2071-2100 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 | | | | | RCP 8.5 | | | | |
| | Test Z | α level | Q | mean | %Δ | Test Z | α level | Q | mean | %Δ |
| Bukora | 2.50 | * | 0.01 | 17.2 | 2.3 | 5.17 | *** | 0.04 | 17.8 | 6.1 |
| Busogo | 2.43 | * | 0.01 | 11.2 | 2.5 | 5.42 | *** | 0.04 | 11.7 | 9.4 |
| Butare | 2.64 | ** | 0.01 | 14.7 | 2.0 | 5.17 | *** | 0.03 | 15.3 | 6.4 |
| Byimana | 2.64 | ** | 0.01 | 13.0 | 2.4 | 5.03 | *** | 0.03 | 13.5 | 7.4 |
| Byumba | 2.39 | * | 0.01 | 13.0 | 2.1 | 5.28 | *** | 0.03 | 13.5 | 6.6 |
| Cyinzuzi | 2.39 | * | 0.01 | 14.8 | 2.3 | 5.28 | *** | 0.04 | 15.4 | 7.2 |
| Gabiro | 2.53 | * | 0.02 | 15.9 | 3.0 | 5.10 | *** | 0.04 | 16.5 | 7.5 |
| Gatumba | 2.43 | * | 0.01 | 12.4 | 3.1 | 5.42 | *** | 0.05 | 13.2 | 11.3 |
| Gikongoro | 2.28 | * | 0.01 | 12.9 | 2.0 | 5.21 | *** | 0.03 | 13.4 | 7.2 |
| Gisanga | 2.64 | ** | 0.01 | 13.0 | 2.4 | 5.03 | *** | 0.03 | 13.5 | 7.4 |
| Gisenyi | 1.78 | + | 0.01 | 16.6 | 1.9 | 5.53 | *** | 0.04 | 17.2 | 7.3 |
| Gitarama | 2.64 | ** | 0.01 | 13.0 | 2.4 | 5.03 | *** | 0.03 | 13.5 | 7.4 |
| Gitega | 2.39 | * | 0.01 | 14.8 | 2.3 | 5.28 | *** | 0.04 | 15.4 | 7.2 |
| Kamembe | 2.11 | * | 0.01 | 12.9 | 1.7 | 5.28 | *** | 0.03 | 13.3 | 6.2 |
| Kanombe | 2.39 | * | 0.01 | 14.8 | 2.3 | 5.28 | *** | 0.04 | 15.4 | 7.2 |
| Kansi | 2.64 | ** | 0.01 | 14.1 | 2.1 | 5.17 | *** | 0.03 | 14.7 | 7.0 |
| Kawangire | 2.53 | * | 0.01 | 16.4 | 2.5 | 5.10 | *** | 0.04 | 16.9 | 6.4 |
| Kibungo | 2.46 | * | 0.01 | 15.9 | 2.3 | 5.32 | *** | 0.03 | 16.5 | 6.2 |
| Masaka | 2.46 | * | 0.01 | 15.8 | 2.2 | 5.32 | *** | 0.03 | 16.4 | 5.9 |
| Muganza | 2.28 | * | 0.01 | 13.6 | 1.8 | 5.21 | *** | 0.03 | 14.1 | 6.7 |
| Mushubi | 2.43 | * | 0.01 | 11.1 | 2.6 | 5.17 | *** | 0.04 | 11.7 | 9.1 |
| Ntaruka | 2.46 | * | 0.01 | 11.8 | 2.1 | 5.46 | *** | 0.03 | 12.3 | 7.2 |
| Ntendezi | 2.11 | * | 0.01 | 11.9 | 2.1 | 5.28 | *** | 0.03 | 12.4 | 7.7 |
| Nyagatare | 2.71 | ** | 0.02 | 14.7 | 3.7 | 5.14 | *** | 0.05 | 15.3 | 8.9 |
| Nyamata | 2.64 | ** | 0.01 | 15.8 | 2.0 | 5.03 | *** | 0.03 | 16.3 | 6.3 |
| Rubengera | 2.43 | * | 0.01 | 15.4 | 1.7 | 5.17 | *** | 0.03 | 16.0 | 6.1 |
| Ruganda | 2.39 | * | 0.01 | 15.0 | 2.5 | 5.28 | *** | 0.04 | 15.6 | 7.8 |
| Rugobagoba | 2.64 | ** | 0.01 | 13.0 | 2.4 | 5.03 | *** | 0.03 | 13.5 | 7.4 |
| Ruhengeri | 2.07 | * | 0.01 | 10.6 | 2.0 | 5.64 | *** | 0.04 | 11.2 | 9.9 |
| Rutsiro | 2.43 | * | 0.01 | 13.6 | 2.6 | 5.42 | *** | 0.05 | 14.3 | 9.8 |
| Rwamagana | 2.53 | * | 0.01 | 16.4 | 2.5 | 5.10 | *** | 0.04 | 16.9 | 6.4 |
| Rwankeri | 2.43 | * | 0.01 | 11.2 | 2.5 | 5.42 | *** | 0.04 | 11.7 | 9.4 |
| Save | 2.64 | ** | 0.01 | 14.7 | 2.0 | 5.17 | *** | 0.03 | 15.3 | 6.4 |

### 4.8.2 *Temporal analysis of projected number cold nights (TN10p)*

This section presents the analysis of the 10th and 90th Percentile of the minimum temperature trends which show the trends of cold nights and cold days respectively in Table 4-72 to Table 4-73.

Table 4-72 shows that projected annual number of cold nights for the period 2021-2050 ranges from -75.9% or -0.25 days per year (significant, $\alpha \leq 0.05$) in Byimana to -143.94% or -0.48 days per year (significant, $\alpha \leq 0.05$) in Gisenyi under RCP 4.5 w/m$^2$ and ranged from -75.7% or -0.25 days per year (significant, $\alpha \leq 0.05$) in Nyamata to -207.29% or -0.68 days per year (significant, $\alpha \leq 0.05$) in Nyagatare under RCP 8.5 w/m$^2$

Similarly, Table 4-73 show that projected annual number of cold nights for the period 2041-2070 ranged from -78.45% or -0.2 days per year (significant, $\alpha \leq 0.05$) in Kamembe to -128.94% or -0.2 days per year (significant, $\alpha \leq 0.05$) in Butare under RCP 4.5 w/m$^2$ and ranged from -118.79% or -0.18 days per year (significant, $\alpha \leq 0.05$) in Nyamata to -223.46% or -0.13 days per year (significant, $\alpha \leq 0.05$) in Rugunga under RCP 8.5 w/m$^2$

Table 4-73 show that projected annual number of cold nights for the period 2071-210 ranged from +0.0% or +0.001 days per year (not significant, $\alpha > 0.05$) in Byimana to -90.46% or -0.05 days per year (not significant, $\alpha > 0.05$) in Nyagatare under RCP 4.5 w/m$^2$. However, no change was detected under RCP 8.5 w/m$^2$

In overall, the trend of number of cold nights is expected to decrease in most parts of Rwanda with the changes in magnitude as percentage of mean of up to -60% under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ for the period 2021 to 2100.

Table 4-72: Projected trends of number of cold nights (TN10p) for the period 2021 to 2050 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| Stations | 2021-2050 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | Mean | %Δ | Test Z | α level | Q | Mean | %Δ |
| Bukora | -3.23 | ** | -0.32 | 9.83 | -96.61 | -5.31 | *** | -0.58 | 9.90 | -176.53 |
| Busogo | -3.37 | *** | -0.30 | 9.91 | -90.79 | -5.57 | *** | -0.56 | 10.02 | -169.07 |
| Butare | -3.42 | *** | -0.27 | 9.83 | -83.20 | -5.59 | *** | -0.55 | 9.87 | -167.17 |
| Byimana | -2.84 | ** | -0.25 | 9.98 | -75.80 | -5.39 | *** | -0.57 | 9.79 | -175.44 |
| Byumba | -3.43 | *** | -0.31 | 9.91 | -94.82 | -5.70 | *** | -0.59 | 9.87 | -179.61 |
| Cyinzuzi | -3.43 | *** | -0.31 | 9.91 | -94.82 | -5.52 | *** | -0.50 | 9.78 | -153.32 |
| Gabiro | -3.20 | ** | -0.33 | 10.00 | -98.18 | -5.36 | *** | -0.68 | 9.79 | -207.29 |
| Gatumba | -3.37 | *** | -0.30 | 9.91 | -90.79 | -5.75 | *** | -0.57 | 9.99 | -170.17 |
| Gikongoro | -3.45 | *** | -0.26 | 9.89 | -80.08 | -5.68 | *** | -0.59 | 9.86 | -178.41 |
| Gisanga | -2.84 | ** | -0.25 | 9.98 | -75.80 | -5.39 | *** | -0.57 | 9.79 | -175.44 |
| Gisenyi | -3.91 | *** | -0.48 | 9.90 | -143.94 | -5.57 | *** | -0.56 | 10.02 | -169.07 |
| Gitarama | -2.84 | ** | -0.25 | 9.98 | -75.80 | -5.39 | *** | -0.57 | 9.79 | -175.44 |
| Gitega | -3.43 | *** | -0.31 | 9.91 | -94.82 | -5.57 | *** | -0.56 | 10.02 | -169.07 |
| Kamembe | -4.12 | *** | -0.31 | 9.99 | -94.35 | -5.75 | *** | -0.57 | 9.99 | -170.17 |
| Kanombe | -3.43 | *** | -0.31 | 9.91 | -94.82 | -5.57 | *** | -0.56 | 10.02 | -169.07 |
| Kansi | -3.42 | *** | -0.27 | 9.83 | -83.20 | -5.59 | *** | -0.55 | 9.87 | -167.17 |
| Kawangire | -3.20 | ** | -0.33 | 10.00 | -98.18 | -5.31 | *** | -0.58 | 9.90 | -176.53 |
| Kibungo | -4.18 | *** | -0.37 | 9.89 | -112.06 | -5.70 | *** | -0.59 | 9.87 | -179.61 |
| Masaka | -4.18 | *** | -0.37 | 9.89 | -112.06 | -5.70 | *** | -0.59 | 9.87 | -179.61 |
| Muganza | -3.45 | *** | -0.26 | 9.89 | -80.08 | -5.68 | *** | -0.59 | 9.86 | -178.41 |
| Mushubi | -3.77 | *** | -0.27 | 9.95 | -82.41 | -5.57 | *** | -0.57 | 9.93 | -171.20 |
| Ntaruka | -2.90 | ** | -0.29 | 9.90 | -87.72 | -5.36 | *** | -0.68 | 9.79 | -207.29 |
| Ntendezi | -4.12 | *** | -0.31 | 9.99 | -94.35 | -5.59 | *** | -0.55 | 9.89 | -166.89 |
| Nyagatare | -3.29 | ** | -0.35 | 10.01 | -104.90 | -5.36 | *** | -0.68 | 9.79 | -207.29 |
| Nyamata | -2.84 | ** | -0.25 | 9.98 | -75.80 | -2.84 | ** | -0.25 | 9.98 | -75.80 |
| Rubengera | -3.77 | *** | -0.27 | 9.95 | -82.41 | -5.57 | *** | -0.57 | 9.93 | -171.20 |
| Rugunga | -3.43 | *** | -0.31 | 9.91 | -94.82 | -5.59 | *** | -0.60 | 9.94 | -181.15 |
| Ruhengeri | -3.29 | ** | -0.30 | 10.03 | -89.70 | -5.59 | *** | -0.60 | 9.94 | -181.15 |
| Rutsiro | -3.37 | *** | -0.30 | 9.91 | -90.79 | -5.52 | *** | -0.50 | 9.78 | -153.32 |
| Rwamagana | -3.20 | ** | -0.33 | 10.00 | -98.18 | -4.91 | *** | -0.61 | 9.99 | -183.46 |
| Rwesero | -3.37 | *** | -0.30 | 9.91 | -90.79 | -5.52 | *** | -0.50 | 9.78 | -153.32 |
| Zaza | -3.42 | *** | -0.27 | 9.83 | -83.20 | -5.59 | *** | -0.55 | 9.87 | -167.17 |

Table 4-73: Projected trends of number of cold nights (TN10p) for the period 2041 to 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

| Stations | 2041-2070 | | | | | | | | | | 2071-2100 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | | RCP 4.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | Mean | %Δ | Test Z | α level | Q | Mean | %Δ | Test Z | α level | Q | Mean | %Δ |
| Bukora | -2.97 | ** | -0.18 | 4.33 | -126.92 | -3.76 | *** | -0.11 | 1.78 | -177.41 | -0.78 | | -0.01 | 1.48 | -28.90 |
| Busogo | -3.22 | ** | -0.18 | 5.02 | -107.50 | -4.51 | *** | -0.13 | 1.84 | -203.44 | -1.67 | + | -0.04 | 2.62 | -46.89 |
| Butare | -3.79 | *** | -0.20 | 4.65 | -128.94 | -4.46 | *** | -0.14 | 2.29 | -183.41 | -0.93 | | -0.02 | 1.64 | -36.55 |
| Byimana | -3.95 | *** | -0.18 | 4.63 | -118.79 | -3.78 | *** | -0.12 | 2.18 | -163.67 | -0.61 | | 0.00 | 1.63 | 0.00 |
| Byumba | -2.76 | ** | -0.13 | 4.30 | -89.77 | -3.51 | *** | -0.12 | 2.34 | -156.92 | -1.59 | | -0.03 | 1.70 | -58.82 |
| Cyinzuzi | -2.76 | ** | -0.13 | 4.30 | -89.77 | -4.92 | *** | -0.16 | 2.60 | -180.06 | -1.59 | | -0.03 | 1.70 | -58.82 |
| Gabiro | -3.06 | ** | -0.18 | 4.24 | -123.82 | -3.99 | *** | -0.08 | 1.45 | -165.90 | -1.18 | | -0.02 | 1.47 | -45.00 |
| Gatumba | -3.22 | ** | -0.18 | 5.02 | -107.50 | -4.06 | *** | -0.16 | 2.40 | -194.44 | -1.67 | + | -0.04 | 2.62 | -46.89 |
| Gikongoro | -3.43 | *** | -0.18 | 4.85 | -113.48 | -3.76 | *** | -0.12 | 2.34 | -148.66 | -0.76 | | -0.01 | 1.79 | -13.76 |
| Gisanga | -3.95 | *** | -0.18 | 4.63 | -118.79 | -3.78 | *** | -0.12 | 2.18 | -163.67 | -0.61 | | 0.00 | 1.63 | 0.00 |
| Gisenyi | -2.63 | ** | -0.13 | 3.78 | -103.69 | -4.51 | *** | -0.13 | 1.84 | -203.44 | -1.45 | | -0.04 | 1.72 | -66.92 |
| Gitarama | -3.95 | *** | -0.18 | 4.63 | -118.79 | -3.78 | *** | -0.12 | 2.18 | -163.67 | -0.61 | | 0.00 | 1.63 | 0.00 |
| Gitega | -2.76 | ** | -0.13 | 4.30 | -89.77 | -4.51 | *** | -0.13 | 1.84 | -203.44 | -1.59 | | -0.03 | 1.70 | -58.82 |
| Kamembe | -2.81 | ** | -0.13 | 4.92 | -78.45 | -4.06 | *** | -0.16 | 2.40 | -194.44 | -2.14 | * | -0.05 | 2.44 | -61.35 |
| Kanombe | -2.76 | ** | -0.13 | 4.30 | -89.77 | -4.51 | *** | -0.13 | 1.84 | -203.44 | -1.59 | | -0.03 | 1.70 | -58.82 |
| Kansi | -3.79 | *** | -0.20 | 4.65 | -128.94 | -4.46 | *** | -0.14 | 2.29 | -183.41 | -0.93 | | -0.02 | 1.64 | -36.55 |
| Kawangire | -3.06 | ** | -0.18 | 4.24 | -123.82 | -3.76 | *** | -0.11 | 1.78 | -177.41 | -1.18 | | -0.02 | 1.47 | -45.00 |
| Kibungo | -2.61 | ** | -0.15 | 4.58 | -96.00 | -3.51 | *** | -0.12 | 2.34 | -156.92 | -1.85 | + | -0.04 | 2.03 | -64.48 |
| Masaka | -2.61 | ** | -0.15 | 4.58 | -96.00 | -3.51 | *** | -0.12 | 2.34 | -156.92 | -1.85 | + | -0.04 | 2.03 | -64.48 |
| Muganza | -3.43 | *** | -0.18 | 4.85 | -113.48 | -3.76 | *** | -0.12 | 2.34 | -148.66 | -0.76 | | -0.01 | 1.79 | -13.76 |
| Mushubi | -3.24 | ** | -0.17 | 5.07 | -100.20 | -3.94 | *** | -0.13 | 2.24 | -174.88 | -2.06 | * | -0.05 | 2.17 | -67.34 |
| Ntaruka | -2.79 | ** | -0.16 | 4.58 | -103.01 | -3.99 | *** | -0.08 | 1.45 | -165.90 | -1.73 | + | -0.05 | 1.89 | -86.15 |
| Ntendezi | -2.81 | ** | -0.13 | 4.92 | -78.45 | -3.39 | *** | -0.14 | 2.39 | -175.49 | -2.14 | * | -0.05 | 2.44 | -61.35 |
| Nyagatare | -2.88 | ** | -0.14 | 4.07 | -104.34 | -3.99 | *** | -0.08 | 1.45 | -165.90 | -1.60 | | -0.05 | 1.57 | -90.48 |
| Nyamata | -3.95 | *** | -0.18 | 4.63 | -118.79 | -3.95 | *** | -0.18 | 4.63 | -118.79 | -0.61 | | 0.00 | 1.63 | 0.00 |
| Rubengera | -3.24 | ** | -0.17 | 5.07 | -100.20 | -3.94 | *** | -0.13 | 2.24 | -174.88 | -2.06 | * | -0.05 | 2.17 | -67.34 |
| Rugunga | -2.76 | ** | -0.13 | 4.30 | -89.77 | -4.55 | *** | -0.13 | 1.79 | -223.46 | -1.59 | | -0.03 | 1.70 | -58.82 |
| Ruhengeri | -1.86 | + | -0.13 | 4.89 | -78.93 | -4.55 | *** | -0.13 | 1.79 | -223.46 | -1.38 | | -0.03 | 2.43 | -41.08 |
| Rutsiro | -3.22 | ** | -0.18 | 5.02 | -107.50 | -4.92 | *** | -0.16 | 2.60 | -180.06 | -1.67 | + | -0.04 | 2.62 | -46.89 |
| Rwamagana | -3.06 | ** | -0.18 | 4.24 | -123.82 | -4.10 | *** | -0.10 | 1.45 | -206.90 | -1.18 | | -0.02 | 1.47 | -45.00 |
| Rwesero | -3.22 | ** | -0.18 | 5.02 | -107.50 | -4.92 | *** | -0.16 | 2.60 | -180.06 | -1.67 | + | -0.04 | 2.62 | -46.89 |
| Zaza | -3.79 | *** | -0.20 | 4.65 | -128.94 | -4.46 | *** | -0.14 | 2.29 | -183.41 | -0.93 | | -0.02 | 1.64 | -36.55 |

