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Research Article

Assessing Variability and Trends of Rainfall and Temperature for the District of Musanze in Rwanda

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Variability in rainfall and temperature results in different impacts on agricultural practices. Assessesment of variability and trend of rainfall and temperature for the district of Musanze in Rwanda was conducted using six meteorological stations for a period of 37 years, ranging from 1981 to 2018, and data were obtained from Rwanda Meteorology Agency. Musanze district is located in highland areas of Rwanda, understanding the variability and trend in rainfall and temperature is paramount to increase the uptake of climate information and support strategic orientation. The Mann–Kendall nonparametric test and modified Mann–Kendall were used to assess the trend in rainfall and temperature, whereas Sen's slope estimator was used to assess the magnitude of change. The results from both methods showed much similarity and consistency. The assessment of variability and trend in rainfall and temperature in Musanza district indicated that increasing temperature and decreasing rainfall trends gave an indication of changes in variability and trend in rainfall and temperature. The annual pattern revealed a substantial downward tendency of −25.7% for Nyange, the only station with constant decreasing trend over all seasons, DJF, −61.4%, SON, −12.2%, JJA, −40.3%, and MAM, −4.35. Temperature analysis for both maximum and minimum indicated increasing trend which was signal for constant warming up in the area. The results from coefficient of variation indicated a high disparity in rainfall variation from June to August which ranged between 51 and 74%, and other seasons changes were moderate.

1. Introduction

The variation in trend of rainfall and temperature over the East African regionnear Lake Victoria basin, where Rwanda is located, showed a significant decreasing trend, as a sign of decreasing rainfall over many parts of the region [1];whereby the dryland areas of Eastern Africa are getting more affected by changes in rainfall and temperature [2]. The majority of East African Countries (EACs) consider agriculture to be one of the key sectors contributing 40% of the Gross Domestic Product (GDP) of the countries where more than 80% of the population depends on agriculture, the variation in rainfall and temperature has a significant impact on the socioeconomic development of East African Countries (EACs). The Inter Tropical Convergence Zone (ITCZ) oscillation, which moves from the northern hemisphere to the southern hemisphere and vice versa, is a contributing factor in the weather and climate variation pattern over the EAC region[3–6]. In light of the research done on data from 1963 to 2012, which showed variability in annual decadal across Eastern Africa and the Greater Horn [7], the trend, regional distribution, and temporal distribution of both rainfall and temperature have been shifting recently. The disparity between rainfall variability and temperature trend has been referred to as the "East African climate paradox," which calls for collaborative research, and improved modeling capabilities with sufficient quality representative using long series of data for the entire region [8–10]. There was a tendency toward decreasing annual precipitation, which was associated with an increase in climatic extremes and low frequency [11]. Variability and change have continued to affect negatively crop outputs, which has impacted on residents' economic empowerment [12]. Strategic actions to adapt and lessen the effects of extreme climatic events that significantly impact farmers have been spurred by variability sensitivity, which has been influenced by changes in temperature and rainfall both in spatial and temporal distribution [13]. According to the research conducted in Ethiopia's Lake Tana Basin, change and volatility have detrimental effects on seasonal rainfall [14]. There is a need for more research studies because of a rise in temperature and a decline in rainfall in Himachal Pradesh, India, without any statistically significant changes [15]. The study was conducted in Dinhata of Koch Bihar district, West Bengal, to detect the trend on five meteorological parameters rainfall, rainy days, temperature, relative humidity, and sunshine hours which were analyzed for the period of 1980–2015 which indicated manifestation of climate change [16]. In order to assess the association between the so-called "short rains" of October and November and four tropical indices, a 139-year rainfall record for East Africa was examined. The results showed a strong wetness that is time dependent [17].

The Intergovernmental Panel for Climate Change [18, 19] projected an increase in temperature and sea-level rise by 1.4–5.8°C and 0.1–0.9 meters, respectively, from 1990 to 2100. The IPCC-2001 further indicates the increase in greenhouse gas concentration which is likely to increase global temperature by 0.6 ± 0.2 degree Celsius since 19^{th} century. Variability in rainfall and temperature has been seen as an important factor that contributes immensely to the water for crops and optimum temperature conditions for living organisms to flourish; on the other hand, extreme events were seen to have impacts associated with floods and drought [20]. Therefore, it is very vividly clear that rainfall, temperature variability, and trend are important when underpinning the impacts of climate change [21]. The study of the winter maximum ($t_{\max}$), lowest ($t_{\min}$), and average (t_{mean}) temperatures at six meteorological stations in North Bengal, India, revealed significant warming [22].

The ENSO and IOD strongly influence annual rainfall variation which was evident in the model and observations [23, 24]. The Madden Julian Oscillation was one of the factors contributing to interannual variability and intraseasonal variability of rainfall and temperature in East Africa [25, 26]. Zonal circulation between the Indian Ocean and the Pacific Ocean contributed to variability in seasonal rainfall, and at the same time, it was seen to be weakening within the Pacific Ocean [27]. The examination of wind gusts over a ten-year period revealed the return period with the aim of reducing their disruptive influence on socioeconomic activity [28].

The climate change and climate variability have greatly exacerbated the existing problems of health, food security, and economy especially in the least developing countries [29, 30]. The studies have indicated that anthropogenic forcing has contributed to the vulnerability and change of Eastern and Greater Horn of African countries, especially seasonal climatic [31, 32], and are likely to keep increasing surface air temperature if nothing is done to reduce greenhouse gases [33]. The study examined the sustainability of extensive groundwater-based irrigation by determining the trend in groundwater depth (GWD) and exploring the factors that characterize the identified trends in India's lower Ganga River basin (LGRB), which covers an area of 195,601 km^2. Seasonal rainfall during the premonsoon, monsoon, postmonsoon and winter seasons each showed increasing trends [34].

According to the study conducted in Bangladesh titled "Assessment and Adaptation Strategies through the Prism of Farmers' Perception," the trend and spatiotemporal distribution of rainfall and temperature are crucial for planning sustainably for available water resources and reducing the adverse effects of climate change on agriculture [35]. According to research conducted in the Bhagirathi River Basin (BRB), Switzerland, between 1996 and 2017 agricultural practices caused the groundwater levels in 168 drilled wells to drop [36]. The study "Spatio-temporal characterization of rainfall in Bangladesh: an innovative trend and discrete wavelet transformation approaches" showed that there had been a significant change in rainfall from 1966 to 2019 that had an impact on the country's agricultural system and was associated with climate change [37]. According to a study on the variables causing extensive unsustainable groundwater development for irrigation in India's lower Ganga River basin, the shallow groundwater resource in the area is quickly running out as the depth of the groundwater increases during the rainy season. The rate of groundwater recharge is substantially lower than the amount of groundwater abstraction during dry seasons, and it has been found that a diminishing trend in rainfall increases groundwater depletion [38]. A study conducted between 1951 and 2015 found that the severe variability in rainfall was attributed to climate change, affecting all agricultural activities in Bangladesh and India [39].

2. Materials and Methodology

2.1. Study Area. Musanze district is located at an altitude of 1,860 m above mean sea level at latitude −1.3°S and longitude 29.3°E (Figure 1). It is one of the fastest growing districts in the country at a rate of 1% per annum, with a population of 398,986 people according to the 2012 census. The district covers 530 km^2 and borders two neighboring countries Uganda and the Democratic Republic of Congo to the north, Gakenke district to the south, Burera district to the east, and Nyabihu district to the west. The mountain gorillas predominately occupy a range of volcanic mountain parks, covering 60 km^2, which include Muhabura, Bisoke, Karisimbi, Sabyinyo, and Gahinga [40, 41]. The area is a tourist attraction for mountain hiking, gorilla trecking, and special species in Virunga Volcanic National Park. The largest water body is Ruhondo Lake which covers 28 km^2. The district is the country food basket, especially on variety crops such as beans, wheat, maize, Irish potatoes, and vegetables; livestock farming is also practiced in the area.

