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Impacts of Climate Variability on Future Water Resources in Upper Akagera Catchment of Rwanda

Manassé Ntakirutimana[1], Theodore Dusabimana[1], Mugabe Assiel[1], Prosper Ayabagabo[2], Anthony Twahirwa[2,3] and Aminadab Tuyisenge[2]

[1]Integrated Polytechnic Regional College-Kigali (IPRC-Kigali), Civil Engineering department, KK 15 Rd, Po. Box: 6579 Kigali-Rwanda
[2]Rwanda Meteorological Agency (Mateo-Rwanda), KN 96 St, Kigali-Rwanda
[3]University of Nairobi, Nairobi, Kenya

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Abstract - *Water is the fundamental resource for sustaining life on earth. Its availability and flow paths are largely affected by the climatic conditions and catchment characteristics. Understanding the impact of climate variability on water resources is a key to the catchment resources planning and management.This study examined the variability of rainfall, maximum and minimum temperature over 1983 -2017 period using Mann Kendall test (MK) and quantile pertubation method (QPM) and analyse the impact the climate varibility may have on streamflow. MK was used to detect monotonic trend and QPM was applied to assess the decadal variations in seasonal climatic data.*

MK results indicated significant negative trend in rainfall long rainy season and significant positive trend in maximum temperature for long dry season. No significant trend was found in minimum temperature in general. It was found that stations with significant trend at 95% confidence interaval have higher magnitude of trend. QPM results highlighted the importance of graphical analysis. All climatic factors analyzed showed a dominance of positive percentage in anomalies. The recent years is characterized by positive decreasing anomalies in rainfall, positive increasing anomalies in maximun temperature and posititive decreasing anomalies in minimum temperature for all seasons. Most of the stations showed significant positive anomalies in rainfall at 95% confidence interval for the period between 1998 and 2011 in all seasons. The results of climate variability indicated that the recent decades were characterized by decrease in water level, in water bodies.

***Key Words*: Trend, Climate variability, Mann Kendall, Quantile perturbation, Akagera catchment**

1. INTRODUCTION

Streamflow variabilty in a catchment has become a global concerns as it leads to either drought or flooding. The relationship between rainfall and streamflow in the context of temporal-spatial variabilities is an important tool to understand the impact of climate change on the hydrological trends as the reports project the reduction in available water resources due to climate change (IPCC,2007).

Climate change in 21st century has become a concern and raised a global attention on water management at basin level [1], [2]. International community and researchers in different corners of the globe are putting effort in discovering the impacts of climate change or climate variability on water resources with the purpose of finding appropriate measures for water management practices [3]. The researches carried out revealed that climate variability has a great effect on hydrological resources and rainfall is the direct climatic factor that influences streamflow patterns [4]–[7]. The spatial variations of rainfall have an effect on hydrology of a region. It was found that a decreasing rainfall resulted in a significant reduction in streamflow[8]–[10], [7], [11] whereas increasing rainfall has increased river flow significantly [12]. However, other studies revealed that the rainfall variabilities are not sufficient to explain the change in the streamflow [13]–[15], the importance of anthropogenic activities in the catchment is of great consideration for hydrological dynamism[16], [17]. Although the rainfall plays an important role in streamflow variation, the importance of temperature can not be ignored. The temperature rise increases evaporation, modifies soil moisture and may lead to floods, drought and global warming, thus affect the water resources [18]. The global projections show that the mean temperature will rise between 1.4 and 5.8 °C by the year 2100 (IPCC, 2007, Locke and Mackey 2009). Africa is actually accounting over one billion people projected to be the continent mostly affected by climate change with frequent and intense droughts in some areas [20] and changes in parts of eastern Africa where drought and floods occurred and affect socio-economic conditions [21].

In his research,[22] outlined inconsistency in the research carries out in Easter Africa where some indicated that there is a general decrease in rainfall and others found that rainfall is expected to increase by 5–20% from December to February and decrease by 5–10% from June to August. Rwanda as a country of East Africa, and whose big part drains to Nile basin, the study shows a decrease in rainfall amount from west to eastern parts for both annual and long rain season and this can be attributed to topographic behaviour in the country [23].