### 4.8.3 *Temporal analysis of projected number of warm nights (TN90p)*

Analysis of the trend of projected number of warm nights (TN90p) during the 30-year period between 2021 and 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ are presented in Table 4-74 to Table 4-76.

Table 4-74 shows that Projected annual number of warm nights for the period 2021-2050 ranged from +153.12% or +0.51 days per year (significant, $\alpha \leq 0.05$) in Gisenyi to +95.21% or +0.32 days per year (significant, $\alpha \leq 0.05$) in Butare under RCP 4.5 w/m$^2$ and ranged from +235.41% or +0.78 days per year (significant, $\alpha \leq 0.05$) in Rutsiro to +110.0% or +0.36 days per year (significant, $\alpha \leq 0.05$) in Nyamata under RCP 8.5 w/m$^2$. The trend of projected number of warm nights shows expected increase during the period 2021-2050 under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$.

Table 4-75 show that projected annual number of warm nights for the period 2041-2070 ranged from +93.35% or +0.76 days per year (significant, $\alpha \leq 0.05$) in Nyagatare to 60.98% or +0.46 days per year (significant, $\alpha \leq 0.05$) in Gikongoro under RCP 4.5 w/m$^2$ and ranged from +153.1% or +1.98 days per year (significant, $\alpha \leq 0.05$) in Kawangire to +67.65% or +0.51 days per year (significant, $\alpha \leq 0.05$) in Nyamata under RCP 8.5 w/m$^2$. The trend of projected number of warm nights showed an increase during the period 2041-2070 under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$.

Table 4-76 show that projected annual number of warm nights for the period 2071-210 ranged from +90.11% or +1.11 days per year (significant, $\alpha \leq 0.05$) in Gikongoro to +40.67% or +0.51 days per year (significant, $\alpha \leq 0.05$) in Nyamata under RCP 4.5 w/m$^2$ and ranged from +48.91% or +0.61 days per year (significant, $\alpha \leq 0.05$) in Nyamata to +9.91% or +0.28 days per year (not significant, $\alpha > 0.05$) in Ruhengeri under RCP 8.5 w/m$^2$. The trend of projected number of warm nights showed an increase during the period 2071-2100 under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$.

Overall, the trend of projected number of warm nights is expected to increase for the period between 2021 and 2100 under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$. However, the changes in magnitude as a percentage of mean under RCP 4.5 w/m$^2$ indicate highest values in 2021-2050 decreasing towards 2100 whereas under RCP 8.5 w/m$^2$, lowest values are reported in 2021-2050 and increases towards 2100.

Table 4-74: Projected trends of number of warm nights (TN90p) for the period 2021-2050 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| Station | 2021-2050 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | Mean | %Δ | Test Z | α level | Q | Mean | %Δ |
| Bukora | 3.59 | *** | 0.42 | 9.89 | 127.44 | 4.75 | *** | 0.56 | 9.92 | 169.75 |
| Busogo | 3.50 | *** | 0.35 | 9.91 | 105.95 | 5.28 | *** | 0.70 | 9.88 | 213.92 |
| Butare | 2.59 | ** | 0.32 | 9.95 | 95.21 | 5.32 | *** | 0.66 | 10.03 | 196.99 |
| Byimana | 2.80 | ** | 0.36 | 9.89 | 110.00 | 5.30 | *** | 0.65 | 9.85 | 197.90 |
| Byumba | 3.48 | *** | 0.43 | 10.03 | 127.08 | 5.77 | *** | 0.69 | 10.00 | 205.84 |
| Cyinzuzi | 3.48 | *** | 0.43 | 10.03 | 127.08 | 5.82 | *** | 0.78 | 9.94 | 235.41 |
| Gabiro | 3.66 | *** | 0.41 | 9.89 | 125.63 | 4.86 | *** | 0.60 | 9.90 | 181.82 |
| Gatumba | 3.50 | *** | 0.35 | 9.91 | 105.95 | 5.52 | *** | 0.74 | 9.94 | 222.06 |
| Gikongoro | 3.04 | ** | 0.39 | 9.87 | 119.68 | 5.80 | *** | 0.67 | 9.86 | 204.36 |
| Gisanga | 2.80 | ** | 0.36 | 9.89 | 110.00 | 5.30 | *** | 0.65 | 9.85 | 197.90 |
| Gisenyi | 3.23 | ** | 0.51 | 9.95 | 153.12 | 5.28 | *** | 0.70 | 9.88 | 213.92 |
| Gitarama | 2.80 | ** | 0.36 | 9.89 | 110.00 | 5.30 | *** | 0.65 | 9.85 | 197.90 |
| Gitega | 3.48 | *** | 0.43 | 10.03 | 127.08 | 5.28 | *** | 0.70 | 9.88 | 213.92 |
| Kamembe | 3.23 | ** | 0.35 | 9.92 | 104.44 | 5.52 | *** | 0.74 | 9.94 | 222.06 |
| Kanombe | 3.48 | *** | 0.43 | 10.03 | 127.08 | 5.28 | *** | 0.70 | 9.88 | 213.92 |
| Kansi | 2.59 | ** | 0.32 | 9.95 | 95.21 | 5.32 | *** | 0.66 | 10.03 | 196.99 |
| Kawangire | 3.66 | *** | 0.41 | 9.89 | 125.63 | 4.75 | *** | 0.56 | 9.92 | 169.75 |
| Kibungo | 3.56 | *** | 0.46 | 10.01 | 137.01 | 5.77 | *** | 0.69 | 10.00 | 205.84 |
| Masaka | 3.56 | *** | 0.46 | 10.01 | 137.01 | 5.77 | *** | 0.69 | 10.00 | 205.84 |
| Muganza | 3.04 | ** | 0.39 | 9.87 | 119.68 | 5.80 | *** | 0.67 | 9.86 | 204.36 |
| Mushubi | 3.23 | ** | 0.37 | 9.85 | 113.56 | 5.78 | *** | 0.74 | 10.01 | 222.13 |
| Ntaruka | 3.68 | *** | 0.35 | 9.98 | 105.21 | 4.86 | *** | 0.60 | 9.90 | 181.82 |
| Ntendezi | 3.23 | ** | 0.35 | 9.92 | 104.44 | 5.75 | *** | 0.77 | 9.95 | 232.08 |
| Nyagatare | 3.55 | *** | 0.34 | 9.97 | 101.59 | 4.86 | *** | 0.60 | 9.90 | 181.82 |
| Nyamata | 2.80 | ** | 0.36 | 9.89 | 110.00 | 2.80 | ** | 0.36 | 9.89 | 110.00 |
| Rubengera | 3.23 | ** | 0.37 | 9.85 | 113.56 | 5.78 | *** | 0.74 | 10.01 | 222.13 |
| Rugunga | 3.48 | *** | 0.43 | 10.03 | 127.08 | 5.39 | *** | 0.75 | 9.97 | 225.75 |
| Ruhengeri | 4.05 | *** | 0.40 | 9.97 | 118.86 | 5.39 | *** | 0.75 | 9.97 | 225.75 |
| Rutsiro | 3.50 | *** | 0.35 | 9.91 | 105.95 | 5.82 | *** | 0.78 | 9.94 | 235.41 |
| Rwamagana | 3.66 | *** | 0.41 | 9.89 | 125.63 | 5.07 | *** | 0.58 | 9.88 | 177.45 |
| Rwesero | 3.50 | *** | 0.35 | 9.91 | 105.95 | 5.82 | *** | 0.78 | 9.94 | 235.41 |
| Zaza | 2.59 | ** | 0.32 | 9.95 | 95.21 | 5.32 | *** | 0.66 | 10.03 | 196.99 |

Table 4-75: Projected trend of number of warm nights (TN90p) for the period 2041-2070 under i) RCP 4.5 w/m$^2$ and ii) RCP 8.5 w/m$^2$ over Rwanda

| Station | 2041-2070 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | Mean | %Δ | Test Z | α level | Q | Mean | %Δ |
| Bukora | 2.59 | ** | 0.65 | 24.61 | 79.25 | 4.82 | *** | 1.98 | 38.70 | 153.10 |
| Busogo | 3.82 | *** | 0.61 | 24.14 | 76.35 | 5.07 | *** | 1.46 | 35.29 | 124.11 |
| Butare | 2.62 | ** | 0.50 | 22.32 | 67.21 | 5.53 | *** | 1.64 | 34.51 | 142.17 |
| Byimana | 2.66 | ** | 0.51 | 22.73 | 67.65 | 5.35 | *** | 1.65 | 35.03 | 141.51 |
| Byumba | 2.66 | ** | 0.55 | 23.75 | 68.98 | 5.41 | *** | 1.89 | 39.93 | 141.85 |
| Cyinzuzi | 2.66 | ** | 0.55 | 23.75 | 68.98 | 5.50 | *** | 1.47 | 35.76 | 122.91 |
| Gabiro | 2.84 | ** | 0.65 | 24.73 | 78.61 | 4.71 | *** | 1.76 | 37.67 | 140.08 |
| Gatumba | 3.82 | *** | 0.61 | 24.14 | 76.35 | 5.50 | *** | 1.59 | 34.50 | 137.98 |
| Gikongoro | 3.16 | ** | 0.46 | 22.41 | 60.98 | 5.55 | *** | 1.52 | 34.46 | 132.31 |
| Gisanga | 2.66 | ** | 0.51 | 22.73 | 67.65 | 5.35 | *** | 1.65 | 35.03 | 141.51 |
| Gisenyi | 2.82 | ** | 0.68 | 26.37 | 76.95 | 5.07 | *** | 1.46 | 35.29 | 124.11 |
| Gitarama | 2.66 | ** | 0.51 | 22.73 | 67.65 | 5.35 | *** | 1.65 | 35.03 | 141.51 |
| Gitega | 2.66 | ** | 0.55 | 23.75 | 68.98 | 5.07 | *** | 1.46 | 35.29 | 124.11 |
| Kamembe | 2.86 | ** | 0.55 | 22.58 | 72.48 | 5.50 | *** | 1.59 | 34.50 | 137.98 |
| Kanombe | 2.66 | ** | 0.55 | 23.75 | 68.98 | 5.07 | *** | 1.46 | 35.29 | 124.11 |
| Kansi | 2.62 | ** | 0.50 | 22.32 | 67.21 | 5.53 | *** | 1.64 | 34.51 | 142.17 |
| Kawangire | 2.84 | ** | 0.65 | 24.73 | 78.61 | 4.82 | *** | 1.98 | 38.70 | 153.10 |
| Kibungo | 3.00 | ** | 0.62 | 25.36 | 73.72 | 5.41 | *** | 1.89 | 39.93 | 141.85 |
| Masaka | 3.00 | ** | 0.62 | 25.36 | 73.72 | 5.41 | *** | 1.89 | 39.93 | 141.85 |
| Muganza | 3.16 | ** | 0.46 | 22.41 | 60.98 | 5.55 | *** | 1.52 | 34.46 | 132.31 |
| Mushubi | 2.78 | ** | 0.48 | 23.20 | 61.42 | 5.74 | *** | 1.53 | 35.33 | 130.19 |
| Ntaruka | 2.82 | ** | 0.56 | 23.45 | 72.23 | 4.71 | *** | 1.76 | 37.67 | 140.08 |
| Ntendezi | 2.86 | ** | 0.55 | 22.58 | 72.48 | 5.57 | *** | 1.77 | 36.59 | 144.85 |
| Nyagatare | 2.95 | ** | 0.76 | 24.33 | 93.35 | 4.71 | *** | 1.76 | 37.67 | 140.08 |
| Nyamata | 2.66 | ** | 0.51 | 22.73 | 67.65 | 2.66 | ** | 0.51 | 22.73 | 67.65 |
| Rubengera | 2.78 | ** | 0.48 | 23.20 | 61.42 | 5.74 | *** | 1.53 | 35.33 | 130.19 |
| Rugunga | 2.66 | ** | 0.55 | 23.75 | 68.98 | 5.28 | *** | 1.58 | 36.14 | 131.35 |
| Ruhengeri | 3.48 | *** | 0.63 | 24.20 | 78.01 | 5.28 | *** | 1.58 | 36.14 | 131.35 |
| Rutsiro | 3.82 | *** | 0.61 | 24.14 | 76.35 | 5.50 | *** | 1.47 | 35.76 | 122.91 |
| Rwamagana | 2.84 | ** | 0.65 | 24.73 | 78.61 | 4.66 | *** | 1.78 | 36.76 | 145.10 |
| Rwesero | 3.82 | *** | 0.61 | 24.14 | 76.35 | 5.50 | *** | 1.47 | 35.76 | 122.91 |
| Zaza | 2.62 | ** | 0.50 | 22.32 | 67.21 | 5.53 | *** | 1.64 | 34.51 | 142.17 |

