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Variabilities and Trends of Rainfall, Temperature, and River Flow in Sipi Sub-Catchment on the Slopes of Mt. Elgon, Uganda

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Abstract: The variabilities in rainfall and temperature in a catchment affect water availability and sustainability. This study assessed the variabilities in rainfall and temperature (1981–2015) and river flow (1998–2015) in the Sipi sub-catchment on annual and seasonal scales. Observed daily rainfall and temperature data for Buginyanya and Kapchorwa weather stations were obtained from the Uganda National Meteorological Authority (UNMA), while the daily river-flow data for Sipi were obtained from the Ministry of Water and Environment (MWE). The study used descriptive statistics, the Standardized Precipitation Index (SPI), Mann–Kendall trend analysis, and Sen's slope estimator. Results indicate a high coefficient of variation (CV) (CV > 30) for August, September, October, and November (ASON) seasonal rainfall, while annual rainfall had a moderate coefficient of variation (20 < CV < 30). The trend analysis shows that ASON minimum and mean temperatures increased at $\alpha = 0.001$ and $\alpha = 0.05$ levels of significance respectively in both stations and over the entire catchment. Furthermore, annual and March, April, and May (MAM) river flows increased at an $\alpha = 0.05$ level of significance. A total of 14 extremely wet and dry events occurred in the sub-catchment during the post-2000 period, as compared to five in the pre-2000. The significant increased trend of river flow could be attributed to the impacts of climate and land-use changes. Therefore, future studies may need to quantify the impacts of future climate and land-use changes on water resources in the sub-catchment.

Keywords: annual and seasonal scales; variabilities; extremely wet and dry; water resources; Mt. Elgon; Uganda

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1. Introduction

Climate variability affects agricultural production, food and water security, and ecosystems' health. Catchment scale knowledge of climate variability is vital for the sustainability of water resources and food production [1]. For decades, climate-variability and river-flow research has revolved around global [2], regional, and basin scales, with less emphasis on small catchments [3]. According to [4], research on climate variability and river flow should extend to small catchments to provide practical applications to multiple sectors. In the field of hydrology, such research can provide knowledge on hydrologic forecasting [4]. Moreover, agriculture extension officers can apply such knowledge in guiding farmers on when to prepare their land and when to plant which type of crops [1,5]. More still, environmentalists and other agencies can use this knowledge in early warning systems for disaster risk reduction [6,7]. As argued by [1], investigation of catchments variability in rainfall and temperature is vital for determining the likelihood of occurrences of extreme precipitation events to support adaptive management of water resources.

Many scholars have investigated the variations in rainfall and river flow in the horn of Africa in the last two decades [8–11]. To illustrate these, ref. [8] studied four selected catchments of River Nile; ref. [7] focused on the Tekeze River Basin in Ethiopia; ref. [9] studied the basin of Lake Tana in Ethiopia; ref. [10] conducted his study in the Iringa region of Tanzania; and ref. [1] focused on the Tana River Basin in Kenya. All of these authors found significant variations in rainfall and river flows. On the other hand, ref. [11] employed trend analysis to inspect changes in both intra- and inter-annual variability of rainfall and temperature in North–Central Ethiopia from 1901 to 2014. Annual rainfall was found to have significantly declined in some stations while others had no significant decline. The study also reported that annual mean temperature increased at statistically significant levels. Similarly, ref. [12] analyzed the trends in extreme temperature and rainfall in major sesame producing areas in Western Tigray in Ethiopia and reported a significant decrease in annual rainfall and number of heavy rainy days, while temperature showed no significant trend. Across Ghana, ref. [13] examined the spatiotemporal variations in rainfall and temperature and reported that Ghana’s climate had become progressively drier and prone to drought conditions over the last century. Furthermore, over East Africa, ref. [14] analyzed long-term trends in rainfall (1981–2016) and maximum and minimum temperature (T-max and T-min) (1979–2010) on seasonal and annual scales. Results showed contradicting statistically significant and non-significant decreasing and increasing trends in rainfall and maximum temperature depending on the locations.

In Uganda, evidence on the variabilities in rainfall and temperature at different spatiotemporal scales is inconclusive and gives mixed results [15–17]. For example, the study by [15] which covered the whole country reported insignificant variations in rainfall and temperature between 1981 and 2008. In the study by [16], a significant decrease in seasonal rainfall in western and central regions of Uganda was reported during 1983–2012. Similarly, ref. [17] found significant decreased trends in the average annual rainfall, and March, April, and May (MAM); January, December, and February (JDF) seasons rainfall in Kasali sub-county in Western Uganda between 1987 and 2017 coupled with significant increasing trends in average maximum, minimum, annual, and seasonal temperature. On the other hand, refs. [18,19] reported significant increased trends in annual and MAM seasonal rainfall in the Mpologoma catchment in Eastern Uganda for the period 1948–2016 and in the Albert-Victoria water catchment area in Uganda for the period 1943–1977, respectively. According to literature, variability in rainfall and temperature in different parts of Uganda indicate variable results, thus underpinning the need to study the variability in rainfall and temperature and how these may have impacted on river flow at micro catchment levels, particularly in the slopes of mount Elgon, which has suffered several climate disasters that have claimed several lives and altered the general landscape over the last two decades.

The water-resources management in Uganda faces several problems, such as changes in rainfall patterns, prolonged droughts, increasing frequency of floods, increasing temperatures deterioration in water quality and quantity, and degradation of watersheds [20]. According to [20], the drivers of lake levels fluctuation and reduced river flows are encroachment on water catchments, increased water abstractions for domestic, industrial, infrastructure development, and production. Sipi sub-catchment on the slope of Mt. Elgon in Eastern Uganda is not an exception to the problems faced by other catchments in the country. More so, the government has planned a water-supply investment project in the sub-catchment. However, the proposed project is bound to reduce the flows in the target rivers, denying the ecosystems and social requirements downstream the opportunity for the associated values [21]. The Sipi River is known for the spectacular Sipi falls and the unique culturally blended recreational activities from the local communities. These activities attract between 10 and 20% of all tourists visiting Uganda every year [22]. The government collects revenue from these tourists and some of the revenue is used to support local communities' livelihoods. The Sipi sub-catchment also lies within one of the most agriculturally productive rural regions of Uganda [23]. Agriculture employs 69% of the close to 40 million Ugandans and contributes about 23% to annual Gross Domestic Product (GDP) [24]. Despite its importance, the sector is predominantly rain-fed and gets challenged by the variability in rainfall. Understanding the variabilities and trends in rainfall, temperature, and river flows is vital for the planning and management of subsistence cropping systems and for the sustainability of water resources and livelihoods in Uganda.

