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Standardized Precipitation Index Comparison along the Limbe-Bamenda Axis of the Cameroon Gulf of Guinea

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Abstract

Mean monthly rainfall decline with continentality is a commonplace phenomenon that has been used in this study to compare its trend in Bamenda in the Western Highlands and Limbe on the Atlantic lowland coast. This study attempts to bridge some of the methodological gaps in the previous studies on rainfall variability in Cameroon that had emphasized only the inter-annual variability and coefficient of variation without focusing on the specific indices and contrasts between different ecological zones. In this study, a comparative analysis has been done of the standardized precipitation index (SPI) for Bamenda and Limbe, using data from 1985–2015. The analysis involved the mean annual rainfall (176.88 mm and 419.9 mm), its standard deviation (SD) (22.98 and 102.42), and the coefficient of variation (CV) (12.99% and 24.41%) for Bamenda and Limbe, respectively. The results show that the mean annual rainfall for Bamenda is decreasing, whereas that of Limbe is increasing. The mean SPI is –0.01 (mild dryness) and 0.02 (mild wetness) for Bamenda and Limbe, respectively. These results have far-reaching implications for the development of agriculture, water resources management, and other man-environment interaction variants.

Keywords

Coefficient of variation; continentality; rainfall reliability

1. Introduction

Rainfall events across the earth's surface are unevenly distributed owing to various reasons. Such variation is reflective of the availability of water for human use and the cycles of activities such as agriculture [1]. In this era of global environmental changes, a sound knowledge of the climate of the human-populated territories is indispensable, considering the current phenomenon of climate change [2]. Rainfall variability, which refers to the change in the amount of rain received in a particular geographical region within a defined period, can be daily, monthly, seasonal, or annual. The change in the precipitation averaged over the global land areas is observed to be low before 1951 and medium afterward because of insufficient data, particularly in the earlier periods of the records [3].

The long-term mean rainfall for a month, season, or year does not often indicate the regularity with which given amounts of rainfall can be expected, especially in the low latitudes where rainfall is known to be highly variable in its incidence from one year to another [1]. In the tropics, rainfall tends to be more variable seasonally than annually [4, 5]. Rainfall variability is a measure of the degree of likelihood that the mean amount of rainfall might be repeated each year, season, or month depending on the period under consideration [6].

In this study, characteristics such as the standard deviation and coefficient of variation have been used to establish the reliability of rainfall for the cities of Bamenda and Limbe in Cameroon, located in contrasting geographic zones, where the local climatic conditions are determined by continentality. While Bamenda is located in the hinterland of the Western Highlands of the Grassfields of Cameroon, Limbe is located along the Atlantic southwest coast of Cameroon. These positions show differences in their climatic conditions evaluated using the standardized precipitation index (SPI). Bamenda and Limbe are areas where agriculture is essentially rainfed. Rainfall is abundant in these regions and appears to be reliable. However, the impact of continentality needs to be understood even on the smaller scale distance using an innovative statistical tool such as SPI.

This study bridges some of the methodological gaps in the previous studies on climate variability in Cameroon. A previous study [7] analyzed the rainfall probability and reliability over Cameroon, using standard deviation (SD) and coefficient of variation (CV), with no other climatic index. Yet another study [8] performed a descriptive analysis of rainfall variability and its impact on the water resources over Cameroon and observed that the mean annual rainfall decreases inversely with latitude, without specifying the indices that show regional variations. Two other studies [9, 10] assessed the susceptibility of water resources to the climate variability on the Bui Plateau, using the rainfall seasonality index (SI) and SPI, which failed to reveal the regional disparities at the mesoscale. Such indices need to be easy to calculate and statistically relevant.

Meteorological drought has different impacts on groundwater, reservoir storage, soil moisture, and streamflow. McKee, Doesken, and Kleist proposed the SPI parameter in 1993, in which precipitation is the only required input parameter that is used in analyzing wet and dry cycles. Datasets required to compute SPI require 90% or at least 85% complete records. SPI was designed to quantify the precipitation deficits for multiple timescales that best reflect the impact of droughts on the availability of water resources. Soil moisture conditions respond to precipitation anomalies on a relatively short scale. Groundwater, streamflow, and reservoir storage reflect the longer-term precipitation anomalies. A previous work [11] originally calculated the SPI for 3-, 6-, 12-, 24-, and 48-month timescales. Positive SPI values indicated greater than median precipitation, whereas negative values indicated less than median precipitation. Since the SPI was normalized, wetter and drier climates could be represented in the same way.

2. Study Area and Methodology

Bamenda, headquarters of the Northwest Region, Cameroon, is located between longitudes 10°09" and 10°11" East of the Greenwich Meridian and between latitudes 5°56" N and 5°58" North of the Equator (Figure 1). The area covers three administrative units (Bamenda I, Bamenda II, and Bamenda III). Limbe is located between latitudes 3°20’ North and 4°15’ North of the Equator and between longitudes 8°15’ East and 9°35’ East of the Greenwich Meridian. The coastal town of Limbe lies to the South-Southeast foot slopes of Mount Cameroon. Limbe is subdivided into three municipalities (Limbe I, Limbe II, and Limbe III).