Table 4-76: Projected trends of number of warm nights (TN90p) for the period 2071-2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda

| Station | 2071-2100 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RCP 4.5 w/m$^2$ | | | | | RCP 8.5 w/m$^2$ | | | | |
| | Test Z | α level | Q | Mean | %Δ | Test Z | α level | Q | Mean | %Δ |
| Bukora | 3.97 | *** | 0.75 | 40.24 | 53.88 | 2.53 | * | 0.65 | 85.83 | 21.96 |
| Busogo | 4.67 | *** | 1.15 | 37.29 | 89.57 | 2.52 | * | 0.37 | 79.07 | 13.65 |
| Butare | 4.69 | *** | 1.08 | 35.90 | 86.97 | 2.59 | ** | 0.47 | 78.81 | 17.26 |
| Byimana | 4.69 | *** | 1.07 | 36.45 | 85.11 | 2.72 | ** | 0.51 | 79.52 | 18.64 |
| Byumba | 4.58 | *** | 0.76 | 37.08 | 59.19 | 2.12 | * | 0.40 | 84.20 | 13.78 |
| Cyinzuzi | 4.86 | *** | 1.10 | 37.08 | 86.02 | 2.12 | * | 0.40 | 75.93 | 15.28 |
| Gabiro | 4.48 | *** | 0.92 | 39.58 | 67.67 | 2.46 | * | 0.60 | 84.07 | 20.70 |
| Gatumba | 4.48 | *** | 1.06 | 37.29 | 82.63 | 2.52 | * | 0.37 | 75.74 | 14.25 |
| Gikongoro | 4.75 | *** | 1.11 | 35.86 | 90.11 | 2.03 | * | 0.40 | 76.61 | 15.14 |
| Gisanga | 4.69 | *** | 1.07 | 36.45 | 85.11 | 2.72 | ** | 0.51 | 79.52 | 18.64 |
| Gisenyi | 4.67 | *** | 1.15 | 44.28 | 75.43 | 1.67 | + | 0.54 | 79.07 | 19.68 |
| Gitarama | 4.69 | *** | 1.07 | 36.45 | 85.11 | 2.72 | ** | 0.51 | 79.52 | 18.64 |
| Gitega | 4.67 | *** | 1.15 | 37.08 | 90.06 | 2.12 | * | 0.40 | 79.07 | 14.67 |
| Kamembe | 4.48 | *** | 1.06 | 36.53 | 84.33 | 2.08 | * | 0.42 | 75.74 | 16.05 |
| Kanombe | 4.67 | *** | 1.15 | 37.08 | 90.06 | 2.12 | * | 0.40 | 79.07 | 14.67 |
| Kansi | 4.69 | *** | 1.08 | 35.90 | 86.97 | 2.59 | ** | 0.47 | 78.81 | 17.26 |
| Kawangire | 3.97 | *** | 0.75 | 39.58 | 54.79 | 2.46 | * | 0.60 | 85.83 | 20.27 |
| Kibungo | 4.58 | *** | 0.76 | 42.37 | 51.80 | 2.18 | * | 0.60 | 84.20 | 20.53 |
| Masaka | 4.58 | *** | 0.76 | 42.37 | 51.80 | 2.18 | * | 0.60 | 84.20 | 20.53 |
| Muganza | 4.75 | *** | 1.11 | 35.86 | 90.11 | 2.03 | * | 0.40 | 76.61 | 15.14 |
| Mushubi | 4.69 | *** | 1.07 | 37.17 | 83.21 | 2.48 | * | 0.46 | 76.38 | 17.54 |
| Ntaruka | 4.48 | *** | 0.92 | 37.17 | 72.05 | 1.58 | | 0.35 | 84.07 | 12.07 |
| Ntendezi | 4.94 | *** | 1.00 | 36.53 | 79.09 | 2.08 | * | 0.42 | 80.10 | 15.18 |
| Nyagatare | 4.48 | *** | 0.92 | 37.86 | 70.75 | 2.42 | * | 0.60 | 84.07 | 20.80 |
| Nyamata | 2.72 | ** | 0.51 | 36.45 | 40.67 | 2.72 | ** | 0.51 | 36.45 | 40.67 |
| Rubengera | 4.69 | *** | 1.07 | 37.17 | 83.21 | 2.48 | * | 0.46 | 76.38 | 17.54 |
| Rugunga | 4.88 | *** | 1.06 | 37.08 | 82.90 | 2.12 | * | 0.40 | 80.45 | 14.42 |
| Ruhengeri | 4.88 | *** | 1.06 | 37.77 | 81.40 | 1.54 | | 0.28 | 80.45 | 9.91 |
| Rutsiro | 4.86 | *** | 1.10 | 37.29 | 85.55 | 2.52 | * | 0.37 | 75.93 | 14.21 |
| Rwamagana | 4.43 | *** | 0.95 | 39.58 | 69.38 | 2.46 | * | 0.60 | 82.17 | 21.18 |
| Rwesero | 4.86 | *** | 1.10 | 37.29 | 85.55 | 2.52 | * | 0.37 | 75.93 | 14.21 |
| Zaza | 4.69 | *** | 1.08 | 35.90 | 86.97 | 2.59 | ** | 0.47 | 78.81 | 17.26 |

### 4.8.4 *Spatial analysis of projected minimum temperature*

Spatial analysis of seasonal (JF, MAM, JJA and SOND) and annual minimum temperature for the period a) 2021-2050, b) 2041-2070 and c) 2071-2100 under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda is presented in the subsequent sections.

#### 4.8.4.1 January February (JF) Season

Analysis of the spatial distribution of JF minimum temperature for the period between 2021 and 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ are presented in Figure 4-27.

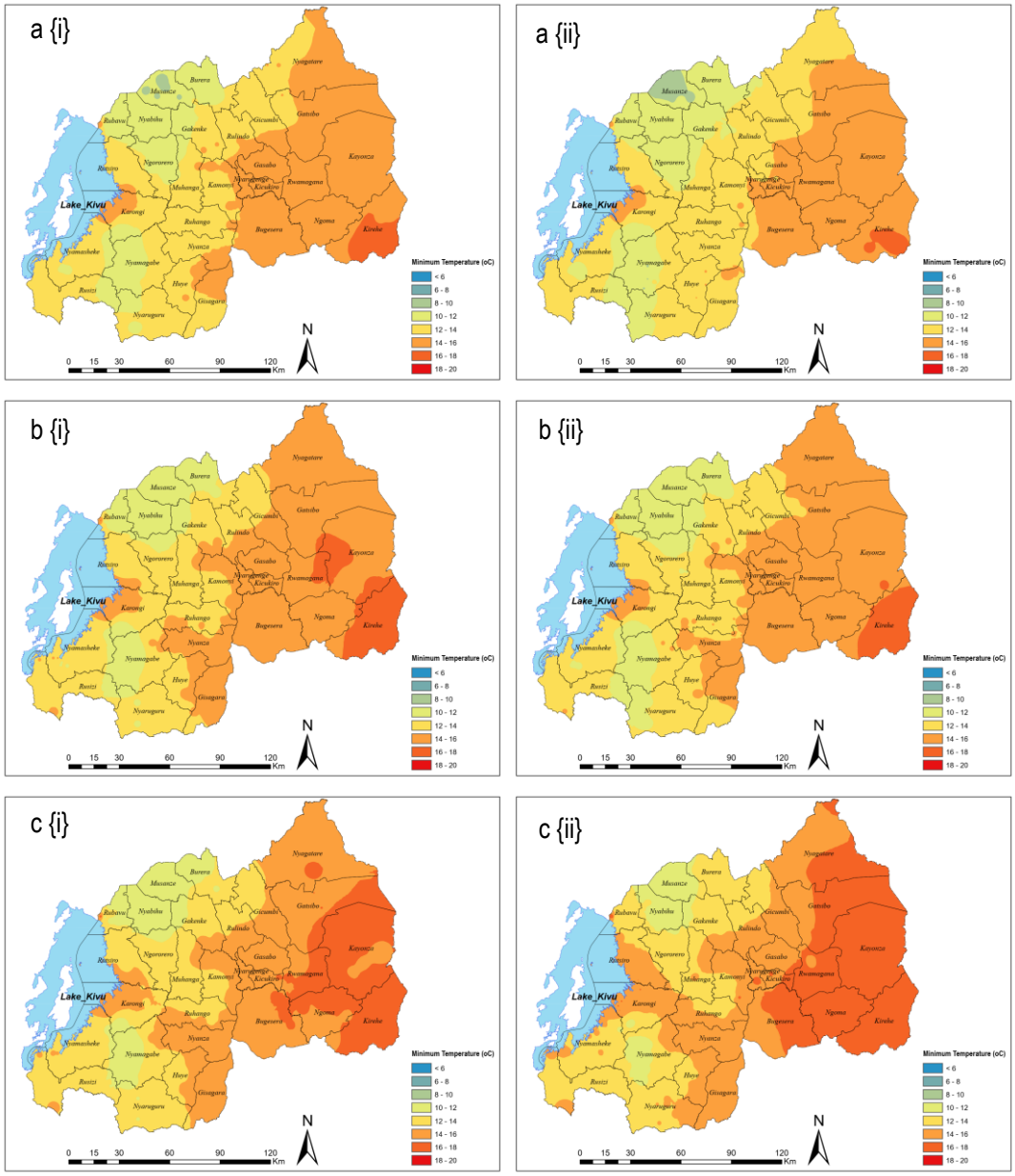


Figure 4-27: Maps of projected JF seasonal minimum temperature for the period a) 2021-2050, b) 2041-2070 and c) 2071-2100 under i) RCP 4.5 w/m$^2$ and ii) RCP 8.5 w/m$^2$ over Rwanda.

Figure 4-27 (a) shows that the Eastern parts of Rwanda are expected to experience higher minimum temperature during the JF season compared to the western parts of Rwanda for the period 2021-2050 under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ with RCP 4.5w/m$^2$ expected to have higher temperatures compared to RCP 8.5 w/m$^2$. During the RCP 4.5 w/m$^2$ scenario the region that is expected to record the highest minimum temperature is Kirehe district of between 18 to 20 degrees celsius, followed by the northeastern, southeastern, and part of Karongi that is expected to record between 16 to 18 degrees celsius. The central, parts of the Northeast, southeast, west, and southwest are expected to record between 12 to 14 degrees celsius and lastly the northern part and part of the southwest will record the least minimum temperature between 10 to 12 ºC. For the RCP 8.5 w/m$^2$ scenario Kirehe is still expected to record the highest minimum temperature of between 18 to 20 degrees Celsius. The north east, south east, part of Karongi district, pockets of Kamonyi, Muhanga,and Gakenke will record between 16 to18 degrees Celsius. Parts of Northeast, central, south, southwest, and west will record between 12-14 ºC. Lastly the northern region and southwest will record the least minimum temperature of between 10-12 degrees Celsius.

Similar patterns of higher minimum temperatures during the JF season over eastern parts of Rwanda compared to western parts of Rwanda are expected for the period 2041-2070 (Figure 4-27b) and for the period 2071-2100 with pockets of the northeast that will record between 18-20 ºC (Figure 4-27c) under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$

In overall, highest projected JF minimum temperatures are expected over eastern parts compared to western parts of Rwanda. In addition, projected minimum temperatures are expected to increase from 2021 to 2100 with more areas under RCP 8.5 w/m$^2$ to experience the highest minimum temperature towards 2100.

### 4.8.4.2 March-April-May (MAM) Season

Spatial distribution of MAM minimum temperature for the period between 2021 and 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ are presented in Figure 4-28.

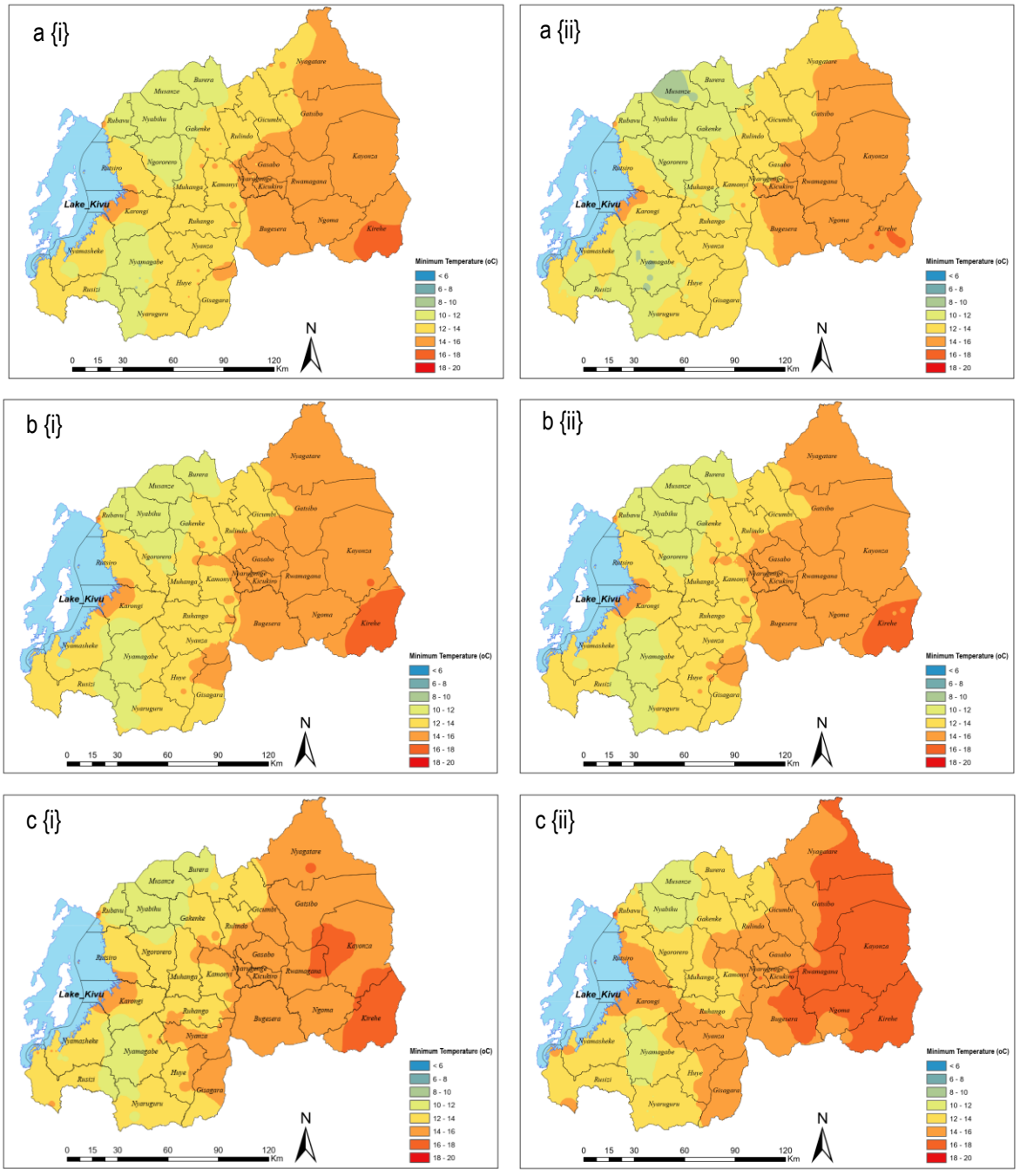


Figure 4-28: Projected MAM seasonal minimum temperature for the period a) 2021-2050, b) 2041-2070 and c) 2071-2100 under i) RCP 4.5w/m$^2$ and ii) RCP 8.5 w/m$^2$over Rwanda.

Figure 4-28 (a) shows that Eastern parts of Rwanda are expected to experience higher minimum temperature during the MAM season compared to western parts of Rwanda for the period 2021-2050 under both RCP 4.5 w/m$^2$ (Figure 4-28a (i)) and RCP 8.5 w/m$^2$ RCP 4.5 w/m$^2$ (Figure 4-28a (ii)). In addition, higher minimum temperatures are expected

under RCP 4.5 w/m$^2$ compared to RCP 8.5 w/m$^2$ for the period 2021-2050. Under RCP 4.5 w/m$^2$, the period 2021-2050 (Figure 4-28a (i)) and 2041-2070 (Figure 4-28b (ii)) the highest record of minimum temperature is expected in Kirehe district that will record between 18 to 20 ºC. The Northeast, southeast, Kigali City, pockets of Kamonyi, Ruhango, Muhanga, Gakenke. Karongi, Rulindo, and Rubavu will have a minimum temperature of around 14 to 16 ºC. The central, south, southwest and some parts of the west will record between 12 to 14 while the northwest, north and Nyamasheke will record the least minimum temperature of between 10 to 12 degrees Celsius.

