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Spatio-Temporal Trend Analysis of Projected Temperature over Rwanda

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Abstract: *This study aims primarily at quantifying the magnitude of projected temperatures over Rwanda on seasonal and annual timescales for the period 1994-2050. The datasets for this period were generated by BCM2.0 for the SRES emissions scenario SRB1, CO_2 concentration for the baseline scenario (2011-2030) using the stochastic weather generator (LARS-WG). Trend analysis of temperatures (minimum, maximum and average) for the period 1994-2050 was performed on projected daily temperature dataset. It was observed that on average, there will be a steady decline in the temperatures. The decreases in temperatures are expected especially during rainy seasons while the increases are predicted during dry seasons.*
Key words: *projection, temperature, trend, Rwanda.*

I. Introduction

Although the increases in temperature patterns have been reported in past centuries, more variability and changes are projected in coming years (IPCC, 2007). Recent progressive increase in temperature results from global warming caused by rapid increase of greenhouse gases concentrations in the atmosphere since the industrial era (Nicholls et al., 1996; Jones et al., 1997; Boko et al., 2007; Vincent, 2007 and Hahn et al., 2009).

On May 9, 2013, the daily mean atmospheric concentration of carbon dioxide (CO_2) of Mauna Loa, Hawaii, surpassed 400 parts per million (ppm) for the first time since measurements began in 1958 (NOAA, 2013). This was bound to result in increases of temperatures of between 0.5 °C and 1 °C; for the period of 1958-2013 (Keeling, 2013). An increase in atmospheric concentrations of greenhouse gases equivalent to a doubling of carbon dioxide (CO_2) would force a rise in global average surface temperature of 2 °C to 4 °C by 2100 (Parry et al., 2007, Duncan et al., 2009 and Davies et al., 2010). In addition, the atmospheric concentration of nitrous oxide (N_2O) and methane (CH_4) in 2010 was about 323.2 ppb and 1808 ppb or 20% and 158% of the pre-industrial level respectively. The impact of nitrous oxide (N_2O) on climate, over a 100-year period, is 298 times greater than equal emissions of carbon dioxide. This shows the degree to which the world is exposed to more warming in future (WMO, 2013) leading to rise in temperatures. This phenomenon is bound to continue in the coming years though Gerald, (2009) argued that the world faced the stagnation of temperature for the period 2000-2010. It is worth noting that this stagnation of temperatures might have negative impacts in predicting the future climatic conditions.

The rise in temperature of between 0.18 °C and 0.6 °C per decade has been seen not only in Rwanda for the period of 1961-1990 (Muhire and Ahmed, 2014), but also in other African countries like Sudan (North and South), Ethiopia and Uganda for the period 1961-2000 (Engelbrecht et al., 2002; Kruger and Shongwe, 2004; Washington and Pearce, 2012). Similarly, an annual mean temperature increase of 0.1 °C to 0.3 °C per decade from 1961 to 2000 was observed in Burundi, inland Kenya and Tanzania, Madagascar, Eritrea and South Africa (Engelbrecht et al., 2002; Kruger and Shongwe, 2004; Washington and Pearce, 2012). Therefore, an analysis of the projected temperatures at local and regional levels is necessary as it forms the basis for better preparedness. It is for this reason that this study attempting to quantify the magnitude of projected temperatures over Rwanda for the period 1994-2050 was conducted.

The projection of temperature trends over Rwanda is important as it helps in understanding the expected changes in temperatures, with a view to predicting their impacts on expected changes and variability of rainfall. The results can also be used in further exploration of the impacts of projected climatic conditions on both natural environment and human activities. Furthemore, this study seeks to shed light on the expected threats of increasing occurrences of droughts so that appropriate measures are taken to counter them. This phenomenon has negative impact on not only agriculture, but availability of water as well (Chamchati and Bahir, 2011; Muhire and Ahmed, 2014).