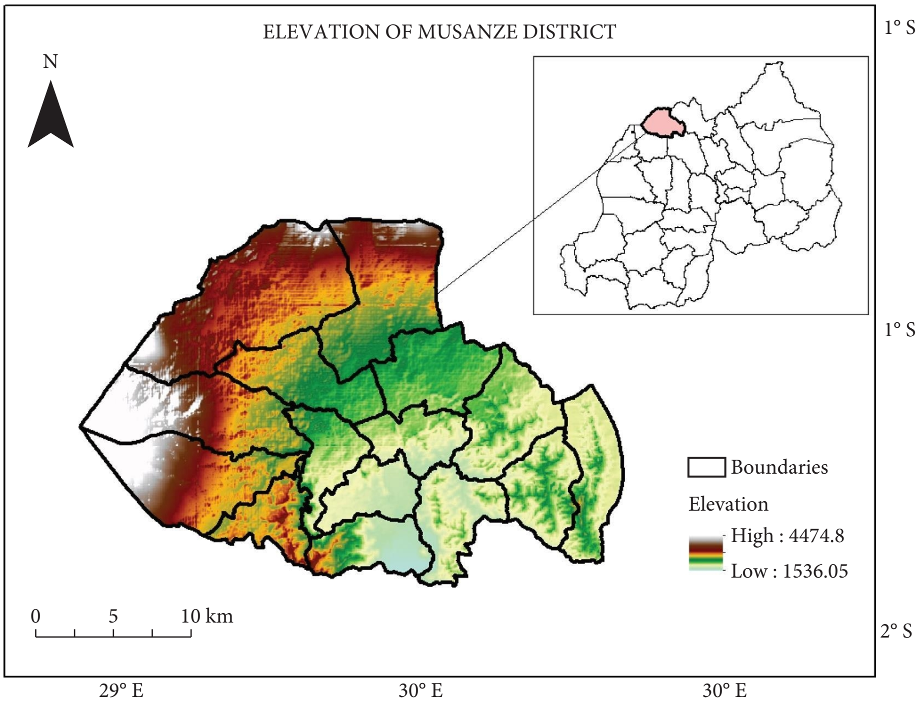

Figure 1: Location of Musanze district on map of Rwanda (elevation in meters-M).

Musanze is characterized by a humid climate with the bimodal type of rainfall having the peaks in April from March to May and November from September to December, respectively; the dry spells are experienced between the two rainy seasons.

The rainfall in Musanze is generally high compared to other parts of the country, ranging from 1184 mm to 1800 mm annually [41]. Musanze has a climate with relatively cool temperatures with warmth during the day and breezy during the nights. The minimum temperature can go as low as 13°C on average, but there are some places where temperature can go as low as 10°C, especially in the high altitudes, and the average maximum temperature of 20°C [42]. The extreme weather and climate events are usually linked with the distraction of property and other severe impacts on agricultural productivity. Some seasons are affected by dry spell conditions; for instance, in the two consecutive seasons 2008A and 2008B, harvest was seriously affected negatively with merely very poor produce by smallholder farmers [43].

2.2. Data Used in the Study. The data used in the study were from a network of meteorological stations within the Musanze district, which was provided by the Rwanda Meteorology Agency (Meteo Rwanda). The network of stations was spatially distributed across the area with available data from 1981 to 2018.

2.2.1. Homogeneity Testing. Numerous statistical approaches, including the Pettitt test, the standard normal homogeneity (SNH) test, the Buishand test, and the sequential Mann–Kendall test, have been widely employed to assess the homogeneity of climate time series [44–46]. The Pettitt test [47] which is frequently used to detect rapid changes or shifts in hydrological or climatic variables was used in this study to examine the homogeneity of rainfall and temperature data over Musanze district. The test can assist in identifying substantial changes in the average or distribution of climatic variables over time, indicating a possible shift in underlying climatic trends. The test is based on the ranking r_i of the k_i values. The ranks r_i are obtained by ordering the data in crescent order, so that the smallest one gets ranked 1 and the highest gets the n-rank. The U_k is then obtained as follows:

$$U_k = \sum_{i=1}^{k} r_i - k(n+1). \tag{1}$$

If a break occurs in the year K, then the U_k is

$$U_k = \max_{1\leq k\leq n} |U_k|. \tag{2}$$

The statistical significance of the break point is checked by comparing the value of U_k to its theoretical value with α as the significance level.

$$U_{k\alpha} = \frac{\left(-L_n\left(\alpha\left(n^3 + n^2\right)\right)\right)^{1/2}}{6}. \tag{3}$$

More information on the homogeneity test and their mathematical formulations can be obtained in [48–50].

Prior to testing the homogeneity test for the data over Musanze district, the meteorological service performs daily quality check. The obtained data have been quality controlled. We also employed the statistical measure to test the findings further. Figure 2 shows the results of the homogeneity test for rainfall data. After detecting a suspicious value, we proceeded on checking the recorded value and compared the values to the nearby stations to confirm or reject the values. It was observed that the days where we thought of having wrong records were in reality not (for rainfall) and the higher amount recorded on those days were correct. In addition to the analysis, based on our local expertise on the areas, the stations that recorded these values were located on the windward sided of the mountain where rain used to be higher than the nearby areas. Similar analysis for temperature was performed and the results are presented in Figure 3. In addition, the suspected values are presented in Figure 3 and the nearby station values are also indicated. We reconfirmed or adjusted the numbers based on all of these factors and proceeded with the data analysis.

2.3. Mann–Kendall. The Mann–Kendall method was used to establish variability and trend in the Musanze district; a nonparametric rank-based test was used to test the statistical significance of the observed trends in a time series [51, 52]. Mann–Kendall was employed in the study to identify hot sites for ground water depletion in the Indian districts of Anantapur, Kurnool, Chittoor, and Prakasham [53]. Positive values denote an increasing trend, whereas negative values denote a downward slope [54]. Using the Mann–Kendall method, the Bhagirathi river basin in India was demarcated using spatial-temporal zoning, which indicated the need for management techniques [55].

A similar approach has been used to study the trend in rainfall over the eastern parts of Rwanda [56]. A similar method was used to examine the rainfall trend over the eastern sections of Rwanda. Ajmer's, India, annual, seasonal, and monthly rainfall trends and fluctuations were studied between 1973 and 2016 [57]. Using data from six meteorological stations in North Bengal between 1915 and 2016, the study [58] looked at recurring trends and turning points in the winter time temperatures. At Dinhata in the Koch Bihar district of West Bengal, for the years from 1980 to 2015, a research study was conducted to analyze trends in rainfall, rainy days, maximum and minimum temperatures, morning and evening relative humidity, and bright sunlight hours [16]. The study looked closely at the spatiotemporal characteristics of precipitation in Bangladesh and India (Tapash et al., 2020). In addition, the study also looked at the regional variations and changes in India's annual and seasonal rainfall (Tapash et al., 2021).

$$\mathbf{S} = \sum_{\mathbf{i=1}}^{\mathbf{n-1}} \sum_{\mathbf{j=i+1}}^{\mathbf{n}} \mathbf{sgn}\left(\mathbf{x_j} - \mathbf{x_i}\right), \tag{4}$$

where **sgn** is the sign function, $\mathbf{x_i}$, $\mathbf{x_j}$ are the sequential data values, n is the number of datasets, and

$$\mathrm{sgn}\left(x_j - x_i\right) = \begin{cases} 1, & \text{if } x_i - x_j > 0, \\ 0, & \text{if } x_i - x_j = 0, \\ -1, & \text{if } x_i - x_j < 0. \end{cases} \tag{5}$$

Under the null hypothesis, if no trend, the statistic in (4) follows an approximately normal distribution with mean zero and variance.

$$\sigma_S^2 = \frac{\mathbf{n(n-1)(2n+5)} - \sum_{\mathbf{k=1}}^{\mathbf{m}} \mathbf{t_k}\left(\mathbf{t_k} - \mathbf{1}\right)\left(\mathbf{2t_k} + \mathbf{5}\right)}{\mathbf{18}}, \tag{6}$$

where m the number of is tied groups and t_k is the number of data points in the group.

