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# Rainfall variability and trends over Rwanda

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**ABSTRACT**

Rainfall is regarded as one of the foundational concepts for comprehending climate variability and/or change. This paper aimed at examining the seasonal and annual rainfall variability and its associated trends over Rwanda between 1981 and 2017. The Coefficient of Variation (CV) was used to determine the rainfall variability. Mann-Kendall test and Sen's slope estimator techniques were used to detect trends and to quantify the magnitude of change. High rainfall variability was observed over eastern Rwanda, around Kigali city and central plateau, while the south-western, western and the north highland revealed lower rainfall variability. Trend analysis of annual and March-May (MAM) rainfall season depicted a significant decrease of -6.7% over south-western region (Kamembe-Aero station) and -9.8% over eastern parts (Kibungo-Kazo) respectively. A significant increase in trend of 4.3% over North-western (Gisenyi-Aero station) during September-December (SOND) season was also obtained. The rest of the stations registered a non-significant trend on both seasonal and annual time scales. Spatially, areas of Kigali City, eastern and central parts of Rwanda revealed a decreasing trend whereas an increasing trend was observed over the western, northern highland, north eastern and southern region except for the areas towards the south-east. The high rainfall variability and significant nature of changing trends demand that rain-dependent sectors of the economy link climate science and policy in order to make proper planning. With proper climate homogeneity zoning, the agricultural sector in particular needs to develop effective techniques that optimize food production including water use rationalisation..

**Key words:** Rainfall, Rwanda, Trend, Variability, Rain-Dependent

## 1. Introduction

Bimodal rainfall patterns occur across the majority of East Africa, including Rwanda. (Mutai and Neil, 2000; Schreck and Semazzi, 2004; Ilunga; Muhire, 2010). Many countries in African rely on seasonal rainfall for domestic and agricultural purposes (Challinor et al., 2007). Variability in rainfall has an impact on agricultural productivity, which changes crop productivity (Mahmudul et al, 2011; Ochieng et al., 2016). Since the economy of Sub-Saharan African (SSA) countries is Hinged on the agricultural sector, rainfall variability will have various effects on farming activities and other socio-economic that contribute to the development of the country. Precipitation patterns over East Africa region are largely controlled by the movement of the Inter-Tropical Convergence Zone (ITCZ) (Okoola, 1999), Sea Surface Temperature (SST), the convergence of Saint Helena Anticyclones from the South Atlantic Ocean and Mascarene Anticyclones from the Indian Ocean (Indeje et al., 2000; Ilunga et al., 2004; Kizza et al., 2009; Gitau et al., 2013). Over East Africa EL-Niño enhances the probability of being unusually wet during the short rains while the long rains remain largely unaffected (Indeje et al., 2000; Nicholson et al., 2001; Schreck and Semazzi, 2004; Hastenrath and Polzin, 2004; Ilunga and Muhire, 2010; Muhire et al., 2015). The positive (negative) phases of the Indian Ocean dipole (IOD) results in an increased (decreased) rainfall over the EA with a strong connection during El Niño/La Niña years (Owiti, 2008). The EA rainfall variability is also linked with the Madden-Julian Oscillation (MJO) with a higher association to the west of the region (Peter. et al., 2008). Research findings have indicated that rainfall in the EA is characterized by immense rainfall variation over short distances. Annual mean rainfall over most parts of the EA ranges between 800 and 1200mm in wet seasons (Nicholson,2017) even though some areas can receive much more rainfall due to highlands particularly in the western and northern parts of the region. In sub-Saharan Africa during the past few decades, smart agriculture has become more prevalent, especially in regions where literature suggests that climatic variability and change will have an impact on agricultural productivity and food security in the absence of adequate interventions. (Zougmoré et al., 2018). Several researches have been made with aim of understanding the behaviour and trend of rainfall in Rwanda. The use of limited data was demonstrated by many researchers (Henninger, 2013; Muhire and Ahmed, 2014; Muhire et al., 2015a; Muhire et al., 2015b; Mohammed et al., 2016; Ntirenganya 2018). In the recent past, the study to understand the climatology of Rwanda has been made using gridded data (Asher et al., 2019); however, rainfall variability and its associated trend was not a subject of this study. Recent research by Kazora et al., (2021) attempted to understand the behavior of rainfall and associated circulation anomalies using Climate Hazards Category Infrared Precipitation with Stations (CHIRPS) rainfall data.

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It is important to understand the rainfall variability and associated trends in Rwanda using a high quality and complete dataset. This study aims at identifying the nature of rainfall variability over Rwanda on seasonal and annual timescale by assessing the spatial and temporal characteristics in the historical rainfall to depict its current variability and trends in the country. The findings from the study will inform decision-makers and policy-makers of the necessity to integrate climate variability and climate change information into developing policies and to formulate strategies that support different economic sectors such as industries, services and agriculture among others.

