Spatio-temporal Variability and Trends of Mean and Extreme Rainfall Events in the Sudano-sahelian Region of Cameroon

Ibrahim NJOUENWET (njouenwetibrahim@yahoo.fr)
University of Yaounde I: Universite de Yaounde I https://orcid.org/0000-0003-1616-2226
Lucie A. Djiotang Tchotchou
Universite de Yaounde 1 Faculte des Sciences
Brian Odhiambo Ayugi
Nanjing University of Science and Technology
Guy Merlin Guenang
Universite de Dschang Faculté des Sciences: Universite de Dschang Faculte des Sciences
Derbetini A. Vondou
Universite de Yaounde 1 Faculte des Sciences
Robert Nouayou
Universite de Yaounde 1 Faculte des Sciences

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Spatio-temporal variability and trends of mean and extreme rainfall events in the sudano-sahelian region of Cameroon

Ibrahim Njouenwet*· Lucie A. Djiotang Tchotchou · Brian Odhiambo Ayugi · Guy Merlin Guenang · Derbetini A. Vondou · Robert Nouayou

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Ibrahim Njouenwet
Laboratory of Environmental Modeling and Atmospheric Physics, Department of Physics, University of Yaounde 1, P.O. Box 812 Yaoundé - Cameroon
Laboratoire Mixte International "Dynamique des écosystèmes continentaux d'Afrique Centrale en contexte de changements globaux" (LMI DYCOFAC), "Institut de Recherche pour le Développement" (IRD, University of Yaoundé 1, IRGM), IRD P.O. Box 1857, Yaoundé, Cameroon
njouenwetibrahim@yahoo.fr
https://orcid.org/0000-0003-1616-2226

Derbetini A. Vondou
Laboratory of Environmental Modeling and Atmospheric Physics, Department of Physics, University of Yaounde 1, P.O. Box 812 Yaoundé - Cameroon
Laboratoire Mixte International "Dynamique des écosystèmes continentaux d'Afrique Centrale en contexte de changements globaux" (LMI DYCOFAC), "Institut de Recherche pour le Développement" (IRD, University of Yaoundé 1, IRGM), IRD P.O. Box 1857, Yaoundé, Cameroon
derbetini@yahoo.fr
https://orcid.org/0000-0002-8681-5328

Brian Odhiambo Ayugi
Jiangsu Key Laboratory of Atmospheric Environment Monitoring and Pollution Control, Collaborative innovation Centre of Atmospheric Environment and Equipment Technology, School of Environmental Science and Engineering, Nanjing University of Information Science and Technology, Nanjing, 210044, China
ayugi.o@gmail.com
https://orcid.org/0000-0003-3660-7755

Guy Merlin Guenang
L2MPS, Department of Physics, Faculty of Science, University of Dschang, Dschang P.O. Box 96, Cameroon
merlin.guenang@yahoo.fr

Lucie A. Djiotang Tchotchou
Laboratory of Environmental Modeling and Atmospheric Physics, Department of Physics, University of Yaounde 1, P.O. Box 812 Yaoundé - Cameroon
angennes@yahoo.fr
https://orcid.org/0000-0003-2860-428X

Robert Nouayou

Laboratory of Geophysics and Geoexploration, Department of Physics, University of Yaounde 1, Cameroon

rnouayou1@yahoo.fr

*Correspondence to: Njouenwet Ibrahim (njouenwetibrahim@yahoo.fr)

Abstract

The Sudano-Sahelian region of Cameroon is mainly drained by the Benue, Chari and Logone rivers, which are very useful for water resources, especially for irrigation, hydropower generation, and navigation. Long-term changes in mean and extreme rainfall events in the region may be of crucial importance in understanding the impact of climate change. Daily and monthly rainfall data from twenty-five synoptic stations in the study area from 1980 to 2019 and extreme indices from the Expert Team on Climate Change Detection and Indices (ETCCDI) measurements were estimated using the non-parametric Modified Mann-Kendall test and the Sen slope estimator. **T**he precipitation concentration index (PCI), the precipitation concentration degree (PCD), and the precipitation concentration period (PCP) were used to explore the spatio-temporal variations in the characteristics of rainfall concentrations. An increase in extreme rainfall events was observed, leading to an upward trend in mean annual. Trends in consecutive dry days (CDD) are significantly increasing in most parts of the study area. This could mean that the prevalence of drought risk is higher in the study area. Overall, the increase in annual rainfall could benefit the hydro-power sector, agricultural irrigation, the availability of potable water sources, and food security.