Few studies has investigated the rainfall variations over Rwanda and East Africa in general, however no one found to have analysed the variation of climatic factors in subcatchments of Rwanda and the impacts the variations may have on water resources. The purpope of this study is to analyze the spatio-temporal variability of rainfall and temperature in Upper Akagera catchment of Rwanda, by focusing on trend characteristics, decadal oscillations in seasonal rainfall and temperature as well as discussing the impact the variability of variations in climatic factors may have on riverflow in Upper akagera Catchment of Rwanda.

2. Materials and Methods

2.1 Study area

The study area is Upper Akagera catchment in Rwanda (Figure 1). The Upper Akager catchment is located in Eastern Province of Rwanda. It covers a total area of 3,053 km^2. In the recent two decades the eastern province of Rwanda (in which Upper Akagere belongs) has known a significant change in land use/land cover where there is increase in agricultural activities and urbanization. Rwanda is known for two rainy and two dry spell which makes the country exibit bimodal type of rainfall pattern: Long rainy season (March-April-May), long dryspell season (June-July-August), short rainy season (September-October-November) and short dryspell season (December-January-Febebruary) [22]. The average annual rainfall ranging from 800mm to 1200mm with annual mean temperature ranging between 20.3°C and 21.3°C. The catchment is characterized by a temperate climate with elevation ranging from 1300m to 1900m which is among the lowest elevation range for a catchment in Rwanda.

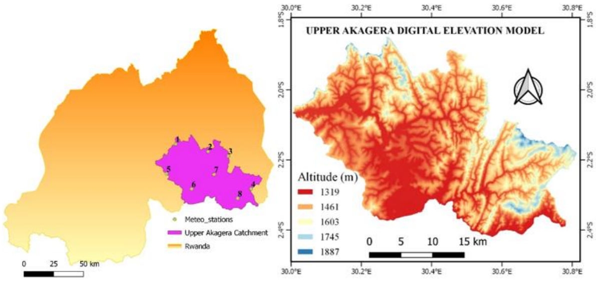


Figure 1: Location of Upper Akagera Catchment on Rwanda Map

2.2 Data source

This study analyses the spatial and temporal variability of rainfall and temperature and its impact on variability on hydrological patterns. The rainfall data (1981 to 2018) and minimum and maximum temperature data (1983 to 2017) for 8 meteorological stations (Table 1) chosen based on spatial distribution (Figure1) were collected from Rwanda Meteorological Agency (Meteo Rwanda). No missing data were found in meteorological records.

Table 1: Meteorological stations in Upper Akagera catchment of Rwanda

Station Number	Station Name	Longitude	Latitude
1	RUBUNGO	30.16	-1.92
2	MWURIRE	30.4	-1.98
3	KABARONDO	30.56	-2.01
4	RUSUMO	30.73	-2.26
5	NYAMATA	30.09	-2.15
6	KARAMA	30.28	-2.26
7	ZAZA	30.45	-2.15
8	MUSAZA	30.63	-2.33

2.3 Methods

In this study, the variations in rainfall and temperature in the Upper Akagera catchment was analyzed with help of Mann-Kendall test (MK test) and quantile perturbation method (QPM). The MK test presents the direction and significance of trends in meteorological time series and to indicate the magnitude of trend, Sen's slope estimator test was used. QPM was used to investigate the decadal variation in rainfall and temperature. These statistical methods were used to test the temporal variability in seasonal rainfall and temperature data for various hydro-meteorological stations in the catchment.

2.3.1 Mann-Kendall

The Mann-Kendall (MK) test is a ranked based non-parametric statistical test which has been used around the world to test the trends in hydrological and meteorological data [24]–[26]. The Mann-Kendall test is done by calculating the statistical test S as follows:

$$S = \sum_{i=1}^{n-1} \sum_{k=i+1}^{n} sgn(x_i - x_k)$$

where n is the number of data points in dataset, x_i and x_k are sequential data value in the time series "i" and "k" (k>i) and sgn ($x_i - x_k$) is the sign function whereby

$$sgn\ (x_i - x_k) = \begin{cases} +1 & if \quad x_i - x_k > 0 \\ 0 & if \quad x_i - x_k = 0 \\ -1 & if \quad x_i - x_k < 0 \end{cases}$$