The Sipi sub-catchment presents a diverse landscape of variable topography, discontinuous land cover types, and seasonally distinct rainfall patterns, all of which influence the distribution of rainfall at fine spatial and temporal scales [25]. However, previous studies [15–17] have not focused on fine-scale investigation of variabilities in rainfall, temperature, and river flow in the Sipi sub-catchment. It is therefore highly possibility that policy and management decisions in the sub-catchment have relied upon country- or regional-scale variabilities and trends analysis that are often of coarse resolution and are not able to capture important variabilities at a finer scale, where management actions operate [25]. This study aimed to investigate such fine-scale variabilities and trends in climate and river flow. Therefore, the specific objective of this study was to determine the variabilities in rain fall, temperature, and river flow in the Sipi sub-catchment, on annual and seasonal scales, for adaptive management of the water resources and the sustainability of subsistence farmers' livelihood in the sub-catchment.

2. Materials and Methods

This study was conducted in the River Sipi sub-catchment (918 km^2) of the Sironko catchment (3997 km^2) on the slopes of Mt. Elgon in Eastern Uganda (Figure 1). The sub-catchment exhibits a bimodal rainfall characteristic where the first rainfall season takes place from March to May, while the second rainfall season takes place from August to November (Figure 2). The mean annual rainfall over the sub-catchment for the period 1981–2015 was 1812.3 mm, and the mean temperature was 21.7 °C. Small-scale agriculture is the prominent source of livelihood in the sub-catchment and the main crops grown are maize, beans, sweet potatoes, banana, and coffee. The local communities in the Sipi sub-catchment use the rivers water for small-scale irrigation, domestic and urban water supply, livestock watering, fishing, and recreational activities.

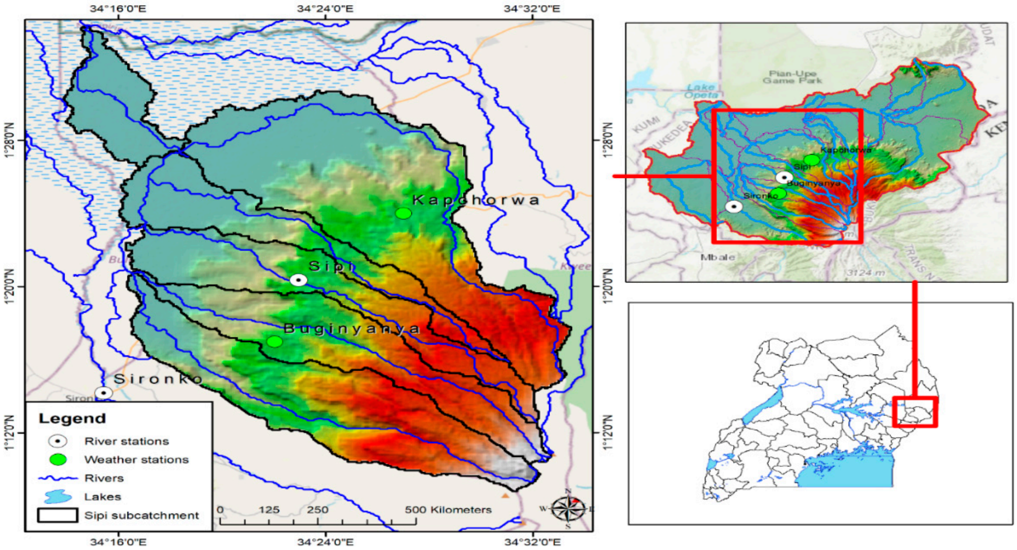

Figure 1. Map of Sipi sub-catchment on the slopes of Mt. Elgon, Uganda.

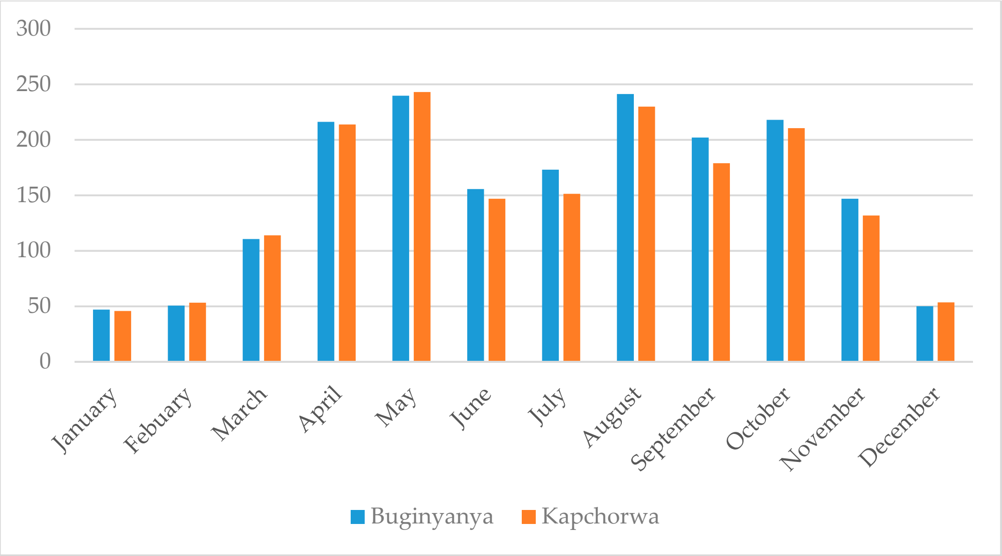

Figure 2. Monthly mean rainfall in Buginyanya and Kapchorwa weather stations (1981–2015).

2.1. Data and Methods

Observed daily rainfall and temperature data (1981–2015) for Buginyanya and Kapchorwa weather stations were obtained from the Uganda National Meteorological Authority (UNMA), while daily river flow data for River Sipi (1998–2015) were obtained from the Ministry of Water and Environment (MWE) (Table 1).

Table 1. The altitudes, longitudes, and latitudes for Buginyanya and Kapchorwa weather stations and river Sipi gauge in the slopes of Mount Elgon.

Climate Data	Altitude (m.a.s.l.)	Longitude (Degrees)	Latitude (Degrees)
Buginyanya	1845	34.37	1.28
Kapchorwa	1920	34.45	1.40
Sipi River gauge	1075	34.15	1.14

Note: m.a.s.l. denotes meters above sea level.

2.2. Data Analysis

The mean, standard deviation (SD), and coefficient of variation (CV) in Equation (1) formed the first analysis for the rainfall, temperature, and river-flow data. These methods have been used by [9,11,18,26]. The analysis was carried out at the individual stations' level and over the entire sub-catchment. The rainfall and temperature data for Buginyanya and Kapchorwa were averaged in order to compute the variability over the sub-catchment. The annual, MAM, and ASON seasons were adopted (Figure 2).

$$\mathrm{CV} = \left[\frac{\delta}{\mu}\right] \times 100 \tag{1}$$

where CV is the coefficient of variation, δ is the standard deviation and μ is the mean of the dataset. When the CV is high, the variability is considered to be high and when the CV is low, the variability is considered low. The rainfall is considered less variable when CV < 20, moderately variable when, 20 < CV < 30, and highly variable when CV > 30 [11,27].