## 2. Material and Methods

### 2.1 Study Area

Rwanda, is known as land of thousand hills, landlocked country located in East Africa, between 1°4′ and 2°51′ South; 28°53′ and 30°53′ east and covers an area of 26,338 km². Rwanda is bordered by Tanzania to the East, Uganda to the North, Democratic Republic of Congo to the West, and Burundi to the South (Figure 1). Diverse climate patterns characterizing the country into complex topographical features. These include the highland areas located in the northwest and successive hills and valleys over the central plateau while the low land areas are the dominant features over the eastern parts of the country. The Crest Congo Nile delineates the western highlands and the central plateau while several mountains predominately occupy the northern region of the country. Due to the complex topography, mean annual rainfall varies geographically across the country (Ntwali *et al*., 2016) with the south-western and north-western highland areas of the country receiving high amount of rainfall while the eastern region receives a low amount of rainfall (Ilunga and Muhire, 2010; Ntwali *et al.,* 2016). Rwanda experiences two major rainy seasons in a year, March to May (MAM) rainy season (locally referred to as 'Itumba') and September to December (SOND) rainy season ('Umuhindo' in local term). A short dry season (commonly known as 'Urugaryi') occurs from January to February (JF) while and a long dry season (kwown as 'Impeshyi' in local language) extends from June to August (JJA) (Muhire *et al.,* 2015a; Siebert *et al*., 2019) with the two monthly rainfall peaks being April and November for MAM and SOND rainy seasons respectively (Ntwali *et al.,* 2016; Muhire *et al.,* 2015b).
Rwanda exhibits six climatic zones from eastern to western parts of the country based on annual rainfall and temperature distribution. The dry and hot lowland climate zone extending from the east of the Southern Province to the Eastern Province of the country. The temperate climate zone of the central highlands with an elevation increasing from east to west, and a less temperature fluctuation separating the southern Rwanda humid mountain climate zone situated south of the Congo-Nile watershed extending to the Volcano National Park in the northern region of the country with the northern mountain ranges exhibiting mountainous climatic zone. The fifth climatic zone is the Lake Kivu sea climate zone extending from Rubavu to Bugarama in the southern parts of Lake Kivu and the last is the Kigali urban climate (Henninger, 2013). Large scale systems that influence the climate of Rwanda, include dry Saint Helena and Azores anticyclones. These systems influence drie conditions over the country during June to August (Ilunga *et al.,* 2004; Ilunga *et al.,* 2008; Kizza *et al.,* 2009). The ITCZ movement southwards, passing over the trough of Lake Victoria and Congo Air mass enhances the rain over Rwanda, before reaching its southernmost location by the end of November. During the short dry season (December to February), northern winter monsoon pushes dry and cold air masses from the Arabian Sea over Lake Victoria and induces little rainfall in the highland regions of the country (Ilunga *et al.,* 2004; Kizza *et al.,* 2009). The mean rainfall significantly reduces when topography reduces (Ntwali *et al.,* 2016).

### 2.2 Data

The daily gridded rainfall dataset which was accumulated to monthly, seasonal and annual total were obtained from Rwanda Meteorology Agency (Meteo Rwanda) with a spatial resolution 0.0375 degrees (~ 4km) for the period of 1981 and 2017. Twelve synoptic stations were chosen for the graphical analysis and seventy-two climatological stations were added to the synoptic stations for spatial analysis. The generation of the gridded dataset improves the accessibility of meteorological data in areas with no or sparse observation resulting from silent weather stations especially during periods of political instability and recovery. This dataset was generated by merging quality-controlled observed data with satellite rainfall estimates data from Tropical Applications of Meteorology using SATellite (TAMSAT). More information on the generation of the dataset is found in (Siebert *et al.,* 2019).

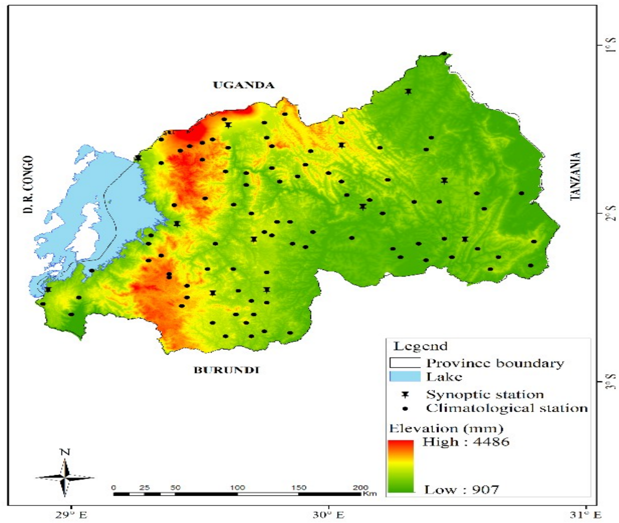


*Figure 1: Geographical location of Rwanda, topographic features and the meteorological station location.*

### 2.3 Methods

Methods of spatial and temporal analysis were employed to evaluate the degree of rainfall variability and its related trend over Rwanda. A graphical method was used to analyse the temporal variability of rainfall. This method's benefit is that it enables immediate visual examination of whether a trend is present in each time series. Mann–Kendall (MK), a nonparametric rank-based test was employed under this study to test the statistical significance of the observed trends where positive values show an upward slope while a downward slope is indicated by a negative value (Safari, 2012; Nsubuga *et al.,* 2014; Ongoma *et al.,* 2017).

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

In equation (1) *sgn* is the sign function and $x_i$ and $x_j$ are the sequential data values $n$ is the number of data points

$$sgn(x_j-x_i)=\begin{cases}1\ if\ x_i-x_j>0,\\ 0\ if\ x_i-x_j=0,\ (2)\\ -1\ if\ x_i-x_j<0.\end{cases} \qquad (2)$$

Under the null hypothesis if no trend, the statistic in (2) follows an approximately normal distribution with mean zero and variance.

$$\sigma_S^2=\frac{n(n-1)(2n+5)-\sum_{k=1}^{m} t_k(t_k-1)(2t_k+5)}{18} \qquad (3)$$

In equation (3) $n$ is the number of is tied groups and $t_k$ is the number of data points in the group $k$. When the sample size , $n\geq 10$ the statistical test $\boldsymbol{Z}$ is computed using equation (4)

$$Z=\begin{cases}\frac{S-1}{\sigma_S}\ if\ S>0,\\ 0\ if\ S=0,\\ \frac{S+1}{\sigma_S}\ if\ S<0.\end{cases} \qquad (4)$$

To compute the change magnitude in rainfall, the Theil–Sen's slope estimator and was employed at 95% significance level.

$$T_i=\frac{(x¿¿k-x_j)}{j-k}, j\neq k, ¿ \quad (5)$$

From equation (5), $x_J$ and $x_k$ are the data values for *j* and *k* times of a period *j>k*. For a time series *x* having observations, there is a possible *N=n(n-1)/2* values of $T_i$ that can be computed. According to Sen's method, slope estimator $Q_i$ is thus the median of these *N* values of *Ti*.

$$Q_i=\begin{cases} T_{(N+1)/2}\ for\ N\ odd\ observations \\ \frac{1}{2}\left(T_{N/2}+T_{(N+1)/2}\right) for\ N\ even\ obesvations. \end{cases} \quad (6)$$

The examination of spatial variability of rainfall at annual and seasonal timescale was done by using the coefficient of variation (CV) which 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 ArcGIS that provided spatial maps, thus these methods enabled us to understand how rainfall varies spatially across the country.