The statistical test S has approximately a normal distribution with the mean for a sample size n≥ 8 [27]. In that case mean S, E(S) = 0 and variance is calculated as follows:

$$V(S) = \frac{1}{18} n(n-1)(2n+5)$$

In case of existence of tied groups, the variance V(S) is calculated as:

$$V(S) = \frac{1}{18}(n(n-1)(2n+5) - \sum_{i=1}^{m}(t_i(t_i-1)(2t_i+5)$$

where m represents the number of tied groups and t_i is the number of data value in m^{th} group.
The standardized MK test (Z) follows a normal distribution with the mean equal to zero and variance of one and is given as

$$Z_{Mk} = \begin{cases} \frac{S-1}{\sqrt{V(S)}}, & if\ S > 0 \\ 0, & if\ S = 0 \\ \frac{S+1}{\sqrt{V(S)}}, & if\ S < 0 \end{cases}$$

The positive value of Z_{MK} signifies an increasing trend, while a negative value indicates a decreasing trend. The hypothesis H_0 of no trend in time series is rejected if $|Z_{MK}| > Z_{1-\alpha/2}$, implying a significant trend in time series. The value of $Z_{1-\alpha/2}$ is taken from the table of standard normal distribution and the value of α=0.05 is selected in this study.
The Mann-Kendall test assumes that time series is serially independent which may not be the case for meteorological series. The existence of serial correlation in the time series inflates the variance of the Mann-Kendall test and rejects the null hypothesis of no trend, while it is true [28]. In case of significant correlation, the effective sample size (ESS) method was used to limit the effect of serial correlation by modifying the original Mann-Kendall variance [26]. The modified variance is calculated as follows:

$$Var*(S) = Var\ (S).\frac{n}{n^*}$$

where n* is effective sample size, n is actual sample size, Var(S) is the variance of the Mann–Kendall statistic and Var*(S) is the modified variance. The coefficient of auto correlation (r_k) at lag k and effective sample size (n*) are calculated as follows:

$$r_k = \frac{\frac{1}{n-1}\sum_{i=1}^{n-1}\left(X_i - E(X_i)\right) * \left(X_{i+1} - E(X_i)\right)}{\frac{1}{n} * \sum_{i=1}^{n}(X_i - E(X_i))^2}$$

in which

$$E(X_i) = \frac{1}{n}\sum_{1}^{n}(X_i)$$

$$n^* = \frac{n}{1 + 2 * \sum_{k=1}^{n-1}(1 - \frac{k}{n}) * r_k}$$

In order to determine the trend magnitude, the non-parametric Sen's slope approach is considered [26]. The method is preferably superior to the statistical regression approach because of its robust estimate of the magnitude of the trend [27]. The Sen's slope method estimates the trend magnitude as follows:

$$T_i = Median\left(\frac{x_i - x_k}{i-k}\right)$$

where, x_i and x_k are data values at time i and k respectively and k > i.

2.3.2 Quantile perturbation method

The quantile perturbation method developed by [29], [30], was used to assess the historical variation in extremes quantiles of hydro-meteorological time series. It has been applied around the globe to detect the spatiotemporal variability in rainfall, temperature and river flows [29]–[33] and it was found to be robust in quantifying the variability in hydro-meteorological data.

The approach determines the relative change in extremes quantiles between a baseline and a block period [29]. The baseline refers to full time series and blocks are the subseries derived from full times series. The block period of 10 years with one year moving window was chosen for this study. To determine the variability in extremes values by QPM, the extreme values in baseline period of length N and extreme values in the block period of length L are selected and ranked from largest to smallest. The probability of exceedance (empirical return period) for each extreme value in block period is calculated as L/i (where "i" is the rank of each extreme value in block period) and the corresponding quantile values are x (L), x (L/2) … x (L/i), where x is the extreme value in block period. Similarly, the probability of exceedance for each extreme value in the baseline period is given by N/j (where "j" is the rank of each extreme value in baseline period) and the quantile value associated to each empirical return period is y(N), y(N/2) …., y(N/j), where y is the extreme value in baseline period).

To determine the relative change, the quantiles with the same return period are compared. In case the return period (L/i) in block period does not match a corresponding value (N/i) in baseline period, a linear interpolation is applied between the closest values [29]. Then, the relative change is calculated as the ratio between the extreme quantile value of block period x (L/i) to the extreme quantile value of baseline period y (N/j) of the same return period (L/i = N/j). The perturbation factor (anomaly) is the average of all relative changes above a certain threshold for each block period which represents the deviation in extreme quantiles in each block period to the corresponding long-term based quantiles.