The Standardized Precipitation Index (SPI) formed the second part of the analysis for rainfall data. It was used to determine the sensitivity of the sub-catchment to extremely wet and dry periods. SPI is calculated based on long-term precipitation data for a given location and a specific period. The scale of SPI can start from 1 month, 3 months, 6 months, 9 months, 12 months, 24 months, 36 months, and 48 months). The selection of the SPI scale is determined by the purpose for which it is being calculated. However, irrespective of the scale, SPI gives information on the impacts of wet/dry conditions on water availability for different needs. In this study, the 3-month, 6-month, and 12-month SPIs were calculated using the Meteorological Drought Monitor [28] method to determine extremely wet and dry periods in the Sipi sub-catchment Equation (2).

$$\text{SPI} = \frac{\chi - \mu}{\delta} \tag{2}$$

where χ is the SPI monthly total precipitation, μ is the SPI long-term mean precipitation, and δ is the standard deviation for the SPI precipitation. SPI measures the deviation in standard units between a dataset and its mean [29,30]. This study adopted the classification scheme of Reference [28] in Table 2. The (3-month, 6-month, and 12-month) SPIs were selected to identify the relative tendency towards above or below normal seasonal and annual precipitation [31]. Each SPI scale is a comparison between the specific SPI time scale for the same period recorded in all the other years included in the dataset. A 3-month SPI estimated at the end of September 2010 compares the precipitation total recorded during July, August, and September 2010 and the precipitation total recorded during the same set of months in all years before 2010 in the same dataset. As stated before, a 3-month SPI was selected to represent the seasonal estimations of precipitation and to provide a measure of the short-term moisture conditions. The 6-month and 12-month SPIs, on the other hand, were selected because they reflect the medium- and long-term moisture conditions, respectively. According to [32,33], information retrieved from the 6-month and 12-month SPIs can be used to capture variability in streamflow regimes and reservoir levels. The 6-month and 12-month SPIs can also provide information about the precipitation fallen during a 6-month and 12-month period [32]. According to [31], comparing short-term SPI with medium- and longer-term scale SPIs is vital because a relatively normal or even a wet 3-month period can occur in the middle of a long-term drought, and that, in turn, can be captured only by a long-term SPI.

Table 2. SPI thresholds for wet and dry periods. Adopted from [34].

Extremely Wet	2.00 and Above
Very wet	1.5 to 1.99
Moderately wet	1.00 to 1.49
Normal	−0.99 to 0.99
Moderately dry	−1.00 to −1.49
Very dry	−1.50 to −1.99
Extremely dry	−2.00 and below

The Mann–Kendall trend analysis and Sen's slope estimator [35] formed the last part of the analysis. The Mann–Kendall (MK) test is a nonparametric test, it was used because it does not require the data to be normally distributed, and is not very sensitive to missing data values [35]. The test has been used to detect both trends and shifts in climate and hydrological time-series datasets [36,37]. The test statistic, S, is based on the null hypothesis that there is no trend or serial correlation in a set of observations. S was calculated by using Equations (3)–(5):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\left(x_j - x_i\right) \tag{3}$$

where x_j are x_i the sequential data values, n is the length of the dataset, and we have the following:

$$sgn\ (t) = \begin{cases} 1,\ for\ t > 0 \\ 0,\ for\ t = 0 \\ -1\ for\ t < 0 \end{cases} \tag{4}$$

$$E(S) = 0 \tag{5}$$

If n is 9 or less, the absolute value of S is compared directly with the theoretical distribution of S derived by Mann–Kendall [35]. In MAKESENS, the two-tailed test is used for four different significance levels of α: 0.1, 0.05, 0.01, and 0.001 [35]. At a certain probability level, H_0 is rejected in favor of H_1 if the absolute value of S equals or exceeds a specified value $S\alpha/2$, where $S\alpha/2$ is the smallest S which has the probability less than $\alpha/2$ to appear in case of no trend [35]. A positive/(negative) value of S indicates an upward/(downward) trend. The significance level of 0.001 means that there is a 0.1% probability that the values x_i is from a random distribution and with that probability we make a mistake when rejecting H_0 of no trend. Thus, the significance level of 0.001 means that the existence of a monotonic trend is very probable. In the same way, the significance level of 0.1 means there is a 10% probability that rejecting H_0 is a mistake.

If n is at least 10, the normal approximation test is applied. The validity of the normal approximation reduces for the number of data values close to 10 for several tied values in the time series. The variance of S is first computed by following Equation (6) which takes into account that ties may be present:

$$Var(S) = \frac{1}{18}\left(n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)\right) \tag{6}$$

where m is the number of tied groups, and t_i is the size of the ith tied group.

The standardized test statistics, Z, is computed as from Equation (7):

$$Z = \begin{cases} (S-1)/\sqrt{Var\ (S)} \\ 0 \\ (S+1)/\sqrt{Var\ (S)} \end{cases} \begin{cases} for\ S > 0 \\ for\ S = 0 \\ for\ S < 0 \end{cases} \tag{7}$$

The presence of a statistically significant trend is confirmed using the Z value. A positive/(negative) value of Z indicates an upward/(downward) trend. The statistic Z has a normal distribution. To test for either an upward or downward monotone trend (a two-tailed test) at α level of significance, H_0 is rejected if the absolute value of Z is greater than Z_1-$\alpha/2$, where Z_1-$\alpha/2$ is derived from the standard normal cumulative distribution [35]. In MAKESENS, the tested significance levels α are 0.001, 0.01, 0.05, and 0.1. For the four tested significance levels, the following symbols are used: *** if trend at α = 0.001 level of significance, ** if trend at α = 0.01 level of significance, * if trend at α = 0.05 level of significance, and + if trend at α = 0.1 level of significance. If the cell is blank, the significance level is greater than 0.1. In this study, trends were reported at (α = 0.001 and α = 0.05) levels of significance.

The Sen's slope estimator, Q, is a nonparametric method developed by [38]. Sen's slope estimated the magnitude of trends in time series data. For N pairs of data, Q is given by Equations (8) and (9):

$$\mathrm{Q} = \frac{x_j - x_i}{t_j - t_i} \text{ for } i = 1,\ 2, \ldots..\mathrm{N} \tag{8}$$

where Q is the slope between $x_{i,}$ and x_j at times t_i and t_j for ($I < j$). The value of Q is derived from the median slope for N numbers of slope from the following equation:

$$\mathrm{Q} = \begin{cases} \mathrm{Q}_{[(\mathrm{N}+1)/2]} \text{ if N is even} \\ \frac{(\mathrm{Q}_{[\mathrm{N}/2]} + \mathrm{Q}(\mathrm{N}+2)/2)}{2} \text{ if N is odd} \end{cases} \tag{9}$$

3. Results

3.1. Seasonal Variability in Rainfall and Temperature

Results indicate a general variability in mean seasonal rainfall (Table 3). The mean of MAM rainfall was highest (190.58 mm) in Kapchorwa. This was followed by the mean of