## 3. Results

### 3.1 Rainfall Distribution

The climatological distribution of monthly, seasonal and annual mean rainfall over Rwanda were analysed to understand the spatial distribution and their corresponding patterns over the country. The distribution in monthly mean rainfall shows that rainfall over Rwanda follows a bimodal pattern with MAM and SOND being the rainy seasons. It is also clear that JJA is the long dry season while from JF is a short dry season. On a monthly basis, rainfall is observed over Rwanda through the year which may be an indication of a potential for activities relying on rainfall for their performance (Figure 2).

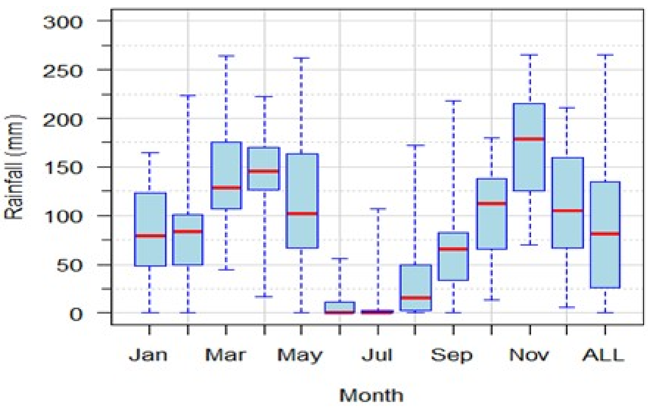


*Figure 2: A box-and-whiskers plot showing the amount of rain each month over Rwanda (1981-2010). Data from the second and third quartiles are shown as boxes. First and fourth quartiles are shown by whiskers. The median value for each month is shown by the red line.*

The mean rainfall distribution presented in Figure.3 indicated a non-homogeneous pattern over different regions of the country. During MAM, analysis of rainfall distribution shows a low amount of rainfall over the eastern parts of the country (Kirehe, Ngoma and Kayonza, eastern part of Bugesera, southern of Rwamagana, southern parts of Gatsibo district extending to the central parts and southern parts of Kigali City) increasing towards the north-eastern parts of the country over the central and northern parts of Gatsibo and Nyagatare districts, along the central parts of the country and the areas bordering Lake Kivu in the western parts of the country. The highland region in the areas surrounding the Crest Congo Nile extending to the Nyungwe National Park and the surrounding areas (Nyamagabe and Nyaruguru Districts) of the southern province, Volcano National Park, , north-western region in the areas of Ngororero, Nyabihu and Rutsiro districts surrounding Gishwati National Park and over northern parts (Gicumbi, Burera, Gakenke and Musanze districts) revealed higher amount of rainfall which may be attributed mainly to the influence of the topography (Figure 3).

The mean rainfall distribution during SOND rainy season showed higher amount of rainfall in the south-western parts (areas around Kamembe extending to Nyungwe National Park, Nyamagabe and Nyaruguru) areas bordering Lake Kivu except the areas over Gisenyi-Aero and north-western Rutsiro, the highland region along Crest Congo Nile, Volcano National Park and northern highlands of Burera, Musanze, Gakenke and Ngororero extending to the north-western highland of Muhanga district. A lower amount of rainfall was obtained over the eastern parts of the country (Kirehe, Ngoma and Kayonza, Eastern part of Bugesera, Akagera National Park and north-eastern parts of Gisagara district increasing towards western Rwamagana, central and north-western Bugesera, Gatsibo and Nyagatare district extending to the Central plateau (Kigali City and central part of the southern region) (Figure 3). The spatial distribution of annual mean rainfall shows a low rainfall in the eastern lowlands (Kirehe, Kayonza, areas around Akagera National Park and the south-eastern parts of Gatsibo District) increasing towards the central, north-eastern and central plateau. Higher rainfall was observed over the south-western parts of the southern region in the areas surrounding Nyungwe National Park extending along the western, northern and north-western highlands of the country. Highland region along Crest Congo Nile extending to the Nyungwe National Park, Volcano National Park , south-western parts (Rubona, Nyamagabe and Kamembe), areas over north-western parts (Gakenke, Gicumbi, Burera and Musanze districts) areas received a high amount of rainfall reducing towards the central parts of the country (Figure 3).