The statistical significance of the anomalies at the 95% confidence level will be tested using the non-parametric bootstrapping Monte Carlo method according to the following steps:

1. The baseline series was re-shuffled to obtain new temporal series.
2. The new series was divided into block period of length L (L=10years)
3. The new temporal variation of anomalies is calculated using QPM procedure to the re-shuffled series.
4. The steps 1, 2, 3 are repeated 1000 times to obtained 1000 anomaly factors for each block period.
5. The anomaly values will be ranked from highest to the lowest and the limit of 95% confidence interval for each block period will be taken as 2.5th

percentile for lower limit and 97.5th percentile for upper limit. The anomalies out of confidence limit were considered to be statistically significant.

3. Results and discussion

3.1 Mann-Kendall and Sen's slope statistics

The Mann-Kendall trend analysis for rainfall, maximum temperature and minimum temperature data was applied for 8 stations distributed over the catchment. The Mann-Kendall test was used to determine the trend direction and Sen's slope estimator was used to determine the trend magnitude. The trend was determined at the 95% confidence level. Since the existence of serial correlation in the data may nullify the presence of trend in the time series, the test of serial correlation was applied prior to the trend analysis.

Table 2: Mann-Kendal test and Sen's slope estimates results for Rainfall over Akagera catchment of Rwanda (1981-2018), * indicates significant trend at 95% confidence interval and negative sign indicates the decreasing trend.

Station number	Long rain season		Long dry season	
	MK test	Magnitude	MK test	Magnitude
1	0.24	0.55	0.58	0.33
2	-0.67	-1.33	-0.03	0
3	-1.01	-1.73	0.65	0.42
4	-3.72 *	-5.44	-0.44	-0.14
5	-1.92	-2.83	0.04	0
6	-1.02	-1.27	-0.49	-0.33
7	-2.00 *	-2.64	0.72	0.43
8	-2.94 *	-4.78	0.83	0.3
Station number	Short rain season		Short dry season	
	MK test	Magnitude	MK test	Magnitude
1	-1.02	-1.47	-0.72	-1.04
2	0.33	1	0.09	0.42
3	-0.75	-0.93	0.35	0.41
4	-2.30 *	-2.92	-2.08 *	-3.6
5	0.92	1.88	-1.86	-2.47
6	-0.64	-0.91	0.61	0.88
7	-1.22	-1.33	-0.65	-1.02
8	-1.53	-2	-1.65	-2.78

The knowledge of trends in meteorological data gives the baseline understanding of increasing or reducing streamflow in the catchment.
Table 2, Table 3 and Table 4 indicate the trends and magnitude for four seasons in rainfall, maximum temperature and minimum temperature respectively in Upper Akagera catchment.

The MK results in rainfall indicate that there are stations with increasing and stations with decreasing rainfall in all seasons over the catchment. It was found that rainfall tends to decrease in Upper Akagera catchment. As shown in Table 2, 87.5% of stations in long rainy season, 75% in short rainy season and 62.5% in short dry season present decreasing rainfall.
Contrary to the other seasons, the long dry season present 62.5% of increasing rainfall. In long rainy season, three stations out of eight present negative significant trends at 95% confidence interval where only one station in short rainy and short dry season present negative significant trend at 95% confidence interval. No station was found to have significant trend in rainfall at 95% confidence interval for long dry season.

Table 3: Mann-Kendal test and Sen's slope estimates results for Maximum temperature over Akagera catchment of Rwanda (1983-2017), * indicates significant trend at 95% confidence interval and negative sign indicates the decreasing trend.

Station Number	Long rain season		Long dry season	
	MK test	Magnitude	MK test	Magnitude
1	0.31	0	2.07*	0.01
2	1.19	0.02	2.70*	0.02
3	0.97	0.01	2.07*	0.02
4	1.82	0.03	2.13*	0.02
5	-0.4	-0.01	1.76	0.02
6	0.09	0	2.19*	0.02
7	0.11	0	0.6	0
8	1.48	0.02	2.27*	0.02
Station Number	Short rain season		Short dry season	
	MK test	Magnitude	MK test	Magnitude
1	0.36	0	1.22	0.02
2	1.36	0.02	1.81	0.03
3	1.07	0.02	1.6	0.02
4	1.22	0.02	2.02*	0.04
5	0.74	0.01	0.27	0
6	0.44	0.01	0.47	0.01
7	0.18	0	0.68	0.01
8	1.25	0.02	1.96	0.03

It was found that stations with significant trend in rainfall at 95% confidence interval have high magnitude of trend than stations with non-significant trend. Additionally, stations with decreasing trend in rainfall have high magnitude of trend, except stations in long dry season where stations with decreasing trend in rainfall have lower magnitude of trend. Consequently, the rainfall presents higher magnitude of trends in long rainy season than other seasons.