MAM rainfall (189.58 mm) over the sub-catchment. The lowest mean of MAM rainfall was 188.87 mm recorded in Buginyanya. In ASON, however, Kapchorwa recorded the lowest mean rainfall of 187.8 mm, followed by the ASON mean rainfall of 194.94 mm over the entire sub-catchment, and the highest ASON mean rainfall was 202.08 mm recorded in Buginyanya. The CV for rainfall indicates that the ASON season varied more than MAM season. The long-term mean minimum temperature recorded in MAM was 15.52 °C for Kapchorwa station, 16.20 °C for Buginyanya, and 15.58 °C for the whole Sipi sub-catchment. Therefore, Kapchorwa is 0.68 °C cooler than Buginyanya, and this is because Kapchorwa lies at a higher altitude compared to Buginyanya. Similarly, Kapchorwa recorded the lowest mean minimum temperature of 14.99 °C in ASON as compared to 15.51 °C for Buginyanya. In terms of the entire sub-catchment, the average mean temperature is 15.25 °C. Seasonal minimum temperature revealed that Kapchorwa is slightly colder than Buginyanya in both the MAM and ASON seasons. The seasonal mean maximum temperature revealed that Buginyanya recorded the highest 28.38 °C in MAM, followed by 28.26 °C recorded over the sub-catchment, and the lowest was 28.14 °C recorded in Kapchorwa. The trend was the same in ASON, where Buginyanya recorded a mean maximum temperature of 27.47 °C, followed by 27.23 °C recorded over the entire sub-catchment, and the lowest was 27.17 °C, recorded in Kapchorwa. Less surprising, therefore, the patterns were the same for mean temperature.

Table 3. Seasonal variabilities of rainfall and minimum, maximum, and mean temperature (1981–2015).

			MAM			ASON	
	Variables	**Mean**	**SD**	**CV**	**Mean**	**SD**	**CV (%)**
Buginyanya	Mean rainfall (mm)	188.87	46.84	24.8	202.08	76.1	37.66
	T minimum (°C)	16.2	0.48	2.94	15.51	0.53	3.42
	T maximum (°C)	28.38	0.84	2.96	27.47	0.94	3.42
	T mean (°C)	22.29	0.58	2.58	21.49	0.67	3.12
Kapchorwa	Mean rainfall (mm)	190.28	49.74	26.14	187.8	70.19	37.37
	T minimum (°C)	15.52	0.61	3.96	14.99	0.59	3.94
	T maximum (°C)	28.14	0.93	3.32	27.17	0.98	3.61
	T mean (°C)	21.83	0.7	3.19	21.08	0.72	3.42
Sub-catchment	Mean rainfall (mm)	189.58	47.61	25.11	194.94	72.85	37.37
	T minimum (°C)	15.86	0.53	3.36	15.25	0.55	3.59
	T maximum (°C)	28.26	0.87	3.09	27.32	0.95	3.48
	T mean (°C)	22.06	0.62	2.82	21.28	0.69	3.22

3.2. Annual Variability in Rainfall, Temperature, and River Flow

The results in (Table 4) indicate that annual rainfall has been very stable in Buginyanya, Kapchorwa, and over the sub-catchment. According to [11,27] annual rainfall in Buginyanya, Kapchorwa, and over the sub-catchment is moderately variable ($20 < CV < 30$). The annual-temperature minimum, maximum, and mean reflected seasonal variability. Table 4 also indicates that the minimum temperature in Buginyanya was more than that recorded in Kapchorwa by 0.61 °C and more than the average over the entire sub-catchment by 0.3 °C. Similarly, the maximum temperature in Buginyanya was higher than that recorded in Kapchorwa by 0.29 °C and more than the average over the whole sub-catchment by 0.15 °C. The long-term mean temperature was similarly higher in Buginyanya by 0.45 °C and in Kapchorwa by 0.023 °C against that over the entire sub-catchment. As mentioned before, Buginyanya is slightly warmer than Kapchorwa since Buginyanya is located at a lower altitude as compared to Kapchorwa (Table 1). Annual mean flow of River Sipi showed a very high level of variability CV = 45.66%. The very high variability in the river flow corresponds with the high variability in seasonal rainfall (Table 3) and could also indicate extreme events.

Table 4. Annual variability of rainfall; minimum, maximum, and mean temperature (1981–2015); and flow (1998–2015).

Variables	Buginyanya			Kapchorwa			Sub-Catchment		
	Mean	**SD**	**CV (%)**	**Mean**	**SD**	**CV**	**Mean**	**SD**	**CV (%)**
Rainfall (mm)	1851.57	466.1	25.17	1773.04	444.35	25.06	1812.3	451.56	24.92
T min (°C)	15.73	0.47	3.01	15.12	0.58	3.83	15.43	0.52	3.34
T max (°C)	28.07	0.85	3.02	27.78	0.9	3.25	27.92	0.87	3.1
T mean (°C)	21.9	0.6	2.75	21.45	0.68	3.18	21.67	0.63	2.92
Flow (m^3/s)							2.36	1.08	45.66

3.3. Monthly and Annual Patterns of Rainfall and River Flow

In terms of monthly patterns of rainfall and river flow (Figure 3), the Sipi sub-catchment exhibits a bimodal rainfall characteristic. The months of MAM and ASON are the wet months. The river flow pattern mimics the rainfall seasons where the peak of flow pattern during the second rainfall season is higher than that of the first rainfall season for reasons as later discussed.

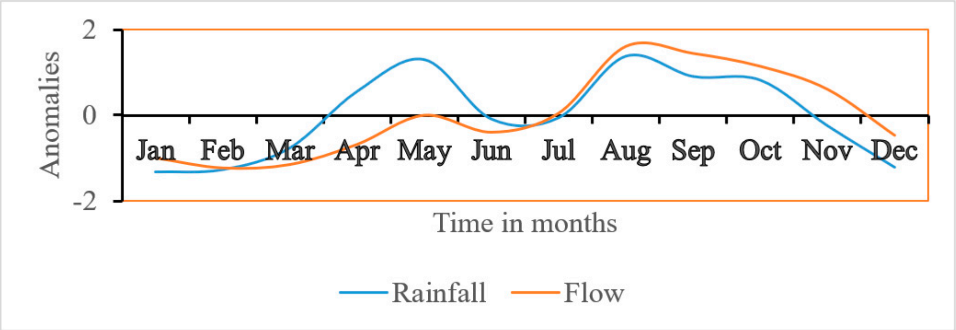

Figure 3. Monthly patterns of mean rainfall and flow in Sipi sub-catchment (1998–2015).

According to (Figure 4), annual rainfall in both Buginyanya and Kapchorwa ranged from about 1500 to 2000 mm between 1998 and 2012 except in 2007 where Buginyanya received up to 3783.3 mm and Kapchorwa received 3403.2 mm of annual rainfall respectively. The figure also indicates a shift in annual rainfall amount above 2000 mm in both Buginyanya and Kapchorwa, starting from 2013. On the other hand, annual mean flow remained below 1.95 m^3/s from 1998 to 2005, where it hiked to 3.43 m^3/s in 2007 before dropping to 1.64 m^3/s in 2009. However, there was a sharp rise in annual mean flow in 2009, reaching the highest peak ever of 5.37 m^3/s in 2010, before sharply dropping to 3.35 m^3/s in 2011, where it continued to decline to 1.87 m^3/s in 2015. The highest annual mean flow in 2010 could be a result of extremely wet event in 2010, but the event was not captured by the rainfall data.