II. Study area

Rwanda is one of African countries located in eastern part of the continent which covers an area of 26,338 square kilometres. The topography varying between 900 m to 4,500 m above mean sea level is ascending from East to West of the country and it gives rise to a spatial variability of temperatures increasing from 22 °C in the east of the country to 14 °C in north western highlands (Figure 1B) (Sirven et al., 1974; Ilunga et al., 2004).

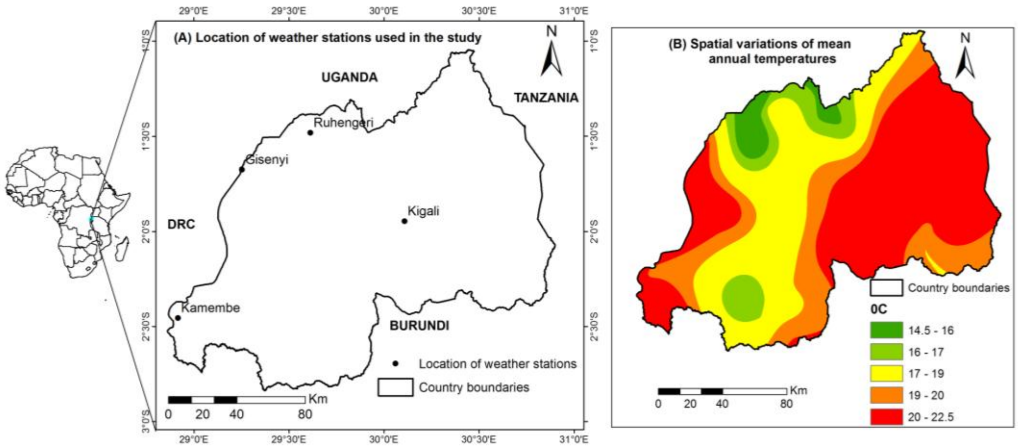

Figure 1: Location weather stations used in the studyand spatial variations of annual mean temperatures ver Rwanda for 1961-1993

Mean annual temperatures range between 19 °C and 22 °C in the eastern lowlands while they vary between 18 °C and 20 °C in the central plateau region. The regions around Kivu Lake and Bugarama plains, have mean annual temperature of between 19 °C and 22 °C with the mean temperatures fluctuating between 14 °C and 18 °C in the northern highlands and over the Congo-Nile crest (Ilunga et al., 2004; REMA, 2009).

III. Materials and methods

Daily temperature (minimum, maximum and average) used in this study were obtained from Rwandan Meteorological Center based in Kigali. Projected daily temperature data for 1994-2050 were derived from daily temperature datasets of 1961-1993 from 4 stations using the stochastic weather generator (LARS-WG) (Semenov and Brooks, 1999; Semenov and Stratonovitch, 2010). The projections of observed temperature data (1961-1993) were made with help of four GCMs used in the IPCC AR4 named as BCM2.0 (Bjerknes Centre for Climate Research), CSIRO-MK3.0 (Commonwealth Scientific and Industrial Research Organisation), MPI-M-EH5 (Max-Planck Institute for Meteorology) called also ECHAM 5-OM for the SRES emissions scenarios SRB1 and CNRM-CM3 (Centre National de Recherches Météorologiques) for the SRES emissions scenario SRA2.

SRES emissions scenarios SRB1 and SRA2 were selected to be used in projecting data from the assumptions that Rwanda is one of the countries characterized by high population growth with rapid changes in economic structures and improved equity and environmental concern (Nakicenovic and Swart 2000; MINERENA, 2010; NISR, 2011; NIRS, 2012). The CO_2 concentration for the baseline scenario (2011-2030) was chosen to be used as it falls in study period. The projection of temperature data using all above mentioned four GCMs used in the IPCC AR4; have been performed in process of selecting the appropriate GCM to be used in projecting Rwandan temperature data. Thus, the selection and validation of GCM (Figure 2-5) to be used in projecting Rwandan temperature data were made after correlating the observed and projected temperature data by LARS-WG for 1995-2010.

