A Statistical Analysis of the Historical Rainfall Data Over Eastern Province in Rwanda

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ABSTRACT

Rainfall is the climatic factor of maximum significance for the East African countries, with extreme occurrences resulting in droughts and floods, which are often associated with food, energy and water shortages, loss of life and property, and many other socio-economic disruptions. Aim of the study was to investigate the extent of possible trends in annual rainfall total, annual rainy days and seasonal rainfall totals in the eastern province of Rwanda. Thirty-five years daily rainfall observations from nine ground weather stations collected from Rwanda Meteorology Agency were used to visualize and test trend in rainfall patterns over Eastern Province of Rwanda. Mann Kendell trend analysis was used to test the significance of trend in annual rainfall totals, number of rain days and seasonal rainfall totals for both long and short rainy seasons. The study revealed that in March to May (MAM) rain season, three out of nine stations registered a decreasing trend and only one station registered a significant increasing trend. During September to December (SOND) rain season, two out of nine stations showed a significant increasing trend and the remaining stations have non-significant trend. On annual basis, two stations revealed a significant increasing trend whereas one station indicated a decreasing trend. Furthermore, the results show that two stations revealed a significant increasing and decreasing trend respectively whereas the remaining stations show a non-significant trend in rainy days. Based on the findings we do not have conclusive evidence on rainfall variability in Eastern Province. Therefore, the study recommends more analysis associating the impact of ENSO phenomena on rainfall distribution over the Eastern Province of Rwanda and a more detailed study of the intra-seasonal rainfall characteristics over the study area.

Keywords: Statistical Analysis, Historical Rainfall Data, Eastern Province, Rwanda

1. Introduction

The economies of East African countries largely depend on rain-fed agriculture (Gitau *et al*., 2013) where crop and animal production directly rely on rainfall (Challinor and Garforth, 2007), which is highly vulnerable to the amounts and distribution of rainfall (Indeje *et al*., 2000). Most of East Africa region where Rwanda is located, experiences bimodal rainfall (Ilunga and Muhire, 2010; Mutai *et al*., 2000; Schreck and Semazzi, 2004; Mutai *et al*., 1998 Camberlin and Wairoto, 1997. The variability in rainfall frequency and intensity has been observed with Africa being the most affected during the past century (Sokona and Denton, 2001; Huq *et al*., 2004; FAO, 2008;Stringer *et al*., 2010). The sub-Saharan Africa has become more arid (Niasse *et al*., 2004; Gharbi *et al*., 2016; Ringler *et al*., 2010) impacting crop and animal production (Challinor and Garforth, 2007). Rainfall is the climatic factor affecting East African countries, with extreme occurrences resulting in droughts and floods, which are often associated with food, energy and water shortages, loss of life and property, and many other socio-economic disruptions (Indeje *et al*., 2000).The timely long-range rainfall prediction and early warning products can be used to mitigate the negative impacts, and also to take maximum advantage of the positive impacts (Mutemi, 2003).

The movement of inter-tropical convergence zone (ITCZ) determines the rainfall patterns during March to May (long rains) and September to December (short rains) over East Africa and Rwanda included (Okoola, 1999; Anyamba, 1984). The position and intensity of anticyclones such as Saint Helena, Mascarenes, Siberian and Azores control the rainfall seasons over Rwanda (Mutai *et al*., 2000; Ilunga *et al*., 2004; Kizza *et al*., 2009). During the long dry season (June to August), Rwanda is influenced by the dry Saint Helena and Azores anticyclones which cause the dry conditions over the country (Mutai *et al*., 2000; Ilunga *et al*., 2004; Kizza *et al*., 2009; Clark *et al*., 2003; Ilunga *et al*., 2008).

Rwandan farmers practice rain-fed agriculture with rainfall being one of the most significant factors influencing the crop production (Gitau *et al*., 2013; Yemenu, 2013) and remained as the most important limiting weather element in agricultural sector (Yemenu, 2013) yet it displays the largest variability in both spatial and temporal distribution and magnitudes (Gitau *et al*., 2013). Rainfall occurrence analysis is extremely helpful in planning of agricultural and water resources development (Yemenu, 2013; Vasanthkumar, 2015).

A considerable amount of research work has been done in the East African region to explore rainfall relationships. A study applying a trend analysis on annual rainfall totals, number of rain days, mean rain per rain days, seasonal rainfall totals for the long and short rainy seasons over Rwanda has indicated that there is no conclusive evidence of climate change and trends are not statistically significant in the rainfall while there is a highly statistically significant trend in daily temperature (Ntirenganya, 2016) However, this study has concentrated in Kigali city but no information was captured over the eastern region of the country, which is known as the food basket of the country. This study aims to identify the aspects of rainfall variability over the Eastern province of Rwanda with trend analysis on annual rainfall totals, number of rain days, mean rain per rain days, seasonal rainfall totals for the short and on long rainy seasons.

2. Materials and Methods

2.1. Area of study

The Eastern Province of Rwanda (known as" Intara y'Iburasirazuba") is the largest, the most populous and the least densely populated of Rwanda's four provinces and Kigali city. It was created in early January 2006 as part of a government decentralization program that re-organized the country's local government structures. It has seven districts namely: Bugesera, Gatsibo, Kayonza, Ngoma, Kirehe, Nyagatare and Rwamagana. The Eastern Province headquarter is located in Rwamagana district. This Province covers an area of 9,813 square kilometer corresponding to 37.26% of the total area of the Rwanda with a total population of 2,660,814(NISR, 2012b). The Eastern Province is the less densely populated Province with 274 inhabitants per square kilometer (Results, n.d.). In general, districts with lowest density are Bugesera (280 inhabitants/km^2), Gatsibo (274 inhabitants/km^2), Nyagatare (242 inhabitants/km^2), Kayonza (178 inhabitants/km^2) all of which are located in eastern province (NISR, 2012a)