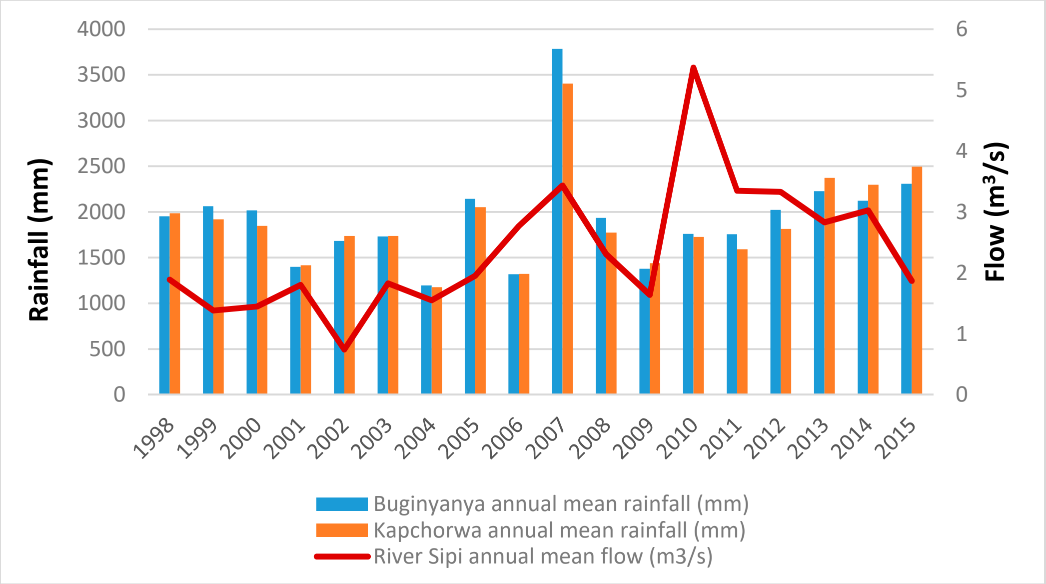

Figure 4. Annual patterns of rainfall in Buginyanya and Kapchorwa and River Sioi flow (1998–2015).

3.4. Frequency of Extremely Wet and Dry Events in Sipi Sub-Catchment

The occurrence of extremely wet and dry events in the Sipi sub-catchment (Table 5) and (Figure 5) based on the 3-month SPI revealed that there were six extremely wet years in the Sipi sub-catchment between 1990 and 2015. The first extremely wet period occurred from March to August 1990. In 1998 it occurred in February and then it started from July 2007 and lasted till April 2008. In 2015, it was from April to September 2015. On the other hand, there were five extreme dry periods under the 3-month SPI in the Sipi sub-catchment for the period 1981–2015. The first dry period was between January 1994 and April 1994. In 2004, it was from July to October. In 2006, it began in June and lasted till August. In 2009, it was from August to October, and in 2012, it was from March to June. Most of the extreme events were in the second rainfall season.

Table 5. Frequency and percentage of extremely wet and dry years in the Sipi sub-catchment between 1981 and 2015 under the 3-month, 6-month, and 12-month SPIs.

	Frequency		**Frequency**	
%SPI	**Extremely Wet**	**Extremely Dry**	**Extreme Events Pre-2000**	**Extreme Events Post-2000s**
3 Months	4	5	3	6
6 Months	3	2	2	4
12 Months	2	2	0	4

It is seen from Table 5 that there were more extreme events (14) during the post-2000 period as compared with five in the pre-2000. It, therefore, implies that the Sipi sub-catchment has become more prone to extreme events in the recent period than before.

The 6-month SPI (Figure 6) revealed that there were four extremely wet periods during the period 1981–2015. The first extremely wet months occurred from March to July 1990. The second extremely wet months were from April to May 1998. The third extremely wet months lasted from July 2007 to May 2008. The fourth was from June 2015 to September 2015. On the other hand, there were two extremely dry periods recorded under the 6-month SPI. The first one occurred between July and October 2004 while the second occurred between July and October 2006. All the extremely dry periods under 6-month SPI were in the second rainfall season. On the other hand, two out of three of the extreme wet months under the 6-month SPI were also in the second rainfall season. Therefore, the extreme events under the 6-month SPI were more pronounced in the second rainfall season.

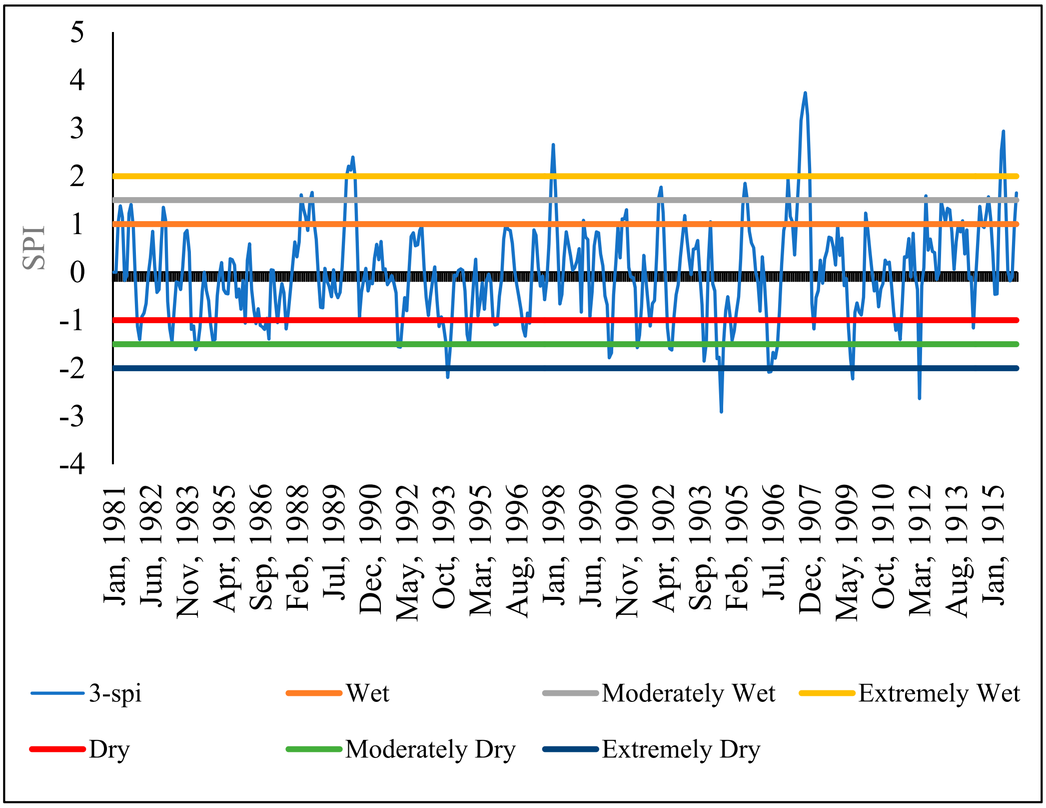

Figure 5. Three-month SPI over Sipi sub-catchment (1981–2015).