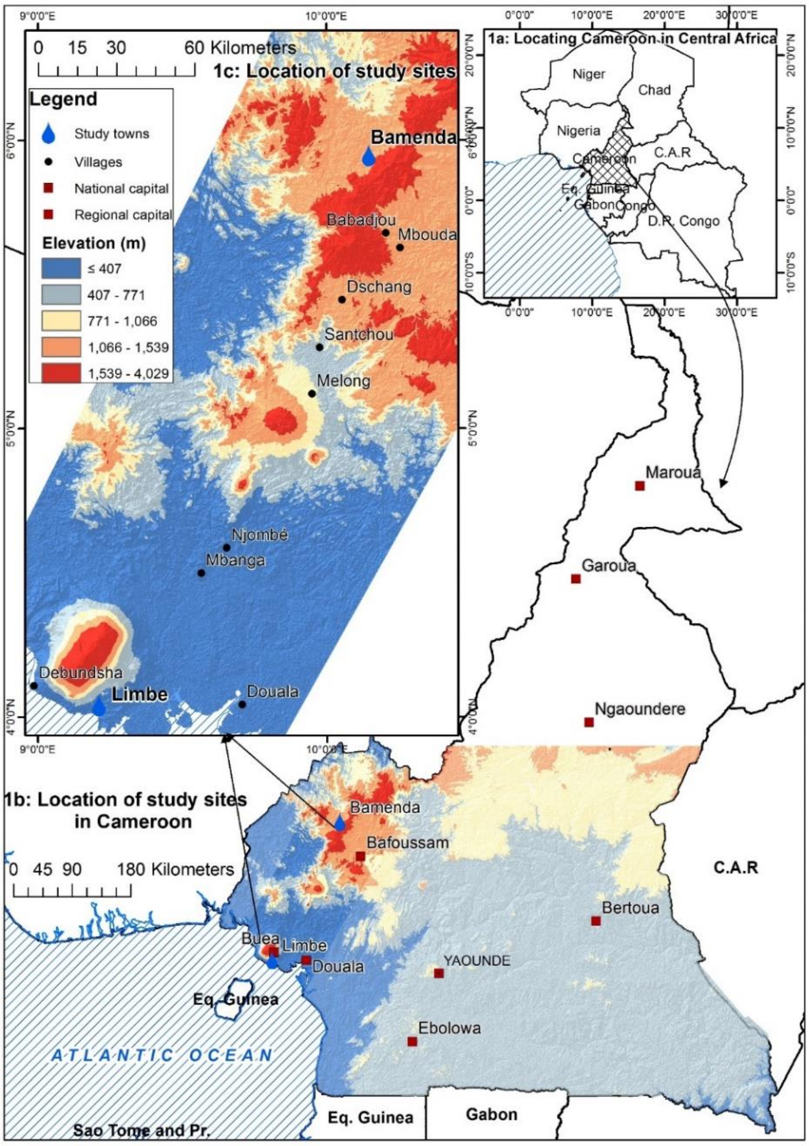

Figure 1 Location of Bamenda and Limbe.

Ground surface measurements of the mean annual rainfall for 31 years (1985–2015) were collected from the Cameroon Development Corporation Head Office, Bota-Limbe, and the Regional Meteorological Service for the Northwest in Bamenda, with the aim of showing the similarities and differences between the rainfall characteristics between Bamenda and Limbe. Measures of the central tendencies included the standard deviation (σ) and CV, which were calculated using the following formulae:

$$\sigma = \frac{\sqrt{\Sigma(Y-\bar{Y})}^2}{N} \tag{1}$$

$$CV = \sigma * \frac{100}{\bar{Y}}. \tag{2}$$

where $\bar{Y}$ is the mean and N is the sample size.

The main index used for establishing the differences between the climates of Bamenda and Limbe is a 12-month SPI, which indicates the intensities of extreme rainfall (wet and dry conditions) and criteria for different timescales. Drought events were noted when the SPI was continuously negative and reached an intensity of –1.0 or less and ended when the SPI became positive. Each drought event had a duration and an intensity for each month that the event stayed on.

The positive sum of the SPI values for all months within a drought event constituted the drought's magnitude (Table 1).

Table 1 SPI classification.

SPI Value	Category	Probability (%)	Frequency (100 years)	Severity of event (years)
>2.00	Extreme wet	2.3	100	1 in 1
1.5 to 1.99	Severely wet	4.4	70	1 in 1.1
1.00 to 1.49	Moderately wet	9.2	50	1 in 1.3
0 to 0.99	Mildly Wet	34.1	45	1 in 1.5
–0.1 to –0.99	Mild dryness	34.1	33	1 in 3
–1.00 to –1.49	Moderate dryness	9.2	10	1 in 10
–1.50 to –1.99	Severe dryness	4.4	5	1 in 20
<–2	Extreme dryness	2.3	2.5	1 in 50

Source: Refs. [11, 12]

The SPI determines the frequency of anomalously wet episodes at a given time scale (temporal resolution) for any rainfall station. This can be understood as SPI being the number of standard deviations by which the precipitation values recorded for a location would differ from the mean over certain periods. In statistical terms, SPI is equivalent to the Z-score.

$$\mathrm{Z-score} = x - \frac{\mu}{\delta} \tag{3}$$

where Z-score expresses the distance of the *x* score from the mean (μ) in standard deviation (δ) units.

Statistically, SPI is based on the cumulative probability of a given rainfall event occurring at a station. All the graphs generated from the data were fitted with trend lines and linear equations. The trend lines indicate an increase or decrease in rainfall. From this analysis, tables were generated to summarize the rainfall in the regions and the SPI characteristics.

