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Analysis of Spatio-temporal rainfall trends and rainfall variability in Botswana between 1958 and 2019

Hüseyin Gökçekuş [a], ***Youssef Kassem*** [a, b] **and *Lorato Precıous Mphinyane*** [a,*]

[a] *Department of Civil Engineering, Civil and Environmental Engineering Faculty, Near East University, 99138 Nicosia, Cyprus*

[b] *Department of Mechanical Engineering, Engineering Faculty, Near East University, 99138 Nicosia, Cyprus*

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ABSTRACT

Environments with a climatic characteristic of semi-aridity exhibit high rainfall variability, increasing significantly as the climate changes. In this study, rainfall concentration and Spatio-temporal trends in annual and seasonal (November to March) rainfall in Botswana were analyzed. The satellite data (1958-2019) is obtained from the Southern African Science Service Centre for Climate Change and Adaptive Land Management and the Climate Toolbox. The Mann–Kendall trend test (MK), autocorrelation function (ACF), relative percentage change (RPC), precipitation concentration index (PCI), and Theil–Sen's slope estimator (β) methods were adopted for data analysis. The regions include Gaborone, Maun, Francistown, Serowe, Kasane, Tsabong, Ghanzi, and Pandamatenga. The results indicated that the magnitude of change of change of the significant downward trends in the annual rainfall was found to be -1.11 mm/year at Maun, -1.62 mm/year at Ghanzi, -0.33 mm/year at Pandamatenga, and -0.25 mm/year at Tsabong. The magnitude of change of change of the significant downward trends in the seasonal rainfall was between -0.60 mm/year at Pandamatenga and -0.19 mm/year at Tsabong. All these regions, except Ghanzi, experienced a downward trend in the rainfall distribution. This is owing to the synoptic characteristic of the below-average geopotential heights over Ghanzi. Which might exacerbate the formation of convective systems, leading to a positive rainfall trend at Ghanzi. The annual calculated PCI values are divided into three classes; PCI>10≤15, PCI>16≤20, and PCI>20. The Mann-Kendall analysis of the PCI values indicates that all the regions experienced a downward rainfall trend, implying that it is heading toward a uniform to a moderate distribution. There were distinct patterns that emerged from the Pandamatenga region, indicating a strongly irregular distribution. The regions of Kasane, Maun and Francistown, demonstrated moderate to an irregular distribution. For Gaborone and Francistown, results showed occurrences of a moderate to strongly irregular distribution.

1. Introduction

The variability of rainfall in Southern Africa has undergone significant changes, particularly in recent decades, since the late 1960s, increasing inter-annual variability. In particular, droughts are now affecting different regions worldwide and are becoming more intense [1]. The rainfall patterns are spread and distributed across these regions. With this, there seems to be a link to El Niño Southern Oscillation (ENSO) [2]. The Southern African Development Community (SADC) countries experienced almost close to severe droughts in the 1980s to 1990s. From 2015 – 2016, Botswana experienced water scarcity because of extremely low rainfall seasons [3]. Nevertheless, rainfall and temperature patterns analysis are often used to track climate change intensity and size [4–6]. Evaporation rates have been increasing in staggering amounts, one of the most significant influences of climate variability, causing similar increases in extreme rainfall [7].

Like most Southern African nations, Botswana undergoes extremely volatile rainfall patterns, contributing to droughts [8]. Droughts in southern Africa appear to occur after an El Niño incident in the rainy season from December to March [9]. Impacts of rainfall variability, causing droughts, have generally increased because of the lack of rainfall and at increased degrees of temperatures. Thereby increases the stresses on evapotranspiration rates [10, 11]. Semiarid

* Corresponding author. Tel.: +90-392-223-6464.

E-mail addresses: huseyin.gokcekus@neu.edu.tr (*H. GökçekuŞ*), yousseuf.kassem@neu.edu.tr (*Y. Kassem*), mphinyanelorato@icloud.com (*L. P. Mphinyane*)

ORCID: 0000-0001-5793-4937 (*H. GökçekuŞ*), 0000-0002-1451-5457 (*Y. Kassem*), 0000-0003-0575-8710 (*L. P. Mphinyane*)

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climates are a climate over a region that receives rainfall potentially below evapotranspiration. These climates are determined by one of the widely used climate systems, the Koppen Climate Classification. Group B is Dry climates. That is where most countries in the southern part of Africa fall. It is necessary to have up-to-date information regarding climate patterns and climate changes. It will be essential for future predictions, planning, management, and water resources sustainability [10–12].

Botswana is a landlocked country situated on the African plateau. It is a deserted area with 582,000 km^2 and inhabitants reaching 2,3 million people [15]. The seasonal rainfall occurs from November to March. The country experiences dry spells of two to four days, where no rainfall falls in particular regions (Table 1) [16]. In the early summer to late summer, there are increases in westerly thermal waves that move across Botswana edges, causing increases in the isolated showers of rainfall experienced in Botswana [17]. The mean annual rainfall is 412.19mm, from 1901 to 2016 [18].