Keywords: Extreme precipitation indices, Sudano-sahelian regions, Precipitation, Irrigation, Food security

1- Introduction

The Sahelian region has been identified as the region with the highest rainfall variabilities in the world over the last century (Nicholson, 2000). Subsequently, it is presented as one of the world's largest semi-arid regions, where people's sources of income are mainly based on rain-fed agriculture and animal husbandry (Leisinger and Schmitt, 1995). However, Kharin et al., (2007) and Field (2012) have found that in the 21st-century climate change will negatively influence established resilience in the area, not only by increasing the year-to-year variability of rainfall patterns but also by also increasing unpredictable seasonality and an altered number of heavy rainfall events and droughts (Fischer et al., 2013; Taylor et al., 2017). The date of beginning and length of the dry and wet season and the amount of annual rainfall vary across the region (Niasse et al., 2004). However, agricultural crops are closely linked to factors such as water availability and seasonal parameters (onset and retreat date) (Berg et al., 2009; Sultan et al., 2005). Predominantly, the economies of West African countries including the Sahelian regions are directly affected through agriculture which is essentially rainfed, poor water quality, and poor management of water reservoirs for hydroelectric dams and irrigation (Niasse et al., 2004). However, data from stations in West Africa, and particularly the Sahel, are missing due to different policies in different countries (Sanogo et al, 2015). For this reason, a review of the Intergovernmental Panel on Climate Change special report on extreme events (Field et al, 2012) highlighted the lack of studies on regional variability and trends in extreme rainfall and drought due to lack of data.

The sudano-sahelian region is the area's highest population density and also most vulnerable to climate change particularly, in the Cameroon region (Molua and Lambi, 2006). In terms of administration, it includes the far north and the northern regions and accounts for over one-fifth of Cameroon's total territory. The far north region has 74.3% of the population living below the poverty line (INS, 2015). Subsistence agriculture (rainfed, irrigated) accounts for 65% of the region's economic activity (DSCN, 2002). The sudano-sahelian region holds a strategically important position in Cameroon's economic development due to its vast area, water resources which is the major source of electricity by hydropower plants, high agricultural productive potential, and nomadic animal husbandry. The Benue and Logone-Chari Rivers are the main source of stream in the Sudano-Sahelian regions of Cameroon, which extend from the Adamawa region in the south through Nigeria to the Niger River in the west and from Lake Chad in the north to Chad and Central Africa republic in the south of the study area respectively. The Benue River also feeds the Lagdo Reservoir. Lagdo dam on the river Benue, with a useful capacity of close to 6 billion m^3, is the only classical

multipurpose dam in Cameroon because it facilitates at the same time the hydro-electricity production with a capacity of 84 MW, irrigation of 80000 ha of plantation, and river regulation for navigation (Kamga 2001). Thus, the rainfall distribution caused by climate change may severely affect the water cycle, and food security in the sudano-sahelian region of Cameroon.

From September 1982 to 2000, the sudano-sahelian region of Cameroon has suffered climate extreme events such as drought causing considerable impacts on the country's environment, human activities, and economy (MINEPDED, 2016). For instance, the September 2012 floods in Maga and Yagoua resulted in many lives being lost while others were displaced, and the main hospital and other public infrastructures destroyed due to heavy rainfall (Igri et al, 2015; Igri et al, 2018). During the same year, a serious threat to food security was reported in more than half of the administrative units with more than 14000 hectares of crops such as; 12000 hectares of cotton (6% of cotton crop cultivated) and 12375 fruit plants destroyed (Ministry of Agriculture and Rural Development, 2012). Cheo et al. (2010) showed that water resources vary with the changing climatic condition and the severity of the impact varies from region to region. As such, local studies are essential to analyze the changes in precipitation extremes.