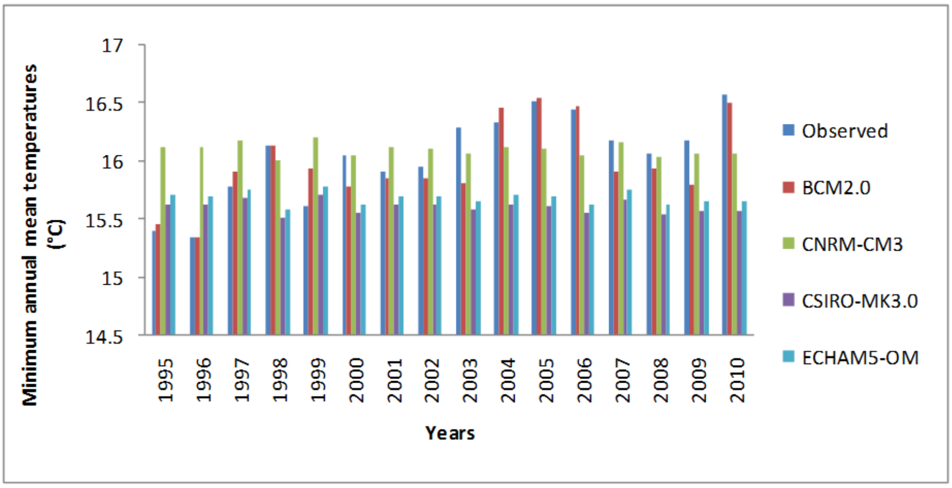

Figure 2: Observed and projected minimum annual mean temperature (by four GCMs) at Kigali weather station (1995-2010)

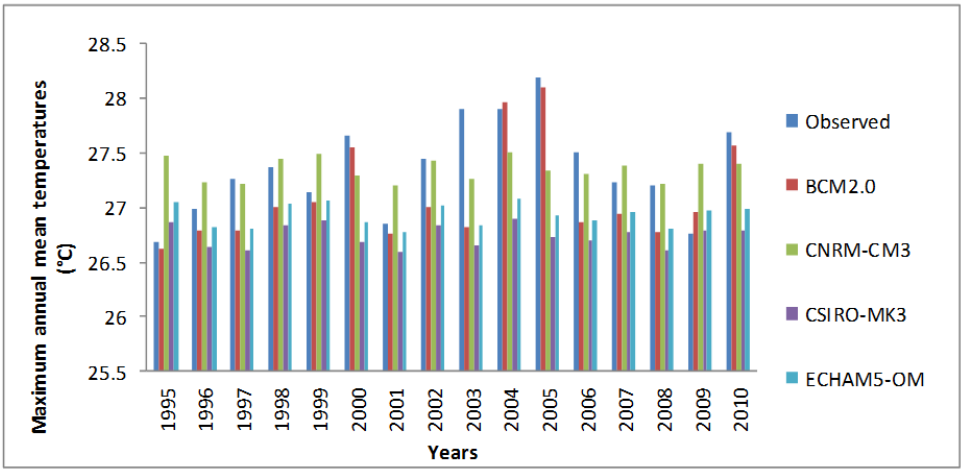

Figure 3: Observed and projected maximum annual mean temperature (by four GCMs) at Kigali weather station (1995-2010)

Regression analysis between observed and projected minimum annual temperatures (1995-2010) by four GCMs named as BCM2.0, CNRM-CM3, CSIRO-MK3.0, ECHAM5-OM at Kigali weather station revealed a high correlation coefficient of 0.848, 0.766, 0.778 and 0.733 respectively. Correlation coefficient of 0.826, 0.764, 0.774 and 0.756 was also seen between observed and projected maximum annual temperatures (1995-2010) by BCM2, CNRM-CM3, CSIRO-MK3.0 and ECHAM5-OM respectively at the same Kigali weather station.