When the sample size $n \geq 10$, the statistical test Z is calculated from

$$Z = \begin{cases} \dfrac{S-1}{\sigma_S}, & \text{if } S > 0, \\ 0, & \text{if } S = 0, \\ \dfrac{S+1}{\sigma_S}, & \text{if } S < 0. \end{cases} \tag{7}$$

2.4. Sen's Slope Estimator. To estimate the magnitude of rainfall change, Theil–Sen's slope estimator [59, 60] was used. The statistical significance was reported based on a level of significance (p value or alpha) of 0.05.

$$\mathbf{T_i} = \frac{\left(\mathbf{x_k} - \mathbf{x_j}\right)}{\mathbf{j} - \mathbf{k}}, \quad \mathbf{j} \neq \mathbf{k}, \tag{8}$$

where x_j and x_k are the data values for j and k times of a period ($j > k$). The slope is estimated from each observation. For a time series having observations, there are possible $N = n\,(n-1)/2$ values of T_i that can be calculated. According to Sen's method, the overall estimator of the slope is the median of these N values of T_i. The overall slope estimator Q_i is thus

$$Q_i = \begin{cases} T_{(N+1)/2}, & \text{for N odd observations,} \\ \dfrac{1}{2}\left(T_{N/2} + T_{(N+1)/2}\right), & \text{for N even obesvations.} \end{cases} \tag{9}$$

An attempt has been made to examine the spatial variability of rainfall at annual and seasonal by using the coefficient of variation (CV); the percentage ratio of the standard deviation to the mean is expressed as a percentage [61–63] and measures the degree of variability in a dataset. The results from seasonal mean rainfall distribution, trend magnitude, and coefficient of variation were presented spatially using a tabular table, indicating how rainfall values have changed.

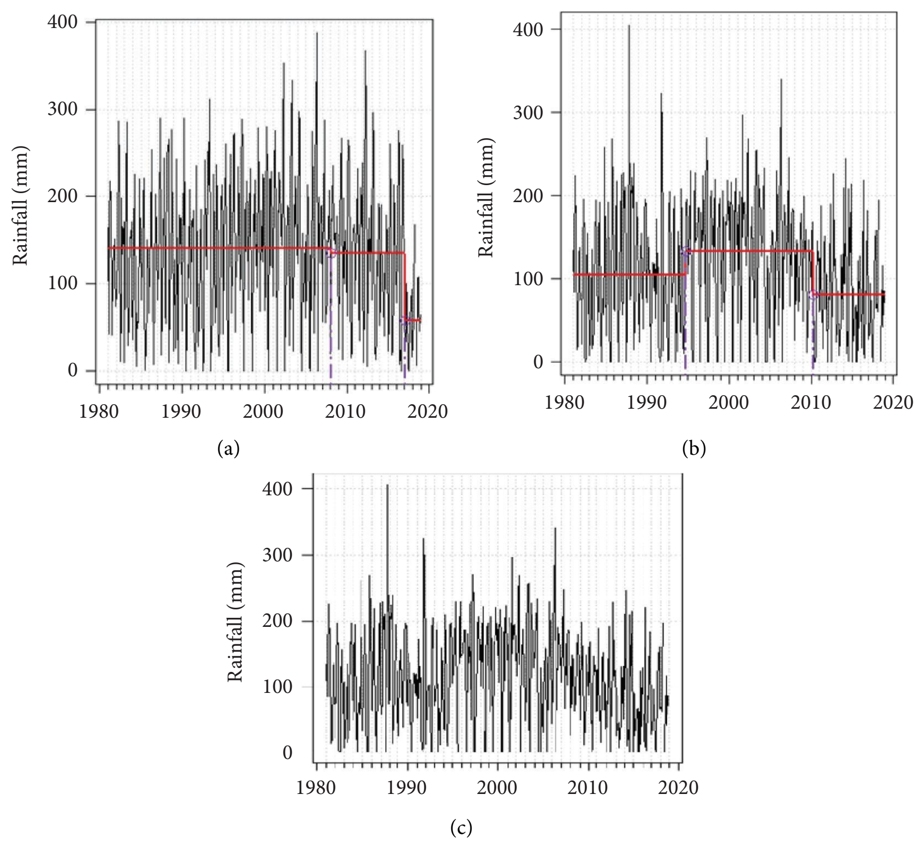

Figure 2: Homogeneity test results for rainfall over Kinigi station (a), Remera station (b), and the corrected data over Remera station (c).

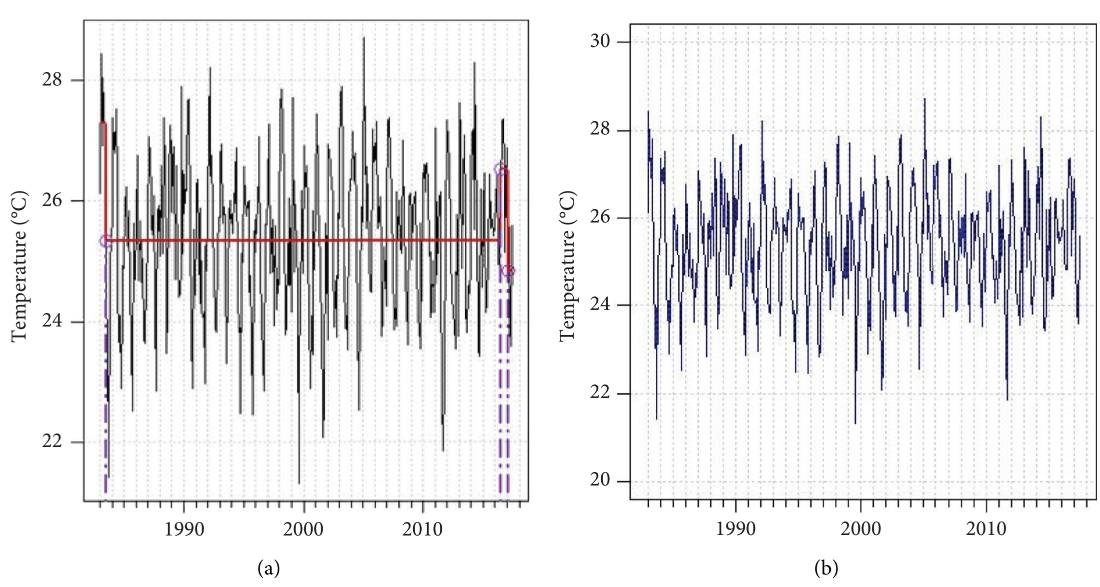

Figure 3: Homogeneity test results for temperature over Rwaza station (a) and the corrected values over the same station (b).