There will be more pockets of increased minimum temperature in the period 2071-2100 in both RCP 4.5 w/m$^2$ (Figure 4-28c (i)) and RCP 8.5 w/m$^2$ (Figure 4-28c (ii)). Those regions are pockets of Rubavu, Nyamagabe, parts of Huye, Nyanza, Ruhango, Gisagara, Kamonyi, Muhanga, Gakenke, Rulindo and Kigali city which will record between 14 to 16. The central region, southwest, parts of west, parts of North and south will record between 12 and 14 and lastly the northern region and Nyamagabe district will record between 10 and 12 degrees Celsius. Similar patterns of higher MAM minimum temperatures during the MAM season over eastern parts of Rwanda compared to western parts of Rwanda are expected for the period 2041-2070 (Figure 4-28b) and for the period 2071-2100 (Figure 4-28c) under both RCP 4.5w/m$^2$ and RCP 8.5 w/m$^2$ even if the period 2070-2100 will have more high minimum temperature compared to the other periods.

In overall, highest projected MAM minimum temperatures are expected over eastern parts compared to western parts of Rwanda. In addition, projected minimum temperatures are expected to increase from 2021 to 2100 with more areas under RCP 8.5w/m$^2$ to experience the highest minimum temperature towards 2100.

### 4.8.4.3 June-July-August (JJA) Season

Analysis of the spatial distribution of JJA minimum temperature for the period between 2021 and 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ are presented in Figure 4-29.

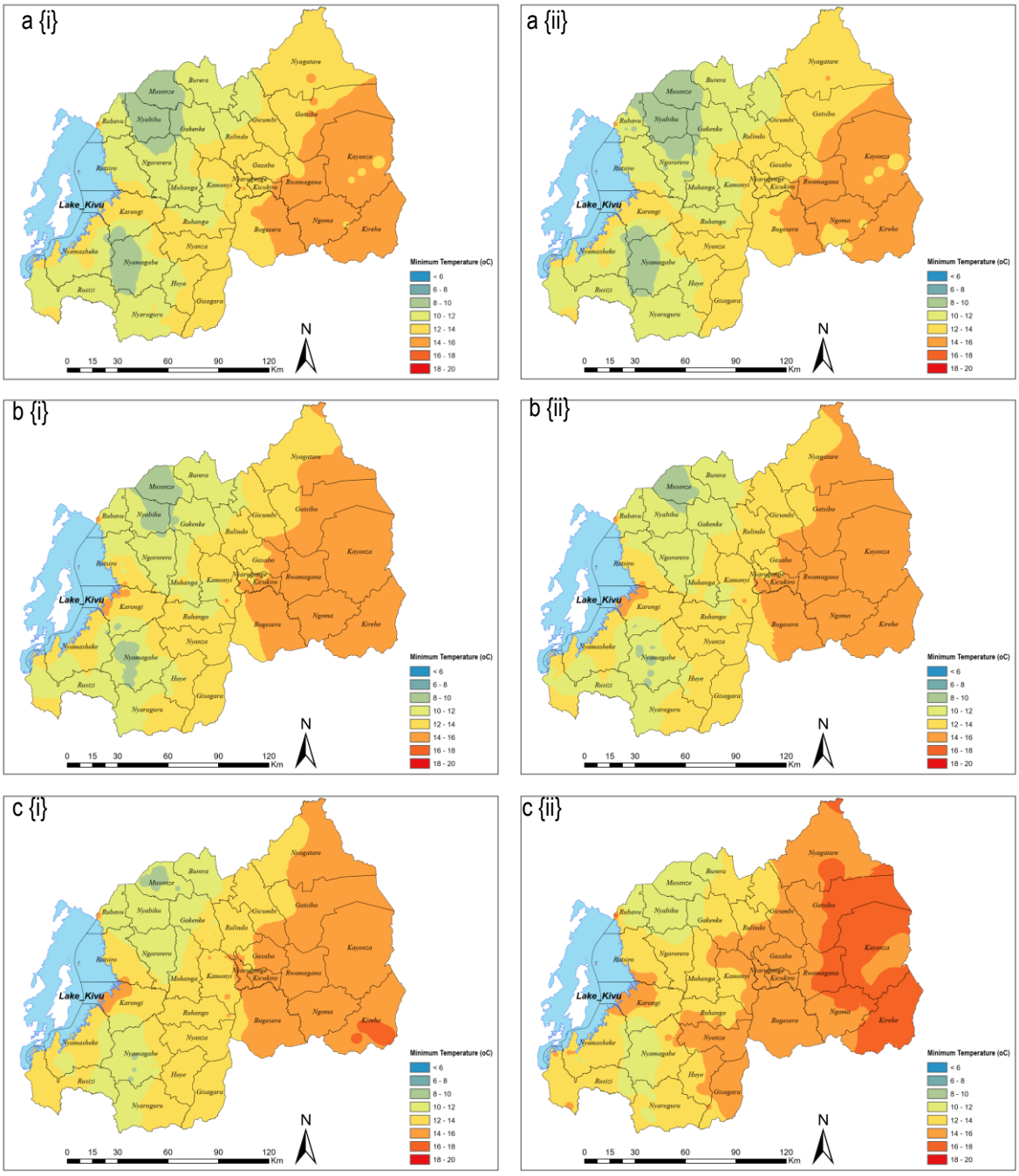


Figure 4-29:Projected JJA seasonal minimum temperature for the period a) 2021-2050, b) 2041-2070 and c) 2071-2100 under i) RCP 4.5 w/m$^2$ and ii) RCP 8.5 w/m$^2$ over Rwanda.

Figure 4-29 (a) shows that Eastern parts of Rwanda are expected to experience higher minimum temperature during the JJA season compared to western parts of Rwanda for the period 2021-2050 under both RCP 4.5 w/m$^2$ (Figure 4-29a (i)) and RCP 8.5 w/m$^2$ (Figure 4-29a (ii)). During this period, the southeast and pockets of Nyagatare will record

minimum temperature between 14 and 16 ºC. The northeast, central, southeast and some parts of Karongi, Nyamasheke, Bugarama and some pockets of Kayonza and Ngoma will record between 12 and 14 degrees Celsius. Parts of the North, and southwest will record between 10 and 12 degrees Celsius. In addition, the northern part and Nyamagabe district will record the least minimum temperature of between 8 and 10 degree Celsius.

Similar patterns of higher minimum temperatures during the JJA season over eastern parts compared to western parts of Rwanda are expected for the period 2041-2070 (Figure 4-29b) and for the period 2071-2100 (Figure 4-29c). Parts of Southeast, pockets of Nyagatare, Rubavu, Karongi, Kamonyi will record between 14 and 16 degrees Celsius. The Northeast, parts of southeast, central, parts of western Karongi, Bugarama, Nyamasheke, Rutsiro will record between 12 and 14 degrees Celsius. The northern parts of central, south, parts of southwest and north west will record between 10 and 12 degrees Celsius while the north and Nyamagabe district will record between 8 and 10 degrees Celsius which will be the lowest record. For the period 2071-2100 (Figure 4-29c), Kirehe district will experience between 16 and 18 degrees Celsius under both RCP 4.5 w/m$^2$ (Figure 4-29c (i)) and RCP 8.5 w/m$^2$ (Figure 4-29c (ii)). The northeast, southeast, Kigali city and pocket of Rubavu will record between 14 and 16 degrees Celsius. Parts of northeast, central, south, Rutsiro, Karongi, Rusizi and Nyamasheke will record between 12 and 14. The north and south west will experience 10 to 12 degrees Celsius while Musanze and pockets of Nyamagabe will record between 8 and 10 degrees Celsius.

Overall, the highest projected JJA minimum temperature is expected over eastern parts compared to western parts of Rwanda. In addition, projected minimum temperatures are expected to increase from 2021 to 2100 with more areas under RCP 8.5 w/m$^2$ to experience the highest minimum temperature towards 2100.

#### 4.8.4.4 September-October-November-December (SOND) Season

Analysis of the spatial distribution of SOND minimum temperature for the period between 2021 and 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ are presented in Figure 4-30.

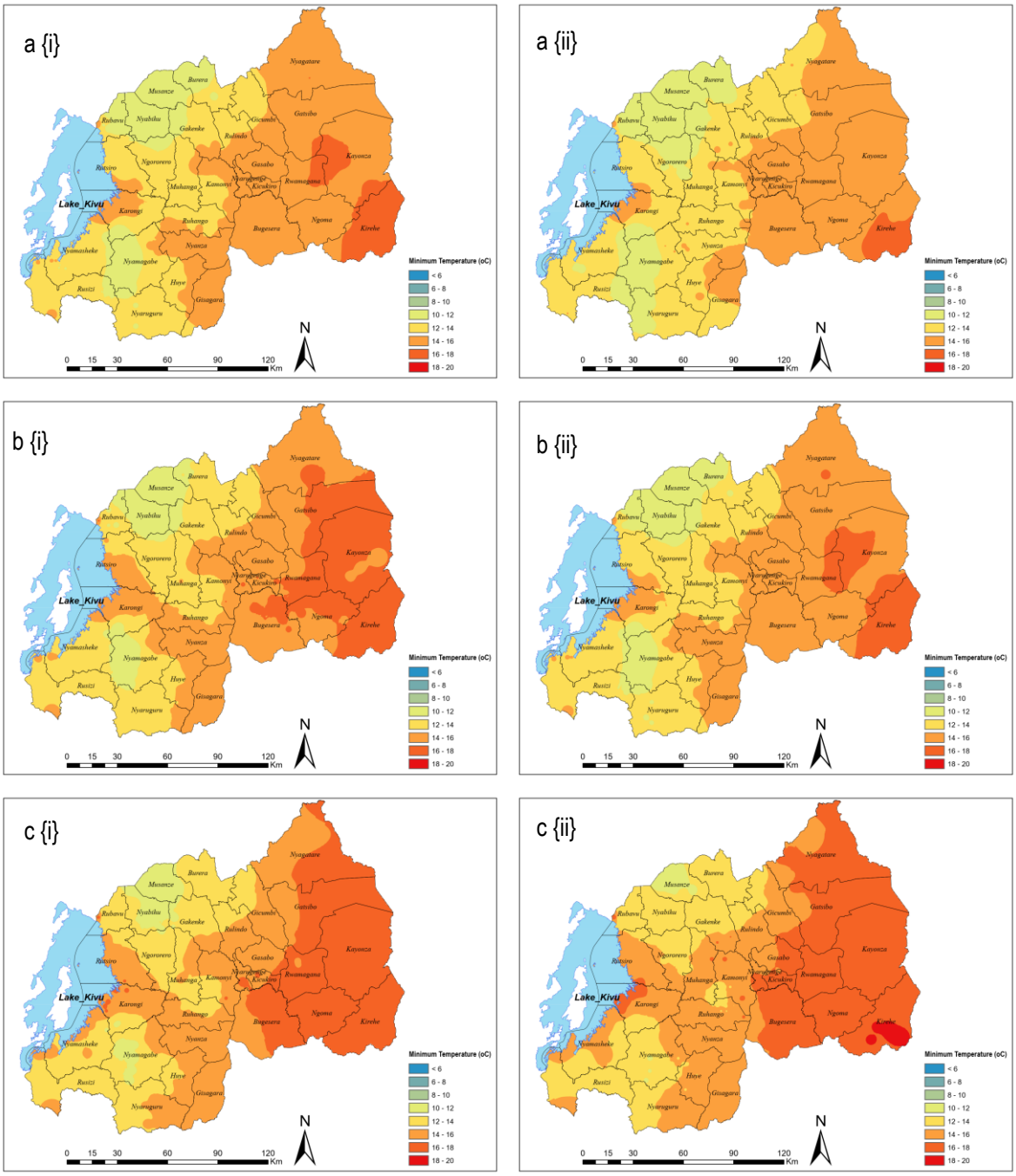


Figure 4-30: Projected SOND seasonal minimum temperature for the period a) 2021-2050, b) 2041-2070 and c) 2071-2100 under i) RCP 4.5 w/m$^2$ and ii) RCP 8.5 w/m$^2$ over Rwanda.

Figure 4-30 (a) shows that Eastern parts of Rwanda are expected to experience higher minimum temperature during the SOND season compared to western parts of Rwanda for the period 2021-2050 under both RCP 4.5 w/m$^2$ (Figure

4-30a (i)) and RCP 8.5 w/m$^2$ (Figure 4-30a (ii)) with RCP 4.5 w/m$^2$ expected to have higher temperatures compared to RCP 8.5 w/m$^2$. Kirehe and parts of Kayonza and Rwamagana will record the highest minimum temperatures ranging between 16 and 18 degrees Celsius. The Northeast, southeast and parts of the south will record between 14 and 16 degrees Celsius. The south, southwest part of the west, parts of the North and central will record between 12 and 14. The remaining part of the north, northwest and Nyamagabe district will record between 10 and 12 degrees Celsius.

Similar patterns of higher minimum temperatures during the SOND season over eastern parts of Rwanda compared to western parts of Rwanda are expected for the period 2041-2070 where between 16 and 18 degrees Celsius will be recorded in part of the Northeast, southeast and the central. The other parts of the Northeast, southeast, south, parts of the west, and pockets of Rubavu, Nyamasheke and Bugarama will record between 14 to 16 degrees Celsius. The North, central, parts of west and south will record between 12 and 14 degrees Celsius and lastly the North, Northwest and parts of Nyamagabe district will record between 10 and 12 degrees Celsius as shown in (Figure 4-30b) under both RCP 4.5 w/m$^2$ (Figure 4-30b (i)) and RCP 8.5 w/m$^2$ (Figure 4-30b (ii)). For the period 2071-2100 (Figure 4-30c) under both RCP 4.5 w/m$^2$ (Figure 4-30c (i)) and RCP 8.5 w/m$^2$ (Figure 4-30c (ii)). The Northeast, southeast, pockets of Kigali City, Karongi and Rubavu will record between 16 and 18. The Northeast, central, southeast, and parts of the west will record between 14 and 16 degrees Celsius. The North, central, southwest, south, and part of west will record between 12 and 14 degrees Celsius and lastly the North, Northwest, and Nyamagabe will record between 10 and 12 degrees Celsius.

In overall, the highest projected SOND minimum temperature is expected over eastern parts compared to western parts of Rwanda. In addition, projected minimum temperatures are expected to increase from 2021 to 2100 with more areas under RCP 8.5 w/m$^2$to experience the highest minimum temperature towards 2100.

### 4.8.4.5 Annual minimum temperature

Analysis of the spatial distribution of annual minimum temperature for the period between 2021 and 2100 under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ are presented in Figure 4-31.

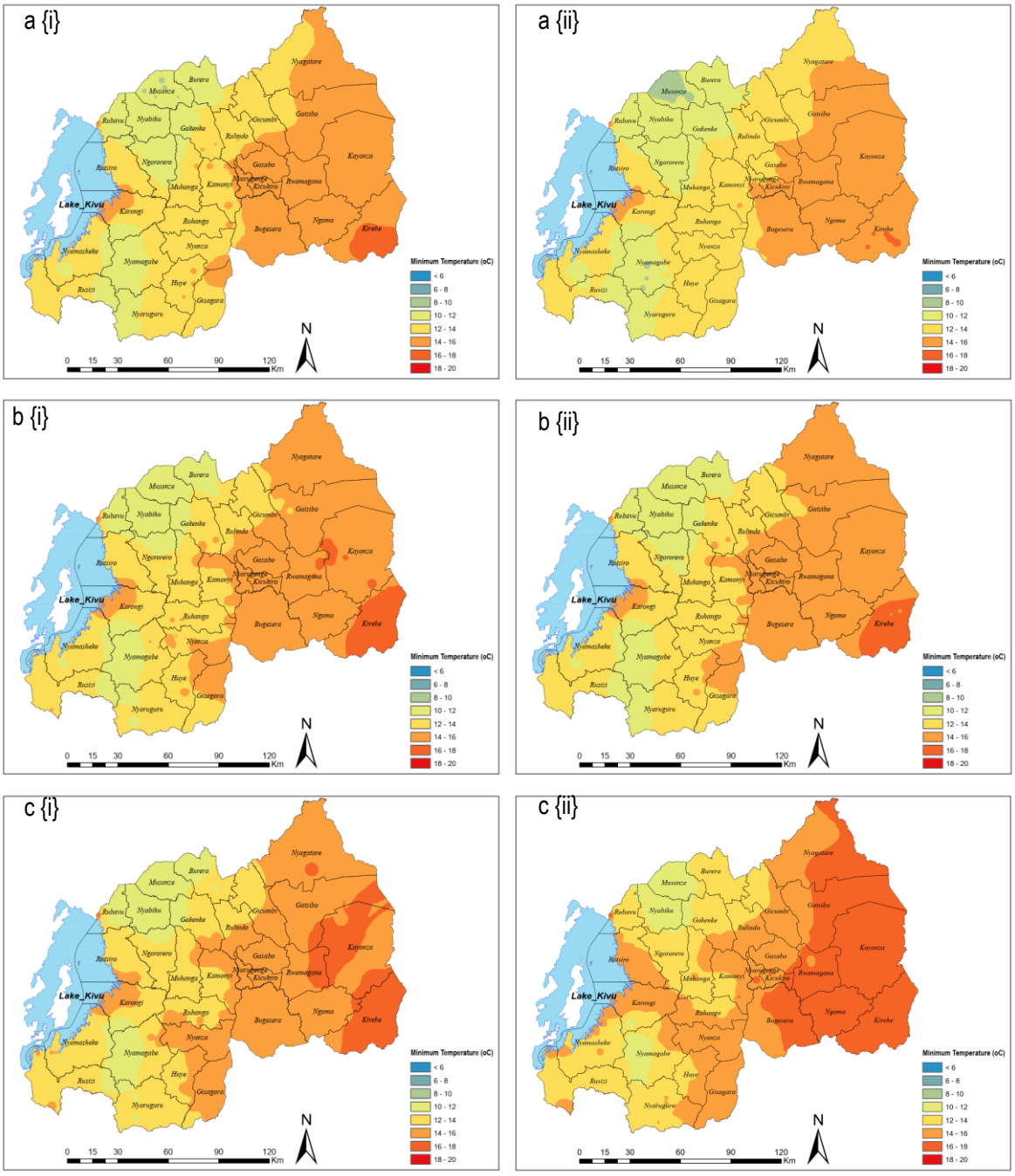


Figure 4-31: Projected annual minimum temperature for the period a) 2021-2050, b) 2041-2070 and c) 2071-2100 under i) RCP 4.5 w/m$^2$ and ii) RCP 8.5 w/m$^2$ over Rwanda.