Table 4: Mann-Kendal test and Sen's slope estimates results for Minimum temperature over Akagera catchment of Rwanda (1983-2017), * indicates significant trend at 95% confidence interval and negative sign indicates the decreasing trend.

Station Number	Long rain season		Long dry season	
	MK test	Magnitude	MK test	Magnitude
1	0.94	0.01	2.16*	0.02
2	0.06	0	1.33	0.01
3	-0.17	0	0.28	0
4	-0.09	0	1.28	0.01
5	1.51	0.01	2.56*	0.02
6	-0.74	-0.01	-0.03	0
7	0.28	0	1.68	0.01
8	-0.28	0	1.53	0.01
Station Number	Short rain season		Short dry season	
	MK test	Magnitude	MK test	Magnitude
1	1.69	0.01	1.36	0.01
2	1.1	0.01	0.59	0.01
3	-0.21	0	0.53	0.01
4	0.18	0	0.89	0.01
5	2.05*	0.02	2.64*	0.02
6	1.39	0.01	0.98	0.01
7	1.39	0.01	1.84	0.02
8	0.47	0	1.39	0.01

Table 3 indicates the trend direction and trend magnitude in maximum temperature. Generally, there is increasing trend in maximum temperature for all stations considered over Akagera catchment of Rwanda. Only station number 5 in long rain season shows decreasing trend in maximum temperature. No significant trend at 95% confidence interval was found in maximum temperature for long and short rainy season. However, 75% of all stations in long dry season and 12.5% in short dry season present significant increasing trend at 95% confidence interval. The increasing magnitude of trend for all stations range approximately between 0 °C to 0.03°C per season with only decreasing trend in maximum temperature of 0.01°C at station 5 in long rainy season.

Contrary to maximum temperature, we observed 50% stations in long rainy season, 25% stations in long dry season and 12.5% station in short rainy season with decreasing trend in minimum temperature (Table 4). No station with decreasing minimum temperature was found in short dry season.

Generally, the trends in minimum temperature are not significant at 95% confidence interval. Only station 5 presents increasing trend for long dry, short rainy and short dry season as well as station 1 in long dry season.

Most of the stations presented an increasing magnitude of trend ranging from 0°C to 0.01°C per season in all seasons. Only station 6 showed a decreasing magnitude of trend of 0.01°C per season in minimum temperature for long rain season.

3.2 QPM results in meteorological timeseries

According to [34], the results of statistical tests such as Mann Kendall or Spearman's rho applied to entire timeseries are meaningless if not supported by graphical analysis which can detect sub-trends in climatic data. Therefore, in addition to Mann-Kendall test, this study investigated the temporal oscillations in seasonal rainfall, maximum and minimum temperature using QPM. Due limited space, a sample of QPM plots are presented. The quantile oscillations in extremes rainfall and temperature are shown from Figure 2 to Figure 4.

As the Figure 2 shows, the long-term rainfall pattern presents a dominant positive anomaly for all stations in all seasons. Generally, the rainfall pattern is characterized by positive increasing percentage of anomalies in the earlier period and decreasing positive anomalies for recent period which leads to negative anomalies in recent years for most of the stations in all seasons.

In long rain season, except station 7 and 8, all other stations showed significant positive anomalies at 95% confidence interval for the period between 1998 and 2011, however, the period of significant anomalies varies from station to station. During this season all stations present significant negative anomalies at 95% confidence interval for the recent years. QPM results in long rain season present a decreasing flank in anomalies in recent year (Figure 2). These results correlate with MK results that showed 87.5 % of all stations present downward trend in rainfall for long rain season.