Several studies have been reported assessing the spatiotemporal trends in mean and extreme rainfall events across West Africa (Sanogo et al, 2015; Zhang et al, 2017; Barry et al, 2018) which includes the sudano-Sahelian regions due to global warming. Most of these studies observed an increasing trend in annual mean rainfall and extremes events during 1980-2010. Likewise, over Central Africa, Fotso-Nguemo et al (2018) projected the increased trends in heavy rainfall over sudano-sahelian of Cameroon by 2100. However, most of these studies are limited in their assessment to specific regions delimited by the lack of station data in West Africa especially the sudano-sahelian region of Cameroon. At the local scale, only one study has been conducted. Fita et al, (2016) have analyzed long terms trends in the mean and climate variability (only rainfall) over the study area and found that at the 95% level of confidence 10% of stations displayed statistically significant decreasing while 5% of stations showed statistically significant increasing using homogeneous monthly and annual rainfall database of twenty-five stations located in Northern Cameroon. As such on a local scale, this study is unique in terms of its use of station density, comprehensive assessment of trends and changes in rainfall, its variability, and extreme events.

Accordingly, the objectives of this study are to fill this gap of data and extends the work of Sanogo et al, (2015), Zhang et al, (2017) Barry et al, (2018) in the Sahel West Africa an in by performing a more comprehensive assessment of the spatial variability and trends in rainfall amounts and extremes using three decades of station data with stations distributed all over sudano-sahelian of Cameroon.

Such information is important for decision-makers and farmers to address climate change through sustainable adaptation strategies. The rest of this paper is organized as follows: section two describes study area, data and methods while section three presents results and discussion. Final section elucidates the conclusion of the study.

2-Study area, data and method

2.1 Study area and data

The Sudano-Sahelian region lies between 7°N to 13°N longitudes and 11.5°E to 16°E latitudes (Fig. 1). It is a relatively flat topography. It has a drainage area of about 100,000 km^2 with a population of about 5,530,643 inhabitants. It is located in the north of Cameroon and covers two administrative regions (the Far North and North). The sudano-sahelian region has geostrategic importance as a source of water resources, a potential of hydropower, and is favorable to the livestock and growth of cotton, millet, sorghum, maize, rice, groundnuts and onions. All these crops are supervised by major companies such as "Société de Développement du Coton (SODECOTON)" and "Société d'Expansion et de Modernisation de la Riziculture dans la ville de Yagoua (SEMRY)". The climate of the study area can be broadly divided into two: the Sahelian and Sudanian zone located northward and southward of 9°N, respectively. Generally, the climate is under the influence of the thermodynamic properties of the African monsoon which brings rains between June-September in Sahelian zone and May-October in sudanian zone. Rainfall increases from the north toward the south between 328 mm and 1708 mm. This area is under the strong influence of humidity advected from the Atlantic Ocean and southwesterly flow (Penlap et al, 2004). The daily temperatures are usually between 25-34°C

Data sets used in this work are daily and monthly rainfall from 25 stations across the Sudano-Sahelian region of Cameroon for the 40-year period. This data set is collected by the support services of the SODECOTON. Their locations are shown in Fig. 1 and they are described in Table 1.

2.2 -Method

2.2.1 - Statistical test of homogeneity

Data homogeneity was first tested using the Standard Normal Homogeneity Test (SNHT) for a single break (Alexandersson, 1986), the Buishand range test (Buishand, 1982), the Pettitt test (Pettitt, 1979) and the Von Neumann ratio test (Von Neumann, 1941) at 1% significance level. Three of the four tests are used to determine the years of a break (location-specific tests) while the Von Neumann ratio test (not location specific) does not specify the year of rupture but rather a value that, when

compared with a threshold set in relation to the number of years used in the test, indicates whether the null hypothesis is rejected or not. The analysis is based on four tests, including three possible results which depend on the number of tests rejecting the null hypothesis (breakpoint); when there is zero or one test that rejects this hypothesis (useful), two tests (doubtful) and three tests (suspect). The test variable is the annual rainfall. In the following, when a station is labeled either useful or doubtful it may be used for trend analysis and variability; while when she is labeled suspect, she lacks credibility. Details on the description of these four methods can be found in Wijngaard et al, 2003.

2.2.2 Precipitation concentration index

The PCI is known as an indicator powerful of rainfall concentration, droughts or floods risk prediction and soil erosivity for annual and seasonal scales (wet and dry seasons) (de Luis et al. 2011). PCI was calculated on the annual and seasonal scale for each climate station. The PCI for a given station data series can be calculated as below,

$$PCI_{annual} = \frac{\sum_{i=1}^{12} P_i^2}{(\sum_{i=1}^{12} P_i)^2} \times 100 \quad (1)$$

$$PCI_{wet} = \frac{\sum_{i=1}^{nw} P_i^2}{(\sum_{i=1}^{nw} P_i)^2} \times \frac{100 \times nw}{12} \quad (2)$$

$$PCI_{dry} = \frac{\sum_{i=1}^{nd} P_i^2}{(\sum_{i=1}^{nd} P_i)^2} \times \frac{100 \times nd}{12} \quad (3)$$

where P_i is the monthly amount of rainfall in month i, calculated for each climate station. The seasonal PCI_{dry} and PCI_{wet} was computed on a seasonal scale based on the dry season from October-May and the wet season from June-September; now and nd represent, respectively, the number of rainy and dry season months.