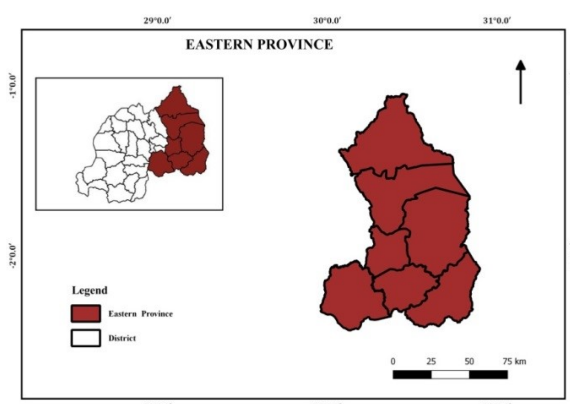


Figure1: Map showing the location of the Eastern province in Rwanda

2.2. Materials

Long and temporally consistent rainfall time series are essential in climate analyses and applications. Rainfall data from station observations are inadequate over many parts of the world due to sparse or non-existent observation networks, or limited reporting of gauge observations (Dinku *et al*., 2018). Rwanda had a large number of active meteorological stations prior to the mid-1990s. However, the number of active stations greatly reduced from around the time of the genocide against the Tutsi, in 1994 and remained very low until about 2010 (Siebert *et al*., 2019). The Enhancing National Climate Services (ENACTS) initiative reconstructs rainfall data by combining station data with satellite rainfall estimates to address temporal and spatial gaps in rainfall observation in Rwanda. Bias correction factors were applied to the satellite data and the resulted merged rainfall dataset is spatiotemporally complete that covers the period from 1981 to the present at a high spatial resolution (4–5 km) (Siebert *et al*., 2019; Dinku *et al*., 2014; Dinku, 2015; Faniriantsoa, 2017; Dinku *et al*., 2017). The base period 1981-2010 was chosen in order to have at least 30 years of rainfall data, the minimum period for judging the climate of a given region (WMO 2003). The stations used in this study are presented in **Table 1**, where latitude and longitude are in degree while elevation is in meter (m).

Table1: The meteorological stations used and theirs coordinates.

Station name	Longitude	Latitude	Elevation
Mwurire	30.38	-1.98	1520
Kagitumba	30.21	-1.36	1505
Ngarama	30.23	-1.58	1500
Gahini	30.5	-1. 85	1534
Rwinkwavu	30.63	1.96	1420
Mpanga	30.81	2.06	1400
Nyamugali	30.73	-2.28	1700
Zaza	30.4	-2.11	1515
Nyamata	30.45	-2.15	1428

2.3. Methodology

The Temporal analysis methods were used to assess the variability of rainfall and their corresponding trend. The temporal analysis of seasonal rainfall consisted of determining the seasonal rainfall climatology and subjected to a time series analysis. For this purpose, graphical method was adopted to assess the nature of trend in historical data by plotting observed rainfall against time. The advantage of this method is that it provides quick visual observation of the presence of a trend in a given time series. Moreover, the use of the graphical approach for trend analysis is simple. On the other hand graphical methods has shortcoming such as its subjectivity as it depends on individual judgments and some data set are lost by some smoothing techniques (Ogallo, 1981). Statistical methods were used to test the statistical significance of the observed trends in a time series (Hamisi, 2013; Muhati *et al*., 2007). The Mann–Kendall (MK) test is used to determine the nature of the trend of a given time series (Ongoma *et al*., 2017; Blain, 2013; Drapela and Drapelova, 2011; Kendall, 1975). The MK test has been used in many studies over East Africa (Safari, 2012; Ongoma *et al*., 2013; Nsubuga *et al*., 2014;Ongoma and Chen, 2017). Positive values denote an increasing trend whereas negative values denote a downward slope (Ongoma *et al*., 2017). To estimate the magnitude of rainfall change, the Theil–Sen's slope estimator (Theil, 1950; Sen, 1968) was used. The statistical significance was reported based on level of significance (p-value or alpha) of 0.05. Visual representation of graphics was generated using OriginPro 8 tool to illustrate the rainfall pattern at different time scale for each station considered while ArcGIS software was adopted to characterize the spatial pattern in rainfall over the eastern province.

3. Results and discussion

The results section summaries and discuss the obtained results for the assessing the nature of rainfall variability over the region by using graphical and statistical methods. The results obtained are discussed in the subsection section for the annual rainfall total, annual number of rainy days, March to May and September to December rainy season respectively.

4.1.2 Mean rainfall distribution

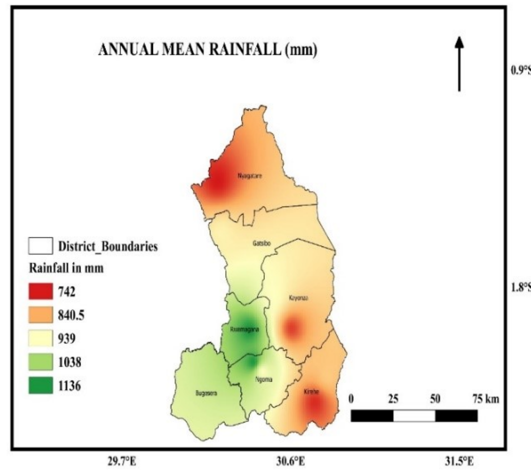
The distribution of mean annual rainfall, mean number of rainy days, mean seasonal (March to May known as MAM and September to December known as SOND) calculated from 1981 t0 2016 (Figure 2 a, b, c and d) indicated a clear varied pattern. To obtain the annual rainfall totals, monthly rainfall total aggregated from the daily rainfall over the selected stations in the eastern province was used. The annual mean rainfall ranges between 740 and 1130mm where the , spatial distribution (Figure 2 a) revealed that the area over Kirehe, the central part of Kayonza and western part of Nyagatare districts receive low rainfall increasing toward the northern and western parts of Kayonza district all along Gatsibo district extending to the central and eastern part of Nyagatare district while considerable annual rainfall was observed over the area surrounding the central part of Ngoma and Bugesera districts increase toward Rwamagana district.

The mean annual rainy days was computed to determine the climatological number of rainy days over the study area. It was indicated that the mean annual rainy days varies across the stations and ranges from 65 rainy days over Nyamugali to 106 rainy days over Kagitumba. The stations having the number of rainy days less than 90 rainy days are Nyamugali, Rwinkwavu, Mpanga, Nyamata and Ngarama while Gahini, Mwurire, Zaza and Kagitumba have the rainy days above 90 days.