Figure 4-31 (a) shows that Eastern parts of Rwanda are expected to experience higher minimum temperature in its annual minimum temperature compared to western parts of Rwanda for the period 2021-2050 under both RCP 4.5w/$m^2$ (Figure 4-31a (i)) and RCP 8.5 w/$m^2$ (Figure 4-31a (ii)) with RCP 4.5w/$m^2$ expected to have higher temperatures compared to RCP 8.5 w/$m^2$. Kirehe district expected to record the minimum temperature ranging between 16 and 18 degrees Celsius. The northeast, southwest, Kigali-City, part of Karongi, Rutsiro, Gisagara, Nyanza, and pockets of Huye, Ruhango, Kamonyi, Muhanga,Gakemke, Rubavu will record between 14 and 16 $^oC$. Parts of Northeast, central, North, southwest, and west will record between 12 and 14 degrees Celsius. The remaining part of the North, Northwest and southwest will record between 10 and 12 degrees Celsius.

Similar patterns of higher minimum temperatures for the annual analysis over eastern parts of compared to western parts of Rwanda are expected for the period 2041-2070 (Figure 4-31b); Kirehe district and pockets of Kayonza will record between 16-18 degrees Celsius. The Northeast, southeast, part of Gisagara, Nyanza, Ruhango, Huye, Gicumbi, Rulindo, Karongi, Kamonyi, Muhanga, pockets of Gakenke, Nyamagabe and Rubavu will record between 14 and 16 degrees Celsius. Part of the Northeast, central, southwest, south, and part of the west will record between 12-14 degrees Celsius under both RCP 4.5 w/$m^2$ (Figure 4-31b (i)) and RCP 8.5 w/$m^2$ (Figure 4-31b (ii)).

Finally, the remaining part of the North, Northwest, southwest, pockets of Nyamasheke, Nyaruguru will record between 10 and 12 degrees Celsius. For the period 2071-2100 (Figure 4-31c) under both RCP 4.5 w/$m^2$ (Figure 4-31c (i)) and RCP 8.5 w/$m^2$ (Figure 4-31c (ii)), Kirehe, Kayonza and pockets of Nyagatare, Gatsibo will record between 16 and 18 degrees Celsius. The northeast, southwest part of the north south, Kigali city, Karongi, pockets of Rubavu, Rusizi, Nyamagabe and Nyamasheke will record between 14 and 16 degrees Celsius. Part of the North, central, southwest, and south will record between 12 and 14 degrees Celsius. Finally, part of the North Nyamagabe and pockets of Nyaruguru will record between 10 and 12 degrees Celsius.

Overall, the highest projected annual minimum temperature is expected over eastern parts compared to western parts of Rwanda. In addition, projected minimum temperatures are expected to increase from 2021 to 2100 with more areas under RCP 8.5 w/$m^2$ to experience the highest minimum temperature towards 2100.

### 4.8.5 *Spatial analysis of projected change of minimum temperature*

Spatial analysis of seasonal (JF, MAM, JJA and SOND) and annual changes of projected climate (2021-2100) against baseline (1981-2010) minimum temperature under both RCP 4.5 w/m$^2$ and RCP 8.5w/m$^2$ over Rwanda is presented in the subsequent sections.

#### 4.8.5.1 January -February (JF) Season

Analysis of the changes of projected (2021-2100) minimum temperature against its baseline (1981-2010) during the JF season under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ are presented in Figure 4-32.

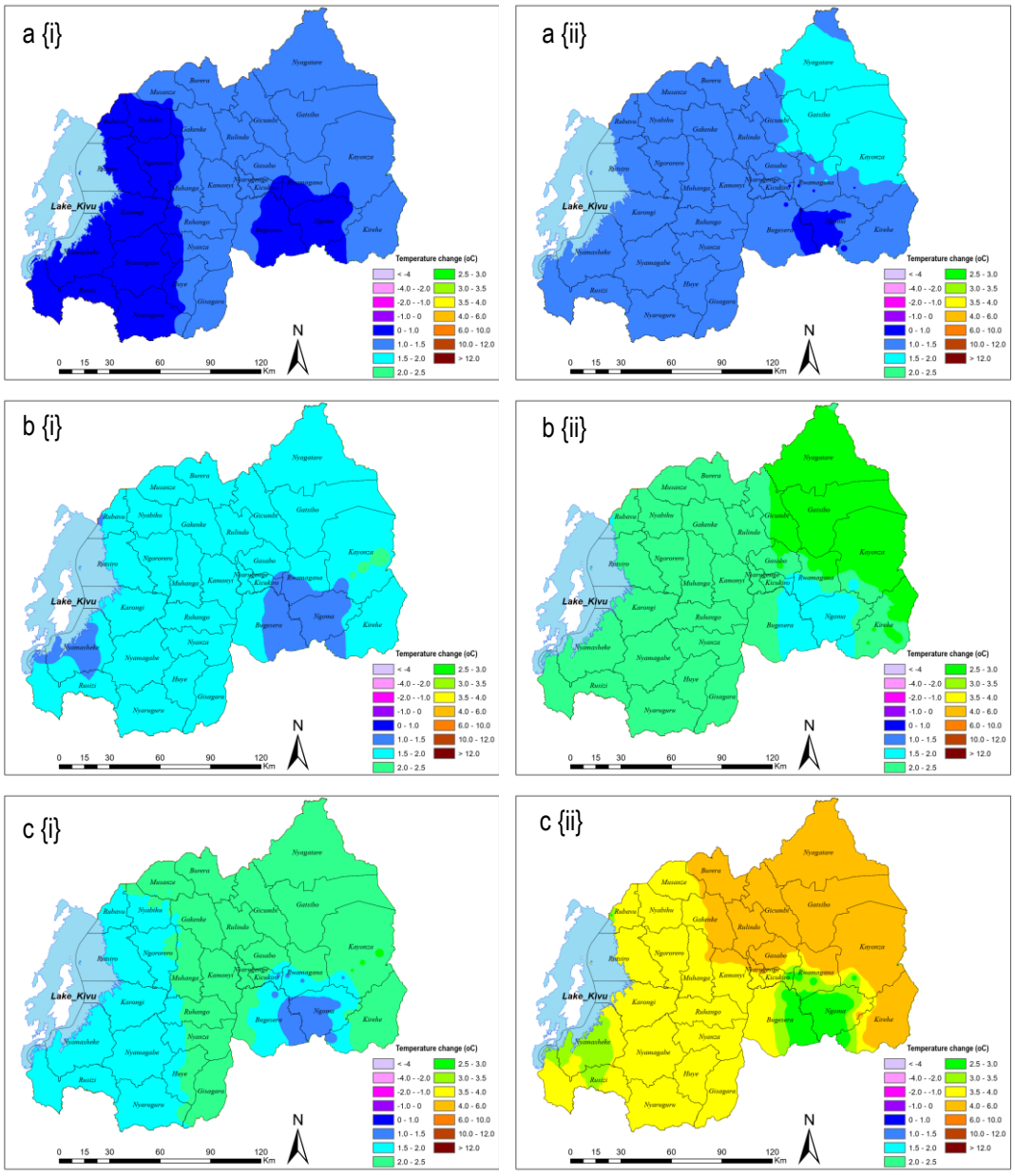


Figure 4-32: Analysis of changes of projected minimum temperature for the period a) 2021-200, b) 2041-2070 and c) 2071-2100 against its baseline (1981-2010) during JF season under i) RCP 4.5 and ii) RCP 8.5 w/m$^2$ over Rwanda.

Figure 4-32 (a) indicates that a positive percentage change in projected minimum temperature is expected under RCP 4.5 w/m$^2$ of between 1.0$^o$C and 1.5$^o$C over most of the eastern, southern and northern province with exception of western province and parts of southern province (Ngoma, Bugesera and Rwamagana) that are expected to receive slightly lower values of between 0$^o$C and 1.0$^o$C during JF for the period 2021-2050. Positive changes of projected minimum tempetarure are also expected under RCP 8.5 w/m$^2$ with most parts of western, southern, northern and southern parts of eastern province to be between 0$^o$C and 1.5$^o$C whereas northmost parts of southern province (Kayonza, Gatsibo and Nyagatare to be between 1.5$^o$C and 2.0$^o$C for the period 2021-2050.

The period 2041-2070 indicates a positive change of between 1.5$^o$C and 2.0$^o$C of projected minimum temperature for the JF season over most of the country with slightly lower changes over parts of Ngoma, Bugesera, Rwamagana and Nyamasheke districts of between 0$^o$C and 1.0$^o$C under RCP 4.5 w/m$^2$ (Figure 4-32b (i)) whereas higher changes of between 1.5$^o$C and 2.0$^o$C over Ngoma and Bugesera, between 2.0$^o$C and 2.5$^o$C over Kigali, western, southern and northern province and between between 2.5$^o$C and 3.0$^o$C over north of eastern province are expected under under RCP 8.5 w/m$^2$ for the period 2041-2070 (Figure 4-32b (ii)).

During the period of 2071-2100, positive changes of between 0$^o$C and 2.0$^o$C are expected over the western province, parts of eastern province (Ngoma and Bugesera) while positive changes of between 2.0$^o$C and 3.0$^o$C expected over parts of southern province (Gisagara, Huye, Nyanza, Muhanga and kamonyi), northern province and parts of southern province (Kirehe, Kayonza, Rwamagana, Gatsibo, and Nyagatare) under RCP 4.5 w/m$^2$ (Figure 4-32c (i)). Significantly higher positive change in minimum temperature for the period 2071-2100 under RCP 8.5 w/m$^2$ (Figure 4-32c (ii)) are expected especially western and southern province of between 2.5$^o$C and 3.5$^o$C and over parts of southern province (Kirehe, Kayonza, Rwamagana, Gatsibo, Nyagatare) and whole of northern province of between 4.0$^o$C and 6.0$^o$C under RCP 8.5 w/m$^2$

Overall, changes in minimum temperatures are expected to increase from approximately 0 $^o$C over western and eastern (Bugesera, Bgoma and Rwamagana) provinces in 2021 to 2.5 $^o$C over Kigali city and the northern, southern (Gisagara, Nyanza, Ruhango, Muhanga and kamonyi), and eastern (Kirehe, Kayonza, Gatsibo, Nyagatare, Gicumbi) provinces in 2100 under RCP 4.5 w/m$^2$ and from 1.0 $^o$C over western, northern, southern and south of eastern provinces in 2021 to 6.0 $^o$C over mostly north of eastern provinces and east of northern province in 2100 under RCP 8.5 w/m$^2$ during JF season.

### 4.8.5.2 March-April-May (MAM) Season

Analysis of the changes of projected (2021-2100) minimum temperature against its baseline (1981-2010) during MAM season under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ are presented in Figure 4-33.

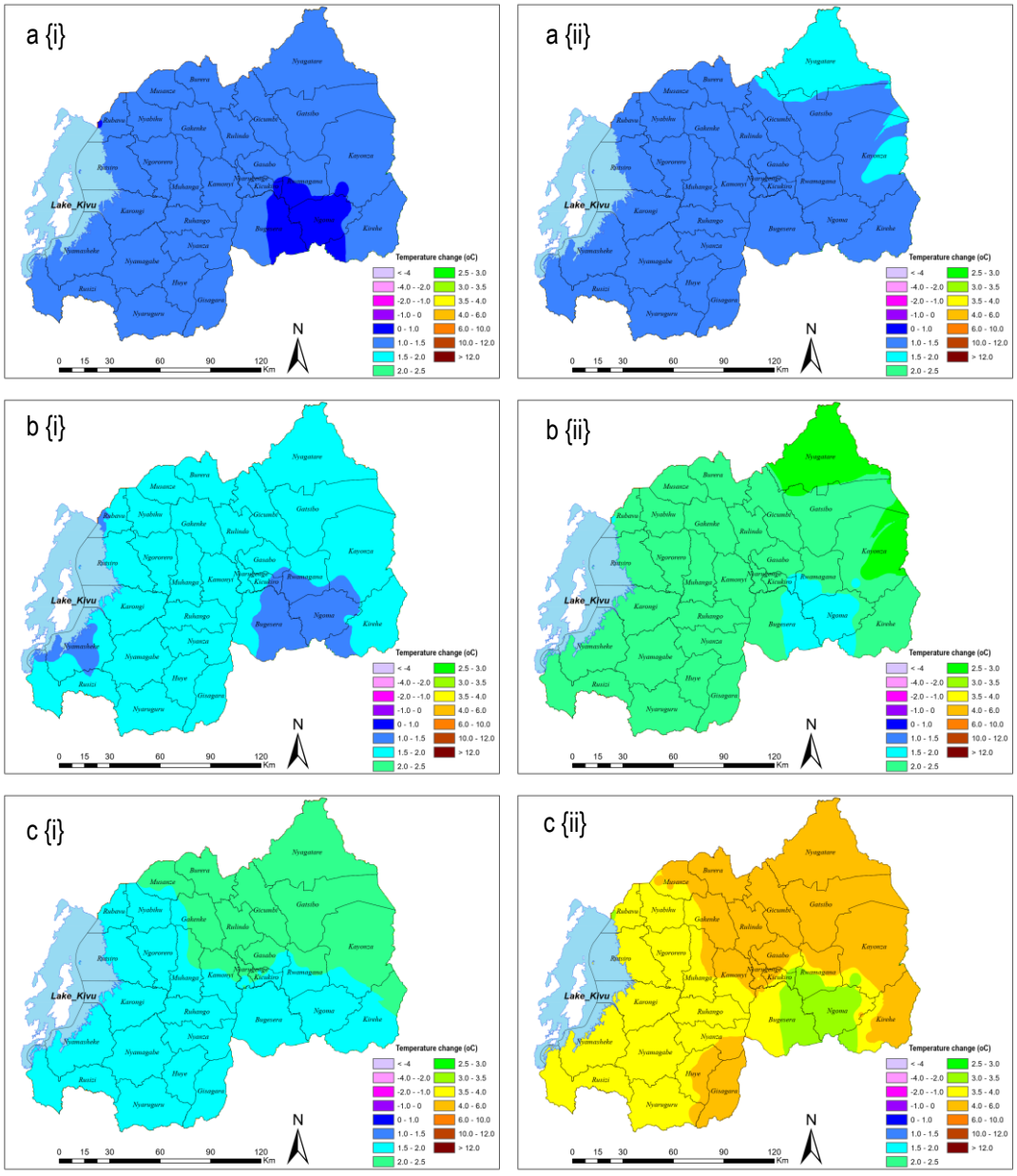


Figure 4-33: Analysis of changes of projected minimum temperature for the period a) 2021-2050, b) 2041-2070 and c) 2071-2100 against its baseline (1981-2010) during MAM season under i) RCP 4.5 w/m$^2$ and ii) RCP 8.5 w/m$^2$ over Rwanda.