Mphale et al. [19], It showed analyses of a period of 30 years of annual rainfall for Botswana from 1971 to 2000. Their studies noted that Botswana's yearly rainfall decreased significantly in its hard veldt region, values being -1.097, -0.029, -0.407, and -1.327 mm/year. While Batisani et al. [20] used a 31-year-long dataset, researchers looked at yearly rainfall trends in Botswana's sand and hard veldt areas. From 1975 to 2005, annual rainfall data confirmed the same patterns throughout the country. Besides, Kenabatho et al. [21] attempted to analyze rainfall and temperature changes at four anchor climates, and they concluded that Between 1926 and 2011. They explained that if the current trend continues, average annual rainfalls will be reduced by around 30 mm by 2050. However, Da Silva [22] and Lazaro et al. [23] observed two significantly contrasting results in both of their studies.

The variability of rainfall is likely to rise as Botswana continues to dry. Climate change estimates from the (Intergovernmental Panel on Climate Change) predict a 30 to 40 percent decline in rainfall from 2080 to 2099, with the most significant drops occurring during the already dry winter season. Over time, research has shown a decrease in the patterns of mean temperatures and annual amounts of rainfall in Africa, respectively. Predictions state that these increments will surpass 4 degrees Celsius around the ending of the 21st century [5, 31].

Several studies have been undertaken to probe into climate variability by analyzing rainfall and temperature trends, both on a regional and a global scale. Groleau et al. [25] undertook a study from 60 stations where they utilized data that consist of January and February daily rainfall and the bootstrap-based Mann-Kendall and Sen's slope estimator. Meanwhile, in India, Da Silva [18] researched the annual and seasonal total rainfall, which occurred over 33 years from 1976 to 2008. They employed the non-parametric Mann–Kendall, Z, and Sen's Slope methods. From 1935 through 1992, they used monthly, seasonal, and yearly statistics. Muhire et al. [26] stations in Rwanda used linear regression analysis.

Similarly, Recha et al. [27] used annual and seasonal rainfall alongside the Mann-Kendall trend analysis and Sen's slope estimator from Kenya. Moreover, Che Ros et al. [28] performed an in-depth study in Malaysia, analyzing the daily and monthly rainfall trends from 1940 to 2010. Again, Nenwiini et al. [29] in South African areas, yearly and seasonal rainfall were similarly examined using the Mann-Kendall trend analysis and Sen's slope estimator. The annual rainfall analysis from 1940 to 2015 in Benin was reported by Ahokpossi [30], which showed that trends can be affected by the selected statistical trend test. For instance, the MK variance correction with complete autocorrelation showed significant trends in the number of stations studied by Wang et al. [31]. Meanwhile, Elzopy et al. [32] analyzed annual, seasonal, and monthly time scales, from 1901-2015, using the Modified MK trend test; seasonality index (SI), PCI, the rainfall departure analysis (RDA) and rainfall anomaly index (RAI) in Ethiopian areas. Arragaw and Woldeamlak [24], also worked on the spatiotemporal variability and trends in rainfall and temperature in the central highlands of Ethiopia from 1983-2013.

From the recent studies that have been performed in the last year, Sezen et al. [33] and Tokgoz et al. [34] performed an analysis of the annual and seasonal rainfall from 1960 to 2015 using the Mann-Kendall trend analysis and Sen's slope estimator in Turkey's various regions. Also, Harmse et al. [35] analyzed the monthly rainfall data for 30 years, from 1989 to 2018. Rahardjo et al. [36], analyzed daily rainfall data from 1982 to 2011 using Slope stability analysis in Singapore. Ibrahim et al. [7] performed a study on the time scales covering monthly, annual, and seasonal periods of 1970–2016 in Nigeria. Wang et al. [31] used the innovation trend analysis on the yearly and Seasonal data from 1961 to 2018 in China (Table 6).

The methodologies used in this study are not suited for data with periodicities such as seasonal data only. For the method to be effective, recently developed software that can analyze seasonal data was employed in this study. Another disadvantage of the methodology is that; more negative results will be produced for shorter datasets hence why rainfall data was used for a more extended period.

This study aims to to carry out a long term (62 years) rainfall trend analysis in Botswana using MK trend test applied on PCI values, (β), ACF and RPC analysis applied in the towns of Gaborone, Maun, Francistown, Serowe, Kasane, Tsabong, Ghanzi, and Pandamatenga, since there are few works reported on rainfall trend analysis in Botswana. This is also the most recent study done which covers more regions of Botswana when compared to previous works on rainfall trend analysis. The method employed in this study covers long term periods with different procedures different from other reported works [16, 37–39]. The results explain the analysis of rainfall trends and rainfall variability that can be used to understand the current rainfall trends and make future predictions showing the impacts of climate change.

2. Materials and Methods

2.1 Data used

The annual and seasonal (November to March) satellite rainfall data that is used in this paper is from the Southern African Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL) and the Climate Toolbox, which was developed by members of the Applied Climate Science Lab (ACSL) at the University of California Merced and the UW Hydro group at the University of Washington. The selected regions for the study and all the satellite data coverage of annual and seasonal was for 62 years (Table 2). The seasonal data is the wet months, which is from November all through to March. This is when the country receives the most rain, especially in January and February.