As defined in the classification range of PCI values, Oliver (1980) detailed as follows: the rate of positive values of PCI which has ≤ 10 termed as a uniform distribution (i.e., low precipitation concentration); PCI>10 $\leq$15 refers moderate precipitation distribution; PCI>16 $\leq$ 20 refers irregular precipitation distribution, and PCI >20 describes strong irregularity of precipitation distribution.

2.2.2 Calculation of PCD and PCP

The PCD and PCP were proposed by Zhang and Qian (2003) to measure the distribution of rainfall and the month in a year in which total precipitation concentrates respectively. They showed that the length of the rainy season or the number of rainy days is inversely related to the PCD value. It is developed based on the assumptions that the monthly total precipitation is a vector containing both magnitudes. They can be defined as below:

$$\theta_j = \left(360° \times \frac{j}{n}\right) \quad (4)$$

$$R_i = \sum_{N} r_{ij} \quad (5)$$

$$R_{xi} = \sum_{i=1}^{N} r_{ij} \times \sin\theta_j \quad (6)$$

$$R_{yi} = \sum_{i=1}^{N} r_{ij} \times \cos\theta_j \quad (7)$$

$$PCD_i = \frac{\sqrt{R_{xi}^2 + R_{yi}^2}}{R_i} \quad (8)$$

$$\alpha_i = \tan^{-1}\left(\frac{R_{xi}}{R_{yi}}\right) \quad (9)$$

$$PCP_i = \alpha_i \times \left(\frac{n}{360}\right) \quad (10)$$

Where i is the year (i = 1980, 1981, ..., 2012), and Ri is the amount of rainfall of a year. j is the month (j = 1, 2, ... 12). θ_j represents the corresponding azimuth angle of the j^{th} month, while the year can be seen as 360 °. Rij represents the precipitation of the j^{th} month in the i^{th} year.

2.2.3 Precipitation Indices

Eleven indices of extreme precipitation defined by the Expert Team on Climate Change Detection and Indices (ETCCDI) were considered (Zhang et al., 2011) and calculated using the R-climdex model (Table 2).

2.2.4 The Modified Mann-Kendall trend tests

The Modified Mann-Kendall (MMK) trend test was applied respectively to examine trends in the precipitation and the extreme precipitation indices and to identify trends from 1980 to 2012. These methods are regularly used by researchers to separate natural variability of climate from unidirectional climate change due to global warming (Shiru et al., 2019; Iqbal et al, 2019; Ayugi et al., 2021; Ngoma et al., 2021). The classical Mann-Kendall test statistic (S) for a time series, x with n number of data points can be computed as below (Mann, 1945; Kendall, 1975) :

$$S = \sum_{k=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i) \quad (11)$$

where

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

The Mann-Kendall Z statistics are calculated from Eq. (12)

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & if\ S < 0 \end{cases} \quad (12)$$

where, Var (S) is the variance of S.

The significance of trend estimated by the use of MK test is first removed from the time series in MMK test (Rao and Hamed, 2008), then equivalent normal variants of rank (R_i) of the detrended series is estimated as:

$$Z_i = \phi^{-1}\left(\frac{R_i}{n+1}\right) \text{for i =1:n} \quad (13)$$

where, Φ^{-1} is the inverse standard normal distribution function. The self-similarity correlation matrix of the time series or the Hurst coefficient (H) is derived using the equation that defines as: (Koutsoyiannis, 2003):

$$C_n(H) = \left[\rho_{|j-i|}\right], \text{ for i=1:n; j = 1:n} \quad (14)$$

$$\rho_l = \frac{1}{2}(|l+1|^{2H} - 2|l|^{2H} + |l-1|^{2H}) \quad (15)$$

where, ρ_l is the autocorrelation function of lag l for a given H, and is computed by the use of maximum log likelihood function. The significance level of H is estimated by the use of mean and standard deviation for H = 0.5. If H is found significant, the biased estimate of the variance of S is calculated using the following equation for given H:

$$V(S)^{H'} = \sum_{i<j}\sum_{k<l} \frac{2}{\pi} \sin^{-1}\left(\frac{\rho|j-i| - \rho|i-l| - \rho|j-k| - \rho|i-k|}{\sqrt{(2-2\rho|i-j|)(2-2\rho|k-l|)}}\right) \quad (16)$$