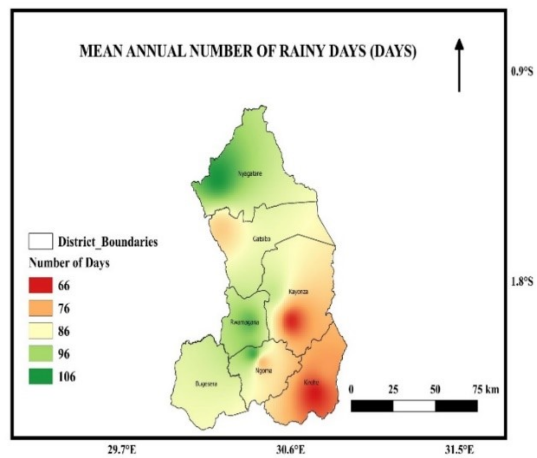
The spatial distribution in the mean number of rainy days (Figure 2 b) revealed a lower number of rainy in the areas around Kirehe, central Ngoma extending to central and eastern part of Kayonza district bordering Akagera national while a higher number in rainy rays was observed over the area north western part of Ngoma district, Rwamagana district, the central and western part of Nyagatare district. It is also important to note that the areas receiving higher number of rainy days are the areas extending to the western part of the province which boarders areas with higher elevation compared to the eastern part of the province and this explains the effect to topography to influence rainfall pattern of the area. At seasonal time scale, the mean seasonal rainfall varies across the stations. During the March to May season, the mean rainfall was observed to vary between 265 and 547 while during September to December the mean rainfall was revealed to be in range of 260 and 537mm.

The spatial pattern during March to May (MAM) (Figure 2 c) revealed that the area over Kirehe, western Ngoma and the central part extending to north eastern of Kayonza all along the area surrounding Akagera national park and the extreme western part of Gatsibo district exhibit a low rainfall whereas the central part of the eastern province in the area of Bugesera, Rwamagana, western part of

Kayonza extending to Gatsibo and Nyagatare receives relatively considerable amount of rainfall. The areas of the north western part of Ngoma and western part of Nyagatare districts are the area receiving higher rainfall during March to May over the eastern province. During September to December (Figure 2 d), the area over Kirehe, central to western Ngoma extending to the central and western part of Kayonza all along the area surrounding Akagera national park and the extreme north western part of Gatsibo district exhibit a low rainfall while the central part of the eastern province in the area of Bugesera, southern to central and north eastern part of Gatsibo extending to eastern part of Nyagatare receives relatively considerable amount of rainfall. High amount of rainfall during September to December rainy season was observed in the area of north western part of western Ngoma, Rwamagana and western part of Nyagatare districts.



(a)



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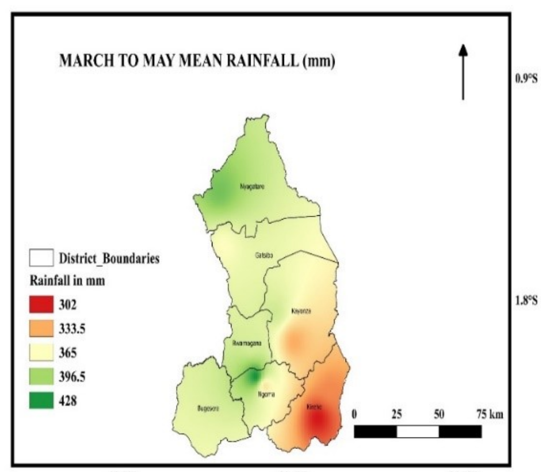
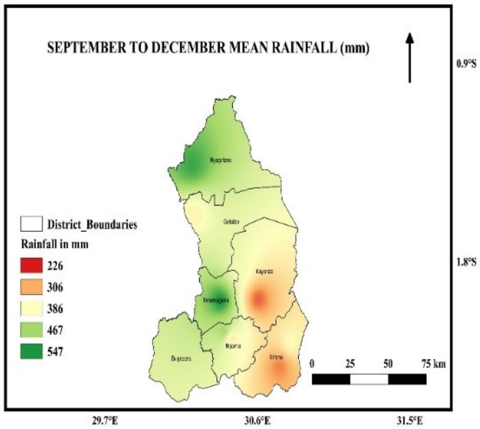


(c)



(d)

Figure 2: The spatial distribution of the annual mean rainfall (a), number of rainy days(b), March to May(c) and September to December(d) over the eastern province of Rwanda from 1981 to 2016

Annual trend analysis of rainfall total

The analysis of the annual rainfall totals consisted of determining the mean annual rainfall for stations used under this study and trend analysis at 5% significance level