2.5. Modified Mann–Kendall. Theexistence of positive autocorrelation in the data increases the probability ofdetecting trends when actually none exist, and vice versa. To remove theeffect of autocorrelation, we employed a modified Mann Kendell non-parametrictrend test which is suitable for auto correlated data.

$$Z_i = Q^{-1}\left(\frac{R_i}{n+1}\right), \quad \text{for } i = 1\text{: } n. \tag{10}$$

Given R_i is the detrended denoted by x_i^l length given by n, and inverse for statistical measure is Q^{-1} where normal distribution ranges between 0 and 1. The Hurst coefficient is

H which can be derived McLeod and Hipel [64] function. The H takes care of uncorrelated values and exact H should be 0.5. The formula for computing the value of H is given by the following equation:

$$C_n(H) = \left[\rho_{[j-i]}\right], \quad \text{for } i = 1: n, j = 1: n, \tag{11}$$

$$\rho_i = \frac{1}{2}\left([L+1]^{2H} - 2[L]^{2H} + [L-1]^{2H}\right). \tag{12}$$

Take ρ_i as the autocorrelation with a lag l for a given H, which does not act as a function time (Koutsoyiannis 2003). The value of H is derived using measure of log as a function of H which is given by the following equation:

$$\text{logL}(H) = -\frac{1}{2}\log\left|C_n(H)\right| - \frac{Z^t\left[C_n(H)\right]^{-1}}{2\Upsilon_0}. \tag{13}$$

Take $|C_n(H)|$ as the determinant of correlation factor $[C_n(H)]$, Z^t is the transpose vector of equivalent normal variants Z, $[C_n(H)]-1$ where inverse matrix, and Υ_0 is the variance of z_i. Equation (13) can be obtained by taking different values of H, where the value for which log $L(H)$ is considered maximum when H value is taken for certain period of time xi. The method will consider the value of H to be solved between 0.50 and 0.98 with continuous an iteration of 0.01.

The remarkable value of H will be determined using average (μ_H) and standard deviation (σ_H) when $H = 0.5$ (normal distribution) which is indicated by the following equations [65]:

$$\begin{aligned}\mu_H &= 0.5 - 2.87n^{-0.9067},\\ \sigma_H &= 0.7765n^{-0.5} - 0.0062.\end{aligned} \tag{14}$$

The significance of H is determined using μ_H and σ_H in equation (14). When H is found to be significant, the variance of S is determined the following formula:

$$V(S)^{H'} = \sum_{i<j} \cdot \sum_{k<l} \frac{2}{\pi}\sin^{-1}\left(\frac{\rho|j-i| - \rho|i-l| - \rho|j-k| + \rho|i-k|}{\sqrt{(2-2\rho|i-j|)((2-2\rho|k-l|)}}\right). \tag{15}$$

Given that ρ_i is calculated using equation (12) when H and $V(S)^{H'}$ is the biased estimate. The unbiased estimate $V(S)^H$ is calculated by multiplying by a bias correcting factor B given as follows:

$$V(S)^H = V(S)^{H'} X B, \tag{16}$$

where B is a function of H given as follows:

$$B = a_0 + a_1H + a_2H^2 + a_3H^3 + a_4H^4. \tag{17}$$

The coefficients $a_0, a_1, a_2, a_3,$ and a_4 can be found in equation (17) which are the functions of the sample size n.

3. Results and Discussion

3.1. Monthly Analysis of Rainfall and Temperature. The rainfall and temperature exhibited a bimodal type of pattern with variations over different parts of the country. The March-April-May (MAM) rainfall season is the longest rainy period, and the peak is in April, whereas the shortest rainy period is September-October-November (SON), where the peak is realized in November. December-January-February (DJF) and June-July-August (JJA) are considered as seasons with slightly less rainfall than MAM and SON, and the dry spells are normally experienced in JJA and DJF seasons, respectively [23, 32]. The graphical whiskey plots indicated in Figure 4 are the monthly variations of temperature and rainfall observed in Musanze. The plot in the top panel is rainfall, and the lower panel is maximum and minimum temperature, respectively. The box and whisker plot includes a horizontal line showing a median line, which is supposed to be in middle position of normal distribution; however, in most cases, skewness tend to occur where the distribution deviates from the center. The length of the interquartile range (IQR), which is indicated by the box plot, is a measure of the relative distribution of the middle, 50% of the dataset, just as the length of each whisker is a measure of the relative dispersion of the dataset's outer range (10^{th} to 25^{th} percentiles and 75^{th} to 90^{th} percentiles). The total monthly rainfall and temperature were obtained by totaling the daily values of each month for each year. The plots shows the relatively maximum amount of rainfall in April and November; since the length of the boxes and whiskers are longer, the variability is greater than the other months, and for the temperature, February and July shows high variability [66].

3.2. Spatial Variation of Rainfall and Temperature

3.2.1. Spatial Variation of Seasonal Rainfall. The spatial distribution of maps in Figure 5 shows the seasonal pattern of December to January (DJF), March to May (MAM), June to August (JJA), September to November (SON), and annual. The annual climatological rainfall indicates the central areas with yellow-colored spots experiencing minimal rainfall compared to other parts of the district. The surrounding areas of the central parts are high grounds which receive higher rainfall than the central region ranging between 1184 and 1471 mm. The spatial distribution for December-January-February indicated enhanced rainfall over western parts of the district which is influenced by advection of Congo air mass which is a deep-seated low-pressure area in equatorial rainforest covering the equatorial tropical central African region. The Congo Basin spans across six countries: Cameroon, Central African Republic, Democratic Republic of Congo, Republic of Congo, Equatorial Guinea, and Gabon.