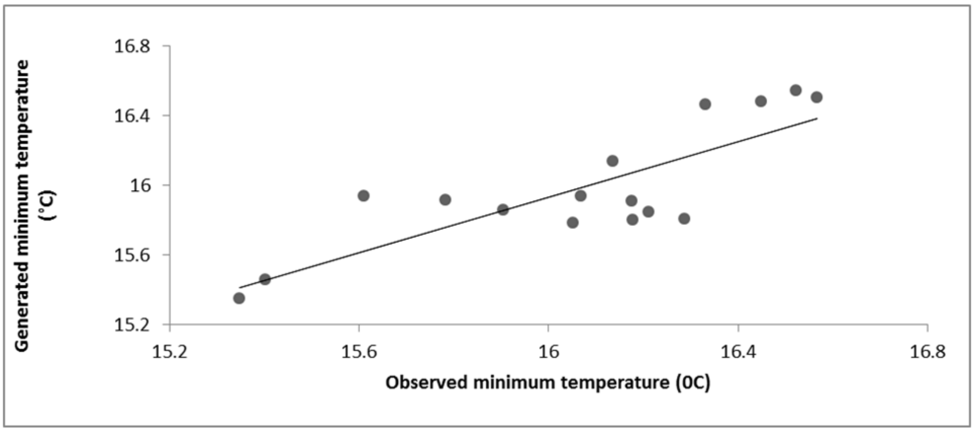

Figure 4: Correlation between observed and projected minimum annual temperature (by BCM2.0) at Kigali weather station (1995-2010)

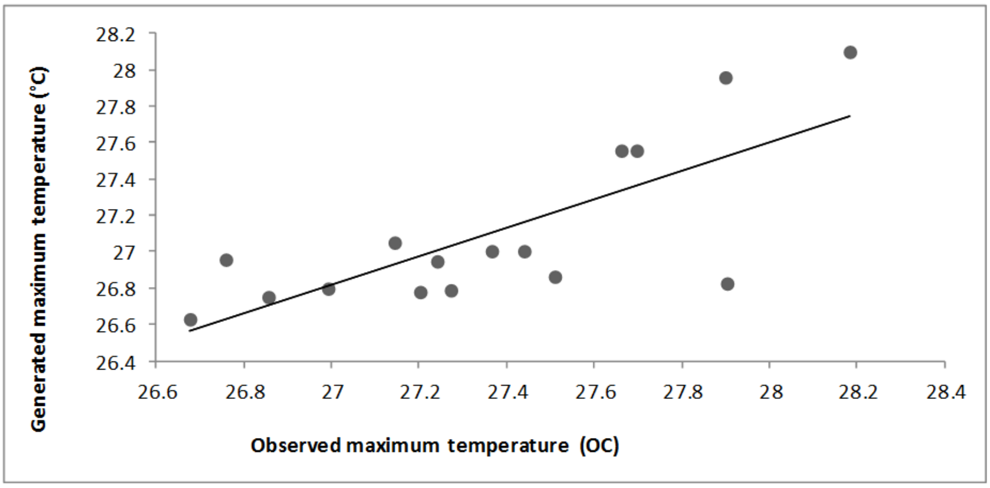

Figure 5: Correlation between observed and projected maximum annual temperature (by BCM2.0) at Kigali weather station (1995-2010)

Therefore, the temperature data projected by BCM2.0 was selected to be used in this study for having higher correlation between observed and projected temperature data. However, the use of temperature data from only four weather stations resulting from the lack of comprehensive daily temperature data for the period 1961-1993 constitutes a major drawback in spatio-temporal trend analysis of projected temperature data over Rwanda. The lack of comprehensive temperature data for 1994-2012 is an added drawback in projecting the temperatures over Rwanda. Consequently, the temperature data for this period (1994-2012) were used in validation of generated data by LARS-WG.

IV. Methods

The mean standardized anomaly indices for each year, j(X_j), for representative weather stations were calculated as follows: $X_j = \frac{R_{ij} - \overline{R}_i}{\sigma_i}$ where: R_{ij} is the annual projected temperatures in °C; $\overline{R_i}$ is the mean annual projected temperature over the study period (1995-2050); σ_i is the standard deviation of annual mean projected temperatures over the study period (Mutai et al., 1998). These mean standardized anomaly indices were calculated to assess the temporal variability (1994-2050) of projected annual mean temperatures of selected weather stations.