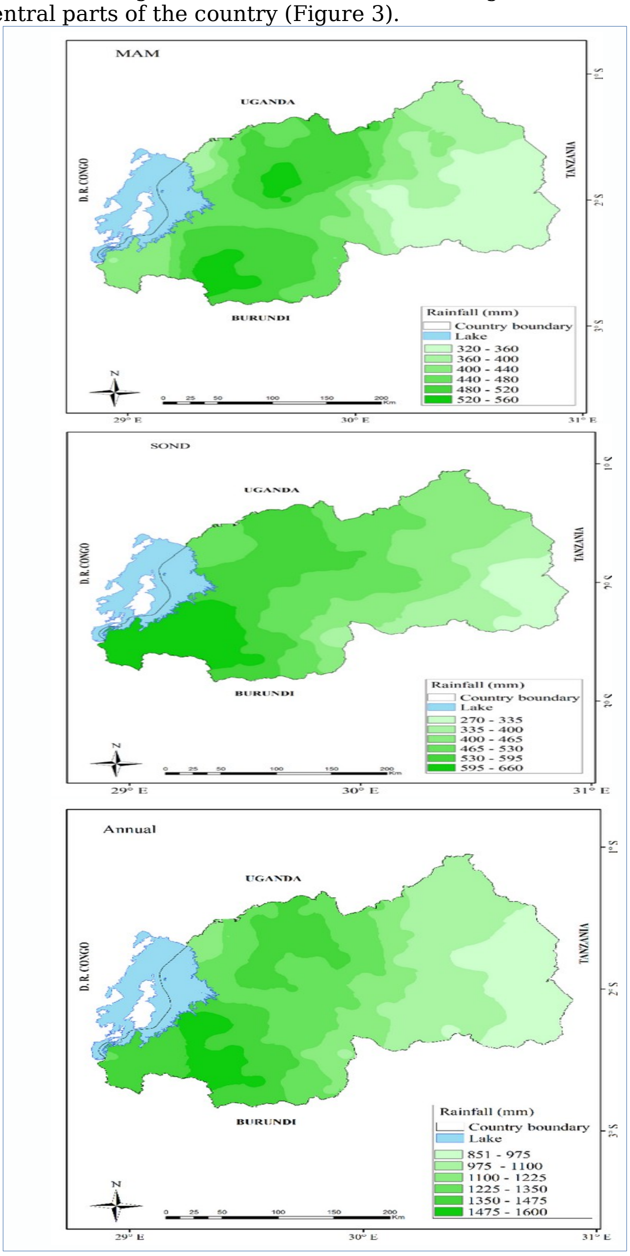


*Figure 3*: Rwanda's rainfall distribution in space from March to May (left), September to December (center) and mean yearly rainfall (right) from 1981-2017.

### 3.2 Rainfall Variability

The coefficient of variation during the MAM showed that the areas to the extreme eastern region of the country (Kirehe district), the central region (northern Rwamagana extending to south-western of Gatsibo bordering southern Gicumbi and the south-eastern parts of the southern region of the country (Huye and Gisagara) exhibited more pronounce rainfall variability indicating less reliability to rainfall over the area. The central and north-eastern parts of the eastern areas extending to the central region of the country (Kigali city, Kamonyi, Ruhango Nyanza, southern region of Muhanga) registered a less pronounced variability while the south-western and northern highland areas of the country showed less variability (high reliability) during MAM rainfall season (Figure 4). During the SOND season, a more pronounced variability in rainfall was observed in the areas of south-eastern parts of the dry and hot lowland climate zone (Kirehe District). A considerable magnitude of rainfall variability was registered over Kigali City, the central-eastern parts towards the areas around Akagera National Park and the extreme South-eastern parts of the southern region reducing towards the north-eastern parts and the central areas of the southern region. The western region in the areas bordering Lake Kivu and Nyungwe National Park extending to the northern highland and the areas around the Volcano National Park revealed a lower variability in rainfall (Figure 4). Spatial distribution of the annual coefficient of variation indicated a higher rainfall variation over Kigali City, the central-eastern part (Rwamagana, Gatsibo, northern Kayonza and southern part of Nyagatare) reducing towards the southern and extreme northern parts of the eastern region and the south-eastern extending to the central parts of the Southern province of the country. The lower annual rainfall variation over the western parts of the country in the areas bordering Lake Kivu extending to the highland areas of the country in the areas bordering Nyungwe National Park, Crest Congo Nile and the Volcano National Park areas over the northern and north-western highland of the country was observed (Figure 4). The spatial distribution in seasonal and annual mean rainfall results indicated that the western and the northern highlands receive higher amounts of rainfall reducing towards the central and low amount of rainfall over the low land thus confirming the results of (Ntwali *et al.*, 2016).

During the SOND season, five stations out of twelve registered a decreasing trend while seven stations out of twelve indicated an increasing trend (Fig 5). On an annual timescale, only three out of twelve stations namely Kawangire, Nyagatare and Gisenyi_Aero revealed an increasing trend while the rest of the stations had decreasing trends (Fig 5).

The trend results obtained using the statistical method indicated a non-homogeneity during both the annual and seasonal time scales. The results from the twelve synoptic stations revealed that the MAM season has decreasing rainfall trends. The twelve stations with decreasing trends included Kigali_Aero located in Kigali City, Byimana, Rubona-Colline and Gikongoro Met located in the southern parts. In the northern areas, the stations of Ruhengeri_Aero and Byumba registered decreasing trends. The stations located in the Eastern Province showed decreasing trends over Nyagatare, Kawangire and Kibungo-Kazo respectively. The stations located in the Western region (Kamembe_Aero, Gisenyi_Aero and Rubengera) show a decrease of 3.3 mm year$^{-1}$, 1.3 mm year$^{-1}$ and 1.8 mm year$^{-1}$ corresponding to 5.7%, 15.5% and 5.8% respectively. During the SOND rainy season, a significant increasing trend of 3.1 mm year$^{-1}$ corresponding to 4.3% was revealed over Gisenyi-Aero station located in the Western region. Other stations located in Western (Kamembe-Aero and Rubengera), Kigali City (Kanombe-Aero), northern areas (Ruhengeri-Aero) and North-eastern parts of the country (Nyagatare) had non-significant decreasing trends. Non-significant increasing trends were observed over stations located in the southern parts of the country (Byimana, Rubona-Colline and Gikongoro Met). The same was observed for stations located over eastern parts (Kawangire and Kibungo-Kazo stations) and northern parts (Byumba station).On the annual timescale, three stations out of twelve stations namely Kawangire and Nyagatare located in the eastern region as well as Gisenyi-Aero located in north-western parts of the country revealed non-significant increasing trends.A significant decreasing trend was observed over the south-western parts (Kamembe-Aero) of 9.1 mm year$^{-1}$ corresponding to -6.7%. Out of twelve stations eight stations registered a non significant decreasing trend. The stations located in the Southern Provice (Byimana,