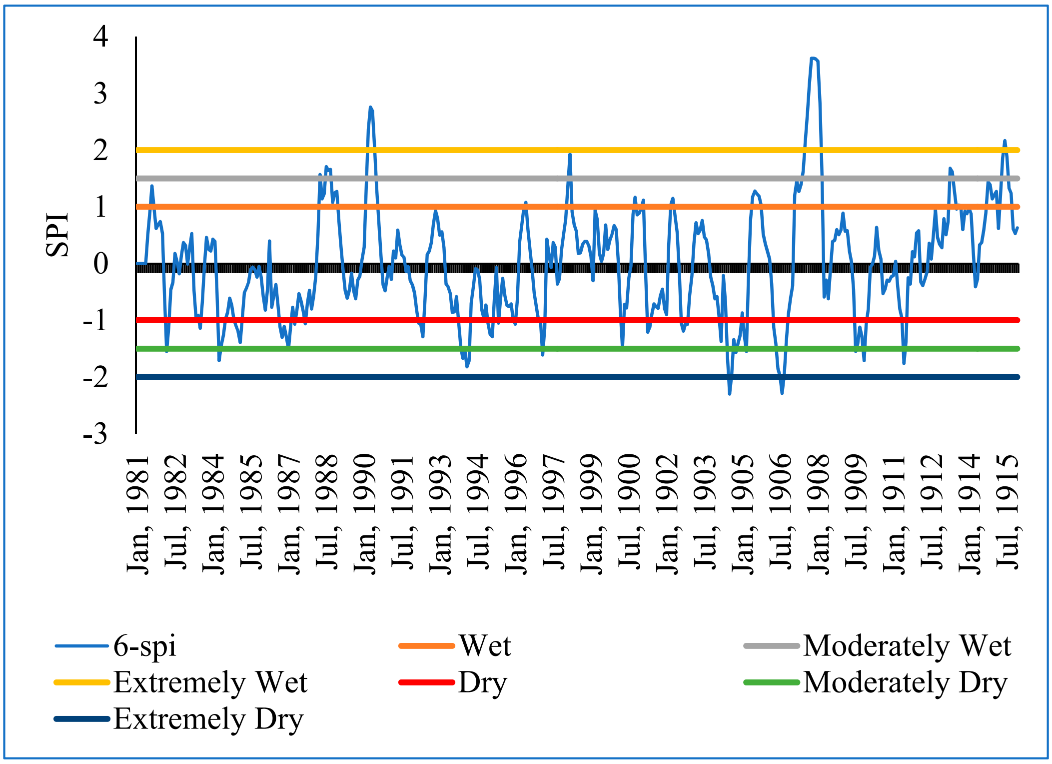

Figure 6. Six-month SPI over Sipi sub-catchment (1981–2015).

The 12-month SPI (Figure 7) revealed that there were two extremely wet periods and two extremely dry periods over the sub-catchment. The first extremely wet event occurred between September 2007 and October 2008. The second one occurred between June and August 2015. For the extremely dry periods, the first occurred between August and September 2004, while the second period started in February 2005 and lasted until April. The 12-month SPI revealed that the two extremely wet events and one extremely dry event all occurred in the second rainfall season.

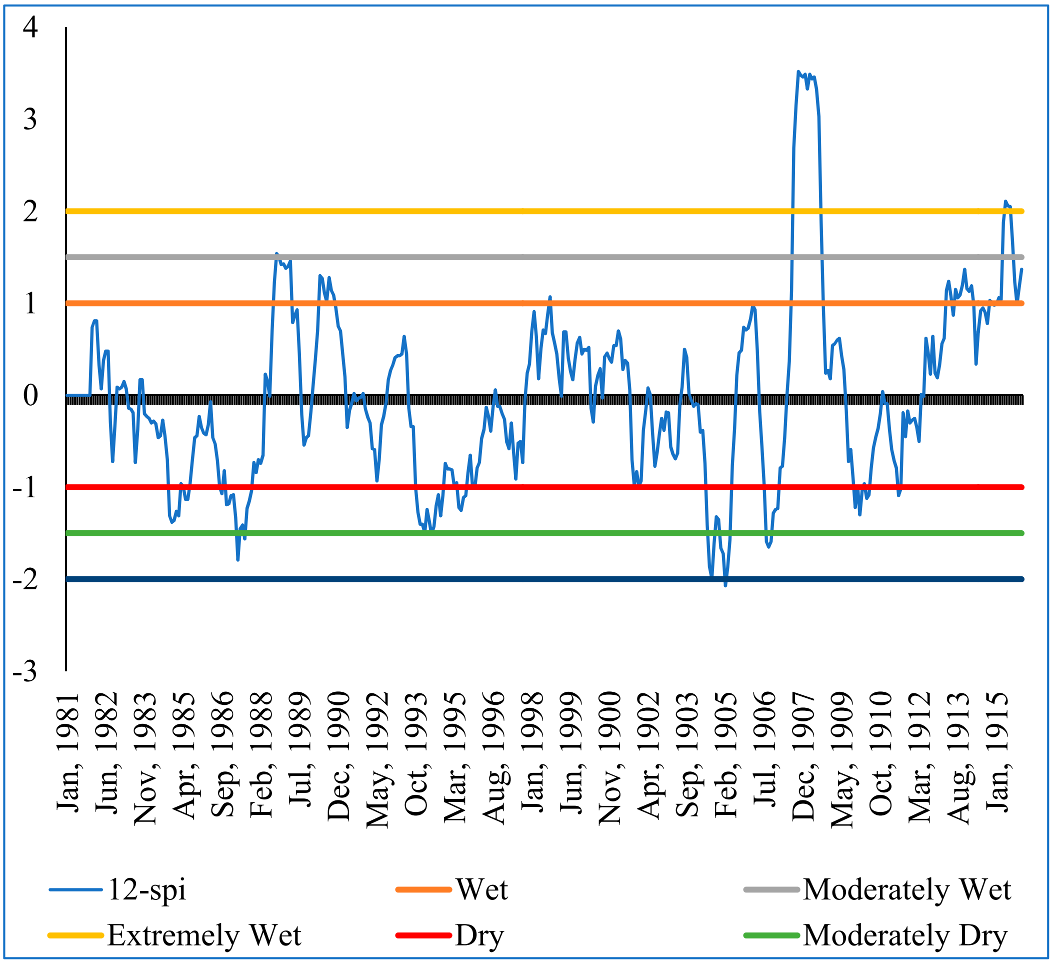

Figure 7. Twelve-month SPI over Sipi sub-catchment (1981–2015).