A trend analysis of mean temperature was undertaken for the period 1994-2050 using the projected daily records from which seasonal and annual trend values were derived. Statistical techniques were applied on projected data from every weather station to determine the magnitude of trends in mean temperatures at seasonal and annual resolutions (Kizza et al., 2009; Del Río et al., 2012, Muhire and Ahmed, 2014; Muhire et al., 2015).

V. Results and discussion

Figures 6-8 show the projected annual standardized temperatures for four selected weather stations. Gisenyi and Kamembe represent the region around Kivu Lake, Kigali is located in the eastern lowlands, and Ruhengeri lies in the highlands.

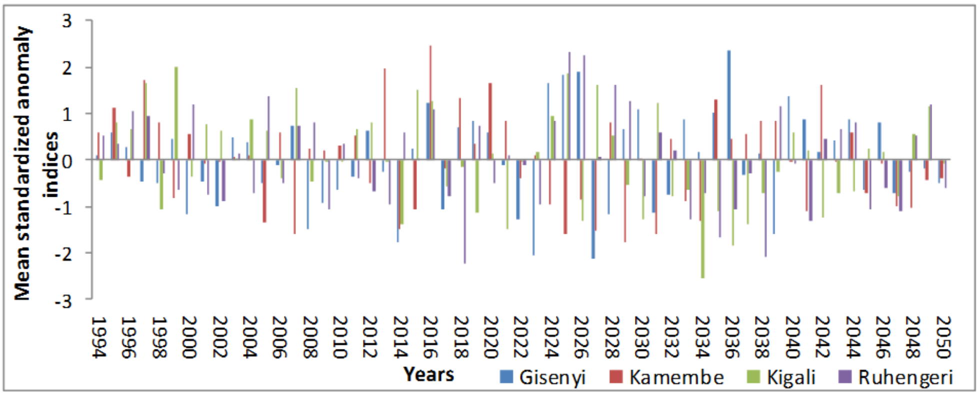

Figure 6: Projected annual minimum standardized temperatures (1995-2050)

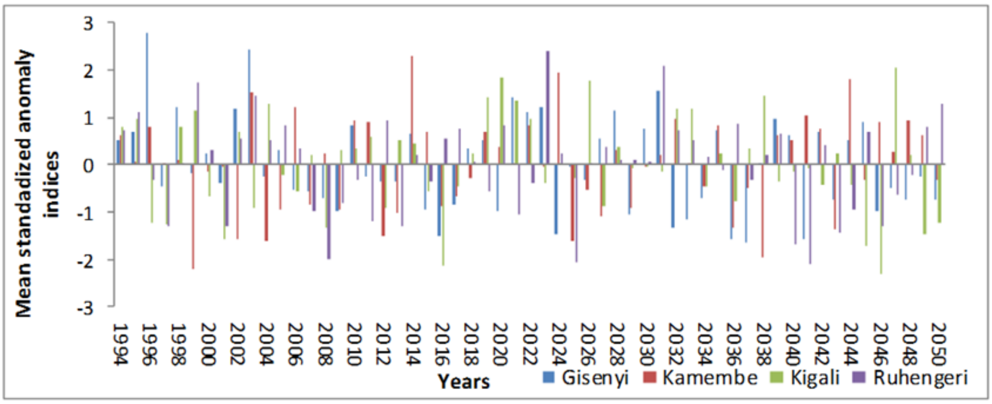

Figure 7: Projected annual maximum standardized temperatures (1995-2050)