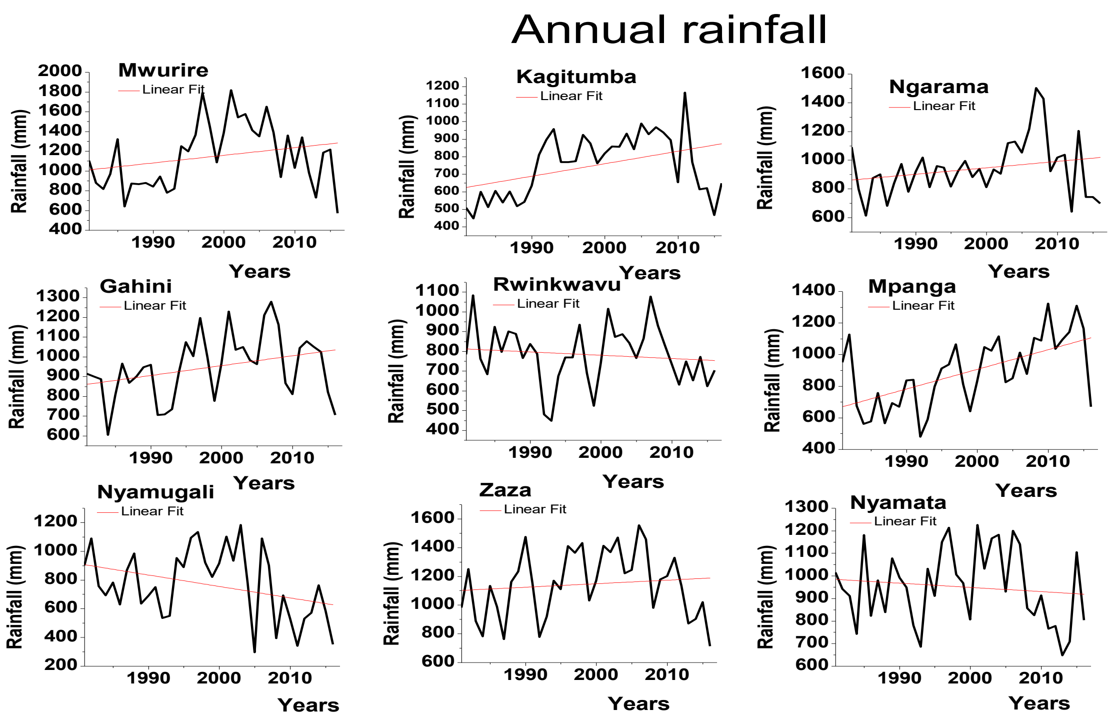


Figure 3: The rainfall trend in annual rainfall total.

The annual rainfall totals (Figure 3) indicate a clear variability pattern over all stations used in this study with a different nature of variability. The results obtained using graphical method indicated an increasing trend at Mwurire, Kagitumba, Ngarama, Gahini and Mpanga stations while a decreasing trend was revealed at Rwinkwavu, Nyamugali, Zaza and Nyamata stations. The Mann–Kendall trend analysis

(Table 2) indicate that Mwurire, Ngarama, Gahini and Zaza stations revealed a non-significant increasing trend. Kagitumba and Mpanga, stations revealed a significant increasing trend with an increasing slop of 8.2mm per year, 13.7mm per year respectively. Nyamugari shows a significant decreasing trend with a reduction of 9.5mm per year while Rwinkwavu, and Nyamata stations indicate a non-significant decreasing trend.

Table 2: Statistical Test of significance of trend (5%) at all stations used in this study

Time scale	Test/Station	MWURIRE	KAGITUMBA	NGARAMA	GAHINI	RWINKWAVU	MPANGA	NYAMUGALI	ZAZA	NYAMATA
	Kendall's tau	0.011	0.494	-0.041	-0.003	-0.45	0.161	-0.321	-0.042	-0.266
	p-value	0.927	**< 0.0001**	0.724	0.979	**< 0.0001**	0.162	**0.005**	0.714	**0.021**
MAM	Sen's slope	0.211	9.784	-0.786	-0.1	-5.388	2.274	-5.183	-0.667	-3.318
	Kendall's tau	0.077	0.416	0.223	0.147	0.101	0.34	-0.149	-0.012	-0.15
	p-value	0.505	**0**	0.053	0.2	0.381	**0.003**	0.195	0.917	0.191
SOND	Sen's slope	2.493	8.829	2.667	2.167	1.243	7.433	-2.573	-0.168	-2
	Kendall's tau	0.105	0.269	0.116	0.192	-0.185	0.384	-0.239	0.023	-0.141
	p-value	0.37	**0.019**	0.314	0.094	0.108	**0.001**	**0.038**	0.844	0.219
Annual	Sen's slope	5.595	8.208	3.886	4.38	-2.998	13.733	-9.464	0.845	-3.814
	Kendall's tau	-0.175	0.321	0.093	-0.279	0.41	-0.066	-0.211	0.019	-0.376
	p-value	0.134	**0.006**	0.429	**0.017**	**0.001**	0.576	0.072	0.87	**0.001**
Rainy days	Sen's slope	-0.719	8	0.192	-1.25	0.933	-0.304	-0.586	0.019	-0.75

The analysis of wet and dry years was analyzed using standardized rainfall anomalies for all stations considered and the obtained results are presented in the Figure 4 for the whole period under study.

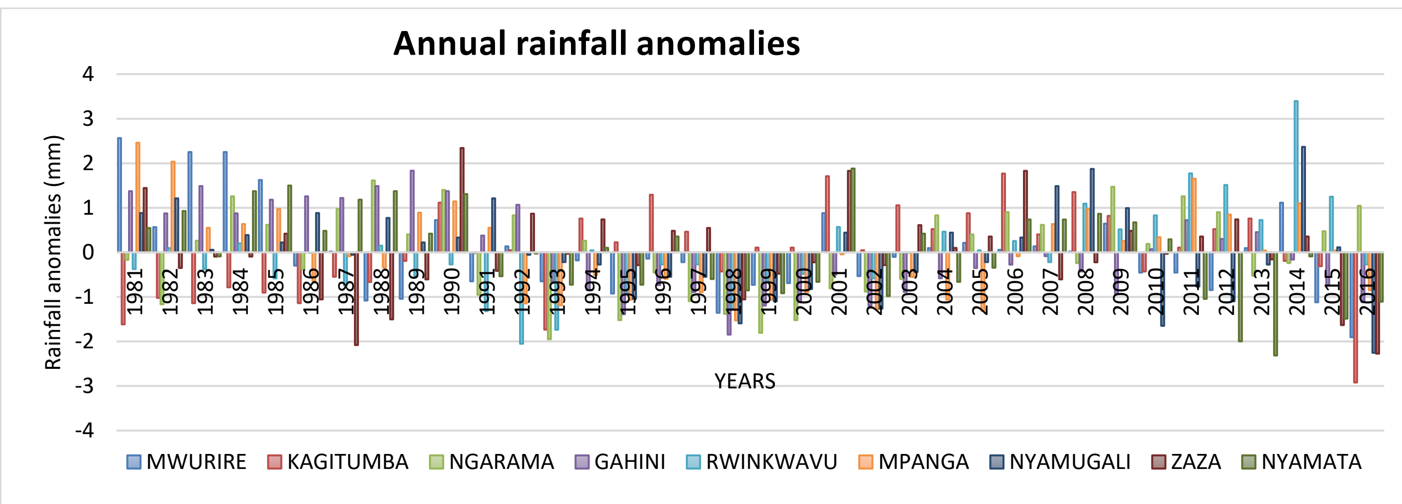


Figure 4: Annual rainfall anomalies over Mwurire, Kagitumba, Ngarama, Gahini, Rwinkwavu, Mpanga, Nyamugali, Zaza and Nyamata stations

The results obtained (Figure 4) indicating annual rainfall anomalies from 1981 to 2016, in general the analysis from most of the stations used in this research show that some years such as 1997 to 2000, and the years of 1993, 1995, 2002 and 2016 are the hot year anomalies. The same analysis, show that the year periods from 1981 to 1985, 2006 to 2010, and single year of 1989 to 1990 are wet annual years. The results also show that there a shift from wet year of 2014 and become abnormally dry in 2016.