The study found the negative anomalies in rainfall for the stations 1,2,5 and 7 for the period between the year 1986 and the year1995 and negative anomalies for recent year in all stations for short rainy season with significant negative anomalies at station 4,7 and 8 in recent year. Except station 6 and 8, all other stations have shown significant positive anomalies between the year 1997 and the year 2008 with number of years with significant positives anomalies varies from station to station. The oscillations of rainfall pattern in short dry season behave more less the same as short rainy season (Figure 2).

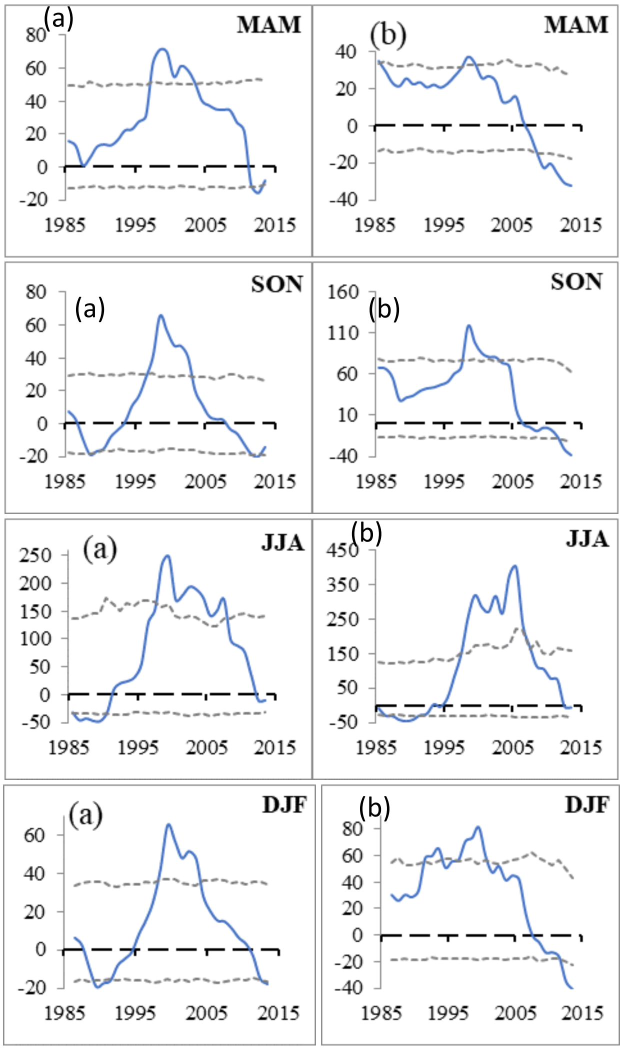


Figure 2: Temporal anomalies in seasonal rainfall for long rainy season (MAM), short rain season (SON), long dry season (JJA) and short dry season (DJF) at the station 1(a) and station 4 (b). The y-axis indicates the anomaly index in percentage. The dotted line denotes the 95% confidence intervals.

The temporal variations of rainfall in all seasons are dominated by positive anomalies with decreasing tendency in recent year. However, we observed exceptional dominance of positive anomalies in long dry season with significant positive anomalies for all stations between year 1998 and year 2005. Number of years of significant positive anomalies varying from station to station. This confirms MK results that showed larger percentage of stations with positive trend and lower magnitude of trend for stations with negative trend in seasonal rainfall. In general, the percentage of anomalies oscillations are high for positive anomalies than negative anomalies in all seasons (Figure 2).