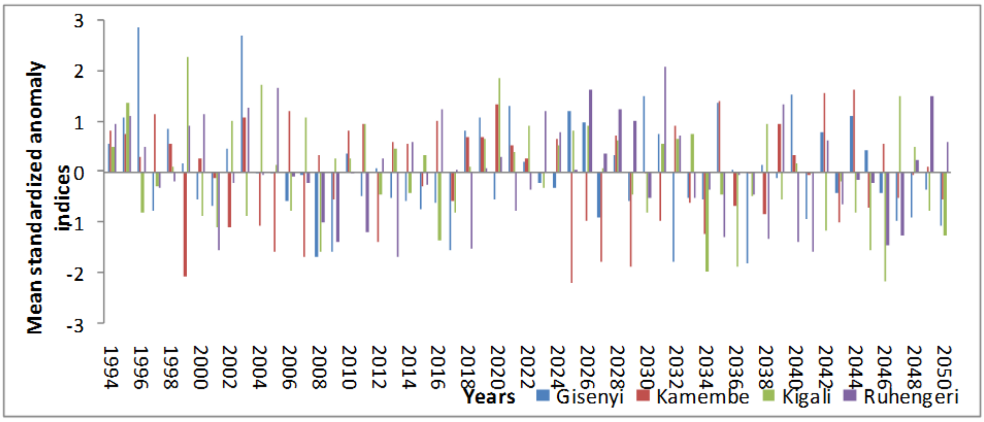

Figure 8: Projected annual mean standardized temperatures (1995-2050)

It is estimated that the periods 1994-2000 and 2020-2026 are to have an increasing temperature trend while the periods 2006-2016 and 2031-2050 will register decreasing temperatures (minimum, maximum and average) at most of the weather stations under investigation. Notwithstanding that, a high variability in annual temperatures (minimum, maximum and average) tending to decrease is projected in the coming years up to 2050 in most of these weather stations (Figure 6-8). More fluctuations are expected in annual minimum temperatures especially in the periods 2012-2027 and 2034-2048. This may result into high fluctuations in precipitation frequency, patterns and intensity; the end results being into low agricultural production (Muhire et al., 2015). However, Figure 6-8 do not give a clear picture of the magnitude and direction of changes in temperatures over the period of study (1995-2050). It is with this in mind that the magnitude and direction of trends in temperatures (minimum, maximum and average) were calculated and presented (Figure 9-11 and Tables 1) at monthly, seasonal and annual timescales with a view to giving a realistic outlook of what is anticipated in the coming years.

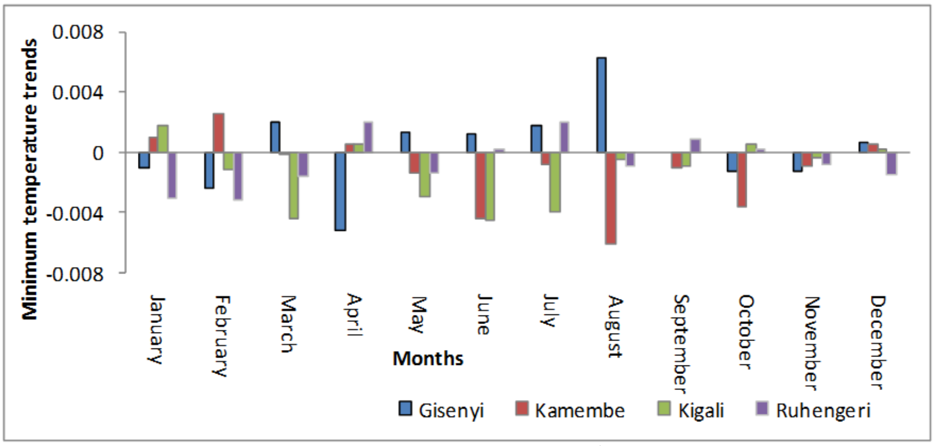

Figure 9: Projected monthly minimum temperature trends (˚C per year) for the period 1995-2050