Figure 4-33 (a (i)) shows that a positive percentage change in projected minimum temperature is expected under RCP 4.5 w/m$^2$ of between 1.0$^o$C and 1.5$^o$C over most of the country except in parts of eastern province (Ngoma and Bugesera and Rwamagana) which expects a positiove change of between 0$^o$C and 1.0$^o$C for the period 2021-2050 during MAM season. Further, a positive change of projected minimum tempetarure is expected under RCP 8.5 w/m$^2$ (Figure 4-33 (a (ii)) over most parts of the country of between 1.0$^o$C and 1.5$^o$C with parts of eastern province (Nyagatare

and Kayonza) expected to have positive changes of between 1.5°C and 2.0°C for the period 2021-2050 during MAM season.

Figure 4-33 (b (i)) shows that a positive percentage change in projected minimum temperature is expected under RCP 4.5 w/m$^2$ of between 1.5°C and 2.0°C over most of the country with parts of eastern province (Ngoma and Bugesera and Rwamagana) and western province (Nyamasheke) expected to have a positive change of between 1.0°C and 1.5°C for the period 2041-2070 during MAM season. Further, a positive change of projected minimum tempetarure is expected under RCP 8.5 w/m$^2$ (Figure 4-33 (b (ii)) over most parts of the country of between 2.0°C and 2.5°C with parts of eastern province expected to have positive changes of between 1.5°C and 2.0°C for the period 2041-2070 during MAM season.

Figure 4-33 (c (i)) shows that a positive percentage change in projected minimum temperature is expected under RCP 4.5 w/m$^2$ of between 1.5°C and 2.0°C over western, southern and parts of eastern (Bugesera, Ngoma and Kirehe) and increased to between 2.0°C and 2.5°C over northern and parts of eastern (Kayonza, Gatsibo and Nyagatare) for the period 2071-2100 during MAM season. Further, a positive change of projected minimum tempetarure is expected under RCP 8.5 w/m$^2$ (Figure 4-33 (c (ii)) over most parts of the country of between 3.0°C and 3.5°C (parts of Ngoma and Bugesera), between 3.5°C and 4.0°C over western and parts of southern (Nyaruguru, Nyamagabe, Nyanza and Ruhango) province and between 4.0°C and 6.0°C over northern, parts of eastern (Kayonza, Gatsibo, Nyagatare and southern (Gasagara) provinces for the period 2071-2100 during MAM season.

Overall, changes in minimum temperatures are expected to increase from approximately 1.0 °C over most parts of Rwanda in 2021 to 2.5 °C over Kigali city, Musanze, Burera and Rulindo in the northern province and Nyagatare, Gatsibo, Gichumbi and Kayonza districts in the eastern province in 2100 under RCP 4.5 w/m$^2$ and from 1.0 °C over western, northern, southern and most parts of eastern provinces in 2021 to 6.0 °C over mostly northern provinces, gatsibo, Kirehe, Gichumbi and Nyagatare districts in the eastern province and Gisagara district in southern province in 2100 under RCP 8.5 w/m$^2$ during MAM season.

### 4.8.5.3 June -July- August (JJA) Season

Analysis of the changes of projected (2021-2100) minimum temperature against its baseline (1981-2010) during JJA season under RCP 4.5w/m$^2$ and RCP 8.5w/m$^2$ are presented in Figure 4-34.

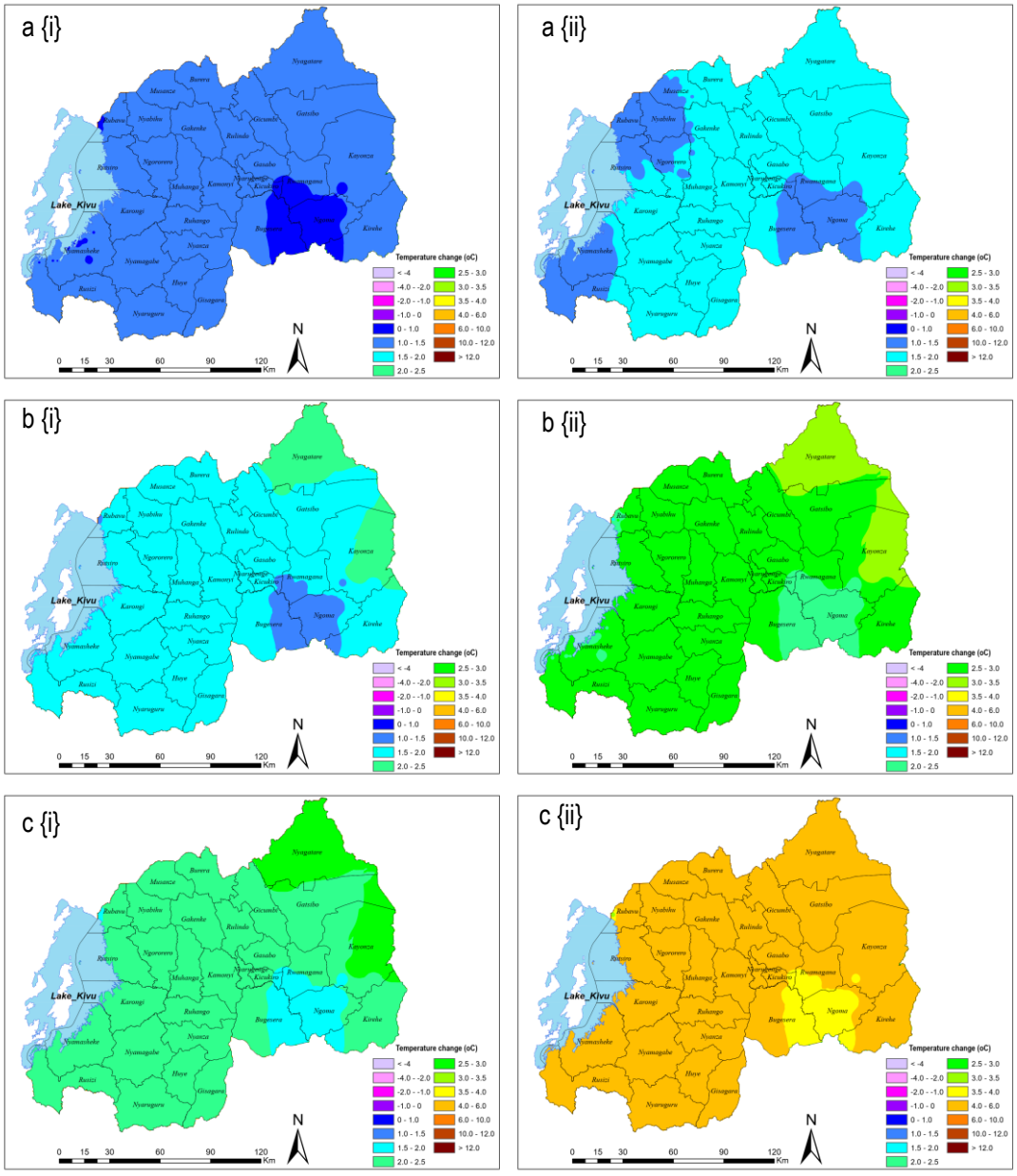


Figure 4-34: Analysis of changes of projected minimum temperature for the period a) 2021-2050, b) 2041-2070 and c) 2071-2100 with respect to its baseline 1981-2010 during JJA season under i) RCP 4.5w/m$^2$ and ii) RCP 8.5 w/m$^2$ over Rwanda

Figure 4-34 (a (i)) shows that a positive percentage change in projected minimum temperature is expected under RCP 4.5 w/m$^2$ of between 1.0$^o$C and 1.5$^o$C over most of the country except in parts of eastern province (Ngoma and Bugesera and Rwamagana) which expects a positiove change of between 0$^o$C and 1.0$^o$C for the period 2021-2050 during JJA season. Further, a positive change of projected minimum tempetarure is expected under RCP 8.5 w/m$^2$ (Figure 4-34 (a (ii)) over most parts of the country of between 1.5$^o$C and 2.0$^o$C with parts of eastern province (Ngoma and Bugesera and Rwamagana) and western province (Nyamasheke, Rusizi, Rubavu and Ngororero) expected to have positive changes of between 1.0$^o$C and 1.5$^o$C for the period 2021-2050 during JJA season.

Figure 4-34 (b (i)) shows that a positive percentage change in projected minimum temperature is expected under RCP 4.5 w/m$^2$ of between 1.5$^o$C and 2.0$^o$C over most of the country with parts of eastern province expected to have a positive change that range between 1.0$^o$C and 1.5$^o$C (Ngoma and Bugesera and Rwamagana) to between 2.0$^o$C and 2.5$^o$C (Kayonza and Nyagatare) for the period 2041-2070 during JJA season. Further, a positive change of projected minimum tempetarure is expected under RCP 8.5 w/m$^2$ (Figure 4-34 (b (ii)) over most parts of the country of between 2.5$^o$C and 3.0$^o$C except in parts of eastern province which expects a positiove change of between 0$^o$C and 1.0$^o$C (Ngoma and Bugesera and Rwamagana) and of between 3.0$^o$C and 3.5$^o$C (Kayonza and Bugesera) for the period 2041-2070 during JJA season.

Figure 4-34 (c (i)) shows that a positive percentage change in projected minimum temperature is expected under RCP 4.5 w/m$^2$ of between 2.0$^o$C and 2.5$^o$C over Kigali city, western, southern, northern and parts of eastern (Gatsibo, Rwamagana and Kirehe) whereas parts of eastern (Kayonza, Gatsibo and Nyagatare) are expected to have between 3.0$^o$C and 3.5$^o$C for the period 2071-2100 during JJA season. Further, a positive change of projected minimum tempetarure is expected under RCP 8.5 w/m$^2$ (Figure 4-34 (c (ii)) over most parts of the country of between 4.0$^o$C and 6.0$^o$C with exception of parts of Ngoma, Rwagana and Bugesera whose positive temperature change was lower of between 3.5$^o$C and 4.0$^o$C for the period 2071-2100 during JJA season.

Overall, changes in minimum temperatures are expected to increase from approximately 1.0 $^o$C over most parts of Rwanda in 2021 to 3.0 $^o$C over Nyagatare and Kayonza districts in the eastern province in 2100 under RCP 4.5 w/m$^2$ and from 1.0 $^o$C over Rubavu Nyabihu, Rutsiro, Nyamasheke and Rusizi districts in western province, and Rwamagana, Bugesera and Ngoma districts in southern and provinces in 2021 to 6.0 $^o$C over mostly parts of Rwanda in 2100 under RCP 8.5 w/m$^2$ during JJA season.

#### 4.8.5.4 September-October-November-December (SOND) Season

Analysis of the changes of projected (2021-2100) minimum temperature with respect to its baseline (1981-2010) during SOND season under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ are presented in Figure 4-35.

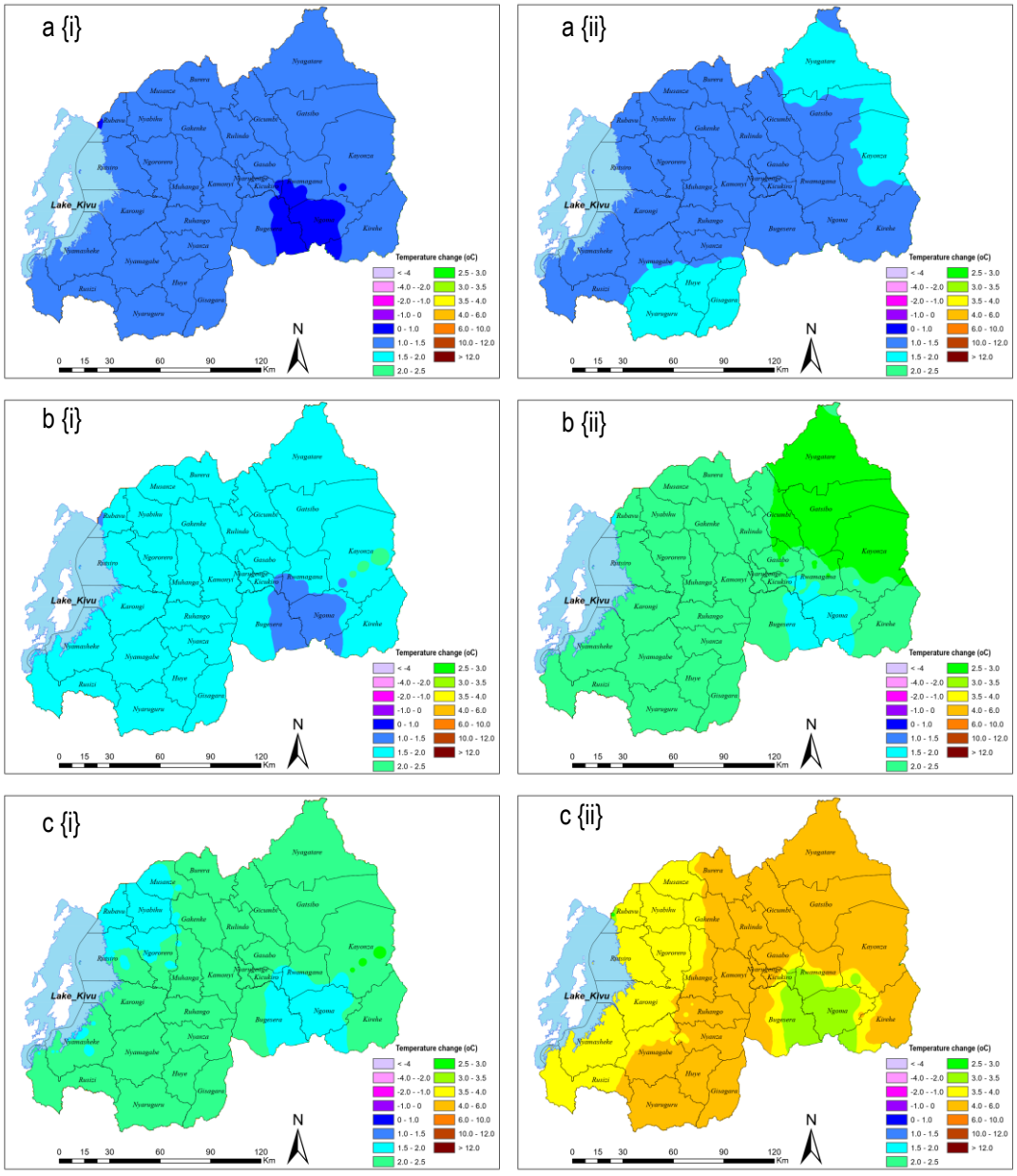


Figure 4-35: Analysis of changes of projected minimum temperature for the period a) 2021-2050, b) 2041-2070 and c) 2071-2100 with respect to the baseline 1981-2010 during SOND season under i) RCP 4.5 w/m$^2$and ii) RCP 8.5 w/m$^2$ over Rwanda

Figure 4-35 (a (i)) shows that a positive percentage change in projected minimum temperature is expected under RCP 4.5 w/m$^2$ of between 1.0$^o$C and 1.5$^o$C over most of the country except in parts of eastern province (Ngoma and Bugesera and Rwamagana) which expects a positiove change of between 0$^o$C and 1.0$^o$C for the period 2021-2050 during SOND season. Further, a positive change of projected minimum tempetarure is expected under RCP 8.5 w/m$^2$ (Figure 4-35 (a (ii)) over most parts of the country of between 1.0$^o$C and 1.5$^o$C with parts of eastern province (Kayonza, Gatsibo and Nyagatare) and southern province (Nyaruguru, Huye, Nyamagabe and Gisagara) expected to have positive changes of between 1.5$^o$C and 2.0$^o$C for the period 2021-2050 during SOND season.