2.2 Data Analysis

The Precipitation Concentration Index (PCI), Mann–Kendall trend test, Theil–Sen's slope estimator (β), Autocorrelation Function (ACF) and relative percentage change (RPC) methods were adopted for data analysis. These tests were performed using the R software, a programming language and a free software environment for statistical computing and data analysis.

2.3 Precipitation concentration index (PCI)

Oliver created the Precipitation Concentration Index (PCI) in 1980 to measure rainfall concentration and erosivity [40]. PCI was computed on an annual and seasonal basis for each grid point in this investigation using Equations (1) and (2).

$$PCIannual = \frac{\sum_{i=1}^{12} P^2}{\left(\sum_{i=1}^{12} P_i\right)^2} * 100 \quad (1)$$

$$PCIseasonal = \frac{\sum_{i=1}^{3} P^2}{\left(\sum_{i=1}^{3} P_i\right)^2} * 25 \quad (2)$$

Table 1. Recording period and location of all the regions

Region	Location		Period
	Latitude	Longitude	
Gaborone	-22.3755	26.7367	1958-2019
Francistown	-24.6720	25.9128	1958-2019
Serowe	-22.3627	26.7437	1958-2019
Kasane	-17.7931	25.1671	1958-2019
Maun	-19.9862	23.4258	1958-2019
Pandamatenga	-17.9389	25.2507	1958-2019
Ghanzi	-21.6830	21.6830	1958-2019
Tsabong	-26.0025	22.4081	1958-2019

2.4 The Serial Correlation Effect

The MK trend analysis is described to be a non-parametric approach that is applied to discover significant trends in times series datasets that are hydrological and meteorological without using predefined parameters. It is a straightforward and robust analysis that can handle undefined parameters as well as values that are below the detection limit [12, 41, 42]. There is a need to analyze and understand meteorological weather patterns across a region [38–41]. To use the Mann Kendall analysis to investigate the dataset, it is necessary to check if there is a significant correlation coefficient or not. This was carried out because the Mann Kendall test requires that a time series dataset has to be serially independent. If the serial correlation is present, this can affect the time series dataset, leading to the rejection of the null hypothesis, which makes the Mann Kendall ineffective [31]. The autocorrelation coefficient is required to be calculated to identify any existence of a significant autocorrelation within the time series.

2.5 Trend Analysis on Yearly PCI values

A trend test was performed on the yearly PCI value to see if it was trending toward a very erratic or uniform precipitation distribution. To determine any rise or reduction in rainfall, the annual and seasonal rainfall data were examined using the trend test. The Mann Kendall test allows researchers to assess if rainfall rises or decreases in the selected locations. The Mann Kendall trend test, with critical values of = 0.01, 0.05, and 0.1, differentiates the importance of upward and downward precipitation distribution. The Mann Kendall;

$$S = \sum_{k-1}^{n-1} \sum_{j=k+1}^{n-1} sign(x_j - x_k) \quad (3)$$

Where;

$$sign(x_j - x_k) = \begin{cases} 1 \ if \ (x_j - x_k) & > 0 \\ 0 \ if \ (x_j - x_k) & = 0 \\ -1 \ if \ (x_j - x_k) & < 0 \end{cases} \quad (4)$$

$$VAR\,(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} ti(ti-1)(2ti+5)}{18} \quad (5)$$

Janni et al. [45] says that a positive z value indicates an increasing trend as well as statistical significance. A negative z value, on the other hand, indicates a downward tendency. The test statistic Z was then computed using Equations (4) and (5) from the following equation:

$$Z = \begin{cases} 1 \ \frac{S-1}{\sqrt{VAR(S)}} & if \ \ S > 0 \\ 0 & if \ \ S = 0 \\ -1 \frac{S+1}{\sqrt{VAR(S)}} & if \ \ S < 0 \end{cases} \quad (6)$$

2.6 Magnitude of change of the rainfall trend (β)

Sen devised a non-parametric technique to assess the magnitude of change (per unit time) in the Theil-Sen slope estimator [46]. To understand the magnitude of change of the trend, alongside these non-parametric tests, Theil's Sen Slope estimator was utilized to understand better what the patterns were alluding to, either a downward or an upward trend.

$$\beta = median\left(\frac{x_j - x_k}{j-k}\right) \forall k < j \quad (7)$$

2.7 Relative percentage change

Equation (8), where n is the length of the trend cycle (years), x is the absolute average value of the time series defined and the Theil-Sen median estimator, and n is the length of the trend period, applied to calculate the RPC of monthly and yearly rainfall. This method was employ by [47], [48], and [7] in a similar study.

$$\text{RPC} = \left(\frac{n\beta}{\bar{x}}\right) 100 \quad (8)$$

3. Results and Discussion

3.1 Precipitation concentration index (PCI)

The PCI values for the study regions of Gaborone, Maun, Francistown, Serowe, Kasane, Tsabong, Ghanzi, and Pandamatenga were estimated to be within 3 and 43 (Table 2), which suggests the distribution of rainfall ranges from low precipitation concentration to a strongly irregular distribution (Table 3). The estimation for all 8 regions was from 1958-2019. The Pandamatenga region indicated the highest values of PCI compared to other regions. The precipitation concentration index in Pandamatenga gears toward a strongly irregular distribution, which means high precipitation concentration than in most regions in the country, as indicated with PCI values between 3 and 43. It is also indicated in the average rainfall that is experienced in this region. Kasane, Maun and Francistown's regions indicated the frequency count for the PCI which revealed that rainfall distribution is moderate, irregular, and strongly irregular. While, the PCI values of Gaborone and Francistown are within the range 9 and 43, having occurrences of a moderate to strongly irregular distribution of rainfall throughout the country. The lowest PCI values were recorded in the Tsabong and Ghanzi regions. As would be expected, these regions' mean annual total rainfall is the lowest in Botswana.