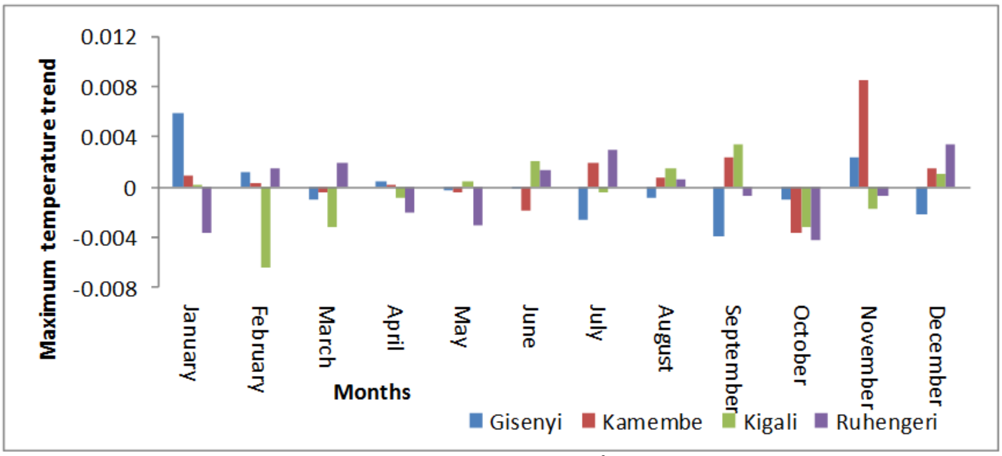

Figure 10: Projected monthly maximum temperature trends (°C per year) for the period 1995-2050

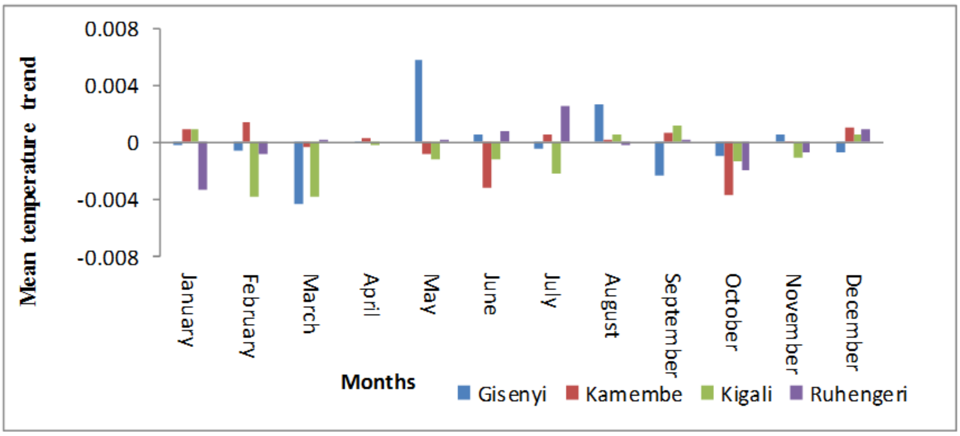

Figure 11: Projected monthly mean temperatures trends (°C per year) for the period 1995-2050

Figure 9 shows a decreasing trend (highest) of between 0.04 °C and 0.06 °C per decade at Kigali weather station in March, June, and July; at Gisenyi in April; and at Kamembe in June and August. The highest increasing trend of 0.063 °C per decade is expected at Gisenyi in August. In addition, Gisenyi is the only station with 6 months (March, May, June, July, August and December) showing an increasing trend of between 0.009 °C and 0.02 °C per decade. The rest of the regions are expected to have less than four months with positive trends. November is the only month showing a decreasing trend of between 0.0039 °C and 0.012 °C per decade in minimum temperatures at all selected weather stations. Arising from these estimates, it is safe to conclude that Rwanda is likely to experience more cool spells in the coming years especially in the northern highlands, which naturally have the lowest temperatures. However, these changes will not have much impact on both natural and human activities as long as they are not significant.