Figure 4-35 (b (i)) shows that a positive percentage change in projected minimum temperature is expected under RCP 4.5 w/m$^2$ of between 1.5$^o$C and 2.0$^o$C over most of the country with parts of eastern province expected to have a positive change that range between 1.0$^o$C and 1.5$^o$C (Ngoma and Bugesera and Rwamagana) for the period 2041-2070 during SOND season. Further, a positive change of projected minimum tempetarure is expected under RCP 8.5 w/m$^2$ (Figure 4-35 (b (ii)) over most parts of the country of between 2.0$^o$C and 2.5$^o$C with parts of eastern province expected to have a positiove change of between 1.5$^o$C and 2.0$^o$C (Ngoma and Bugesera and Rwamagana) and of between 3.0$^o$C and 3.5$^o$C (Kayonza, Gatsibo, Gicumbi and Bugesera) for the period 2041-2070 during SOND season.

Figure 4-35 (c (i)) shows that a positive percentage change in projected minimum temperature is expected under RCP 4.5 w/m$^2$ of between 2.0$^o$C and 2.5$^o$C over the country with eastern (Ngoma, Bugesera and Rwamagana) and western (Nyabihu, Ngororero, Rubavu) expected to have between 1.5$^o$C and 2.0$^o$C for the period 2071-2100 during SOND season. Further, a positive change of projected minimum tempetarure is expected under RCP 8.5 w/m$^2$ (Figure 4-35 (c (ii)) over most parts of the country of between 3.5$^o$C and 6.0$^o$C over western, southern, northern and parts of southern province except in Bugesera, Ngoma and Rwamagana which are expected to have between 3.0$^o$C and 3.5$^o$C for the period 2071-2100 during SOND season.

Overall, changes in minimum temperatures are expected to increase from approximately 1.0 $^o$C over most parts of Rwanda in 2021 to 2.5 $^o$C over most parts of Rwanda in 2100 under RCP 4.5 w/m$^2$ and from 1.0 $^o$C over Kigali city, Northern, western, southern (Nyanza, Ruhango, Muhanga, and Kamonyi districts) and south of the eastern provinces in 2021 to 6.0 $^o$C over southern provinces, east of northern province and north of eastern provinces of Rwanda in 2100 under RCP 8.5 w/m$^2$ during SOND season.

#### 4.8.5.5 Annual minimum temperature

Analysis of the changes of projected (2021-2100) minimum temperature with respect to its baseline (1981-2010) during annual under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ are presented in Figure 4-36.

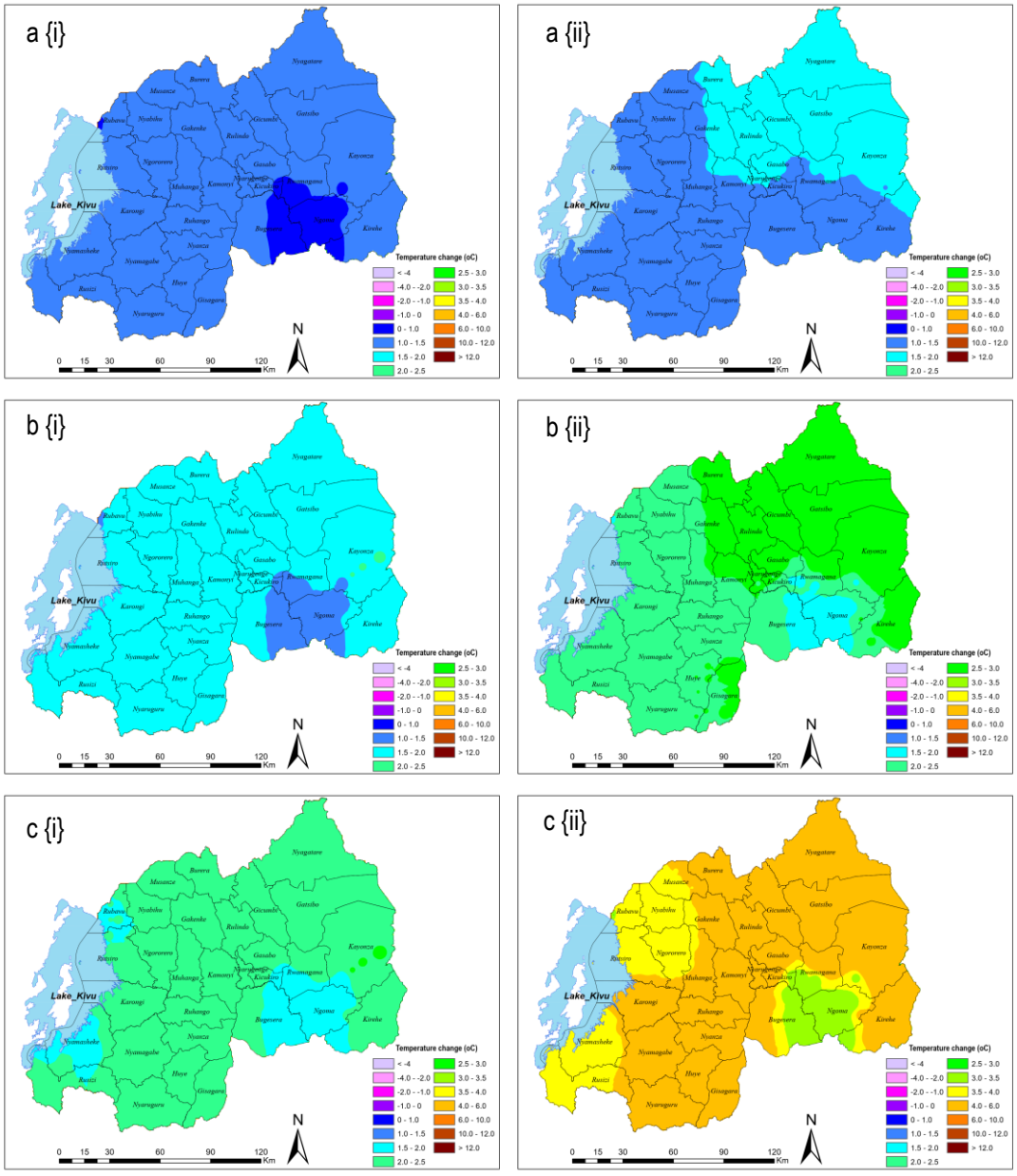


Figure 4-36: Analysis of changes of projected minimum temperature for the period a) 2021-2050, b) 2041-2070 and c) 2071-2100 with respect to its baseline (1981-2010) during annual period under i) RCP 4.5 w/m$^2$ and ii) RCP 8.5 w/m$^2$ over Rwanda

Figure 4-36 (a (i)) shows that a positive percentage change in projected annual minimum temperature is expected under RCP 4.5 w/m$^2$ of between 1.0$^o$C and 1.5$^o$C over most of the country except in parts of eastern province (Ngoma and Bugesera and Rwamagana) which expects a positiove change of between 0$^o$C and 1.0$^o$C for the period 2021-2050. Further, a positive change of projected annual minimum tempetarure is expected under RCP 8.5 w/m$^2$ (Figure 4-36 (a (ii)) over most parts of the country of between 1.0$^o$C and 1.5$^o$C with parts of eastern province (Kayonza, Gatsibo and Nyagatare) and northern province (Burera, Gicumbi, Gakenke, Rulindo) and Kigali city expected to have positive changes of between 1.5$^o$C and 2.0$^o$C for the period 2021-2050.

Figure 4-36 (b (i)) shows that a positive percentage change in projected annual minimum temperature is expected under RCP 4.5 w/m$^2$ of between 1.5$^o$C and 2.0$^o$C over most of the country with parts of eastern province expected to have a positive change that range between 1.0$^o$C and 1.5$^o$C (Ngoma and Bugesera and Rwamagana) for the period 2041-2070. Further, a positive change of projected annual minimum tempetarure is expected under RCP 8.5 w/m$^2$ (Figure 4-36 (b (ii)) over most parts of the country of between 2.0$^o$C and 3.0$^o$C with parts of eastern province (Ngoma and Bugesera and Rwamagana) expected to have a positiove change of between 1.5$^o$C and 2.0$^o$C for the period 2041-2070.

Figure 4-36 (c (i)) shows that a positive percentage change in projected annual minimum temperature is expected under RCP 4.5 w/m$^2$ of between 2.0$^o$C and 2.5$^o$C over the country with eastern (Ngoma, Bugesera and Rwamagana) and western (Nyabihu, Ngororero, Rubavu) expected to have between 1.5$^o$C and 2.0$^o$C for the period 2071-2100. Further, a positive change of projected annual minimum tempetarure is expected under RCP 8.5 w/m$^2$ (Figure 4-36 (c (ii)) over most parts of the country of between 3.5$^o$C and 6.0$^o$C over western, southern, northern and parts of southern province except in Bugesera, Ngoma and Rwamagana which are expected to have between 3.0$^o$C and 3.5$^o$C for the period 2071-2100.

# CHAPTER FIVE

# 5 CONCLUSION AND RECOMMENDATION

This chapter presents the conclusions and recommendations of the study

## 5.1 Conclusion

The availability of regional and local scale climate change scenarios is critical for the assessment of climate change impacts and vulnerability in various socio-economic sectors and for the development of appropriate adaptation strategies. However, the existing global climate models are of course resolution which hinders climate studies at local scales. Therefore, there is a need for downscaled climate projections that can be used by different socio-economic sectors for the National adaptation plan.

This report used different datasets including the ground-based station data s from Meteo-Rwanda and the state-of-the-art Coupled Model Intercomparison Project Phase 5 (CMIP5) GCMs using the Coordinated Regional Downscaling Experiment (CORDEX) RCM model output.

Dynamical and statistical downscaling techniques were used to ensure that key assumptions made in the statistical approach are addressed by the use of the dynamical downscaling approach. The temporal and spatial analysis for the recent, past and projected climate were assessed. The Mann-Kendall (MK) trend test was used to understand the nature of the trend and Sen's Slope Estimator to quantify the magnitude of change in terms of the percentage of the mean Precipitation indices including very wet days (R95p) and very heavy precipitation days (R20 mm) while temperature indices included Cold nights (TN10p), Cold days (TX10p), and Warm nights (TN90p), and Warm days (TX90p) were performed basing on the methodology recommended by WMO Expert Team on Climate Change Detection and Indices (ETCCDI).

Before further analysis, downscaled RCMs were validated against the ground observations to assess their performance in capturing observed Annual, June-July August (JJA), September-October-November-December (SOND), January-February (JF) and March-April-May (MAM) seasonal characteristics in Rwanda.

The future projections were analysed considering two emission scenarios: RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$, representing the middle of road and business as usual scenarios. The 21st century was divided into three-time slices, namely the period 2021-2050 (Near Term), 2041-2070 (Medium-term) and 2071-2100 (Long term). To support impact assessments, a spatial resolution of 0.22$^o$ for rainfall and temperature (maximum and minimum temperature) was used. Bias-correction of the raw climate model outputs to produce climate projections that are a better fit for impact assessments utilized Quantile Mapping (QM) approach.

Validation of satellite-derived rainfall estimates from TAMSAT and CHIRPS against observed data showed comparability with gauge-based rainfall observations from Meteo Rwanda. However, verification metrics indicated that the TAMSAT provided better estimates for rainfall over Rwanda and hence blended with 239 stations to generate a hybrid dataset known as ENACTS. In addition, the JRA55 was considered to have the most comprehensive data and hence blended with observed maximum and minimum temperature. Climate models' datasets were validated against ENACTS datasets at 0.44$^o$ (~ 50km) and 0.22$^o$ (~ 50km). Validation based on CanRCM4 derived by CCCma-CanESM2 on dynamically and statistically downscaled showed that downscaling statistically CanRCM4 of at 0.44$^o$ to 0.22$^o$ is comparable. Therefore, the dynamically downscaled CORDEX data which are available at 0.44$^o$ (~ 50km) were further statistically downscaled to 0.22$^o$ (~ 25km). The RCM selected for validation included CCLM4-8-17, REMO 2009 and RCA4 driven by MOHC, ICHEC and MPI. Validation of climate model output against observed (ENACTS) indicated that REMO 2009 (MPI), REMO 2009 (MOHC) and CCLM4-8-17 (ICHEC) were the best performing models for precipitation, maximum and minimum temperature, respectively.

Trend analysis showed that both seasonal and annual rainfall over Rwanda has been increasing for the period 1981-2010 especially over North-eastern Districts such as Nyagatare and Gatsibo whereas in some areas it has been decreasing hence remaining highly variable in space and time. The number of very wet days and very heavy precipitation days are also noted to have increased especially over the eastern parts of Rwanda. However, the number of consecutive dry days was noted to be high in western parts of Rwanda (Gakenke, Karongi, Nyamasheke and Nyamagabe). Spatial analysis indicated that western parts of Rwanda receive more rainfall during both seasonal and annual rainfall compared to the eastern parts whereas the number of days per year with very heavy rainfall precipitation (R20mm) was higher over south-western reducing toward the central plateau compared to eastern and northwestern parts of Rwanda while the number of very wet days were higher over south-western parts reducing toward the central and less precipitation over the eastern part of Rwanda.

The trend of seasonal and annual maximum temperature for the period 1983-2012 has been increasing over most areas in Rwanda. Similarly, most parts of Rwanda experienced an increasing trend in the number of cold and warm days. Moreover, trend analysis showed that both seasonal and minimum temperatures have been increasing. However, the trend of cold nights indicated a decreasing pattern whereas the trend of warm nights showed an increasing trend. Maximum temperature reduces from eastern toward the central plateau with a maximum temperature ranging between 26-28ºC while lower maximum temperatures are observed over the western and northern highland areas especially over Musanze and Nyabihu with a temperature less than 14ºC. The minimum temperature is higher over eastern parts compared to western parts of Rwanda based on the mean seasonal and annual minimum temperatures. Notably, higher number of cold days (10.0 to 10.2) was observed over the central of Gatsibo and Gicumbi extending to Rulindo Districts and the areas of Kamonyi, Ruhango and Muhanga compared to the rest of the country that reported the lowest number of colds to range between 9.8 and 10 days whereas the number of cold and warm nights over Rwanda was approximately between 9.4 and 10.2 days respectively.

Model verification metrics showed that MPI (driving model) downscaled by REMO2009 was the best performing model for precipitation on monthly timescales whereas MOHC (driving model) downscaled by CCLM4 was the best performing model for maximum temperature and hence selected for further analysis while ICHEC (driving model) downscaled by CCLM4 was the best performing model for minimum temperature Analysis of Bias corrected climate projections – precipitation

Analysis of projected JF, MAM, JJA, SOND and annual precipitation indicates that remains highly variable under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ during the periods 2021-2050, 2041-2070 and 2071-2100 over Rwanda. The analysis of projected very heavy precipitation days shows increasing trends over most parts of the country for the period 2021-2050 whereas the period 2041-2070 indicates that projected very heavy precipitation days will decrease over most parts of Rwanda. However, the projected very heavy precipitation days for the period 2071-2100 showed a decreasing trend over Rwanda. Overall, the annual percentage change shows highly variable changes in projected very wet days under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda. The annual percentage change shows highly variable changes in projected very wet days under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ over Rwanda.

Projected JF precipitation is expected to decrease from the southwest (300-450mm) to the northeast (50-150mm). Projected MAM precipitation for the period 2021-2050, 2041-2070 and 2071-2100 ranged between 300 and 700mm for both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ However, the MAM seasonal totals were observed to decrease in most regions towards 2100 especially most parts of Eastern parts and Karongi. Projected JJA precipitation for the period 2021-2050, 2041-2070 and 2071-2100 ranged between <50mm and 150 mm for both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ and decreased from northwest to southeast. Projected SOND precipitation for the period 2021-2050, 2041-2070 and 2071-2100 ranged between 300 mm and 1000 mm for both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ and decreased from the southwest towards the east, where most parts of the east are projected to have rainfall ranging from 300 to 600mm. Projected annual precipitation for the period 2021-2050, 2041-2070 and 2071-2100 ranged between 700mm and >1400mm for both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ and decreased from the southwest towards the north-east.

The projected JF maximum temperature during the 2021-2050 period indicates an increasing trend with a larger increase under RCP 8.5 w/m$^2$ compared to RCP 4.5 w/m$^2$. Similarly, an increasing trend for both 2041-2070 and 2071-2100 with RCP 8.5 w/m$^2$ is expected to increase at a higher rate compared to RCP 4.5 w/m$^2$. The projected MAM maximum temperature indicates an increasing trend for both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ for the period 2021-2050. However, the period 2041-2070 is marked by a decreasing trend under RCP 4.5 w/m$^2$ compared to increasing trends under RCP 8.5 w/m$^2$ Similarly, the period 2071-2100 is marked by a decreasing trend under RCP 4.5 w/m$^2$ compared to increasing trends under RCP 8.5 w/m$^2$ . The projected JJA maximum temperature indicates an increasing trend for both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ for the period 2021-2050. However, the period 2041-2070 is marked by an increasing trend under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$. Similarly, the period 2071-2100 is marked by a decreasing trend under RCP 4.5 w/m$^2$ with some area in southeastern and north highlands that are indicated by increasing trend under trends under RCP 8.5 w/m$^2$.