3.2 The serial Autocorrelation test performed on rainfall data

The serial autocorrelation analysis were performed on all the annual rainfall data of the regions to show the rainfall trend. The figures (Figures 2, 3, 4, and 5) for Pandamatenga, Serowe, Kasane, and Tsabong represent all the study regions. These results showed that the autocorrelation present is insignificant because most of the vertical spikes resulting from the Autocorrelation function are shown to be compressed between the dotted horizontal lines, suggesting that the rainfall data tested are insignificant. Therefore, the Mann Kendall trend test can be carried out without any corrections to the data.

Table 2. Study stations showing PCI frequency count.

Region	PCI≤10	PCI>10≤15	PCI>16≤20	PCI>20
Gaborone	0	9	10	43
Francistown	0	5	18	39
Serowe	0	4	39	19
Kasane	0	6	23	33
Maun	0	15	30	17
Pandamatenga	0	9	18	35
Ghanzi	0	3	18	41
Tsabong	0	4	20	38

Table 3. Classes of PCI values adapted from Oliver (1980)

PCI values	Distribution of precipitation
PCI≤10	Uniform precipitation distribution (low precipitation concentration)
11-15	Moderate precipitation concentration
16-20	Irregular distribution
PCI>20	Strongly irregular distribution (high precipitation concentration)

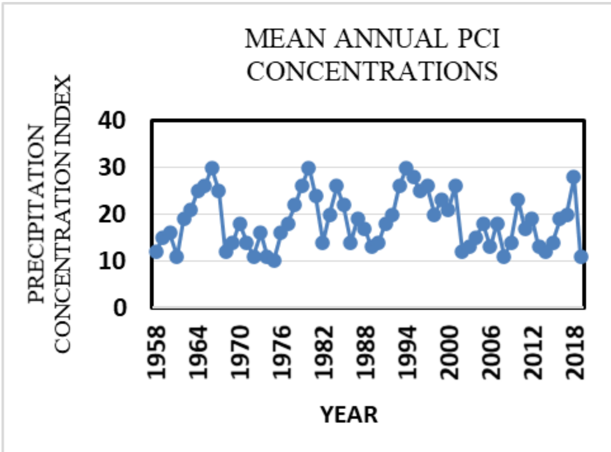

Figure 1. Mean annual PCI concentrations

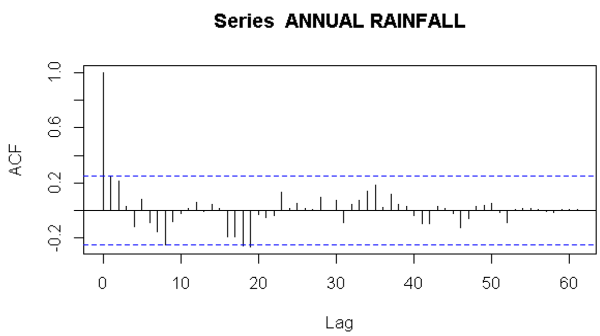

Figure 2. The serial autocorrelation analysis of annual rainfall data, Tsabong

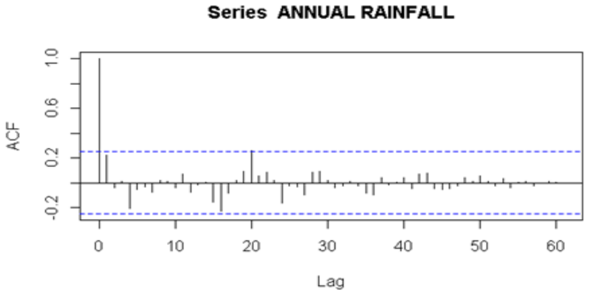

Figure 3. The serial autocorrelation analysis of annual rainfall data, Serowe

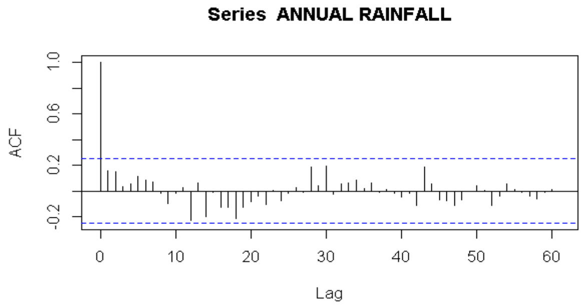

Figure 4. The serial autocorrelation analysis of annual rainfall data, Pandamatenga