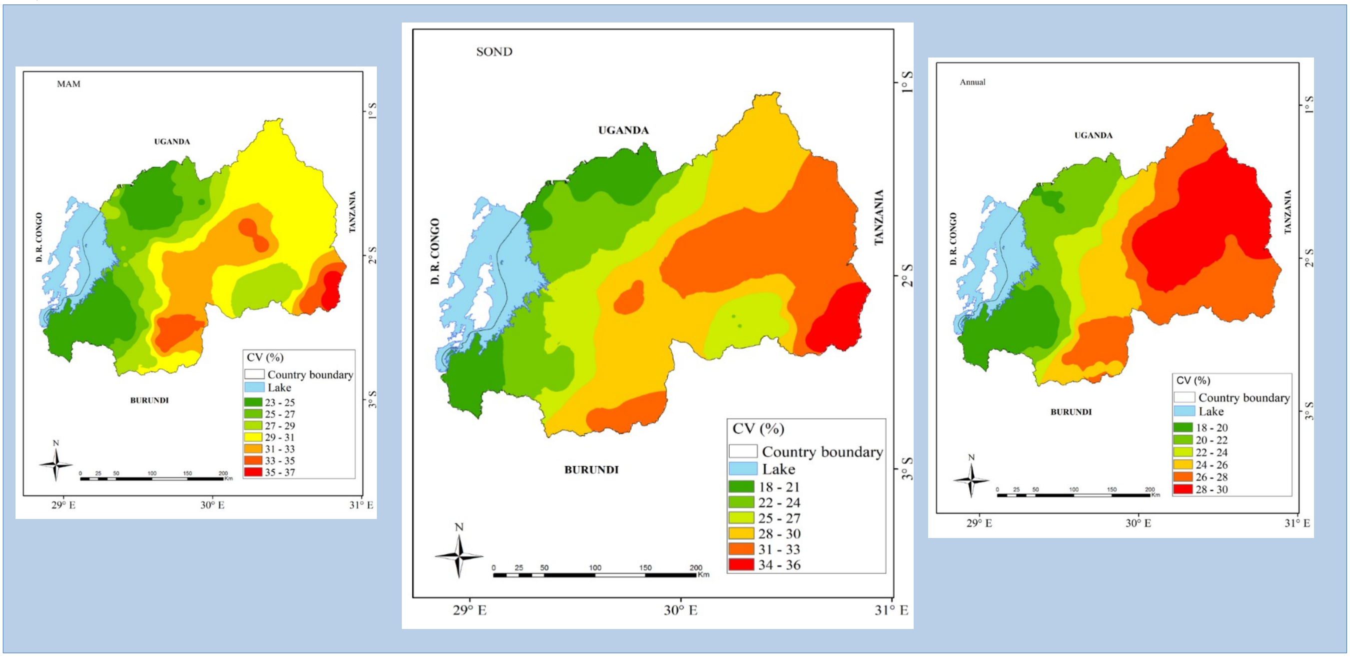


*Figure 4: Rwanda's rainfall variability distribution in space from March to May (left), September to December (center) and yearly rainfall variability (right) from 1981-2017.*

Rubona-Colline and Gikongoro-Met) registered decreasing trends. Over the northern parts (Byumba Met and Ruhengeri-Aero stations) also revealed decreasing trends. In the eastern parts, a decreasing trend of 1.6 mm year$^{-1}$ corresponding to 4.2% was observed over Kibungo-Kazo station as well as Kigali_Aero station located in Kigali city which revealed a negative slope of 4 mm year$^{-1}$ corresponding to 6.7% (Table 1).

### 3.3 Trend Analysis

The temporal variability results obtained using graphical and statistical methods indicated non-homogeneous characteristics during the annual and the seasonal time scale. The corresponding slope and significance test results are presented in the sub-section below. The graphical trend results indicated a decreasing trend during the MAM season for the twelve stations (Fig 5).

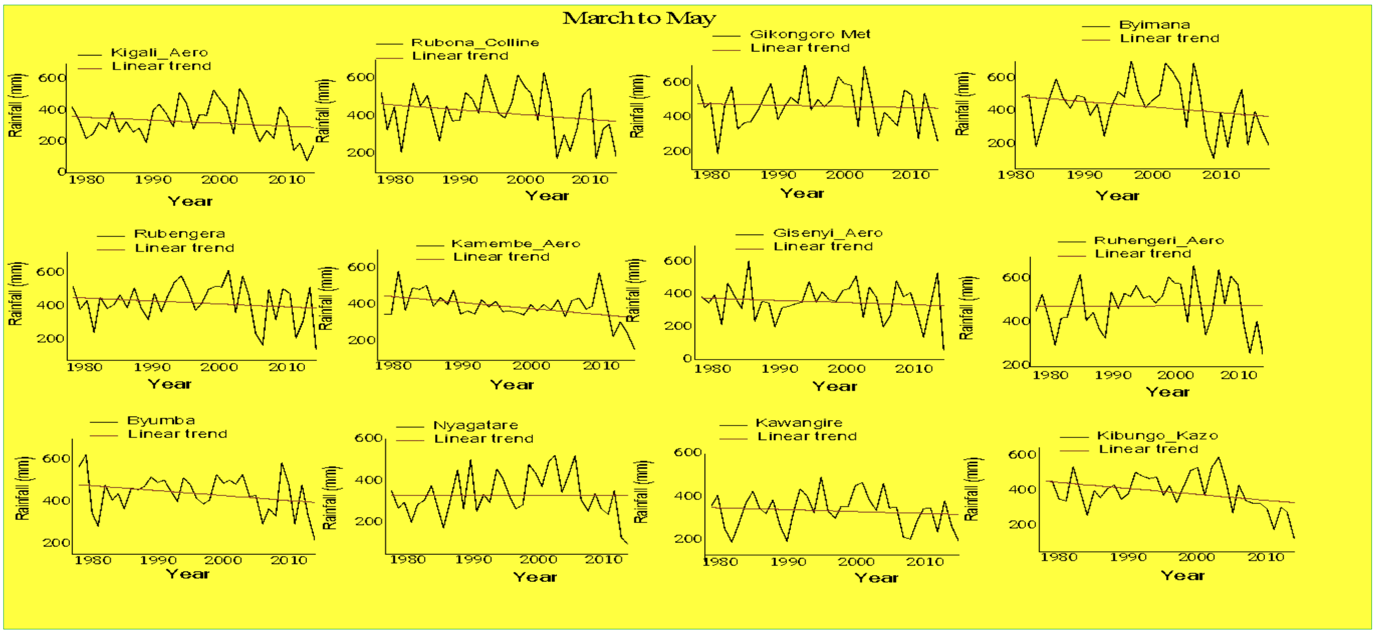


*Figure 5a:* Temporal variability and *trends of March to May seasonal rainfall over selected stations in Rwanda (1981-2017)*