3. Results

The results have been grouped into rainfall characteristics, SPI analysis for Bamenda and Limbe, decadal variations in SPI for Bamenda and Limbe, and well implications for SPI variations.

3.1 Rainfall Characteristics for Bamenda and Limbe

The mean monthly rainfall increases from January to a maximum in July, August, and September in Bamenda, and gradually declines from October to December (Figure 2). Minimum rainfall is recorded from December (11.97 mm) to February (28.61 mm). Conversely, in Limbe, the mean monthly rainfall increases from January to a maximum in June, July, August, and September (Figure 3).

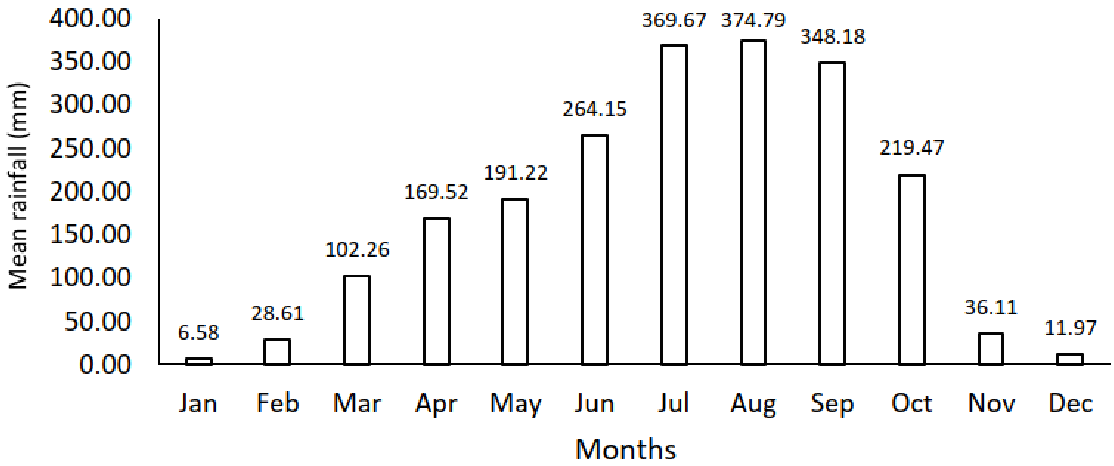

Figure 2 Mean monthly rainfall in Bamenda. Data: Regional Meteorological Service, NW, Bamenda.

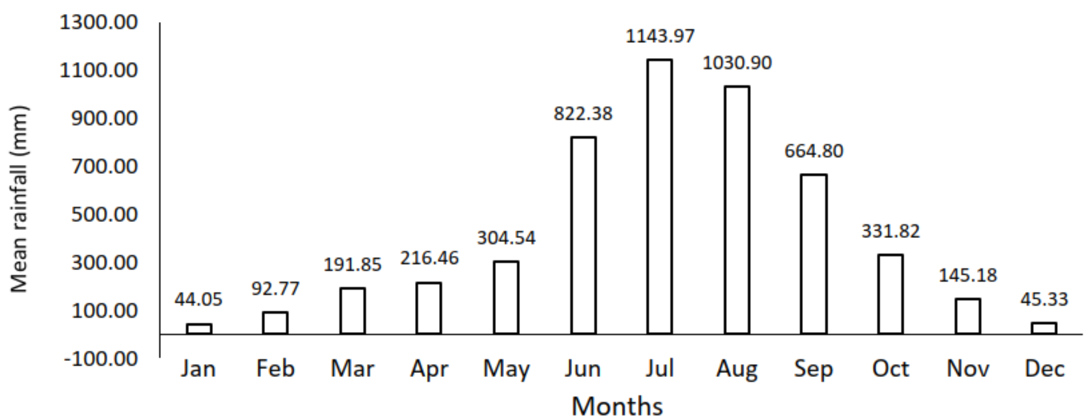

Figure 3 Mean monthly rainfall in Limbe. Data source: Cameroon Development Corporation Head Office, Bota.

Minimum rainfall is recorded from December (45.33 mm) to February (92.77 mm). The difference is in the mean rainfall received. The mean monthly rainfall in Bamenda is 176.88 mm, whereas that of Limbe is 419.5 mm. This reflects the effect of continentality and nearness to the ocean. The rainfall declines with increasing latitude from the Atlantic coast in Limbe toward the north. The general trends in inter-annual rainfall also show some disparities. The inter-annual rainfall has been observed to be decreasing in Bamenda and increasing in Limbe (Figure 4 and Figure 5).