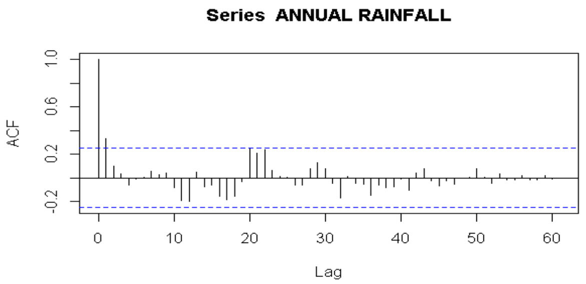

Figure 5. The serial autocorrelation analysis of annual rainfall data, Kasane

3.3 Annual trends in rainfall

On yearly rainfall data from 1958 to 2019, the Mann Kendall trend test was used to examine the precipitation concentration index trend. The Mann Kendall trend test (Table 4) show that the p-values of Gaborone, Francistown, Serowe, and Kasane are greater than the α values suggesting that there is an insignificant trend that indicates an insignificant trend in the rainfall of these regions. Maun, Ghanzi, Pandamatenga and Tsabong's results had a p-value of 0.079, 0.0023, 0.029 and 0.058, respectively, which is less than the α values. These figures demonstrate that all of these areas are seeing a significant decreasing trend. The findings of the Z-values show a downward trend in all locations.

3.4 Seasonal trends in rainfall

The precipitation concentration index for the seasonal period was analyzed with the Mann Kendall test for all the study regions. The PCI trends for the wet months (Table 5). It shows that the p-values of Gaborone, Francistown, Serowe, Maun, and Ghanzi are more significant than the α values. This suggests an insignificant trend, indicating an insignificant downward trend in Gaborone and Serowe's rainfall. This indicates that rainfall is changing from a regular to an erratic pattern.

Moreover, an insignificant upward trend at Francistown, Maun and Ghanzi was experienced. However, for Pandamatenga and Tsabong, there was a significant upward trend. The test statistic, Z-value, reveals a negative trend for Gaborone, Serowe, Kasane, Pandamatenga and Tsabong. In Gaborone, there exists significance at α=*0.01*.

3.5 Relative Percentage Change analysis performed on annual rainfall data

The RPC in annual rainfall data (Table 4 and 5) indicated that most of the areas that were studied have a negative RPC. The decrease of annual rainfall with the highest percentage change was 0.24% for the region of Ghanzi. While, there was an increase in seasonal rainfall that was experienced (Table 5) at Francistown, Maun and Tsabong at 0.03%, 0.04% and 0.04%, respectively.

3.4 The magnitude of change of annual and seasonal rainfall trends

The analysis of the annual precipitation concentration index (Table 4) using the Theil-Sen slope estimator (β) indicated that the regions of Gaborone, Francistown, Serowe, and Kasane experienced a magnitude of change of the rainfall trend of -1.36 mm/year, -0.16 mm/year, -0.22 mm/year, and -0.50 mm/year, respectively and for all these, there was an insignificant downward trend of rainfall, while the regions of Maun, Ghanzi, Pandamatenga, and Tsabong experienced a magnitude of change of -1.11 mm/year, -1.62 mm/year, -0.33 mm/year and -0.25 mm/year.

Table 4. Annual PCI trends, relative percentage change(%Δ)

Region	Z-Value	p-value	β	x̄(mm)	%Δ
Gaborone	-1.422	0.145	-1.361	452.65	-0.186
Francistown	-0.207	0.836	-0.167	450.27	-0.023
Maun	-0.280	0.080*	-1.115	440.76	-0.157
Ghanzi	-1.634	0.0023***	-1.615	406.69	-0.246
Pandamatenga	-0.268	0.029*	-0.336	652.09	-0.032
Serowe	-0.392	0.695	-0.224	418.03	-0.033
Kasane	-0.504	0.614	-0.500	613.95	-0.051
Tsabong	-0.442	0.058*	-0.253	306.31	-0.051

**** Significant trend at α=0.01,* * Significant trend at α=0.05,* Significant trend at α=0.1*

Table 5. Seasonal PCI trends, RPC (%Δ)

Region	Z-Value	p-value	β	x̅(mm)	%Δ
Gaborone	-1.0691	0.135*	-0.920	380.06	-0.150
Francistown	0.2734	0.785	0.237	404.85	0.036
Serowe	-0.2794	0.780	-0.200	370.18	-0.033
Kasane	-0.7168	0.474	-0.750	573.69	-0.081
Maun	0.06682	0.947	1.652	406.85	0.041
Pandamatenga	-0.5528	0.040**	-0.600	626.36	-0.059
Ghanzi	0.8686	0.385	1.038	370.01	0.173
Tsabong	-0.23084	0.017***	-0.190	261.10	-0.045

**** Significant trend at α=0.01, * * Significant trend at α=0.05, * Significant trend at α=0.1*

The result indicated that there was a significant trend present in Maun, Ghanzi, Pandamatenga and Tsabong. All these regions, except Ghanzi, experienced a downward trend in the rainfall distribution. This is due to the synoptic characteristic of below-average geopotential heights over Ghanzi, which might exacerbate the formation of convective systems, leading to a positive rainfall trend at Ghanzi. [19]. The analysis of the seasonal precipitation concentration index indicated that the regions of Gaborone, Francistown, Serowe, Kasane, Maun and Ghanzi experienced a magnitude of change of -0.92mm/year, -0.24 mm/year, -0.20 mm/year, -0.75 mm/year, 1.65mm/year and -1.04 mm/year, respectively and for all these, there was an insignificant downward trend, except the region of Ghanzi, which experienced an insignificant downward trend in the rainfall distribution. Moreover, the regions of Pandamatenga and Tsabong experienced a magnitude of change of a significant downward trend of -0.60 mm/year and -0.19 mm/year.