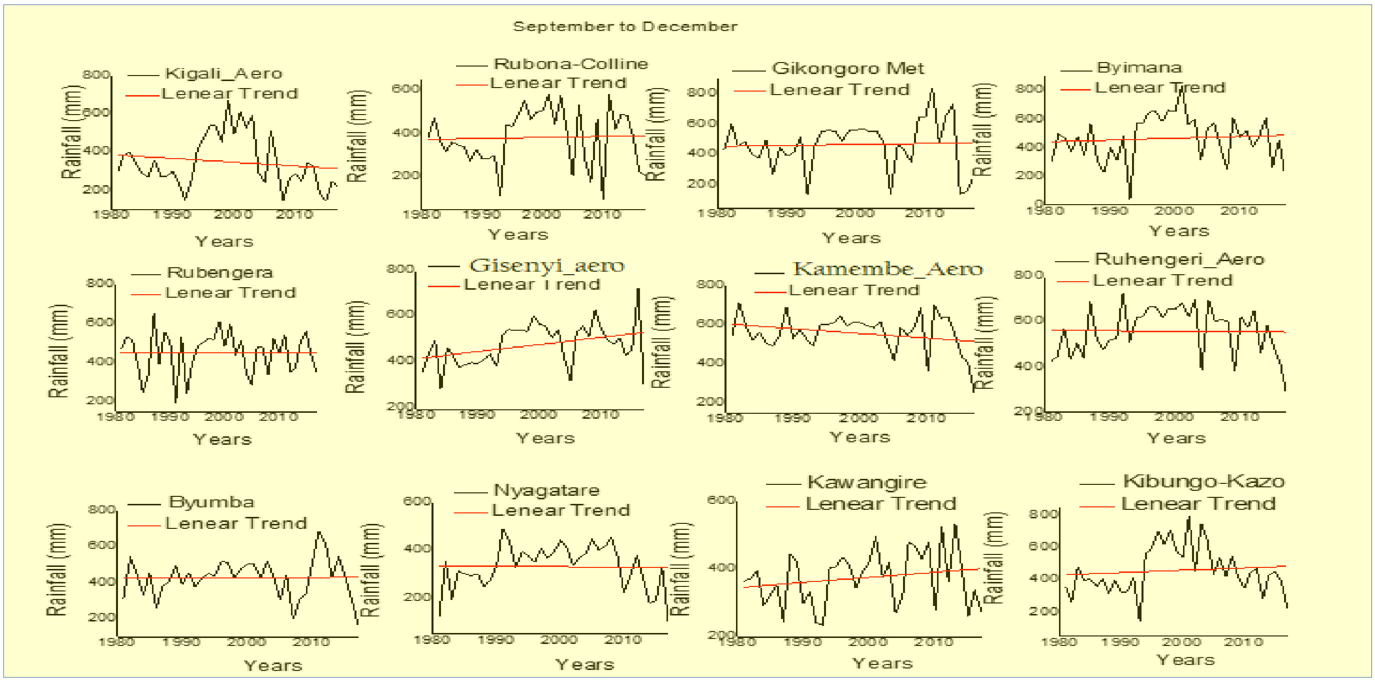


*Figure 5b: Temporal variability and trends of September to December seasonal rainfall over selected stations in Rwanda (1981-2017)*

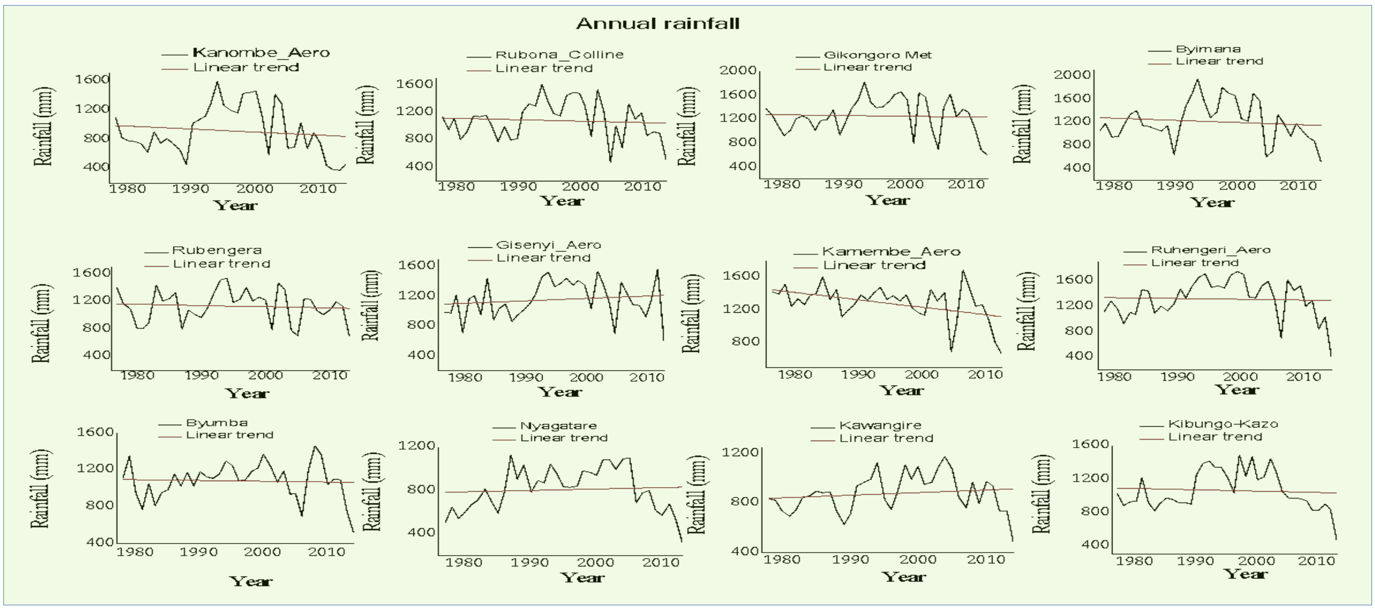


*Figure 5c:* Temporal variability and linear *trends of annual rainfall over selected stations in Rwanda (1981-2017)*