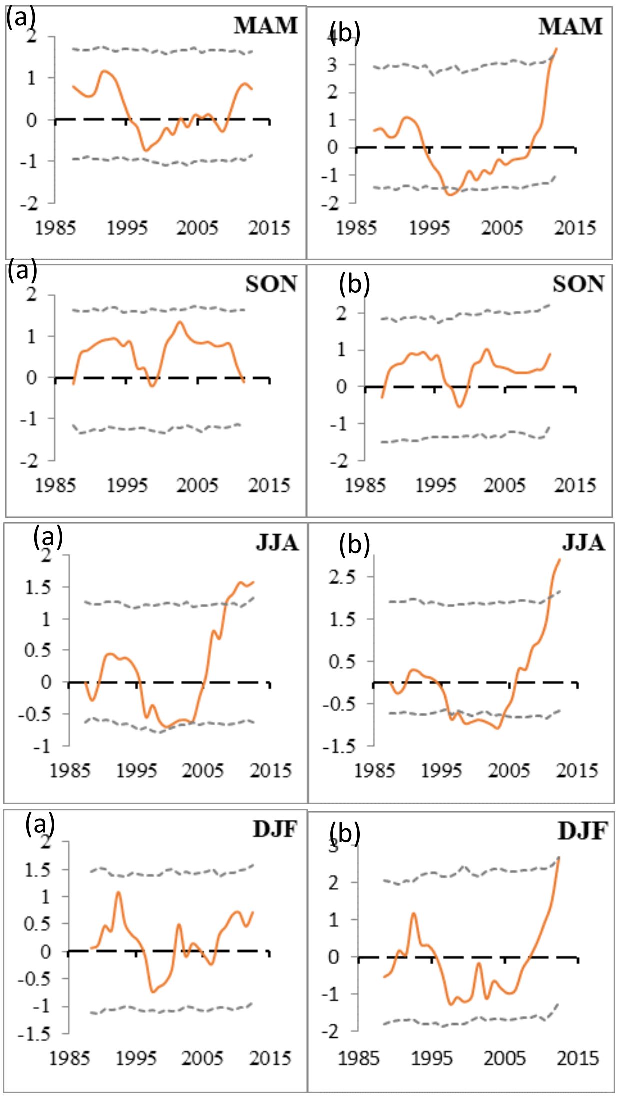


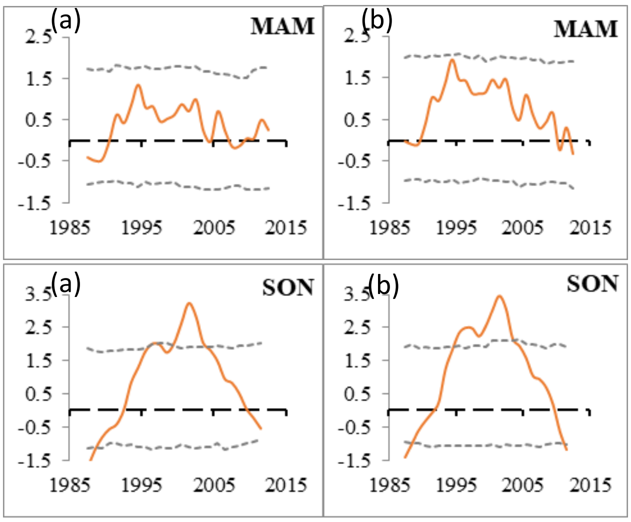
Figure 3: Temporal anomalies in seasonal maximum temperature for long rain season (MAM), short rain season (SON), long dry season (JJA) and short dry season (DJF) at the station 1 (a) and station 4 (b). The y-axis indicates the anomaly index in percentage. The dotted line denotes the 95% confidence intervals.

The oscillations in maximum temperature shows that in each season the temperature pattern behaves the same for all stations (Figure 3). There are positive anomalies for the period before the year 1995 and the period post the year 2008 for the long rainy season and negative anomalies in between. The short rainy season is characterized by positive anomalies in general for all decade. The analysis shows an increasing anomaly in long rainy season and a decreasing tendency in anomaly for short rainy season in recent years for maximum temperature. No significant anomaly was found in maximum temperature for short rainy season. However, significant negative anomalies were observed at the stations 4 and 8 for long rainy season between the year 1997 and the year 2000 in maximum temperature.

The long dry season is characterized by negative anomalies in maximum temperature before the year 1990 for most of the stations and period between 1995 and 2005 for all stations. The positive anomalies are observed between the year 1990 and the year 1995 and the period post 2005. There is a steepness increase in anomaly percentage of maximum temperature which leads to significant positive anomalies in recent years at all stations for long dry season. In short dry season, positive anomalies in maximum temperature were found for the period pre 1995 and post 2005 for all stations, except station 2,4 and 8 which have negative anomalies before the year 1990. No significant anomalies were found in maximum temperature during short dry season (Figure 3).

The QPM analysis in minimum temperature for long rainy season, showed negative anomalies for the period pre-1990 at station 1,4,5 and 7 and positive anomalies after the year 1990 with decreasing flank after 1995 which leads to negative anomalies at the end of study period for most of the stations (Figure 4). No significant anomalies were found at 95% confidence interval in minimum temperature for long rainy season. The short rainy season is characterized with dominant positive anomalies in minimum temperature with similar pattern at all station. Negative anomalies were observed before 1992 and after 2010. The period in between present positive anomalies. All stations present significant positive anomalies between the year 1996 and the year 2005. Most of the stations present significant negative anomalies before the year 1988.