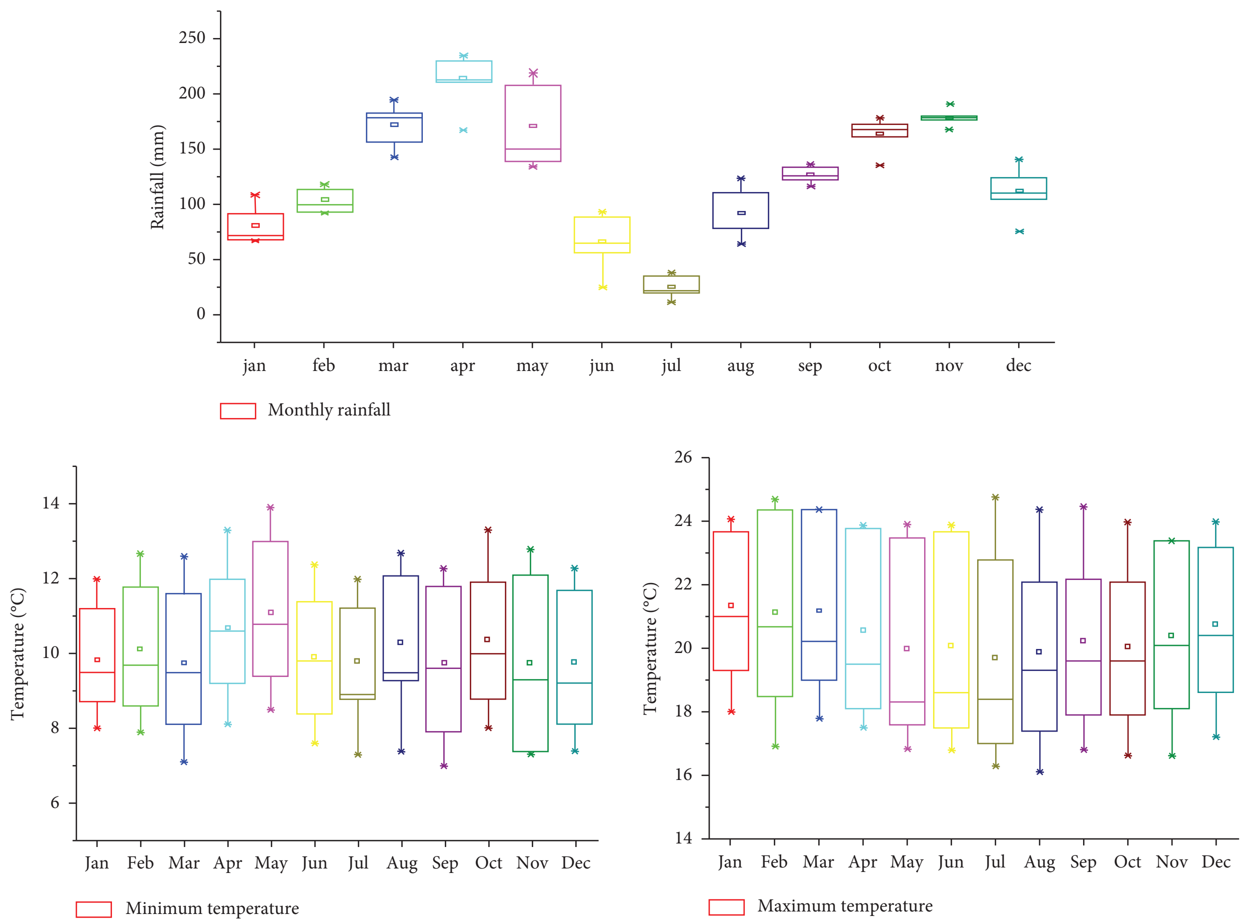

Figure 4: Monthly average rainfall and temperature.

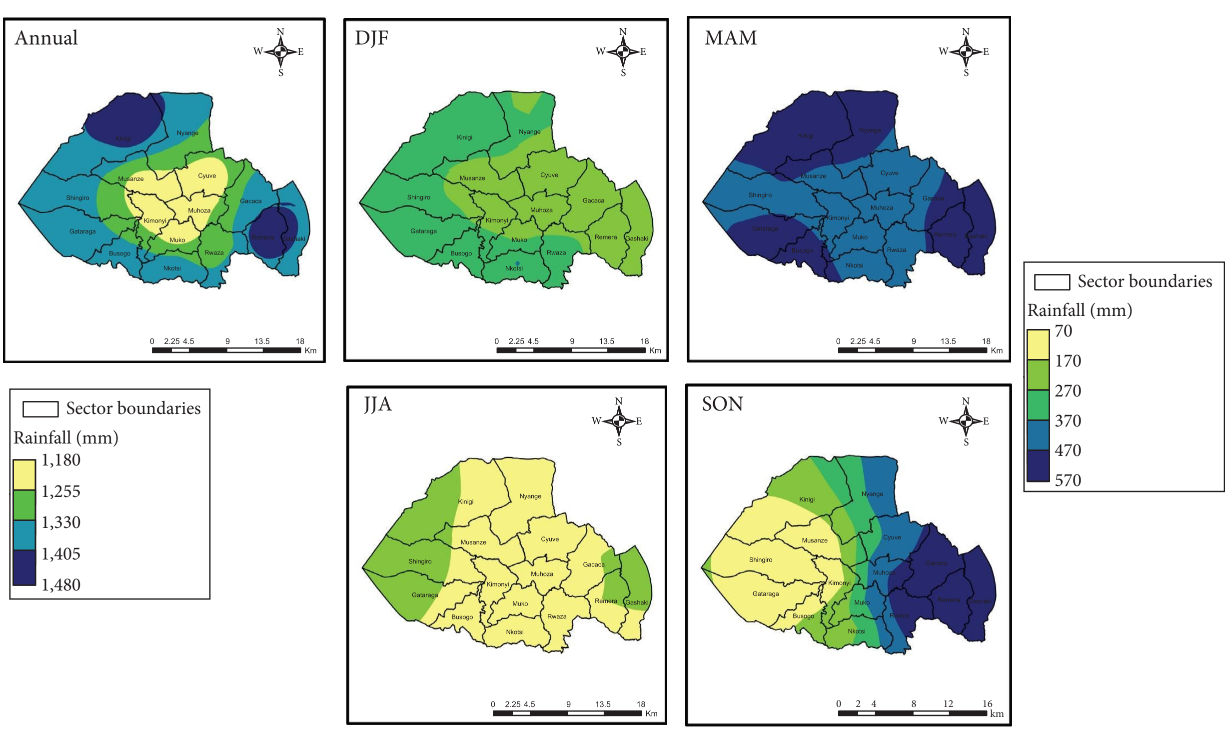

Figure 5: Annual and seasonal rainfall distribution.

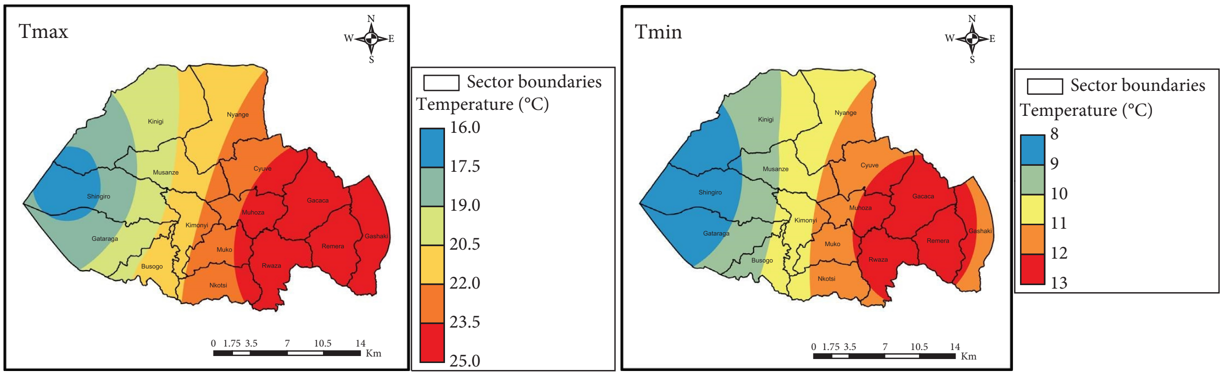

Figure 6: Spatial distribution of annual maximum and minimum temperature.