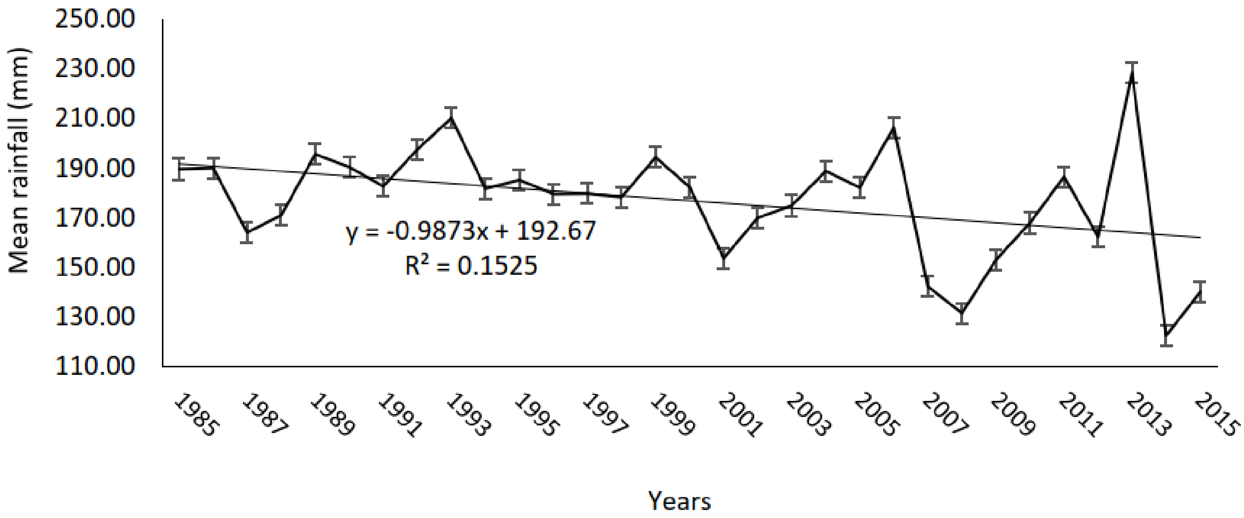

Figure 4 Rainfall trend for Bamenda (1985–2015). Data: Regional Meteorological Service, NW, Bamenda.

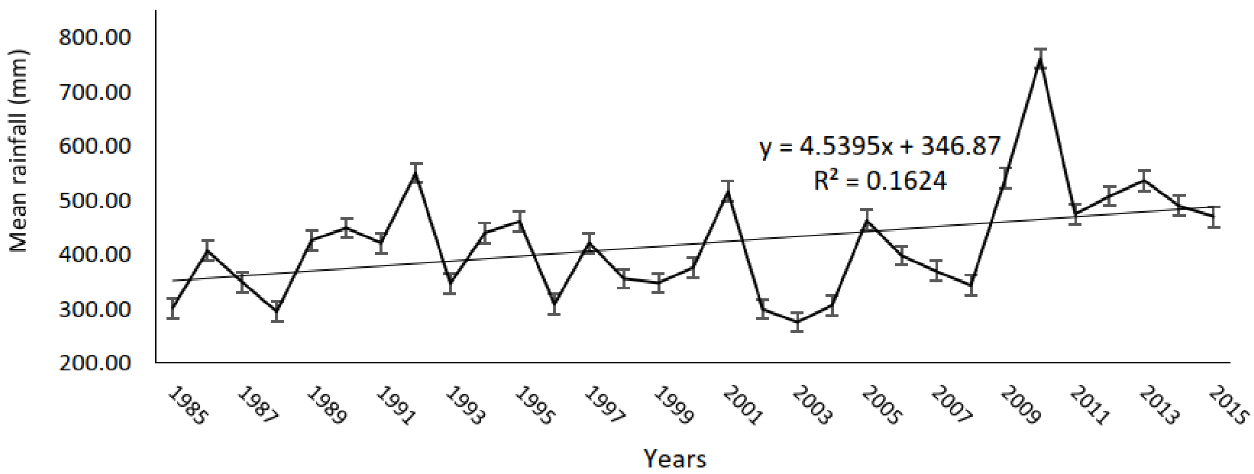

Figure 5 Rainfall trend for Limbe (1985–2015). Data source: Cameroon Development Corporation Head Office, Bota.

The inter-annual rainfall is not always a good measure of rainfall variability because decreasing rainfall can still be reliable, whereas increasing rainfall can be unreliable. Rainfall reliability is efficiently assessed by using the parameter CV. In the tropics, a CV threshold of less than 20% depicts rainfall reliability. The mean annual rainfall for Bamenda is 176.88 mm, with rainfall σ of 22.98, whereas the inter-annual CV is 12.99% (reliable). On the other hand, Limbe has a mean annual rainfall of 419.5 mm and σ = 102.42. Its CV is 24.41% (unreliable). An increasing trend in inter-annual rainfall does not mean that rainfall is reliable. Another clue of rainfall reliability over Bamenda and Limbe is the coefficient of determination (R^2), as indicated in Figure 4 and Figure 5. The R^2 value indicates the contribution of the trends to rainfall reliability. In Bamenda, R^2 contributes to 15.25% of its rainfall reliability, whereas that of Limbe contributes to 16.24% of its rainfall unreliability. This shows a difference of 0.99% between the two stations.

3.2 Analysis of SPI for Bamenda and Limbe

Bamenda and Limbe show different trends in SPI (Figure 6 and Figure 7).