The trend of projected SOND maximum temperature shows a high increase trend under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ for the period 2021-2050 whereas an increasing trend of projected maximum temperature with more increase expected under RCP 8.5 w/m$^2$ compared to RCP 4.5 w/m$^2$ for the period 2041-2070. Similarly, an increasing trend is noted for the period 2071-2100 whereby the RCP 8.5 w/m$^2$ is noted to increase at a bigger magnitude compared to RCP 4.5 w/m$^2$.

The trend of projected annual maximum temperature shows an increase under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ for the period 2021-2050 whereas an increasing trend of projected maximum temperature with more increase expected under RCP 8.5 w/m$^2$ compared to RCP 4.5 w/m$^2$. However, a decreasing trend is noted for the period 2071-2100 over most parts of Rwanda under RCP 4.5 w/m$^2$ whereas RCP 8.5 w/m$^2$ is marked by a significant increasing trend.

Generally, the trend of the projected number of cold days shows a decrease during the period 2021-2050 and 2041-2070 with more areas expected to experience a greater number of cold days under RCP 8.5 w/m$^2$ compared to RCP 4.5 w/m$^2$. However, more increase in the number of cold days is expected under RCP 8.5 w/m$^2$ compared to RCP 4.5 w/m$^2$ during the period 2071-2100.

The trend of the projected number of warm days shows an increase during the period 2021-2050 under RCP 4.5 w/m$^2$. In addition, more areas are expected to experience an increased number of warm days under RCP 8.5 w/m$^2$ compared to RCP 4.5 w/m$^2$. Similarly, the trend of the projected number of warm days is expected to increase during both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ for the period 2041-2070. However, more increase is expected under RCP 8.5 w/m$^2$ compared to RCP 4.5 w/m$^2$ during the period 2071-2100. Both RCP 4.5w/m$^2$ and RCP 8.5 w/m$^2$ show a marked increase in the trend of the projected number of warm days.

The Eastern part of Rwanda is expected to experience higher maximum temperature during the JF, MAM, JJA, SOND and annual period compared to western parts of Rwanda under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ A more negative changes are expected under RCP 8.5 w/m$^2$ whereas most of the eastern parts of the country are expected to have positive changes in projected JF mean maximum temperature for the period 2021-2050. The period between 2041 and 2070 indicates a positive change in the projected JF mean maximum temperature under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$. Notably, the period 2071-2100 shows positive changes under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$. More areas in Rwanda are expected to undergo positive changes in mean MAM maximum temperature under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ during the period 2021-2050. The period 2041-2070 and 2071-2100 indicate positive and increasing changes in mean maximum temperature towards 2100 under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$.

More areas in Rwanda are expected to undergo negative changes in mean JJA maximum temperature under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ for the period 2021-2050. whereas the periods 2041-2070 and 2071-2100 indicate positive and increasing changes in mean maximum temperature towards 2100 under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$.

More areas in Rwanda are expected to undergo negative changes in mean SOND maximum temperature under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ whereas the periods 2041-2070 and 2071-2100 indicate negative and decreasing changes in mean maximum temperature towards 2100 under RCP 4.5w/m$^2$ and positive and increasing changes in mean maximum temperature under RCP 8.5 w/m$^2$. More areas in Rwanda are expected to undergo negative changes of mean annual maximum temperature under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ during 2021-2050 whereas the period 2041-2070 and 2071-2100 indicate positive and increasing changes in mean maximum temperature towards 2100 under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$

The projected minimum temperature during the JF season is expected to increase under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$. However, the projected JF minimum temperature under RCP 4.5 w/m$^2$ shows larger changes for the period 2021-2050 and decreases towards the end of the century (2071-2100) whereas the smaller changes are expected under RCP 8.5 w/m$^2$ during the period 2021-2050 and increase towards 2100. Projected changes in MAM minimum temperature under RCP 4.5 w/m$^2$ show larger changes during 2021-2050 compared to 2071-2100. However, under RCP 8.5 w/m$^2$, larger changes are noted for 2071-2100 compared to 2021-2050. Projected JJA temperatures are expected to increase with changes expected to be highest under RCP 8.5 w/m$^2$ compared to RCP 4.5 w/m$^2$. Projected minimum temperature for the SOND season is expected to increase with the highest changes expected under RCP 8.5 w/m$^2$ compared to RCP 4.5. The trend of projected annual minimum temperature under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ is increasing. However, larger changes in magnitude as a percentage of the mean are expected for the period 2021-2050 and decrease towards 2100 whereas smaller changes in magnitude as a percentage of mean show trends that decrease in magnitude from 2021 towards 2100.

The trend of number of cold nights is expected to decrease in most parts of Rwanda with the changes in magnitude as percentage of mean of up to -60% under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ for the period 2021 to 2100. The trend of projected number of warm nights are expected to increase for the period between 2021 and 2100 under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ However, the changes in magnitude as a percentage of mean under RCP 4.5 w/m$^2$ indicate highest values in 2021-2050 decreasing towards 2100 whereas under RCP 8.5 w/m$^2$, lowest values are reported in 2021-2050 and increases towards 2100.

The highest projected JF minimum temperature is expected over eastern parts compared to western parts of Rwanda. In addition, projected minimum temperature is expected to increase from 2021 to 2100 with more areas under RCP 8.5 w/m$^2$ to experience the highest minimum temperature towards 2100. The highest projected MAM minimum temperatures are expected over eastern parts compared to western parts of Rwanda. In addition, projected minimum temperatures are expected to increase from 2021 to 2100 with more areas under RCP 8.5 w/m$^2$ to experience the highest minimum temperature towards 2100. The highest projected JJA minimum temperature is expected over eastern parts compared to western parts of Rwanda. In addition, projected minimum temperatures are expected to increase from 2021 to 2100 with more areas under RCP 8.5 w/m$^2$ to experience the highest minimum temperature towards 2100. The highest projected SOND minimum temperature is expected over eastern parts compared to western parts of Rwanda. In addition, projected minimum temperatures are expected to increase from 2021 to 2100 with more areas under RCP 8.5 w/m$^2$ to experience the highest minimum temperature towards 2100. The highest projected annual minimum temperature is expected over eastern parts compared to western parts of Rwanda. In addition, the projected minimum temperature is expected to increase from 2021 to 2100 with more areas under RCP 8.5 w/m$^2$ to experience the highest minimum temperature towards 2100.

The projected changes in JF minimum temperature for the period 2021-2100 show negative changes which imply that baseline minimum temperatures are higher than projected minimum temperature under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ However, the positive changes are expected towards 2100 (2071-2100) under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ The projected changes in MAM minimum temperature for the period 2021-2100 show negative changes which imply that baseline minimum temperatures are higher than projected minimum temperature under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$. However, the positive changes are expected under RCP 4.5 w/m$^2$ while negative changes are expected under RCP 8.5 w/m$^2$ towards the end of the century (2071-2100). The projected changes in JJA minimum temperature for the period 2021-2100 show negative changes which imply that baseline minimum temperatures are

higher than projected minimum temperature under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$. However, the positive changes are expected towards 2100 (2071-2100) under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$. The projected changes in SOND minimum temperature for the period 2021-2100 show negative changes which imply that baseline minimum temperatures are higher than projected minimum temperature under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ However, the positive changes are expected under RCP 4.5 w/m$^2$ while negative changes are expected under RCP 8.5 w/m$^2$ towards the end of the century (2071-2100). The projected changes in annual minimum temperature for the period 2021-2100 show negative changes which imply that baseline minimum temperatures are higher than projected minimum temperature under both RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ However, the positive changes are expected under RCP 4.5 w/m$^2$ and RCP 8.5 w/m$^2$ for the medium term (2041-2070). However, positive changes will persist towards the end of the century (2071-2100) under RCP 4.5 w/m$^2$ while negative changes are expected under RCP 8.5 w/m$^2$ towards the end of the century (2071-2100).

## 5.2 Conclusion and Recommendation

This section presents conclusions drawn from the research work which form the basis for recommendations, mainly categorized into (i) data management and quality control, (ii) delineation of the country into near homogeneous rainfall zones (iii) validation of satellite/reanalysis/climate models against observed climate (iv) downscaling climate models, Bias correction of downscaled climate and (v) analysis of past and projected climate change

### 5.2.1 *Climate data management and quality control*

Strengthening the observational network requires that Meteo Rwanda develops the capability to maintain and service instruments (mainframe and software) in order to increase efficiency in addition to training technicians, engineers and data managers on required technologies. Loss of data will also be avoided through building human and technical capacities in addition to having a modern archive for the safe custody of data. With the current number of observation stations having increased, it is also recommended that Meteo Rwanda establishes a mechanism for ensuring calibration of instruments and field data intercomparisons in addition to developing a strategy specifically on data observation and instrument maintenance.

In light of the spatial heterogeneity of this landscape and the severe data gaps, improving the spatiotemporal climatological and meteorological information was based on merging/blending of satellite-derived datasets with stations in order to produce a gridded complete dataset covering the period of 1981 to 2017. Therefore, Meteo Rwanda needs to ensure that the ENACTS datasets remain easily accessible and regularly updated. In addition, continuous improvement to the methodology used to develop ENACTS datasets should be considered such as the inclusion of topography which has significant influence on the weather and climate of Rwanda along with more robust interpolation techniques such as Kriging as opposed to simple IDW currently being implemented.

Notably, different mechanisms associated with seasonal or annual rainfall patterns may lead to increased or reduced number of near homogeneous rainfall zones. Therefore, there is a need for a detailed analysis of rainfall/temperature patterns to delineate the country to near homogeneous rainfall/temperature zones based on data at different temporal resolutions (monthly, seasonal and annual). This is expected to contribute to planning especially in key sectors such as agriculture, management of water resources and other sectors that depend on rainfall and temperature.

### 5.2.2 *Validation of satellite/reanalysis/climate models against observed climate*

Due to the severe gap in data, a detailed methodology was developed to produce ENACTS[10] and CHIRPS* by combining satellite estimates (TAMSAT[11] for ENACTS and CHIRP for CHIRPS[12]*) this included the use of IDW as the main interpolation technique. However, given the complex topography in Rwanda, more robust interpolation techniques that factor the influence of topography should be considered. In addition, with availability of more ground-based data,

10 Enhancing National Climate Services
11 Tropical Application of Meteorology using Satellite and other data
12 Climate Hazard Group InfraRed Precipitation with Station data

update to the ENACTS data is required to improve the correction factors generated through the bias correction techniques used to fill in the gap in missing data.

### 5.2.3 *Downscaling climate models and choice of scenarios*

A combination of both dynamical and statistical downscaling of global climate models was adopted in the present study. Both dynamical and statistical downscaling were used to ensure that key assumptions made in statistical approach are addressed by use of dynamical downscaling approach. Despite the efficiency of statistical downscaling, its relatively lower computational demands, and a diverse range of techniques, the method makes certain assumptions that are not always true. Therefore, it is recommended that efforts should be made to dynamically downscaled GCMs to finer resolution for impact assessments.

A total of three RCMs (CCLM4-8-17, RCA4 and REMO2009) and driven by three GCMs (MOHC, MPI and ICHEC). It is recommended that more RCMs and GCMs models be used. This will improve our knowledge in terms of representing evolution of systems and changes in climate.

Development of climate projections over Rwanda were based on RCPs. To compliments this work, it is recommended that more analysis based on Shared Socioeconomic Pathway (SSPs) be carried out which are based on the framework of the sixth phase of the Coupled Model Intercomparison Project (CMIP6). The CMIP6 data underpins the Intergovernmental Panel on Climate Change 6th Assessment Report. Inclusion of model output under the CMIP6 was aimed at providing insights on climate projection experiments following the combined pathways of Shared Socioeconomic Pathway (SSP) and Representative Concentration Pathway (RCP). This will address the limitation of RCPs i.e., does not include any socioeconomic "narratives" to go alongside them. Considerations of how socioeconomic factors may change over the next century include things such as population, economic growth, education, urbanization and the rate of technological development. This is because the two efforts to develop RCPs and SSPs were designed to be complementary i.e., RCPs set pathways for greenhouse gas concentrations and, effectively, the amount of warming that could occur by the end of the century whereas the SSPs set the stage for which reductions in emissions will – or will not – be achieved.

### 5.2.4 *Bias correction of downscaled climate*

GCM outputs are known to have a "drizzle problem," that is, too many low-magnitude rain events as compared to observations and hence the need for a more sophisticated approach for bias-correcting more stochastic variables (e.g., precipitation and solar radiation). Also, the fact that GCMs do not capture realistic interannual variability associated with events such as El Niño and La Niña. Quantile Mapping (QM) approach was adopted in order to appropriately bias-correct GCM output for monthly totals while ensuring realistic daily and interannual variability. It is however recommended that for more stochastic variables such as temperature, simple techniques such as change factor and delta methods be used. However, like all statistical downscaling approaches, it is assumed that biases relative to historical observations will be constant in the projection period. Therefore, more effort should be put to ensure that observed data used in bias correction are robust and good quality.

### 5.2.5 *Analysis of past and projected rainfall and temperature*

Maximum and minimum temperatures have been on the increase over the past period and are projected to increase under the RCP 4.5 w/$m^2$ and RCP 8.5 w/$m^2$ scenarios. Rainfall continues to be more variable both in space and time with trends showing increased rainfall in some areas and depressed rainfall in others. Global warming as a result of increased greenhouse gas emissions has been attributed to the observed changes in climate. Therefore, the Government of Rwanda through Meteo Rwanda should enhance education on the importance of weather and climate products to key sectors such as agriculture at all levels. This will ensure stakeholders have access to climate information to use in planning their socio-economic activities. On a large-scale landowners can help mitigate this increase in greenhouse gases by practising agroforestry to help reduce carbon emissions.

Rwanda's government has made remarkable efforts to increase agriculture production through many programs such as the crop intensification program introduced in 2007, and scaling up the consolidated land among many others. The

observed increase in temperature will harm agricultural production and food security in Rwanda with small-scale farmers being the most affected. This calls for more measures and new adaptation strategies to ensure future capacity to cope with the challenges caused by the temperature increases. In the same logic, many scholars have concluded that temperature plays a big role in the spatial and temporal distribution of disease vectors (Sun et al., 2017). The policymakers must be aware to take the necessary measures in their national planning program for sustainable development. Therefore, there is a need for policymakers in consultation with scientists to develop climate adaptation strategies for each scenario to mitigate against the negative impacts of changing climate on agricultural production. Increasingly frequent droughts might be offset by improved water and agricultural management practices and raising yields in wetter areas may be a more viable option than extending agriculture into more marginal areas. In addition, policymakers should encourage the use of the available technology such as mobile phones and radios to educate farmers on the effects of different weather conditions on their crops and how to mitigate these effects. The ease of access to weather information builds up the capacity of the community to make the appropriate decisions in case of climate extremes. Encouraging adoption of different approaches are some of the steps donors, policymakers and the government can take to cushion against the adverse effects of changing climate.

Previous studies have focused on temperature trend variability but the importance of topography as a regulator of Rwanda climate has not been well recognized. In addition, those previous studies focus mainly on annual and intra-annual series and use few observatories, which may fail to capture the true image of trend behavior from each season. The present work mainly focuses on the spatial and temporal (seasonal and annual) variability of maximum. The knowledge of seasonal patterns of temperature is very important in understanding changes in land uses, crop Prognostic climate modeling predicts future climate, such as global warming trends, using current or historic data (ocean structure, radiative forcing, etc) as a basis

Continuous research ought to be carried on since rainfall trends and variability are bound to change due to the influence of teleconnections patterns that are highly influenced by climate change. Rainfall during two dry seasons (JJA) and (JF) needs to be analyzed for a better considerate of rainfall changes over the study area

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## ANNEXES

Annex 1: TORs

Annex 2: List of stations used

Annex 3: Manual on downscaling climate projections