Table 1: *Statistical characteristics of rainfall for the 12 stations for March-April- May (MAM) and September-October-November- December (SOND) where, CV (coefficient of variation), Z ( Mann Kendal trend, (-) decreasing and (+) increasing), S (significance of trend at 90% (+) and at 95% (*)), Q (Sen's slope, mm year$^{-1}$), and T ( trend, %/year) in the period 1981 to 2017 over Byimana (BMN), Byumba Met (BYM), Kamembe-Aero (KMB), Kigali_Aero (KGL), Kawangire (KGR), Ruhengeri-Aero (RHR), Kibungo-Kazo (KNK), Nyagatare(NGT), Gikongoro-Met(GRM), Gisenyi-Aero (GSN), Rubengera(RGR) and Rubona-Colline (RNC) respectively.*

| Time | Station | | BYN | BYM | KMB | KGL | KGR | RHR | KNK | NGT | GRM | GSN | RGR | RNC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Annual | Mean | | 1222 | 1082 | 1336 | 1115 | 878 | 1332 | 1063 | 1014 | 1395 | 1168 | 1319 | 1132 |
| | CV | | 24 | 24 | 20 | 27 | 28 | 20 | 25 | 26 | 20 | 21 | 20 | 25 |
| | Trend | Z | - | - | - | - | + | - | - | + | - | + | - | - |
| | | S | | | * | | | | | | | | | |
| | | Q | -3.7 | -0.8 | -9.1 | -4 | 2.4 | -1.9 | -1.6 | 1.3 | -1.2 | 3.2 | -1.9 | -2.1 |
| | | T | -3.1 | -8.5 | -6.7 | -6.7 | 8.5 | -10.1 | -4.2 | 6.5 | -3.7 | 3.6 | -1.8 | -1.3 |
| MAM | Mean | | 472 | 441 | 408 | 327 | 335 | 478 | 363 | 382 | 515 | 386 | 453 | 497 |
| | CV | | 31 | 28 | 23 | 32 | 29 | 23 | 27 | 30 | 26 | 28 | 27 | 33 |
| | Trend | Z | - | - | - | - | - | - | - | - | - | - | - | - |
| | | S | | | | | | | * | | | + | | |
| | | Q | -3.4 | -0.3 | -3.3 | -1.9 | -1 | -0.9 | -3.5 | 0.5 | -0.7 | -1.3 | -1.8 | -2.6 |
| | | T | -9.7 | -19.8 | -5.7 | -13.4 | -31.1 | -17.7 | -9.8 | 3.2 | 0.3 | -15.5 | -5.8 | 0.7 |
| SOND | Mean | | 466 | 426 | 617 | 499 | 373 | 558 | 350 | 432 | 545 | 480 | 561 | 445 |
| | CV | | 31 | 25 | 20 | 32 | 32 | 18 | 32 | 30 | 25 | 20 | 24 | 29 |
| | Trend | Z | + | + | - | - | + | - | + | - | + | + | - | + |
| | | S | | | | | | | | | | * | | |
| | | Q | 1.22 | 0.17 | -2.41 | -1.97 | 1.51 | -0.21 | 1.48 | -0.2 | 0.61 | 3.1 | -0.5 | 0.48 |
| | | T | 9.9 | 1.5 | -17.4 | -23.9 | 16 | -8.8 | 12 | -12 | 2.2 | 4.3 | -8.2 | 1.4 |

The spatial rainfall trend during the MAM showed a decline in the South-eastern region extending to the central parts and Kigali City. The areas of the south-western bordering Lake Kivu and Nyungwe National Park revealed an increasing trend reducing towards the southern region in the areas along Crest Congo Nile extending to the northern highlands and north-western region of the country (Figure 6).

A decreasing rainfall trend during the SOND season was revealed over Kigali City and the north-eastern region in the areas of the Nyagatare district extending to the northern parts of the country surrounding the Volcano National Park increasing in the Western and Southern areas with a peak increasing in the areas around Lake Kivu extending to the lowland of Bugarama (Figure 6). On the annual time scale, a decreasing trend over the southern side of the Eastern province, the central plateau extending to the northern highlands towards the areas of the Volcano National Park increasing to the central and south-western parts of the western region bordering the Lake Kivu areas and the south-eastern areas of the Southern region of the country was indicated on an annual basis. The areas around Nyungwe National Park, the central and north-eastern parts of eastern region extending to the Akagera National Park registered an increase in trend (Figure 6).

The spatial trend analysis indicated a decreasing trend over Kigali City and the central parts during both annual and seasonal timescales extending to the eastern, southern and North-western parts with an increasing trend over the south-western parts during the long rain and through the year. The results obtained for the long rain season confirmed the results obtained by (Nahayo *et al.*, 2018; Sebaziga *et al.*, 2020) while the results obtained during the short rain season and through the year contradicted the results of (Ntirenganya, 2018) which indicated that there is no visible trend. The difference in results may be due to the temporal resolution type of data used in the previous study.