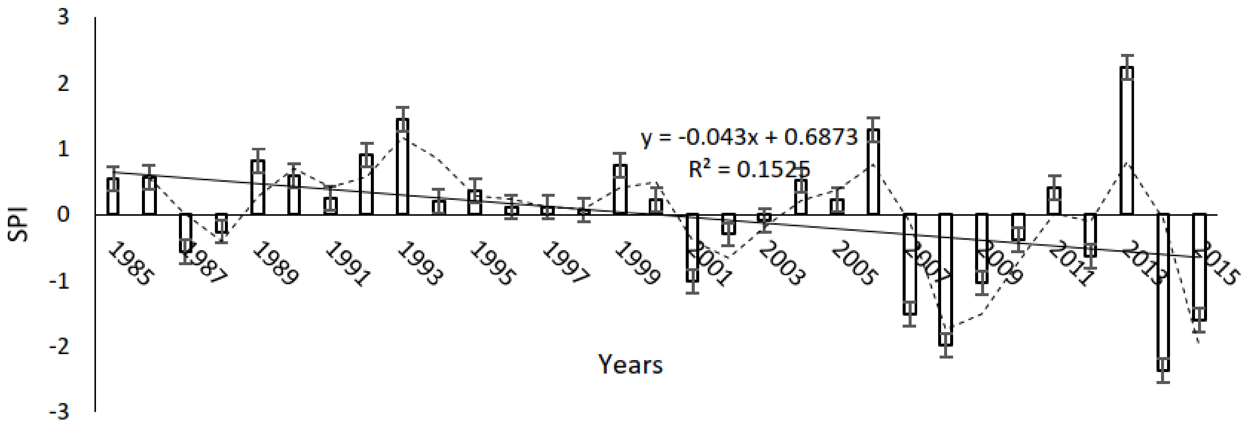

Figure 6 SPI trend for Bamenda (1985–2015). Data: Regional Meteorological Service, NW, Bamenda.

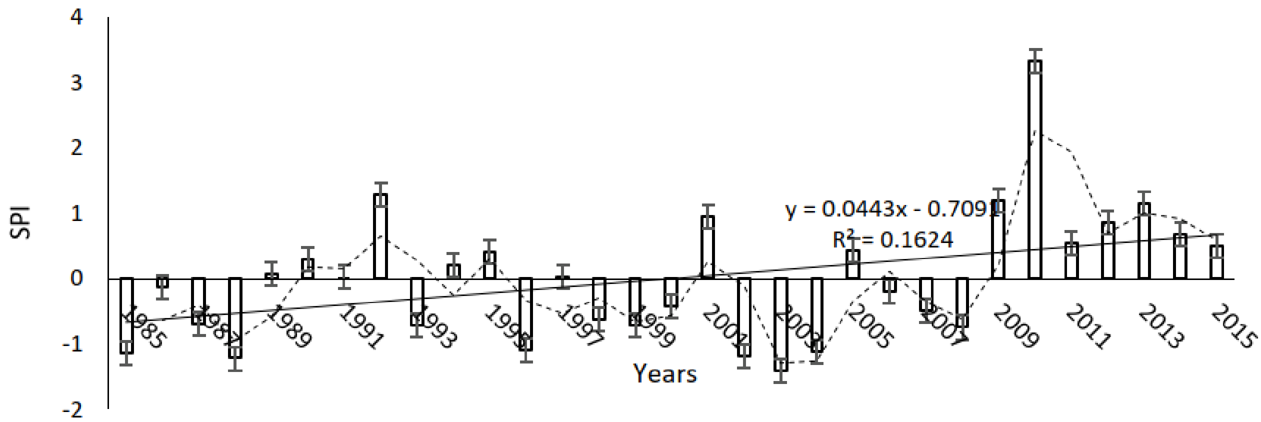

Figure 7 SPI trend for Limbe (1985–2015). Data source: Cameroon Development Corporation Head Office, Bota.

The results reveal that for Bamenda, dry episodes were recorded in 1987, 1988, 2001–2003, 2007–2010, 2012, 2014, and 2015. On the other hand, for Limbe, rainfall deficits were recorded in 1985–1988, 1993, 1998–2000, 2001–2004, 2006–2008. Using the SPI classification table (Table 1), the rainfall episodes for Bamenda and Limbe present the following pattern (Figure 8 and Figure 9).

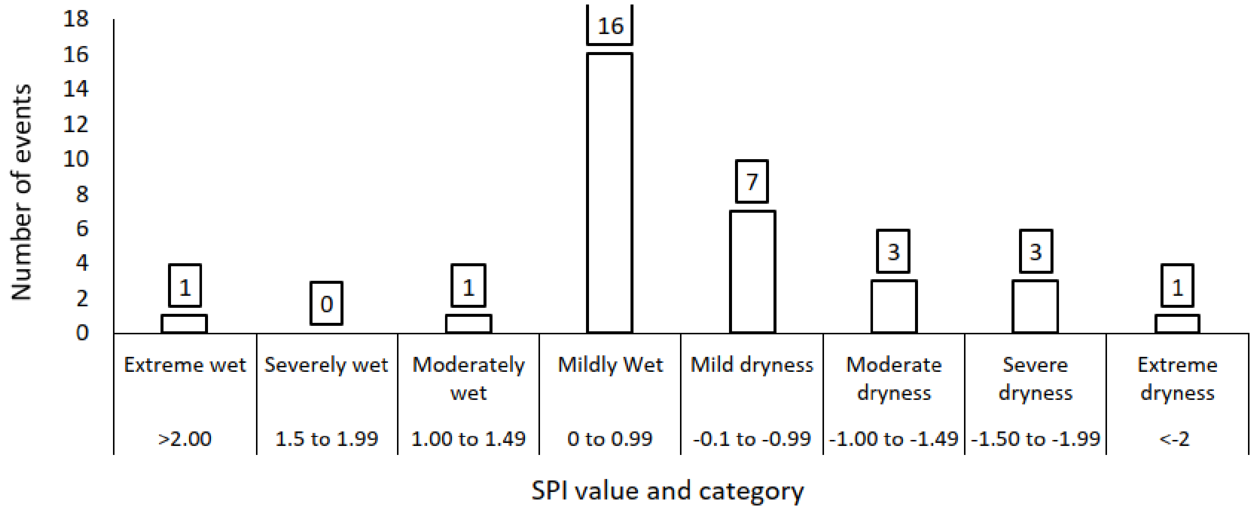

Figure 8 Summary of SPI events for Bamenda (1985–2015).