The unbiased in estimation of $V(S)^H$ is removed using a bias correction factor, B as below:

$$V(S)^H = V(S)^{H'} \times B \quad (17)$$

where, B is a function of H. The significance of MMK test is computed using Eq. (12) by replacing V (S) with $V(S)^H$. where the Z-statistics value exceeds the ± 1.96 level, indicating that the trend is

significant at the 95% significance level. The positive value of Z shows an increasing trend, while the negative value indicates a decreasing trend in the precipitation time series.

2.2.5 Sen's slope estimator

In this case, the true slope (change per unit time) was evaluated using a simple non-parametric procedure developed by Sen, (1968), which assumes that the trend is linear.

$$slope = median\left(\frac{x_i - x_j}{i - j}\right) \quad (18)$$

where 1 < i < j < n and n is the total number of the dataset.

2.2.6 Standardized Precipitation Index

The Standardized Precipitation Index (SPI) was calculated for each climate station and on the long-term precipitation record of the whole study area. The SPI values indicate the quantitative definition of drought conditions that could be computed for different time scales to investigate the variation of groundwater, surface water storage, and agriculture. In this study, 3-month and 12-month SPI were analyzed using monthly rainfall data for the assessment of drought intensity and susceptibility at seasonal and annual precipitation in the Sudano-Sahelian region of Cameroon. McKee et al. (1993) indicate that high positive values correspond to wet sequences and high negative values correspond to drought periods. The SPI values of -1.0 to -1.49, -1.5 to -1.99 and below -2.0 represent moderate, severe, and extreme droughts, respectively (McKee et al. 1993). It is also classified as the range of positive values of SPI which has above 2, 1.99 to 1.5, 1.49 to 1.0 and 0.99 to -0.99 design extremely wet, very wet condition, moderately wet and near-normal condition respectively.

2.2.7 Spatial interpolation

Mean and extreme rainfall are spatially represented using Kriging interpolation method. Geographical information system (GIS) in R software is used for this purpose. Studies show that Kriging gives better local interpolation than other methods in the Sudano-Sahelian of Cameroon (Djoufack et al, 2012; Dassou et al, 2016). Our focus here is given the lack of station observations and the GIS is used to fill gaps and show the spatial variability of precipitation and precipitation extremes.

3. Results and discussions

3.1 Homogeneous assessment

Few stations have missing values, with fewer than 4% (Table 1). Homogeneity results show that

72% of stations are labelled as “useful” as shown in Table 3. Fignole, Guetale, Hina-marbak, Touboro and Maroua stations were classified as ‘’doubtful”. The Mora and Gawar stations are the only remaining stations and labelled “suspect”. After assessment of homogeneity, the Mora and Gawar stations were removed and data from 23 stations should be used for the analysis of trends and variability.

3.2 Precipitation concentration index (PCI)

The mean annual and seasonal PCI values are presented in Fig. 2a, b, and c. Fig. 2a shows complex spatial patterns of the annual average PCI values across the sudano-sahelian region, which varies from values lower than 20 in the south to higher than 25 in the far north-eastern. In addition, the lowest PCI values are observed in the southern part, ranging from 15 to 20 which is a characteristic of seasonality. While, in the central and far north part of the study area, ranging from 20 to 25 suggests that these areas have a strong seasonal precipitation distribution throughout the year (Fig. 2a). However, we detected a general increase in PCI values in most stations. Thus, significant increases and decreases in precipitation concentration values are found mainly in the Fignole and Maroua stations in the southern and northern part, respectively. This result indicates that the intra-annual distribution of rainfall is becoming less and less heterogeneous in the Sudano-Sahelian region and denotes heavy rainfall falling within a few months throughout the study period.