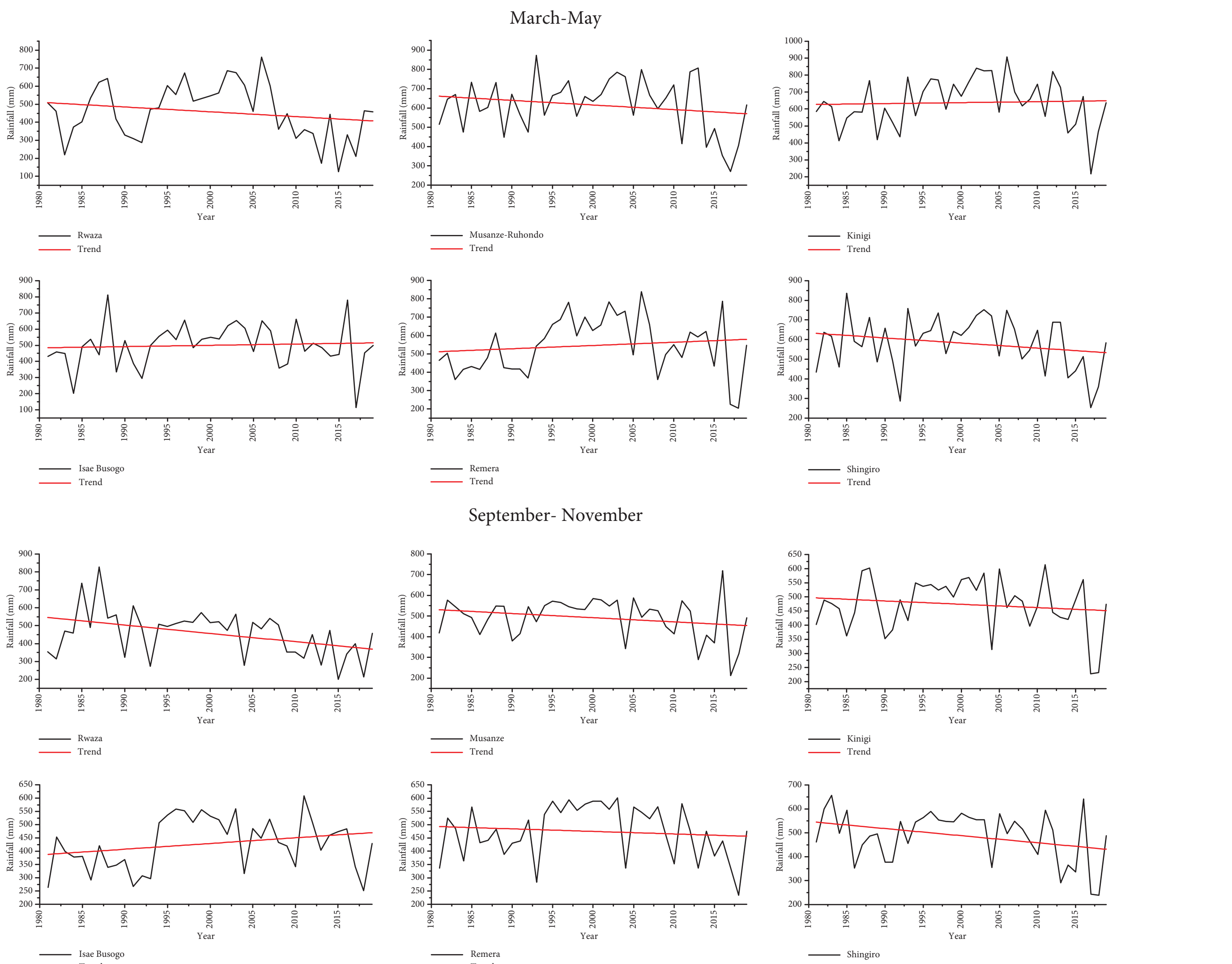

Figure 7: Rainfall trend for March to May and September to November.

The March-April-May (MAM) is considered the long rain season where farmers are expected to get bumper harvest once the season turnout to be very good. The average rainfall ranges between 370 and 570 mm during the season, and the rainfall is evenly distributed compared to other seasons, although the central parts of the district continue to experience slightly lower rainfall than other parts of the district.

During the seasonal rainfall for June-July-August (JJA), farmers experience depressed rainfall with dry spell over

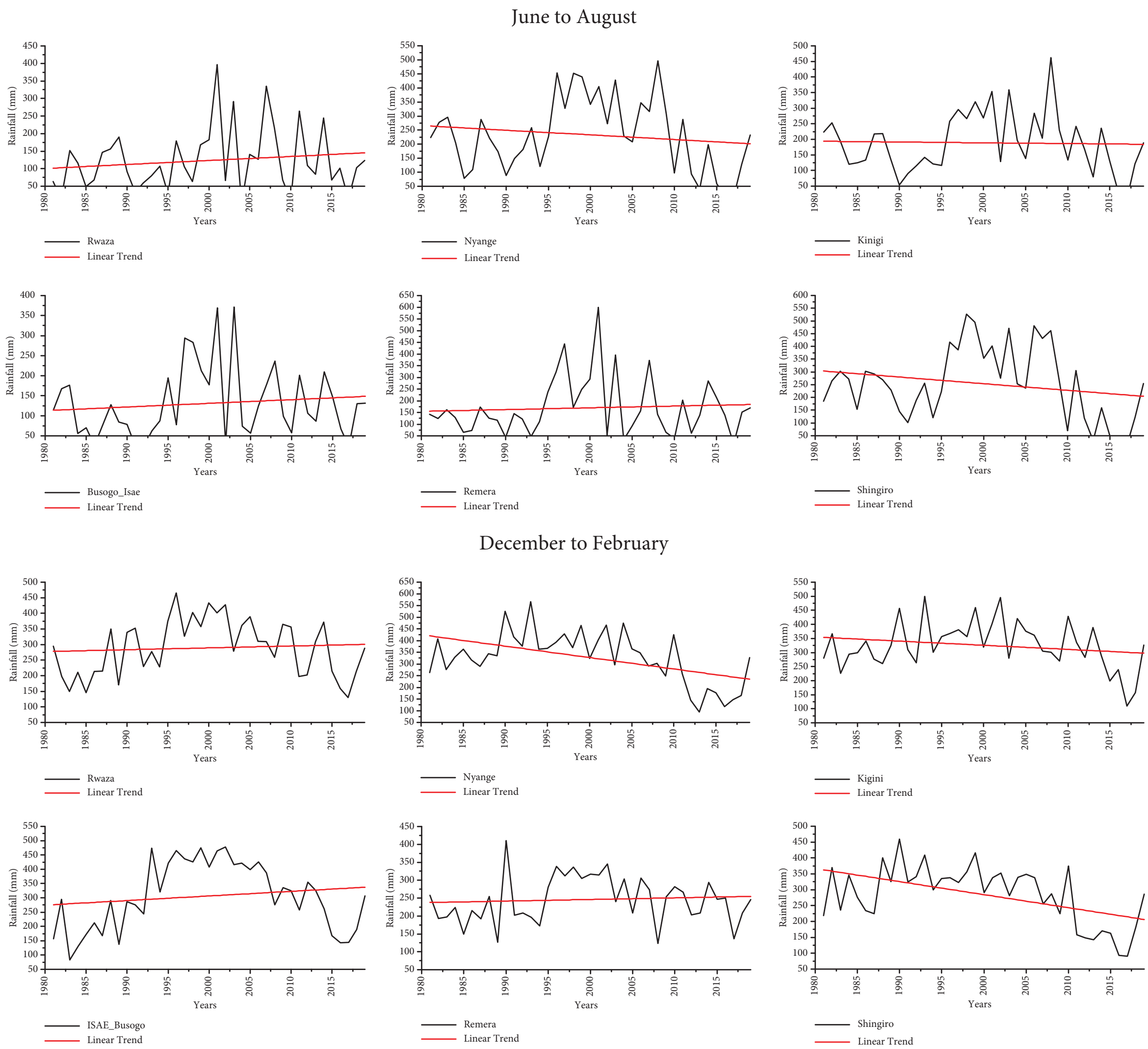

FIGURE 8: Rainfall trend for June to August and December to February for the period 1981–2018.

most parts of the country and entire East African Countries, which is under the influence of the post-ENSO conditions. The rainfall pattern for June-July-August (JJA) ranges between 70 and 270 mm. The rainfall during the season is usually recorded in the western mountains of volcanic areas and small portion of the eastern parts of the district.

The September-October-November (SON) is the beginning of a short rain season where the average rainfall ranges between 70 and 570 mm, which is slightly higher than JJA season. Much of the rainfall is concentrated in eastern parts of the district, where it starts, shifting towards western and northern parts of the country. The eastern parts of the district experiences earlier onset of rainfall during the season. The shifting of rainfall is normally coupled complex system of topographic, inland water bodies and movement of intertropical convergence zone.