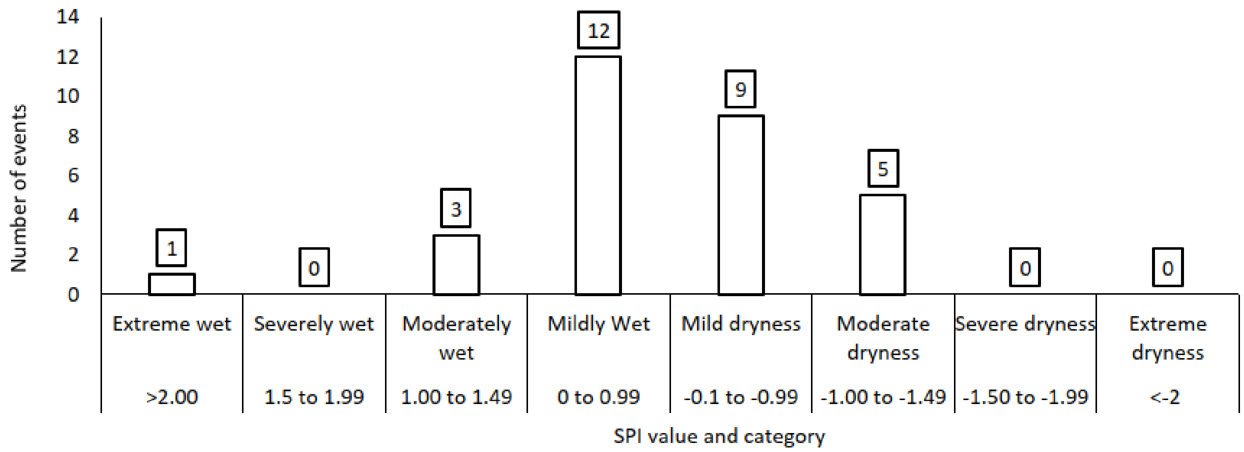

Figure 9 Summary of SPI events for Limbe (1985–2015).

From the year 1985 to 2015, the SPI values for Bamenda indicated 1 extreme wet episode, 0 severely wet, 1 moderately wet, 16 mildly wet, 7 mild dryness, 3 moderate dryness, 3 severe dryness, and 1 extreme dryness. On the other hand, Limbe had 1 extreme wet, 0 severely wet, 3 moderately wet, 12 mildly wet, 9 mild dryness, 5 moderate dryness, 0 severe dryness, and 0 extreme dryness episodes. This shows that Bamenda recorded more episodes of dryness (17) than Limbe (14) between the years 1985 and 2015.

3.3 Analysis of the Decadal Variations in SPI for Bamenda and Limbe

Different decades have exhibited different SPI trends and episodes for Bamenda and Limbe from 1985–2015. The rainfall trend for Bamenda is observed to increase by a factor of 8.78%. The period between 1985–1995 was characterized by mildly wet, mild dryness, and moderately wet episodes. These were 1985 (0.55-mildly wet), 1986 (0.57-mildly wet), 1987 (–0.55-mild dryness), 1988 (–0.25-mild dryness), 1989 (0.81-mildly wet), 1990 (0.58-mildly wet), 1991 (0.25-mildly wet), 1992 (0.89-

mildly wet), 1993 (1.44-moderately wet), 1994 (0.21-mildly wet), and 1995 (0.36-mildly wet). Therefore, this period recorded more wet episodes.

Between 1996–2005, the SPI trend for Bamenda declined above the average. The SPI episodes were 1996 (0.11-mildly wet), 1997 (0.12-mildly wet), 1998 (0.06-mildly wet), 1999 (0.75-mildly wet), 2000 (0,23-mildly wet), 2001 (–1.0-moderate dryness), 2003 (–0.29-mild dryness), 2004 (0.51-mildly wet), and 2005 (0.23-mildly wet). The decreasing trend has been by a factor of 0.27%. The period between 2006–2015 witnessed more rainfall deficits than the preceding decades. The SPI episodes were 2006 (1.26-moderately wet), 2007 (–1.5-severe dryness), 2008 (1.97-severe dryness), 2009 (–1.03-moderate dryness), 2010 (–0.38-mild dryness), 2011 (0.42-mildly wet), 2012 (–0.63-mild dryness), 2013 (2.23-extreme wet), 2014 (–2.36-extreme dryness), and 2015 (–1.6-severe dryness). This revealed that the SPI trend during this decade decreased below the average by a factor of 1.23%.