The rainfall trend results obtained in this study during MAM season confirm the results of other researchers within the region (Funk *et al.*, 2008; Williams and Funk, 2011; Lyon and Dewitt, 2012; Yang *et al.*, 2014) who have indicated that on longer timescales, total precipitation received during the MAM season has declined in recent decades. The results however contradicted the results obtained by Mohammed *et al.*, (2016) which indicated a non-significant trend in rainfall records ranging from 1964 to 2010. The disparities in the results may be attributed to extended periods of meteorological data gaps. Only Kigali Airport meteorological station provided almost complete dataset of continuous records from 1964 to 2010 and it was selected to be the reference rain gauge in filling missing data at other rainfall gauges which were not located in the same climatic zone. Rainfall decline over the regions has been attributed to the changes in the sea surface temperatures (SSTs) in the south-central Indian Ocean (Funk *et al.*, 2008) and western Pacific Ocean (Lyon and Dewitt, 2012; Yang *et al.*, 2014) which favour a local increase in precipitation, with the ensuing latent heating changing regional wind and moisture flow patterns and lowering precipitation during East Africa's lengthy rainy season (Williams and Funk, 2011). During the short rains, a decreasing trend over Kigali City and the central plateau was noticed while the rest of the country registered an increasing trend with a higher increase in the areas surrounding NNP and the north-western parts of the country. The results obtained during the SOND season confirms the results of (Mutai and Neil., 2000; Schreck and Semazzi, 2004; Ummenhofer *et al.*, 2009). It was further indicated that over East Africa, the warming of sea surface temperature anomalies in the western equatorial Indian Ocean dominates the enhanced short rainy season, with the eastern cold pole of the tropical IOD playing a less significant role. (Ummenhofer *et al.*, 2009). Seasonally, the ENSO teleconnection influence is most evident during short rainy season. (Mutai and Neil., 2000; Schreck and Semazzi, 2004).

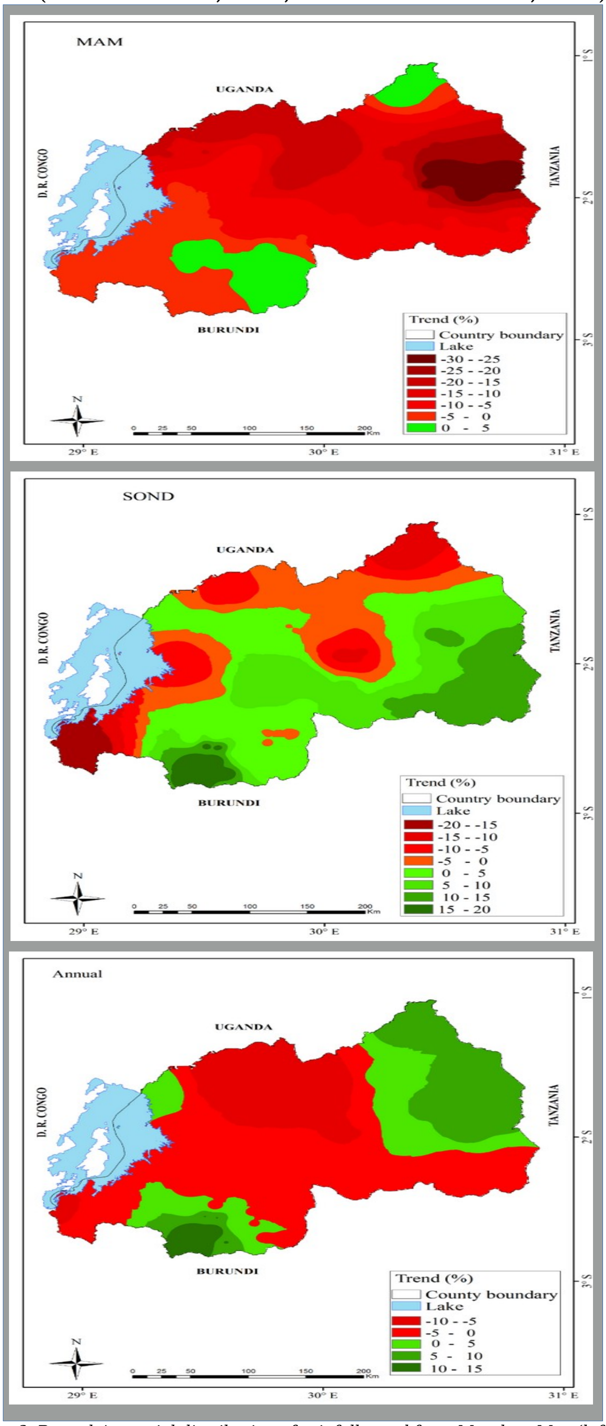


*Figure 6: Rwanda's spatial distribution of rainfall trend from March to May (left), September to December (center) and annual rainfall trend (right) from 1981-2017.*

## 4. Conclusion

In this study, we investigated the temporal variability and trend in rainfall from the year 1981 to 2017 over Rwanda for twelve synoptic rainfall stations using graphical and statistical methods. To carry out spatial analysis, seventy-two rainfall stations were considered in addition to the twelve synoptic stations. Sen's slope estimator and the Mann-Kendall techniques were employed to identify trends and gauge the size of changes, while the variability analysis involved calculating the coefficient of variation.

The results indicated a higher variability in annual rainfall over Kigali City, central and eastern Rwanda whereas lower variation in the western parts of Rwanda. A significant decrease in rainfall of 9.1 mm year$^{-1}$ was observed over the southern parts corresponding to – 6.7%. During the long rain season, a high variability over the extreme eastern parts, central and the southern region of the country was revealed whereas a low variability was registered over northern highland with a significant decreasing slope of 3.5 mm year$^{-1}$ corresponding to – 9.8%. During the short dry season, lower variability was registered over the north-western high land and the western region while pronounced variability was observed over the south-eastern parts of the dry and hot lowland climatic zone. A significantly increasing rainfall of 3.1 mm year$^{-1}$ corresponding to 4.3% was revealed over the western part while the remaining stations revealed a non-uniform trend. The results obtained under this study will improve policy-making and suggest policy implications.

Because the country relies mainly on rain fed agriculture, the resulting variability and trend results may serve as the basis for proper planning, increasing areas under small scale irrigation with best water harvesting techniques, encouraging agronomic practices that improve the soil water holding capacity such as mulching, agroforestry, use of organic manure, crop rotation, minimum tillage, cover crops/plants and zero grazing, introduction of drought resistant crops and varieties should be envisaged as adaptation measures and climate smart agriculture practices as a strategy for mitigation measures. It is also important to note a non-homogeneity in the obtained results which may indicate a need for further refinement of climate zoning over the country.

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