4.1.3 Trend analysis of annual number of rainy days

In this analysis, we looked at the number of rainy days in the year. The yearly rainfall total contained the mixture of zero records (dry days) and those of rain (wet days). The problem with rainfall data is to choose an optimal threshold level needed for the threshold method for measuring rainfall. The precipitation, which is less than 0.85 mm, was not considered as a rainy day. We choose a slight higher threshold, 0.85 mm to avoid any complications for the recording of very small values of rainfall data. It is also important to note that the value of 0.85mm is used operationally in the determination of rain as a rainy day.

number of rain days

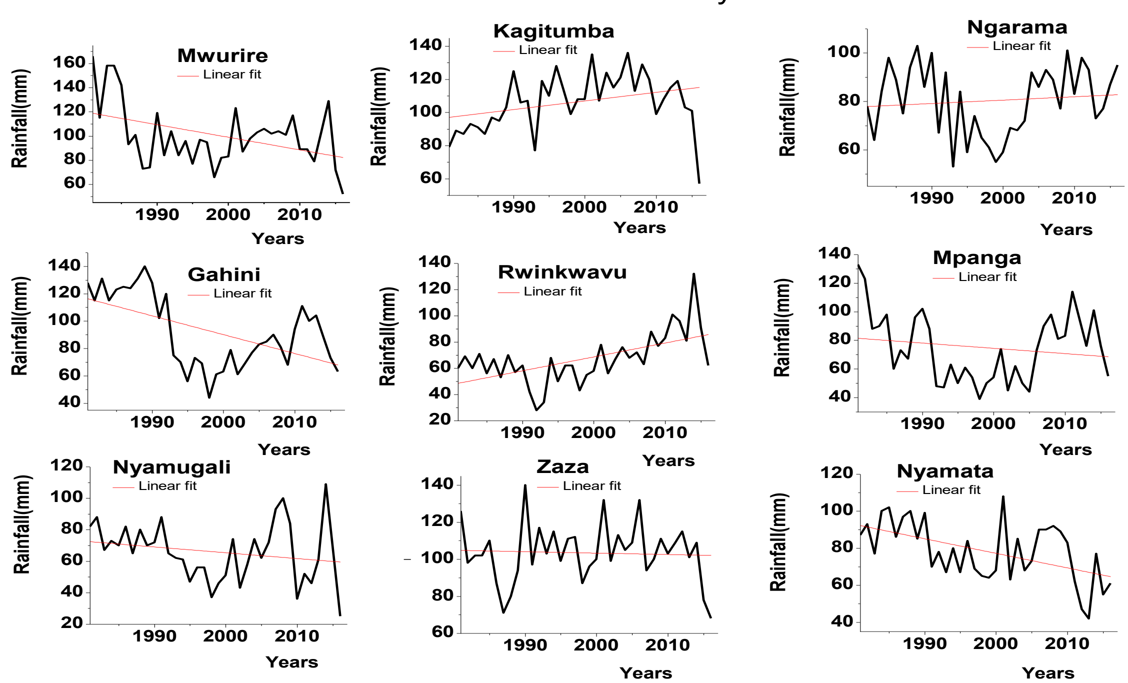


Figure5: Trend in annual rainy days frequency

It is important to note that a clear variability pattern in rainy days was observed based on the results obtained from the nine stations used under this study with a different nature of variability. The results obtained based on graphical method (Figure 5) indicated that Mwurire, Gahini, Mpanga, Nyamugali and Nyamata show a decreasing trend while Kagitumba, Ngarama, Rwinkwavu and Zaza stations indicated an increasing trend.

The statistical significance test using Mann–Kendall test (Table2) indicates that out of nine stations considered in this study, two stations namely Kagitumba and Rwinkwavu shows a significant increasing trend of 8 and 9 rain days per year respectively whereas Ngarama and Zaza stations showed a non-significant increasing trend. A slight significant decreasing trend of almost 1 rainy day per year was identified at Nyamata and Gahini stations respectively while a non-significant decreasing trend was observed at Mwurire, Mpanga and Nyamugali stations.

Seasonal rainfall analysis

The first analysis here was to generate seasonal summaries. The analysis focused on two main rain seasons namely MAM and SOND. In Rwanda, the seasonal rainfall totals were plotted and the linear regression models were fitted with the seasonal totals as the response variable and the year as the explanatory variable. We fitted seasonal curves and trends together in order to graphically test the trend in the season. The MAM rain season was examined and the trend was computed to assess the trend in rainfall.