In the region of Pandamatenga, the minimum amount of rain received was 341mm in 1965, while the maximum amount was 1122mm in the year 1958, and the average rainfall received in a year was 589mm. Pandamatenga is one of the regions that receive a significant amount of rain during the rainy season. Still, as indicated, it is experiencing insignificant declines in the amount of rainfall (Figure 6).

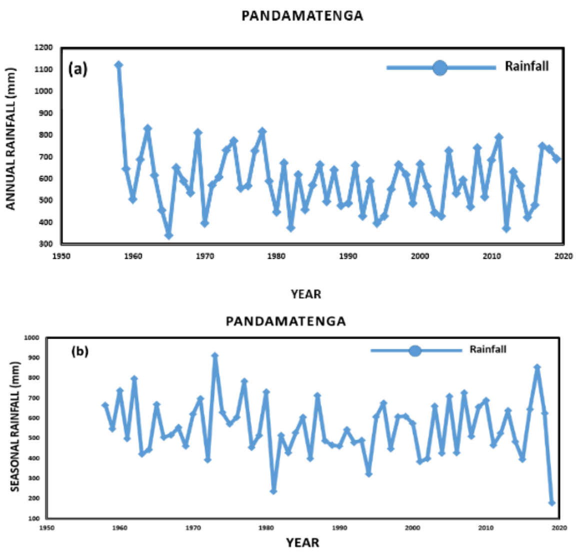

Figure 6. Pandamatenga trend (a) Annual rainfall, (b) Seasonal rainfall

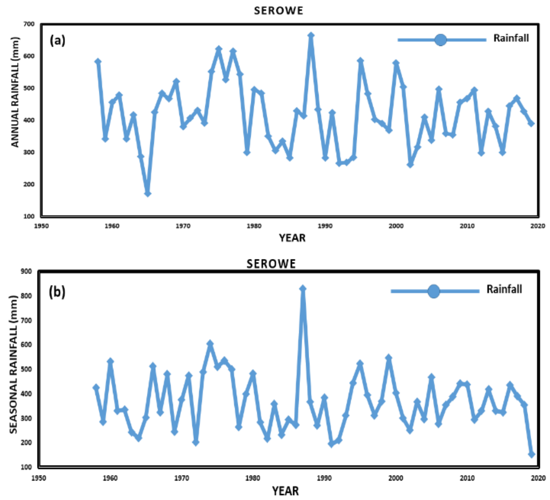

Figure 7. Serowe trend (a) Annual rainfall, (b) Seasonal rainfall

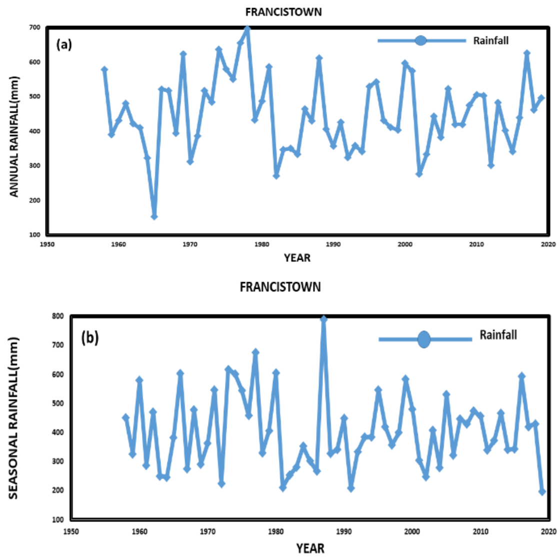

Figure 8. Francistown trend (a) annual rainfall, (b) seasonal rainfall

In the region of Serowe, the minimum amount of rain that was received was 172 mm in the year 1965, while the maximum amount was 665 mm in the year 1988. The average rainfall was 418mm (Figure 7). Although insignificant, there is a decline annually and seasonally in Serowe.

The minimum amount of rain received in the Francistown region was 153 mm in 1965. The maximum amount was 697mm in 1978, and the average rainfall received in a year was 450 mm. Francistown gets a significant amount of rain annually and is the second-highest inhabited location. It is Botswana's second capital city.

In the region of Maun, the minimum amount of rainfall that was received was 235 mm in the year 1965, while the maximum amount was 792 mm in the year 1974. The average rainfall received in a year was 440mm. Maun gets a significant amount of rain annually and has similar climatic characteristics to Pandamatenga.

In the region of Serowe, the minimum amount of rain that was received was 172 mm in the year 1965, while the maximum amount was 665 mm in the year 1988. The average rainfall received in a year was 418mm. Serowe gets a significant amount of rain annually compared to its neighbouring regions.