Limbe has also revealed marked variability in SPI episodes. From 1985 to 1995, Limbe experienced five dry episodes and six wet years. The distribution was 1985 (–1.14-moderate dryness), 1986 (–0.12-mild dryness), 1987 (–0.68-mild dryness), 1988 (–1.21-moderate dryness), 1989 (0.06-mildly wet), 1990 (0.28-mildly wet), 1991 (0.01 (mildly wet), 1992 (1.27-moderately wet), 1993 (–0.71-mild dryness), 1994 (0.20-mild wet), and 1995 (0.4-mildly wet). The SPI exhibits an increasing trend by a factor of 32.26%. The period between 1996–2005 could be considered as a dry decade, with more dry episodes. The SPI characteristics were, 1996 (–1.08-moderate dryness), 1997 (0.02-mildly wet), 1998 (–0.62-mild dryness), 1999 (–0.7-mild dryness), 2000 (–0.42-mild dryness), 2001 (0.94-mildly wet), 2002 (–1.17-moderate dryness), 2003 (–1.4-moderate dryness), 2004 (–1.1-moderate dryness), and 2004 (0.42-mildly wet). The SPI trend showed a slight increase below the average by a factor of 0.07%. The period between 2006–2015 in Limbe could be considered as a wet decade with only three years of rainfall deficits. The SPI characteristics were 2006 (–0.2-mild dryness), 2007 (–0.49-mild dryness), 2008 (0.74-mild dryness), 2009 (1.18-moderately wet), 2010 (3.33-extreme wet), 2011 (0.53-mildly wet), 2012 (0.85-mildly wet), 2013 (1.14-moderately wet), 2014 (0.68-mildly wet), 2014 (0.68-mildly wet), and 2015 (0.49-mildly wet). The SPI trend increased above the average by a factor of 10.43%. The SPI characteristics for both stations have been summarized in Table 2.

Table 2 The number of SPI episodes recorded between 1985 and 2015.

SPI Value	Category	Towns	
		Bamenda	Limbe
>2.00	Extreme wet	1	1
1.5 to 1.99	Severely wet	0	0
1.00 to 1.49	Moderately wet	1	3
0 to 0.99	Mildly Wet	16	12
–0.1 to –0.99	Mild dryness	7	9
–1.00 to –1.49	Moderate dryness	3	5
–1.50 to –1.99	Severe dryness	3	0
<–2	Extreme dryness	1	0

These characteristics were extreme wet (1 for Bamenda and 1 for Limbe), severely wet (0 incidents for both stations, moderately wet (1 for Bamenda and 3 for Limbe), mildly wet (16 for Bamenda and 12 for Limbe), mild dryness (7 for Limbe and 9 for Bamenda), moderate dryness (3 for Bamenda and 5 for Limbe), severe dryness (3 for Bamenda and 0 for Limbe), and extreme dryness (1 for Bamenda and 0 for Limbe). The rainfall and SPI characteristics for Bamenda and Limbe have been summarized in Table 3.

Table 3 Summary of the rainfall characteristics and SPI for Bamenda and Limbe.

Period	MAR (mm)	SD	CV (%)	Mean SPI	R^2	SPI class	Trend	Rainfall reliability
				Bamenda				
1985–1995	187.09	12.56	6.71	0.44	0.0878	Mildly wet	Increasing	Reliable
1996–2005	178.39	10.97	6.15	0.07	0.0027	Mildly wet	Slight decrease	Reliable
2006–2015	164.14	33.98	20.7	–0.55	0.0123	Mild dryness	Decreasing below average	Unreliable
Mean	176.54	19.17	11.19	–0.01	0.0343	Mildly dryness		Reliable
				Limbe				
1985–1995	414.4	75.28	18.28	–0.1	0.3226	Mild dryness	Increasing	Reliable
1996–2005	366.89	78.26	21.33	–0.51	0.0017	Mild dryness	Slight increase below average	Unreliable
2006–2015	488.95	117.23	23.98	0.68	0.1043	Mildly wet	Increasing	Unreliable
Mean	423.41	90.26	21.20	0.02	0.1429	Mildly wet		Unreliable

In Bamenda, the period between 1985–1995 had a mean rainfall of 187.09 mm, with σ = 12.56, CV = 6.71, and mean SPI = 0.44 (mildly wet). The rainfall trend showed an increase. For the 1996–2005 decade, the mean rainfall was 178.39 mm, with σ = 10.97, CV = 6.15%, and mean SPI = 0.07 (mildly wet). The rainfall trend showed a slight decline. Between 2006–2015, the mean rainfall was 166.14 mm, σ = 33.98, CV = 20.7%, and mean SPI = –0.55 exhibiting a decreasing rainfall below average. The overall SPI for Bamenda from 1985–2015 is –0.01 (mildly dry). For Limbe, the period between 1985–1995 had a mean rainfall of 414.4 mm, σ = 75.28, CV = 18.28%, and mean SPI = –0.1 (mild dryness). The rainfall trend showed an increase. The decade of 1996–2005 had a mean rainfall of 366.89 mm, σ = 78.26, CV = 21.33%, and mean SPI = –0.51 (mild dryness). The overall rainfall trend showed a slight increase below average. The last decade (2006–2015) had a mean rainfall of 488.95 mm, σ = 117.23, CV = 23.98%, and mean SPI = 0.68 (mildly wet). The rainfall trend showed an increase. The overall mean SPI for Limbe between 1985–2015 was 0.02 (mildly wet). These characteristics show that Limbe is wetter than Bamenda, even though rainfall is more reliable in Bamenda. The wetness of Limbe is most likely due to its exposure to the Atlantic Ocean and its monsoonal location near (5 km) the second wettest place on earth (Debundscha).