The monthly maximum temperatures present less variability compared to minimum temperatures for the period of 1995-2050 (Figure 10). October is the only month with a decreasing trend of between 0.01 °C and 0.043 °C per decade at all selected weather stations. A high decrease of 0.065 °C per decade in maximum temperature is forecast in February at Kigali weather station, while the highest increase of 0.085 °C and 0.058 °C per decade will be observed in November and January at Kamembe and Gisenyi respectively. Kamembe is expected to register an increasing pattern in 8 months, Kigali and Ruhengeri in six months, and Gisenyi in 4 months within a year. This is a clear indication that warmer spells are likely to be reduced in Rwanda in the coming years. Hence, the frequent occurrences of drought episodes observed especially in eastern and southern regions of Rwanda for the past years (Muhire and Ahmed, 2014) are bound to be reduced.

The highest increase in annual mean temperature (0.058 °C per decade) and decrease (0.043 °C per decade) are expected at Gisenyi weather station in May and March respectively (Figure 11). This translates to more extreme temperatures in the region around Kivu Lake. Low temperatures are expected at Ruhengeri weather station, which is located in the northern highlands. Table 7.1 shows the magnitude and direction of temperature trends (minimum, maximum and average) at seasonal time scale.

Table 1: The seasonal temperature trends (°C per decade) for the period 1994-2050

Stations	Short dry season			Long rainy season			Long dry season			Short rainy season			Annual		
	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.
Gisenyi	-0.01	-0.002	- 0.005	0.009	- 0.033	- 0.012	0.031	-0.01	0.01	-0.01	- 0.008	- 0.095	0.005	- 0.014	- 0.004
Kamembe	0.014	0.009	0.01	- 0.003	- 0.002	- 0.003	-0.019	0.002	- 0.01	-0.019	- 0.002	-0.01	- 0.007	0.002	- 0.003
Kigali	0.003	-0.018	0.01	- 0.023	- 0.012	- 0.017	-0.03	0.01	- 0.01	-0.002	- 0.005	- 0.004	- 0.013	- 0.006	- 0.001
Ruhengeri	-0.03	0.0036	-0.01	- 0.003	-0.01	- 0.007	0.0043	0.016	0.01	0.0012	- 0.019	- 0.004	- 0.006	- 0.002	- 0.004

Key: Min.= Minimum; Max.= Maximum; Av.= Average

It is clear from the Table 1 that increasing trends of between 0.002 °C and 0.031 °C per decade in minimum and maximum temperatures are predicted during both the short and long dry seasons. It is only at Gisenyi and Ruhengeri weather stations where increases of 0.0087 °C and 0.0012 °C per decade are expected during the long and short rainy seasons respectively. Gisenyi weather station presents a decreasing pattern in maximum temperature during the long dry season.

At annual resolution, a negative trend in temperatures (minimum, maximum and average) is predicted at Kamembe and Kigali while an increase in annual minimum and maximum temperatures is expected at rate of 0.005 °C and 0.0018°C per decade at Gisenyi and Ruhengeri respectively. However, the annual mean temperatures are predicted to decrease at all weather stations. This means that the period of 1961-1993 was warmer compare to the period 1994-2050. This will likely reduce the rate of evapo-transpiration leading to general decrease in rainfall over the country especially over central plateau and south-eastern lowlands which receive naturally a low amount of rainfall (Muhire and Ahmed, 2015).

VI. Conclusion

An increase in temperatures (minimum, maximum and average) is projected in the period 1994-2000. A repeat is expected in the period 2039-2042 while a decreasing is expected in the periods 2006-2016 and 2043-2047. The increase in temperatures predicted during the dry seasons particularly the long dry seasons might not add much on the mean rainfall from the fact that the country will be under the influence of dry Saint Helena and Azores anticyclones (Ilunga et al., 2008; Kizza et al., 2009; Muhire et al., 2015). However, the anticipated decrease in temperatures during the rainy seasons might lead to reduced evapo-transpiration, resulting in reduction of intensity, frequency of mean rainfall during the said seasons. Furthermore, to have a comprehensive understanding about the impacts of predicted changes in temperatures over Rwanda will require a correlation between mean temperatures and precipitations.

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