4. Conclusion

The analysis of spatio-temporal rainfall trends and rainfall variability in Botswana demonstrated a decrease in rainfall across the regions of Botswana. The annual rainfall experienced a magnitude of change that has a significant downward trend of -1.11 mm/year at Maun, -1.62 mm/year at Ghanzi, -0.33 mm/year at Pandamatenga -0.25 mm/year at Tsabong.

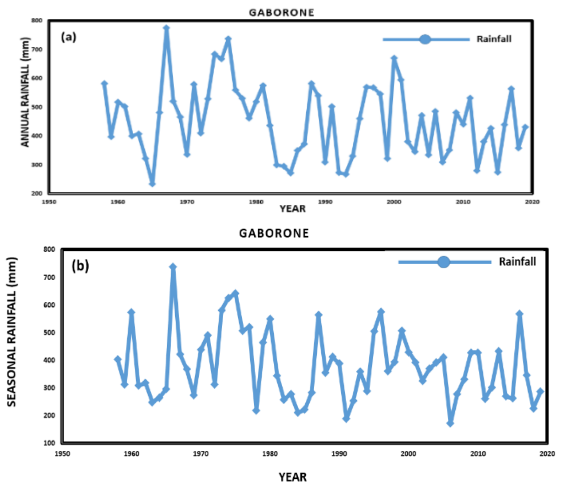

Figure 9. Gaborone trend (a) annual rainfall, (b) seasonal rainfall

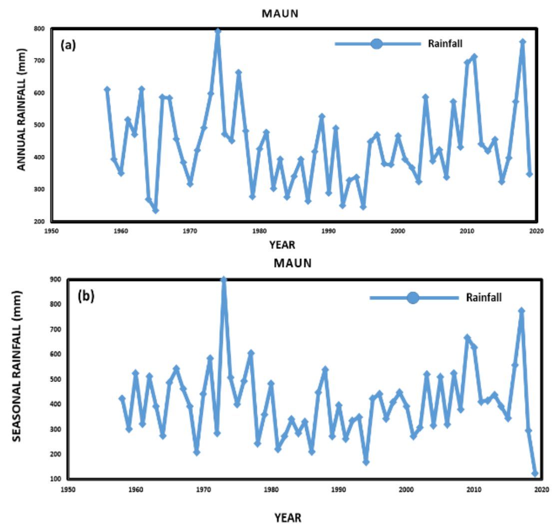

Figure 10. Maun trend (a) annual rainfall, (b) seasonal rainfall

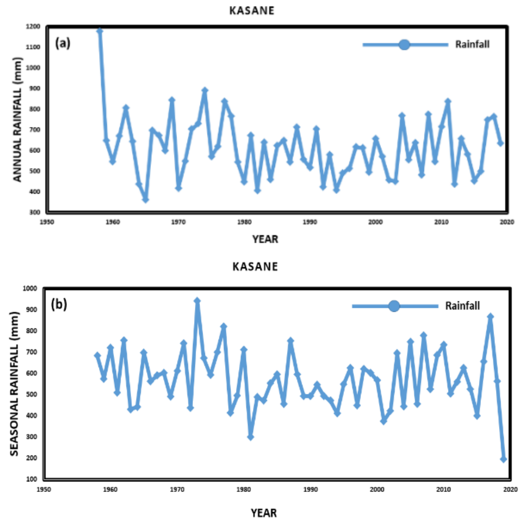

Figure 11. Kasane trend (a) annual rainfall, (b) seasonal rainfall trend

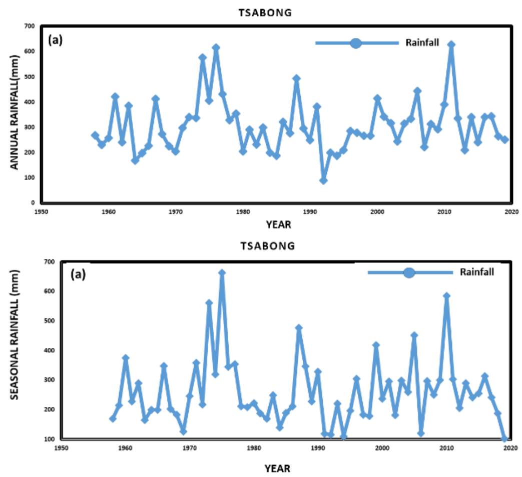

Figure 12. Tsabong trend (a) annual rainfall, (b) seasonal rainfall

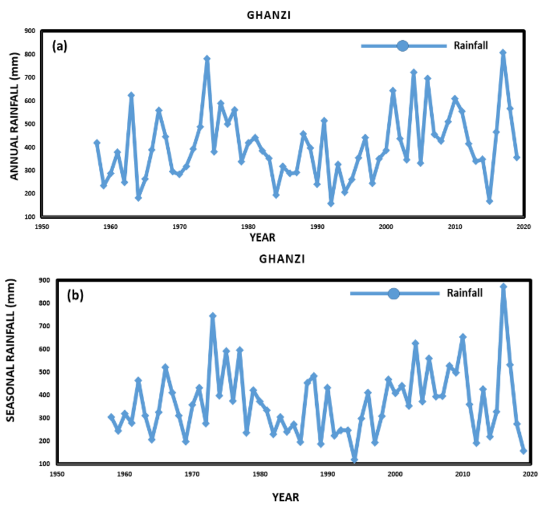

Figure 13. Ghanzi trend (a) annual rainfall, (b) seasonal rainfall

Table 6. Comparison of other related studies with this study

Country	Regions	Period	Method	PCI	RPC	Ref.
Nigeria	Bida, Jos, Yola, Yelwa, Minna, Bauchi, Kaduna, Maiduguri, Kano, Gusau, Sokoto, Nguru, Katsina	1970-2016	PCI, MK trend test, Sen Slope Estimator, RPC	11-15, 16-20, and PCI > 20	Varying changes from the different regions	[7]
India	Andrah Pradesh	1981-2010	PCI, Linear Regression Analysis, Descriptive Statistics	> 16	-	[49]
Iran	Iran	1961-2010	MK trend test, Sequential MK test, Homogeneity Test	< 10	-	[50]
Turkey	Euphrates-Tigris Basin	1987-2011	MK trend test, Sen Slope	-	-	[51]
China	Jiangxi Province	1960-2008	PCI, MK trend test	> 16	-	[52]
Botswana	Maun, Ghanzi, Tsabong, Tshane	1971-2000	MK trend test	-	-	[19]
Botswana	Francistown, Ghanzi, Kasane, Lobatse, Maun, Molepolole, Serowe, Tsabong	1975-2005	Thom Test, MK trend test	-	-	[20]
Botswana	Ghanzi, Maun, Serowe, Tsabong	1975-2005	Descriptive Statistics, MK trend test	-	-	[37]
Botswana	Francistown, Gaborone, Mahalapye, Maun, Ghanzi, Shakawe, Tsabong, Tshane	1965-2008	Intervention Analysis, Correlation Analysis, GLM model	-	-	[21]
Botswana	Gaborone, Francistown, Serowe, Kasane, Maun, Pandamatenga Ghanzi, Tsabong	1958-2019	PCI, MK trend test, RPC, Sen Slope Estimator,	PCI>10≤15, PCI>16≤20 and >20	Varying changes from the different regions	This Study

While the annual rainfall with insignificant downward trends have a magnitude of change which was found to be -1.36 mm/year at Gaborone, -0.16 mm/year at Francistown, -0.22 mm/year at Serowe -0.50 mm/year at Kasane, respectively. The seasonal rainfall with significant downward trends have a magnitude of change that was between -0.60 mm/year at Pandamatenga and -0.19 mm/year at Tsabong. While the seasonal rainfall with insignificant