During the dry season, the spatial pattern demonstrated strong irregular rainfall distribution with PCI value > 20 in the study area (Fig. 2(b)). For the wet season, rainfall was generally uniformly distributed over a 33-year period, analyzed having moderate concentration with PCI<15 as shown in Fig. 2(c). In general, similarly to PCI annual, the spatial map of seasonal PCI shows clear south (lower) to the north gradient (higher). Similar studies in regions such as Ethiopia, (Shawul, et al., 2020), Spain (de Luis et al., 2011) and China (Zhang et al., 2019) all point to the fact that seasonal variation associated with more precipitation has a lower PCI value and inversely.

3.3 Variability of PCD and PCP

Figures 3 (a) and (b) illustrate the spatial distributions of PCD and PCP values and trends, respectively, over the study area from 1980 to 2012. PCD values ranged from a minimum of 0.69 at Ndock in the south-eastern part to a maximum of 0.80 at Lara and Waza in the far north of Cameroon. The number of stations with increasing trends of PCD was greater than that of those with decreasing trends (13 vs. 4). Among the stations with increasing and decreasing trends, only two and one stations showed significant trends at 95 % level respectively. These stations were Touboro and Fignole and Maroua respectively, which are scattered over the southern and northern parts of the

study area. These results indicate that the annual precipitation in a year decreases from the southeast to the far north, implying a higher probability of flood events in a year toward the northeast than in other parts of the study area (Figures 3 (a)).

Mean PCP ranged from a minimum of 7.32 at Sanguere to a maximum of 7.52 at Doukoula et Ndock, which implies that annual rainfall mainly falls in July. The finding indicates that the wet season arrives earlier in the central regions of the study area. The spatial distributions of trend directions of PCP showed 19 stations out of 23 increasing trends, with only three sites (Touboro, Doukoula and Mokolo) being significant at 95 % level. This indicates that the rainy season exhibited a very slight temporal change in an increasing direction over the period 1980-2012, implying a slightly later occurrence of precipitation (Figures 3 (b)).

PCD and PCP are in good agreement with the results of many studies examining rainfall metrics in the wet season (onset and cessation of the wet season, number of rainy days) in and around Sahel regions. For example, Zhang et al, (2018) analyzed the spatial pattern of seasonal-rainfall metrics over the period 2000-2015. They found a clear north-south gradient was observed for the onset date and rainy days (RD). Another study is the one conducted by Sultan et al. (2010). They examined the climate-yields relationships in 28 administrative units in North-Cameroon. They found that the center of North-Cameroon is the most productive area and those with the wettest conditions in June.

3.4 Annual rainfall analysis

Temporal variability of annual rainfall in Sudano-Sahelian is shown in Table 4. Rainfall amounts for the period 1980-2012 displayed high spatial variability which is largely associated with the latitude variation within the study area. Low latitude regions received more precipitation than high latitude regions where the climate varies mainly from semi-arid to arid. In the low-latitude regions in the sudanian region, annual rainfall varied from 660.0 mm at Madingring station to 1708 mm at Ndock station while that in the high-latitude regions in the sahelian region of the study area varied from 329 at Guider station to 1319 mm at Bidzar station. The temporal variability in the annual was assessed using the standard deviation of annual precipitation from the mean rainfall which showed a strong variation from 122.15 mm in the Sahelian region to 225.79 mm in the Sudanian region with the amount of rainfall received during that period. In order, the analysis of annual rainfall by Sen's slope method showed that most of the rainfall stations displayed upward trends.

Only Hina-Marbak, Kaélé, Bere, Garoua, Tchollire and Maroua stations, respectively found to have a statistically significant increasing trend at a rate of +7.0, 6.34, 3.52, 3.82, 10 and 10 mm/year of annual rainfall series as shown in Table 4. Most of the climate stations in the Sudano Sahelian region

have also exhibited an increasing trend of annual rainfall, although the trend is not significant. Similar findings were observed over the last three decades at the global level of West Africa (Barry et al, 2018; Chaney et al. 2014) and at a regional level of Sahel West Africa (Mouhamed Ly et al, 2013; Sanogo et al, 2015).