Short dry season is highly dominated with positive anomalies in minimum temperature with only negative anomalies found at the beginning and the end of study period (Figure 4). No significant anomalies at 95% confidence interval were found in minimum temperature short dry season.



(a) (b)

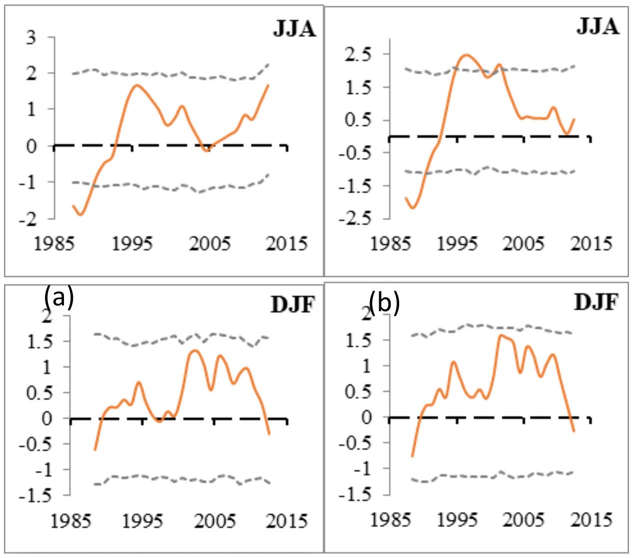


Figure 4: Temporal anomalies in seasonal minimum temperature for long rain season (MAM), short rain season (SON), long dry season (JJA) and short dry season (DJF) at the station 1 (a) and 4 (b). The y-axis indicates the anomaly index in percentage. The dotted line denotes the 95% confidence intervals.

In long dry season, all the stations present negative and positive anomalies for the period pre-1993 and post 1992 respectively, with station 3 and 6 having negative anomalies toward the end of study period. The analysis revealed significant negative anomalies before the year 1990 at all stations and significant positive between year 1995 and year 1998 at all station except station 5. As for rainfall and maximum temperature, the oscillations in minimum temperature are dominated by positive anomalies for most of stations in all seasons.

4. CONCLUSIONS

The study analyzed the rainfall and temperature in Upper Akagera catchment of Rwanda. The area is mainly rural and was unexploited in earlier decades but in recent decades the area is known for increasing agricultural and urbanization activities. The analysis with MK test showed negative and positive trends in rainfall, minimum and maximum temperature. It was noticed that the area has known negative significant trend in rainfall for long rainy season and positive significant trend in maximum temperature for long dry season. Although 62.5% of stations present increasing trends in rainfall for long dry season, the magnitude of trend for both negative and positive trend are small compared to other seasons. In this season, 5 stations present increasing trend in rainfall with magnitude of trend varying from 0.3 mm/season to 0.43 mm per season and 3 stations present negative trend with magnitude of trend varying from -0.33mm/season to 0.00mm/season. In general, the study shows that the trends in minimum temperature have not significantly changed over 1983 to 2017. Only few stations with significant minimum temperature were found for long dry season, short rainy season and short dry season.

The graphical analysis by QPM has revealed the decreasing flank in rainfall in recent decades for all seasons leading to significant negative anomalies in recent years for some stations. Contrary to rainfall, the maximum temperature has shown increasing positive anomalies in recent years. However, the minimum temperature has also shown decreasing flank in percentage of anomalies in recent years. The fact that the maximum temperature has increasing anomalies and minimum temperature has decreasing anomalies in recent years, give more room for water loss through evapotranspiration and lowers the level of water in water bodies.

Additionally, the decreasing percentage in positive anomalies in rainfall for recent years, gives an idea of decreasing water levels in water bodies. It is expected that Upper Akagera catchment may experience decrease in water resources due to current changes and variability in climate. This may lead to food insecurity as large percentage of Rwanda depends on small scale rainfed agriculture. However, [35] concluded that the anthropogenic activities may be considered more important to influence streamflow variability than changes and variability in observed in climatic factors. Therefore, in addition to climate factors, taking into consideration the influence of anthropogenic activities in Upper Akagera catchment, may lead to the better understanding of the cause of streamflow variability.

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