downward trends have a magnitude of change that was between -0.92mm/year at Gaborone, -0.24 mm/year at Francistown, -0.20 mm/year at Serowe, -0.75 mm/year at Kasane, 1.65mm/year at Maun and -1.04 mm/year at Ghanzi respectively. All these regions, except Ghanzi, experienced a downward trend in the rainfall distribution. This is owing to the synoptic characteristic of below-average geopotential heights over Ghanzi, which might enhance the formation of convective systems, leading to a positive rainfall trend at Ghanzi. The Mann–Kendall trend test (MK), autocorrelation function (ACF), relative percentage change (RPC), precipitation concentration index (PCI), and Theil–Sen's slope estimator (β) methods were adopted for data analysis in eight regions of Botswana (Figure 6,7,8,9,10,11,12, and 13).

These findings indicate that Botswana is already impacted by climate change due to the reduction in yearly rainfall amounts, meaning that significant problems are likely to arise because Botswana is water-scarce and heavily depends on groundwater, causing economic and industrial imbalance. Drier conditions signify more considerable variability in the amount of rain that the country is currently receiving.

Declaration

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. The authors also declared that this article is original, was prepared in accordance with international publication and research ethics, and ethical committee permission or any special permission is not required.

Author Contributions

H. Gökçekuş, supervised and developed the work, Y. Kassem, supervised and improved the improved manuscript. L.P. Mphinyane developed methodology, performed analysis, developed and improved manuscript.

Nomenclature

SASSCAL	: Southern African Science Service Centre for Climate Change and Adaptive Land Management
ACSL	: Applied Climate Science Lab
UW	: University of Washington
GEV	: General Extreme Value
UN	: United Nations
UNFCC	: United Nations Framework Convention On Climate Change
DWA	: Department of Water Affairs
IWMI	: International Water Management Institute.
WUC	: Water Utilities Corporation
CSO	: Central Statistics Office
DMS	: Department of Meteorological Services
ENSO	: El-Nino Southern Oscillation
SADC	: Southern African Development Community
WBG	: World Bank Group
CV	: Coefficient of Variation
MIN	: Minimum
MAX	: Maximum

G	: Skewness Coefficient
STAT	: Statistics
GEN	: General
PDF	: Probability Distribution Function
Mm	: Millimeter
MK	: Mann Kendall
PCI	: Precipitation concentration index
RAI	: Rainfall anomaly index
SI	: Seasonality index
DAR	: Departure analysis of rainfall

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