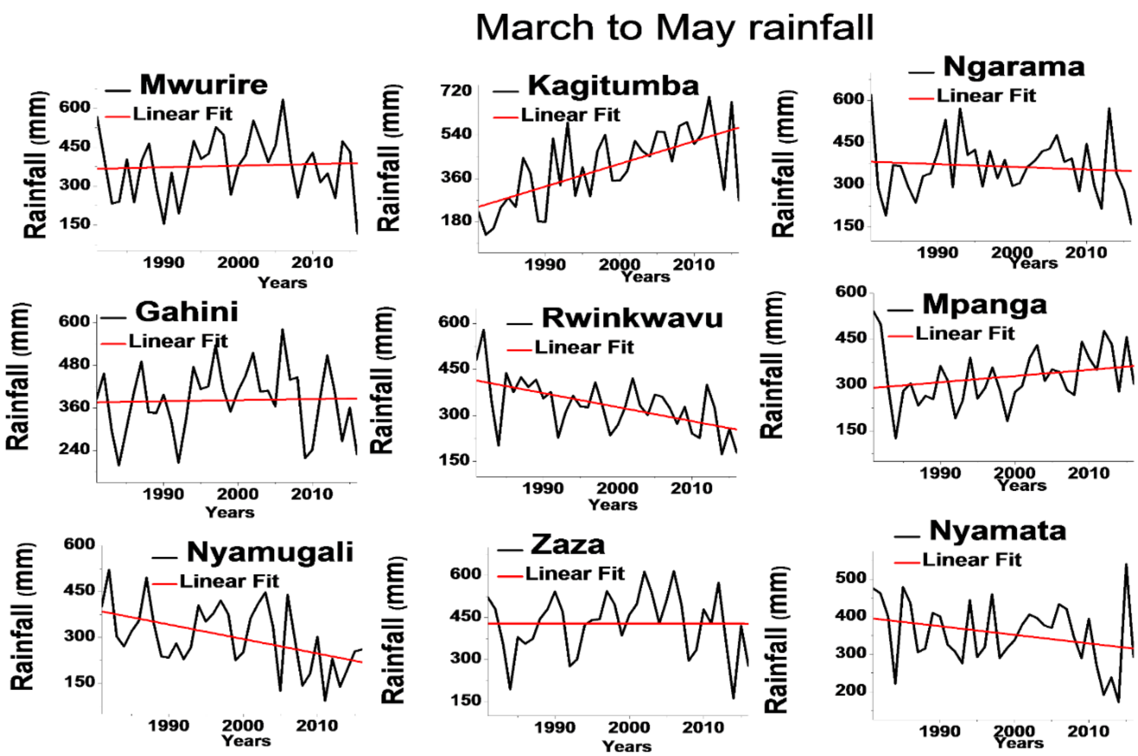


Figure 6: Rainfall trend in March to May seasonal rainfall total

The results (Figure 6) obtained from graphical method indicated that Rwinkwavu, Nyamata and Nyamugali exhibited a decreasing trend whereas Mwurire, Kagitumba, Zaza, Mpanga, Gahini and Ngarama show an increasing trend. Mann–Kendall test results in (Table: 2) confirmed a decreasing trend at Rwinkwavu, Nyamugari and Nyamata stations with a reduction of 5mm in a season at first 2 stations and 3mm at Nyamata station. A non-significant decreasing trend was confirmed at Zaza, Gahini and Ngarama stations while a significant increase of 9.7mm per season was obtained at Kagitumba station and the increasing trend at Mwurire station was found to be not significant.

The statistical analysis of historical rainfall for SOND season was examined and the trend analysis using graphical and statistical measure were carried out to assess the possible trend in rainfall during the short rain season.

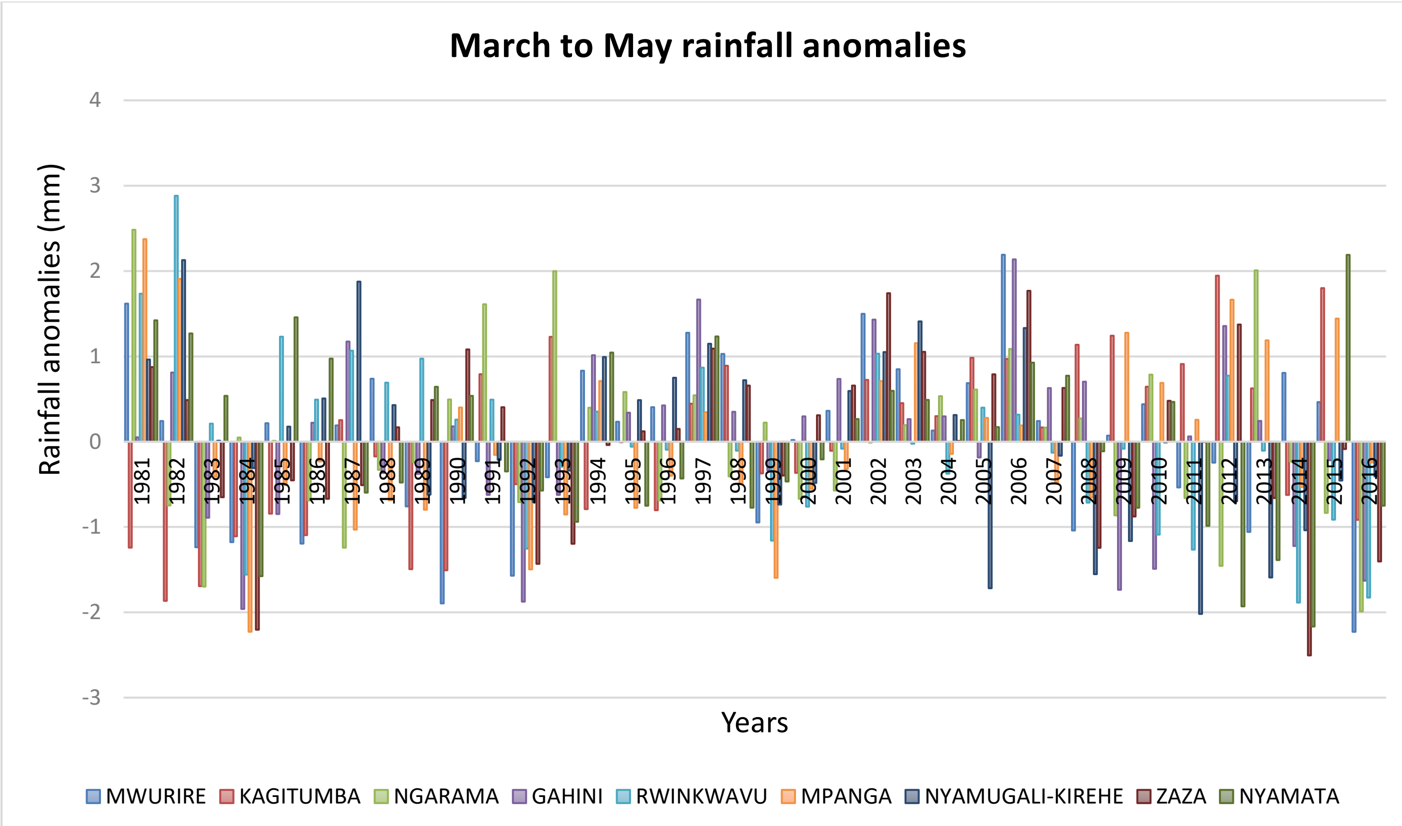


Figure 7: March to May rainfall anomalies over Mwurire, Kagitumba, Ngarama, Gahini, Rwinkwavu, Mpanga, Nyamugali, Zaza and Nyamata stations