The study on rainfall by [67], which is sometimes influenced by propagation of the warming from global oceans in equatorial Pacific to the Indian Ocean, where moisture starts drifting towards east African region and hence enhancing rainfall in Rwanda. Therefore, the western central parts of the district shaded yellow record reduced rainfall during those periods because of late onset.

The movement of Inter Tropical Convergence Zone (ITCZ) influences rainfall pattern over Eastern and Central Africa region [68–70], where Musanze district is located and sometimes it offsets dryspells and farmers continue their farming activities without any interruption. However, dry spells over Musanze district affect farmers which may lead move their farming activities into swampy areas for enough water which can sustain crops [71, 72].

3.2.2. Spatial Variation of Temperature. The spatial distribution of maximum and minimum temperature ranged between 16°C to 25°C and 8°C to 13°C, respectively. The highest temperature was in the district's eastern parts and decreased towards the western parts where Virunga National Park is situated (Figure 6) for both maximum and minimum temperature.

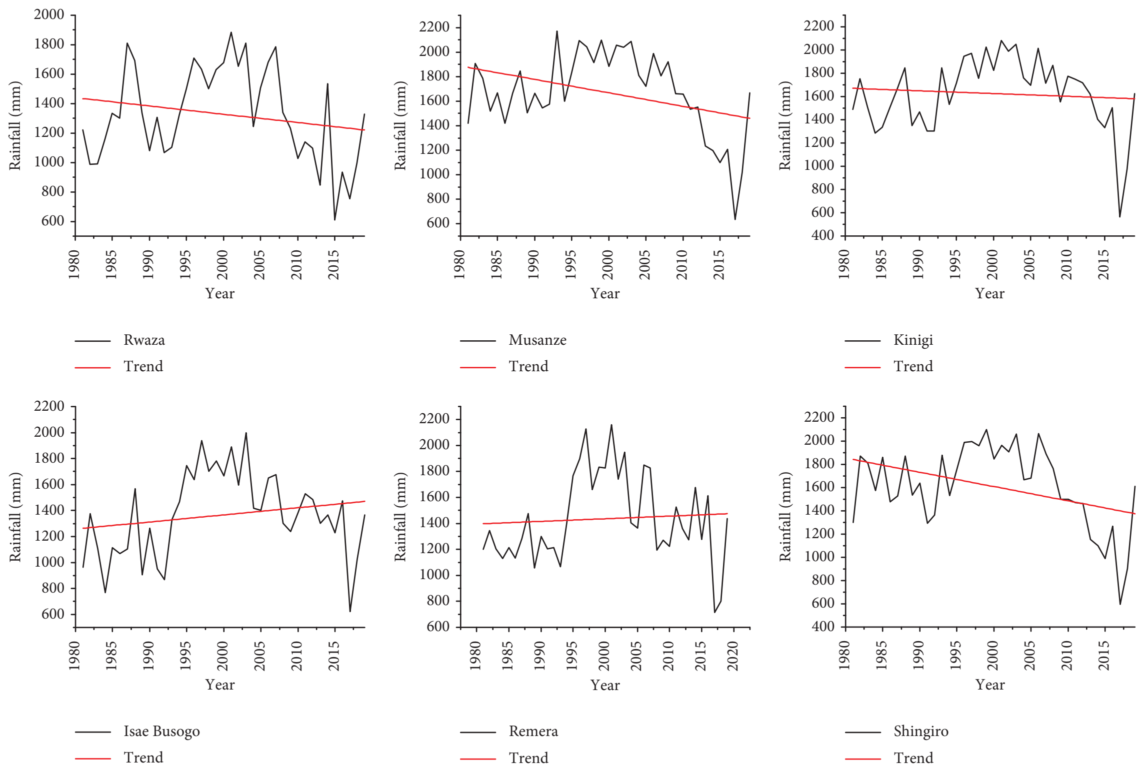

Figure 9: Annual climatological rainfall trend from 1981 to 2018.

3.3. Annual and Seasonal Trend

3.3.1. Seasonal Trend. The March-April-May seasonal trend showed a decreasing trend on three and increasing trend on three stations, respectively, for the MAM rainfall. September-October-November (SON) seasonal analysis indicated a decreasing trend on five stations and an increasing trend on one station. The trend was considerably significant for decreasing trends which evident on five stations out of six (Figure 7).

The June-July-August (JJA) season is normally characterized by minimal rainfall compared to other seasons for all the years. The four stations indicated increasing and remaining two showed a decreasing trend. In the December-January-February seasonal trend, three stations had an increasing and the other three had a decreasing trend (Figure 8).

3.3.2. Annual Trend. In the annual climatological trend (Figure 9), four stations were decreasing, whereas two stations were increasing, signifying that almost above 60% of the annual rainfall pattern was having a decreasing trend which implies reduced farm produce on agriculture sector (Kyei-Mansah et al,. 2019).

3.3.3. Temperature Trend. The annual climatological mean of temperature for both maximum and minimum indicated increasing trend signifying temperature raise within the Musanze district (Figure 10). The increases in mean temperature have negatively impacted hetrogenous crops in different geographical locations across the global [73].

3.4. Measure of Dispersion. The seasonal mean rainfall varied between 70 and 570 mm, and the lowest values were recorded in June-July-August (70–270 mm). The JJA season is normally characterized by little or minimal rainfall and occasionally with dry spells where uphill farming is impossible and farmers shift to swappy areas. The two seasons September-October-November (70–570 mm) and December-January-February (170–370 mm) record moderate rainfall which is above the amount for JJA season. The highest amount of rainfall is experienced in March-April-May (370–570 mm) season.

The coefficient of variation (CV) was categorized by Hare [74] and Amogne et al. [75], under three classes: less ($CV < 20$), moderate ($20 < CV < 30$), and high ($CV > 30$). March-April-May (MAM) season was within moderate category except for one station (Rwaza), which had 34% considered in the high category. June-July-August (JJA) season variability was very high where values ranged between 51% and 74%, which indicated the highest variability within the season during dry periods; September-October-November (SON) season coefficient of variation varied between 20% and 29%, which is the moderate variation; December-January-February (DJF) season variation was moderate to high, 26–39%. The annual variation was low to the moderate category, which ranged between 17% and 25%.

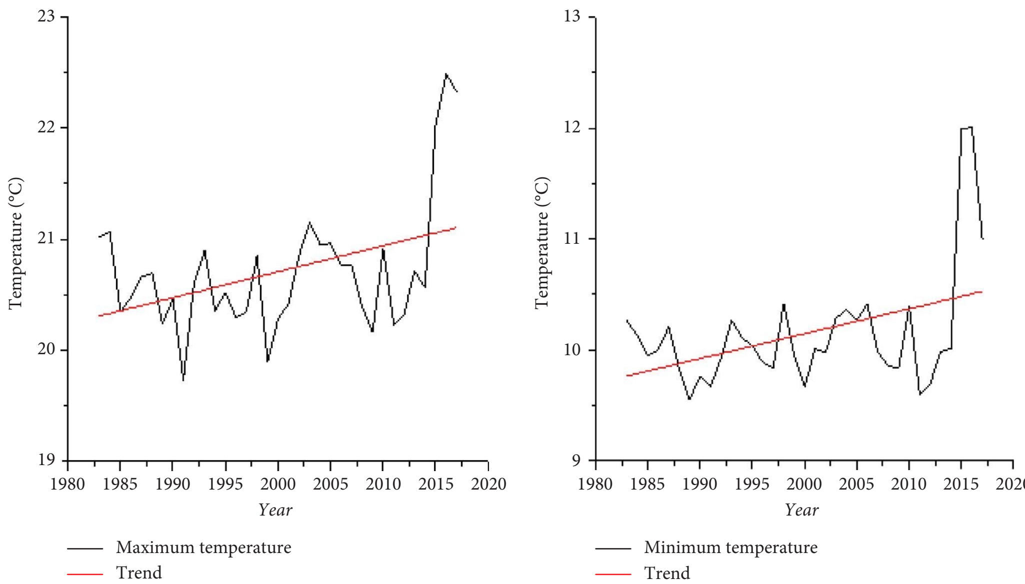

Figure 10: Annual mean trend for maximum and minimum temperature from 1981 to 2018.