4. Discussion

Over the years, many climatic indices have been developed from simple indices, such as the percentage of normal precipitation and precipitation percentiles, to more complicated indices, such as the Palmer drought severity index (PDSI) [12]. Precipitation is the only required input parameter for the SPI. It is effective in analyzing wet and dry cycles with changes in latitude. It is more likely that datasets would only have 90% or only 85% complete records. Many users of SPI do not have this luxury and might have to settle for less (75–85% complete datasets) unless they look for estimation techniques to fill in the gaps in the records. Long and pristine data records are neither practical nor typical in many cases. Thus, the user needs to be aware of the statistical shortcomings of extreme events when dealing with shorter periods of records for various locations [13]. Depending on the confidence and method of calculation, the use of estimated data is acceptable to show climate variability and change. Naturally, the fewer the estimated data used, the more reliable the results are [12]. SPI is a good indicator of the change in the precipitation over time. Its flexibility permits the precipitation change to be calculated over different time scales such as 3, 6, 12, 24, and 48 months. Rainfall deficit assessments using SPI are recorded within a threshold of zero because a drought sets in when the SPI values fall below the zero threshold. In this study, Bamenda was observed to record more rainfall deficit than Limbe, implying that the aridity increases with an increase in latitude. Such dry episodes are in the form of meteorological, agricultural, and hydrological droughts that are recorded in all climatic regions across the globe.

The climates of Bamenda and Limbe broadly fall under tropical climates as per the Köppen classification *(A-climates)*. Limbe has a mixture of *Am* (tropical monsoon)/*Af* (tropical rain forest) climates, whereas Bamenda has Aw (tropical savanna) climate solely. Tropical locations show seasonal precipitation changes [14, 15]. These differences are, in part, due to the influence of the various climatic controls (distance to large water bodies/continentality) [15] (in the case of Bamenda and Limbe). Large water bodies are capable of storing huge quantities of energy during high-energy periods (the Atlantic Ocean that washes the coast of Limbe, during the rainy season) and releasing this energy slowly to the atmosphere during low-energy times (dry season) [6]. These energy fluxes can have a significant effect on the climate of a location adjacent to the water body. Assuming that all other factors are equal, wet seasons over or near oceans (Limbe) are not as warm as they are in the interiors of continents (Bamenda). Likewise, dry seasons in coastal and oceanic locations are generally not as severe as they are in inland locations [15]. In addition, the onset of seasons is delayed significantly over and near oceans because of the oceanic absorption of energy during the rainy season and its slow release to the atmosphere from the onset of the wet season till the beginning of the dry season [2].

The *Am/Af* and *Aw* climatic regimes are directly influenced by the inter-tropical convergence zone (ITCZ). The dominant prevailing winds during the wet season are the warm-moist southeast (SE) winds from the Atlantic Ocean that push the ITCZ northward with the onset of the wet season. As a zone of convergence of the SE and northeast (NE) trade winds, tropical rainfall is largely influenced by the position of the ITCZ. From late October to November, the NE trade winds have a dominating influence, and the ITCZ is pushed to the south, so that dry weather conditions prevail because of harmattan. From March to April, the SE trade winds have an urge over the NE trade winds, such that the ITCZ gradually moves northward, indicating the start of the wet season [6]. The SE trade winds are moisture-laden and favorable for higher relative humidity, condensation, and the development of towering clouds [14]. Consequently, the position of the ITCZ shifts northward, and rainy conditions prevail [16]. The ITCZ is a band of varying width between the wind circulation of the northern and southern hemispheres [2, 17]. It is typically an area with lots of convective activity (thunderstorms), variable wind direction, and fluctuating wind strength.

5. Conclusion

The mean monthly rainfall increases from January to a maximum in July, August, and September in Bamenda and gradually declines from October to December in Bamenda and Limbe. The inter-annual rainfall is decreasing in Bamenda but increasing in Limbe as a result of the continentality effect. Inter-annual rainfall is not always a good measure of rainfall variability because decreasing rainfall can still be reliable, whereas increasing rainfall can be unreliable. Hence, the inter-annual CV for Bamenda is 12.99% (reliable), whereas that of Limbe is 24.41% (unreliable). The overall SPI for Bamenda from 1985 to 2015 is –0.01 (mildly dry), whereas that of Limbe is 0.02 (mildly wet). The summary of these characteristics shows that Limbe is wetter than Bamenda, although rainfall is more reliable in Bamenda. The wetness of Limbe is attributed to its exposure to the Atlantic Ocean and its monsoonal location near the second wettest place on earth (Debundscha). Consequently, Limbe and its environs are fertile ground for tropical plantation agriculture. Spatio-temporal variations of SPI in Bamenda and Limbe have implications for agriculture, water resources, and other aspects of the man-environment relationship. The heavy monsoonal rainfall in Limbe and its environs favors capitalist plantations of rubber, oil palm, and banana. Natural springs are also common in Limbe and its environs, given that the area is underlain by previous volcanic rocks that are constantly recharged by heavy rainfall. The Limbe area hosts water bottling companies (Seme Water) and others. Limbe and its surroundings also have vast areas of tropical rainforest and mangroves. Bamenda, on the other hand, favors subsistence agriculture and other agro-pastoral ventures because it is located in the tropical grasslands. Water resources occur mostly in perched aquifers of volcanic origin and are recharged by seasonal rainfall. The Bamenda highlands have suffered severe highland montane forest loss as a result of deforestation for subsistence agriculture, settlement, and the conversion of patches of natural vegetation into eucalyptus plantations.

Author Contributions

The author did all the research work of this study.

Competing Interests

The author has declared that no competing interests exist.

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