3.5. Seasonal and Annual Trends

Trend analysis revealed increasing seasonal and annual minimum and mean temperature (Table 6), though not significant for rainfall (Figures 8 and 9). MAM rainfall increased at a range of 0.27 mm in Buginyanya to 3.41 mm over the entire sub-catchment. In ASON, the increase in rainfall ranged from 1.25 mm in Buginyanya to 1.78 mm in Kapchorwa. Similarly, annual rainfall increased from 8.68 mm in Buginyanya to 18.32 mm over the sub-catchment. MAM minimum temperature significantly increased at $\alpha = 0.05$ level of significance in Kapchorwa and $\alpha = 0.001$ in ASON in Buginyanya, Kapchorwa, and over the entire sub-catchment. Generally, the minimum temperature for MAM increased by 0.02 °C, while, in ASON, it increased by 0.02 °C in Buginyanya and by 0.04 °C in Kapchorwa and over the sub-catchment, respectively. The annual minimum temperature increased at a range of 0.03 °C in Kapchorwa to 0.04 °C, over the sub-catchment. The maximum temperature did not increase significantly over the entire sub-catchment. The mean temperature increased at $\alpha = 0.05$ level of significance in ASON across the whole sub-catchment, with an overall increase of 0.03 °C. Similarly, both MAM and annual river flow (Figure 9) increased at α = 0.05. A study by [39] also found minimal variation (less than 1 °C) and a very similar CV below 5% between the average maximum and minimum temperature in MAM and ASON for Uganda.

Table 6. Seasonal and annual trends of rainfall and minimum, maximum, and mean temperature (1981–2015) for Buginyanya, Kapchorwa, whole sub-catchment, and river flow (1998–2015).

Seasonal Trends	**Buginyanya**		**Kapchorwa**		**Sub-Catchment**	
	Z	**Q**	**Z**	**Q**	**Z**	**Q**
MAM rainfall (mm)	0.36	0.27	0.77	0.7	0.71	3.41
MAM T minimum (°C)	1.59	0.02	2.30 *	0.02	1.87	0.02
MAM T maximum (°C)	0.34	0.01	1.08	0.01	0.68	0.01
MAM T mean (°C)	1.33	0.01	1.93	0.02	1.45	0.01
MAM Flow (m^3/S)					2.50 *	0.08
ASON rainfall (mm)	1.48	1.25	1.85	1.78	1.78	1.57
ASON T minimum (°C)	4.09 ***	0.02	4.43 ***	0.04	4.29 ***	0.04
ASON T maximum (°C)	1.33	0.04	1.56	0.03	1.28	0.03
ASON T mean (°C)	2.47 *	0.03	2.76 **	0.04	2.64 **	0.03
ASON Flow (m^3/S)					1.52	0.17
Annual trends						
Rainfall (mm)	1.05	8.68	1.65	9.46	1.52	18.32
T minimum (°C)	3.72 ***	0.03	3.95 ***	0.04	4.12 ***	0.03
T maximum (°C)	1.51	0.02	1.42	0.02	1.39	0.02
T mean (°C)	3.01	0.02	2.84	0.03	2.9	0.03
Flow (m^3/S)					2.50 *	0.10

*** Denotes trend at α = 0.001 level of significance, ** denotes trend at α = 0.01 level of significance and * denotes trend at α = 0.05 level of significance, respectively.

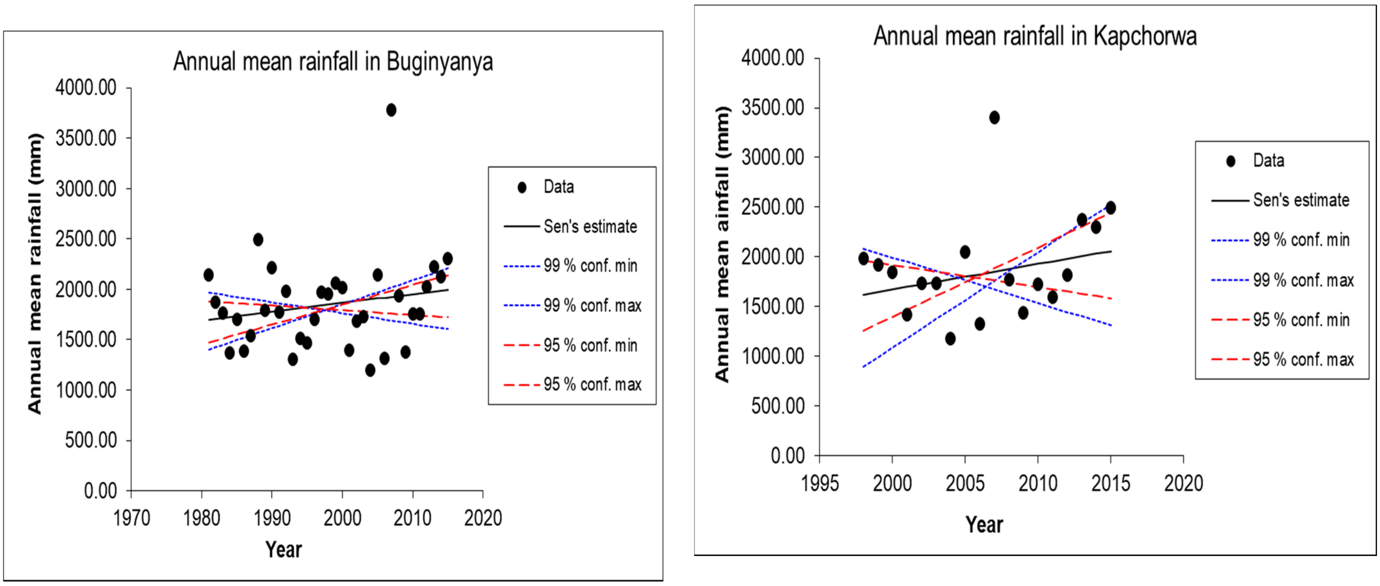

Figure 8. Time series of annual rainfall in Buginyanya and Kapchorwa (1981–2015).