Table 1: Seasonal rainfall characteristics of CV, Z, S, Q, and T in the period 1981 to 2018.

Seasons	Trend	Busogo		Kinigi		Nyange		Remera		Rwaza		Shingiro	
		MK	mMK	MK	mMK	MK	mMK	MK	mMK	MK	mMK	MK	mMK
MAM	S	—	+	—	—	+	+	—	+	—	—	—	+
	Z	0.8	1.7	0.6	1.2	−0.4	0.3	1.6	1.7	−1.0	0.2	1.6	0.0
	Q	1.6	5.1	1.7	2.6	−0.7	1.0	3.8	5.1	−2.3	1.1	3.8	0.0
	T	12.4	39.0	10.1	15.7	−4.3	5.9	26.6	35.8	−19	9.4	24.8	−0.2
JJA	S	—	—	—	—	—	—	—	—	—	—	—	+
	Z	0.9	0.9	−0.1	0.1	−0.9	−0.4	0.3	0.3	0.8	0.3	0.3	0.0
	Q	0.9	0.5	−0.1	0.2	−2.5	−0.3	0.5	0.5	1.0	0.4	0.5	−0.1
	T	25.9	13.9	−2.4	3.6	−40.3	−4.3	10.8	10.8	30.9	13.3	7.2	−1.7
SON	S	—	—	—	—	—	—	—	—	*	—	—	+
	Z	1.2	0.9	−0.2	−0.9	−1.1	−0.5	−0.3	−0.2	−2.2	−0.7	−0.3	−1.8
	Q	2.2	2.2	−0.5	−1.1	−1.3	−1.1	−0.3	−0.3	−4.3	−2.4	−0.3	−2.5
	T	19.2	19.2	−3.9	−8.6	−12.2	−10.1	−2.6	−2.3	−35.6	−19.7	−2.5	−19.5
DJF	S	—	—	—	—	*	—	—	—	—	—	—	—
	Z	0.5	0.5	−0.6	0.1	−2.5	−0.8	0.4	0.3	0.6	0.9	0.4	0.1
	Q	1.0	1.5	−1.0	0.5	−5.3	0.2	0.4	0.4	0.7	1.6	0.4	0.2
	T	12.4	18.6	−12.1	5.9	−61.4	2.8	6.8	6.3	9.5	20.7	5.9	3.2
Annual	S	—	—	—	—	+	—	—	—	—	—	—	—
	Z	0.9	0.5	0.2	0.2	−1.8	−0.1	1.0	0.6	−0.8	0.0	1.0	−0.4
	Q	6.5	5.7	0.8	2.3	−11.3	−0.7	3.2	2.3	4.8	0.0	3.2	−3.9
	T	18.2	15.8	1.9	5.5	−25.7	−1.5	8.5	6.2	13.8	0.0	−7.6	−9.3

CV, coefficient of variation; Z, Mann–Kendall trend, (—) decreasing and (+) increasing; S, significance of trend at 90% (+) and 95% (*); Q, Sen's slope, mm/year; T, (trend, mm/year) in the period 1981 to 2018.

The results are tabulated in Table 1; the seasonal pattern for both Mann–Kendall and modified Mann–Kendall; MAM Mann–Kendall results indicated an increasing trend except for two stations with a decreasing trend (Nyange and Rwaza), where Nyange and Busogo showed a significant trend at 90% percentile. Modified Mann–Kendall indicated increasing trend except for one station Shingiro which showed a decreasing trend and a significant trend was registered on Busogo, Nyange, Remera, and Shingiro at 90%. The JJA season trend, four stations for both Mann–Kendall and modified Mann–Kendall showed an increasing trend except for two stations which had a decreasing trend. SON trend was generally decreasing on five stations for both Mann–Kendall and modified Mann–Kendall, where Rwaza and Shingiro indicated a significant trend at 90 and 95% for Mann–Kendall and modified Mann–Kendall, respectively. One station, Busogo, was having an increasing trend. The DJF season four stations showed an increasing trend for Mann–Kendall and all stations for modified Mann–Kendall; two stations were having with decreasing trend on

Mann–Kendall and nonsignificant for both. The annual trend increased on four stations and two with a decreasing trend for both Mann–Kendall and modified Mann–Kendall with the level of significance at Nyange station with Mann–Kendall at 90%.

4. Discussion

The study conducted on annual mean temperatures in Rwanda revealed a significant change in trend that was thought to be an indication of climate change [76]. Similar findings were made in Nigeria, where smallholder farmers were being negatively impacted socially and economically by attempts for adaptation and mitigation of the severe effects of climate variability and climate change [77]. The Mandi station in Himachal Pradesh, India, provided monthly rainfall, annual maximum temperature, and annual minimum temperature data for the study period of 1981–2010. Modified Mann–Kendall analysis revealed an increasing trend with a 95% confidence level [15]. The research on long-term rainfall in Sharjah City, United Arab Emirates, realized a decreasing trend [11]. The fluctuation and trend in rainfall and temperature in the Musanze district showed signs of warming which is associated with global anthropogenic activities. However, as farmers are disproportionately impacted by these changes, governments must implement compensating strategies.

5. Conclusion

The study analyzed the variability and trend of rainfall and temperature in Musanze district of Rwanda. The analysis was conducted using Mann–Kendall and modified Mann–Kendal, where different tests were performed. The results indicated spatial variations in rainfall decreasing from eastern to the western parts of the district where central parts were more pronounced for all seasons and annually compared to other parts of the district which could be attributed to its location in the leeward low land area. The temperature was significantly increasing in the eastern parts, decreasing towards the central and western parts of the district. The increasing temperature trend at 95% confidence level, where the annual minimum and maximum temperature showed a sharp increasing trend. The annual rainfall showed almost above 60% of stations had a decreasing trend as an indication of high fluctuation of rainfall with negative impacts on the farm produce. The coefficient of variation for rainy seasons, MAM and SON, was moderate ranging from 17% to 34% which was considerably reliable for the farmers involved in agriculture. The coefficient of variation for DJF was slightly higher than moderate range from 27% to 39%. The JJA season was having the highest coefficient of variation ranging between 51% and 74%. The fluctuations in rainfall are very erratic with frequent dryspells during the season. During the day, there is high evaporation from hillside land and farmers usually shift their activities to swapy places and practice irrigation during JJA season. Mann–Kendall and modified Mann–Kendall showed much significance and consistence in the results.

It is very crucial for the region to have this study done because of the unpredictability and trend in the high mountains of the Musanze district. This study attempts to evaluate the variation and trend in rainfall and temperature for the Musanze district in Rwanda. Since no comparable research has been conducted in the region, the study will provide a thorough understanding of the district's variation and any trends or changes that are obvious. By attempting to manage unpredictability and change in this time of climate change, it will also promote strategic orientation.

Data Availability

The rainfall and temperature data were obtained from Rwanda Meteorological Agency (MeteoRwanda) which is the custodian of all climate data. The data can be obtained through an online portal on the link https://mis.meteorwanda.gov.rw/ and can be obtained from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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