The March- May rain season anomalies during the periods under study (Figure 7) shows that the two consecutives MAM periods from 1984 to 1985, 1992 to 1993, 1998 to 2000 were dry seasons for most of the stations used in this study. The single anomalies hot MAM season are 1989, 2009, 2010, 2014 and 2016. Most of the stations used with respect to temporal periods shows that MAM season are normally wet. The two consecutive MAM periods 1981 and 1982, and the MAM from 1994to 1998, 2002 to 2006 and from 2012 to 2013 were extremely wet MAM seasons.

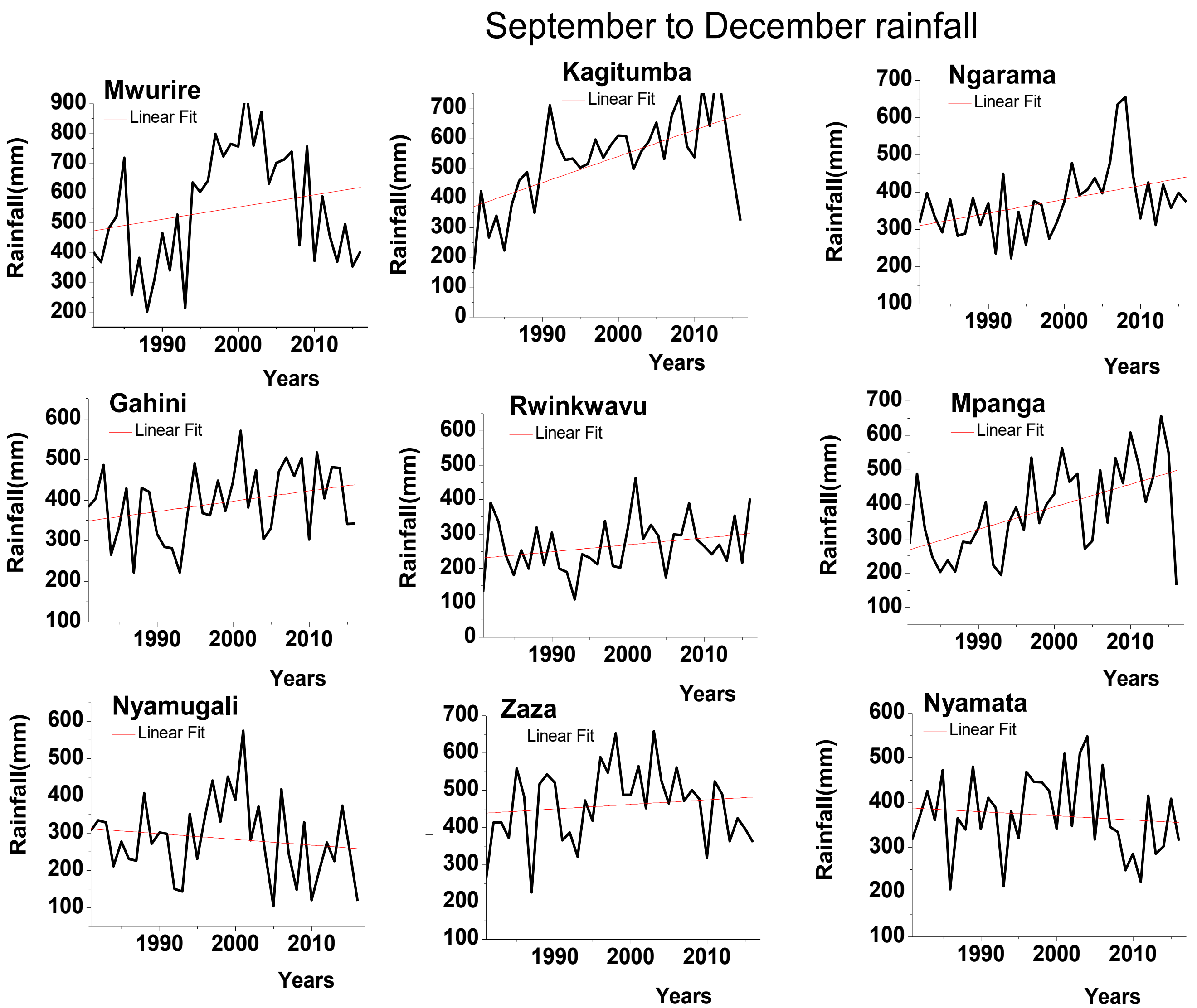


Figure8: Rainfall trend in September to December rainfall total over Mwurire, Kagitumba, Ngarama, Gahini, Rwinkwavu, Mpanga, Nyamugali, Zaza and Nyamata stations

Graphically (Figure 8), the trend analysis revealed that Mwurire, Kagitumba Ngarama, Gahini, Rwinkwavu, Mpanga and Zaza stations recorded an increasing trend while Nyamugali and Nyamata revealed a decreasing trend. However, Man-Kendall trend test analysis revealed that the trend observed graphically is not significant. Based on statistical analysis, it is important to note that a significant increasing trend in rainfall during September to December short rain season was found at Mpanga and Kagitumba stations with an increasing slope of 7mm and 8.8 mm respectively. Trends observed graphically at other stations were proved not significant (Table 2).