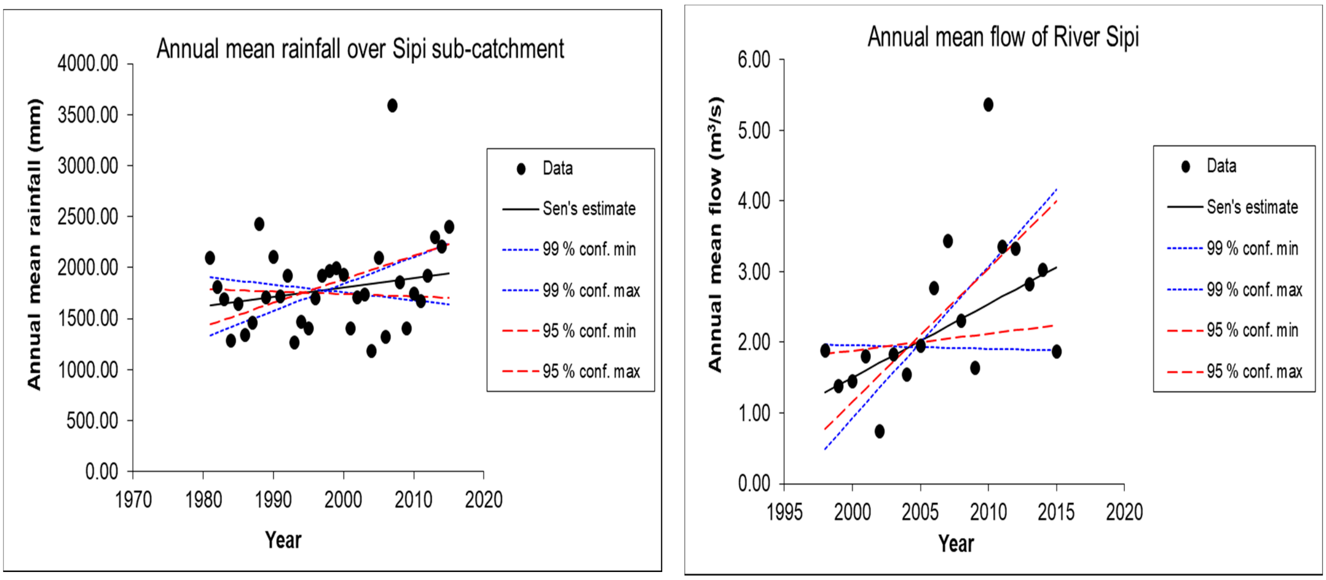

Figure 9. Tine series of annual rainfall over Sipi sub-catchment (1981–2015) and River Sipi flow (1998–2015).

4. Discussion

The results revealed inter-seasonal variation in mean rainfall across the sub-catchment, with ASON rainfall varying more than MAM rainfall. According to [27], ASON mean rainfall across the entire sub-catchment is categorized as highly variable CV > 30, whereas MAM rainfall is grouped under moderately variable 20 < CV < 30. However, the mean of rainfall in MAM and ASON for Buginyanya, Kapchorwa, and the mean of rainfall over the sub-catchment have not varied much. This suggests that the inter-seasonal variabilities could be a result of extreme events, as depicted by the SPIs. In fact, ref. [40] also found variations in the amount of annual and seasonal precipitation in the greater Mt. Elgon region between 1993 and 2013. Looking at the results on seasonal and annual rainfall variabilities from the perspective of water availability, Sipi sub-catchment gets, on average, an equal amount of water in both the MAM and ASON seasons. However, results depict high river flows in the catchment during the ASON season as compared to MAM. The observed patterns of monthly rainfall and river flows can be attributed to many factors, including the following: (a) the development of the tropical cyclone during December, January, and February (DJF); (b) the influence of the El Nino Southern Oscillation (ENSO); (c) during that period, the region had gone through a long dry season (DJF) where the volume of most rivers was reduced due to high evaporation and low rainfall. According to [31] the climate of Uganda is influenced by the Inter-Tropical Convergence Zone (ITCZ), varied relief, geo-location, and inland lakes. In the second rainfall season, the flow pattern pick-up, together with the rainfall, reaches its peak, which is more than the peak of the second rainfall season. This can be attributed to accumulation of water in the river and ground during the first rainfall season. The pattern also indicates no major abstractions of water from the river.

Results of seasonal and annual variabilities therefore point out that water is available (in terms of quantity) in the soil in both MAM and ASON rainfall season and in the river throughout the year. Trend analysis results showed that both annual flow and minimum temperature have increased significantly but annual mean rainfall did not increase significantly. Although result suggests water availability in the catchment throughout the years, the finding presents both opportunities and challenges to water resources management in the future. The opportunity that presents itself is that the Sipi sub-catchment has the potential for irrigation agriculture to support food production even in times of droughts and, hence, increased productivity. However, irrigation agriculture has been associated with intensification and high applications of fertilizers and other agrochemicals that are bound to exacerbate non-point pollution of water resources in the sub-catchment [41,42].

From another angle, the findings suggest that the limiting factor in the Sipi sub-catchment in the two rain fall seasons is not water but could be the variation in temperature. Different crops are known to respond differently to small differences in temperature which may have a direct link to sunshine hours'/day length [43]. Such variation may affect the flowering patterns and may lead to delayed or early maturity in fruits [44,45], which may also exacerbate pre and post-harvest loses. Similarly, little difference in temperature may provide ambient conditions for pest and diseases [46] and hence leading to pre- and postharvest loss or reduced crop yields. In Mt. Elgon, ref. [47] reported that the incidence of coffee leaf miners (CLM) increased significantly ($p = 0.0152$) with increasing altitude. The authors linked the result to variation of rainfall and ambient temperatures which affect the coffee plant and thus, the pest and its natural enemies. A study by [15] found that variation in rainfall and temperature from the long-term mean has significant effects on crop output, while an exponential increase in rainfall has detrimental effect on crop output. In the study by [46], local farmers in Rakai and Hoima districts in Western Uganda reported erratic rainfall onset and cessation, poor seasonal distribution of rainfall and decreased rainfall, variations in temperatures, drought, increasing disease and pest incidences, decreasing water sources, lack of pasture, bush fires, hailstorms, and changes in crop flowering and fruiting times as the major climate-related risks being experienced.

4.1. Conclusions

For the period 1981–2015, there was high variability in ASON rainfall in the Sipi sub-catchment, as indicated by high CV values. Additionally, more extremely wet and dry periods occurred in the Sipi sub-catchment in the post-2000s as compared to pre-2000. This implies that the future is more likely to have more extremely wet and dry events that are likely to pose threats to the surrounding communities; thus, there is a need to develop more capacities by the government and the surrounding communities to anticipate, prepare, and adapt for sustained livelihoods.

The increase in the Sipi river flow in the second seasons may imply more floods to the surrounding areas and policy makers and other relevant stakeholders need to take this into consideration to prepare for such anomalies in order to reduce the associated losses.

A significant increase in the minimum temperature across the Sipi sub-catchment, especially in ASON and in annual scales, may imply a reduction in water availability due to increased evaporation. This may also affect several production sectors, such as agriculture, since an increase in temperature may promote breading grounds for crop pests and diseases. Therefore, policy makers and other stakeholders need to develop strategies for water investment, food security, flood and drought mitigation within the Sipi sub-catchment and the Mt. Elgon region at large.

Future research should investigate and disentangle the impacts of climate and land-use changes on water resources in the Sipi sub-catchment for adaptive management of the resources in the catchment.

4.2. Limitations

Most weather stations in Uganda are agro-metrological and rainfall stations established in the colonial times. Unfortunately, the majority of the stations collapsed in the 1970s, due to insecurity, vandalisms, and lack of maintenance [48]. As a result, there is a serious problem with hydro-meteorological data in Uganda in general [26,39], and in the study catchment specifically. Consequently, data used in this study came from only two weather station within the sub-catchment, and we consider this a limitation. Effort to overcome this limitation by supplementing observed data with the Modern-Era Retrospective Analysis for Research and Applications (MERRA) daily rainfall and maximum and minimum temperatures were rendered fruitless after it was found that the sub-catchment lies within the same grid. Therefore, irrespective of the location of extraction, one would obtain the same data in the 918 km^2 sub-catchment, possibly due to the steep slopes. However, we believe that our results represent close to the best reality in the sub-catchment, considering the data availability. The situation could be improved in the future if more meteorological stations are established in the sub-catchment.

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