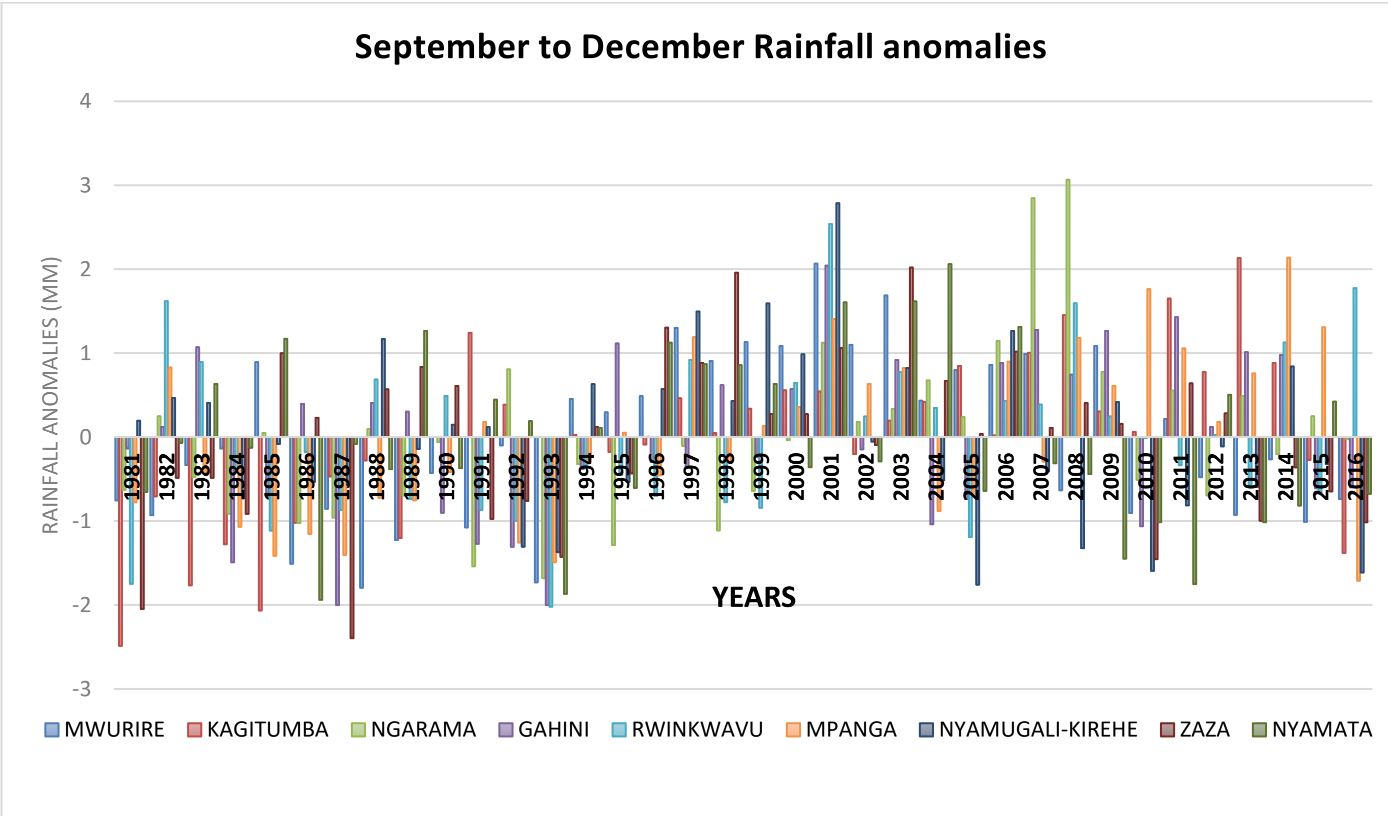


Figure 9: September to December rainfall anomalies over Mwurire, Kagitumba, Ngarama, Gahini, Rwinkwavu, Mpanga, Nyamugali, Zaza and Nyamata stations

The above (Figure:9) shows that in general, the periods from 1981 to 1994, short rain season (SOND) were extremely dry season. From 1996 to 2004 this season, behave like normal to wet season. This normal season continues even from 2006 to 2008, and the year 2009. By analyzing the anomalies on both annual, and rain season (long and short), for most cases where both rain season become anomaly wet, the annual results also become anomaly wet, and vice versa.

5. Conclusion

The statistical analysis of historical rainfall data over the eastern province of Rwanda used daily rainfall data collected from Rwanda Meteorology Agency (Meteo Rwanda) where thirty-five years periods of data for nine stations in the Eastern Province of Rwanda was used. The trend analysis was examined using graphical method, the significance test was performed using Mann Kendell on annual rainfall totals, number of rainy days, and seasonal rainfall totals for the long and short rainy seasons. The mean rainfall during both March to May and September to December rain season was computed and was observed to range between 302 and 428mm during March to May season and between 266 and 547mm during September to December rain season. The results revealed that the annual mean rainfall ranges between 750 and 1125 mm while the number of rainy days observed to range between 65 and 106 Days where the rainy day was considered as any day that received at least 0.85mm and above.

Graphical method was used to visualize trend in annual and seasonal rainfall totals and in number of rainy days. The trend observed graphically was tested statistically by using Man-Kendall trend test to confirm or reject its significance. Analysis indicated that during March to May (MAM) rain season, one nine stations showed a significant trend while three indicated a significant decreasing trend. During September to December (SOND) season, two stations indicated an increasing trend while the remaining showed non-significant trend. The significance test has revealed that Kagitumba station exhibits a significant increasing trend for the both seasonal and annual time scale whereas Mpanga station revealed a significant increasing trend on both annual and September to December season. It was further found that Rwinkwavu and Nyamugali registered a significant decreasing trend during March to May season. On annual basis, the results show that Kagitumba and Rwinkwavu stations revealed a significant increasing trend in number of rainy days while Gahini and Mpanga recorded a slight significant decreasing trend. The remaining stations showed a non-significant trend in number of rainy days. Based on the findings we do not have conclusive evidence on rainfall variability in Eastern Province. Therefore, the study recommends more analysis associating the impact of ENSO phenomena on rainfall distribution over the Eastern Province of Rwanda and a more detailed study of the intra-seasonal rainfall characteristics over the study area.

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