3.4 Annual maximum daily rainfall

Among the parameters needed to calculate extreme precipitation is the maximum daily rainfall, which is commonly used to assess extreme conditions associated with flood risk (Westra et al. 2017, Field et al. 2012; Min et al. 2011). Fig. 4 shows the annual maximum daily (AMD) rainfall series analyzed for whole climate stations that are distributed in the Sudano-Sahelian zone of Cameroon from the year 1980 to 2012. The highest daily rainfall was obtained at Sanguere station which is found to be 184 mm in 1991, whereas the highest mean value of AMD rainfall of 92 mm was obtained at Tchollire station which is located near Adamawa plateau, and the lowest mean AMD value of 66.63 mm was recorded at Yagoua station in Northeastern part of the study area. The mean AMD rainfall corresponding to each weather station has shown a good correlation with latitude and annual rainfall which resulted in the Pearson correlation coefficient of -0.72 and 0.65 respectively. Fig. 4 provides more details on the periods and the return levels determined from GEV law. The highest AMD rainfall predicted over -10, -20, -50, and -100 years was obtained at the Tchollire station, with 129.55, 151.95, 182.46, 209.25 mm respectively. In order to predict the AMD rainfall, most sites showed non-significant increasing trends. Bidzar, Hina-Marbak, Kaele, Tchatibali, Bere, and Garoua stations exhibited significant increasing trends at rates of 0.84, 0.59, 3.62, 0.4, 0.5 and 1.3 mm respectively, in Sudano-Sahelian of Cameroon. Among these stations, Leumbe et al, (2015) map the Maga zone located in the northeast of the study area, in which the Yagoua, Maroua and kaélé stations are subject to flood risks. This increase in extreme daily rainfall suggests an associated increase in intense Mesoscale Convective Systems (MCSs) in the Sudano-Sahelian region (Sanogo et al, 2015).

3.6 Trend and magnitude of extreme precipitation events

Zhang et al. (2011) classified the extreme precipitations into three groups: (1) intensity indices (mm): annual total wet-day precipitation (PRCPTOT), very wet days (R95p), extremely wet days (R99p), highest 1-day precipitation in a year (Rx1d), highest 5-day precipitation in a year (Rx5d) and simple daily intensity index (SDII, mm/day); (2) frequency indices (days): number of heavy precipitation days (R10mm), number of very heavy precipitation days (R20mm) and number of very heavy precipitation days (R25mm) and, (3) duration indices (days): consecutive dry days (CDD) and

consecutive wet days (CWD).

The spatial annual value and trends of duration and intensity indices from 1980 to 2012 over the Sudano-Sahelian are presented in Fig. 5. On average, stations in the northeast had the highest CDD values in the range 180-190 days, while stations in the southeast had the lowest in the range 150-160 days. The trend in CDD is not significant. Subsequently, the CDD trend increased in most (southern and central parts) of the study area and significantly at a rate of 1.07, 0.6, 1.00 and 0.7 days/year in Fignole, Touboro, Bere, and Garoua stations, respectively. While insignificant negative trends are observed in the northern part of the study area (Fig. 5a). However, the opposite mean and no trend were noticed in CWD at most of the stations where the only significant decreasing trend was observed in the Fignole station at -0.05 days/year (Fig. 5b). Based on the spatial distribution of mean SDII values decreasing from south to north, the general trend is increasing at almost all of the stations with significant stations such as Hina-Marbak, Thollire, Pitoa, Lara, Soudounkou, Fignole and Touboro located in the northeast, central, southwest and southeast of the study area as shown in Fig 5f. For the indices representing the number of days of extreme rainfall, maps R10, R20 and R25 showed a spatial pattern almost similar to SDII. In general, increasing trends can be observed with the only significant trend detected at Touboro and Tchollire at 0.25 and 0.4 days/year and negative at Sanguere at -0.16 days/year for R10 (Fig 5c). R20 showed a significant only upward and decreasing trend in Tchollire and Touboro and Doukoula stations, respectively (Fig 5d). R25mm values indicate significant increasing trends at Hina-marbak, Touboro, Bere and Tchollire stations.

As shown in Fig. 6, intensity indices displayed increasing trends, on average, during 1980-2012. A clear north-south gradient was observed for PRCPTOT, R95P, R99P, Rx1day, and Rx5day based on a 33-year (1980-2012) average value. From Fig. 6(a), it can be seen that PTOT increased in the study region. The increase was more evident at the Guidiguis, Hina-Marbak, Soudounkou, Sanguere, Touboro, Tchollire and Ndock stations, distributed over the entire study area. Meanwhile, At the same time, a general increasing trend of R95p was observed with the significant stations being Hina-marbak, Garoua, and Touboro (Fig. 6(b)). Spatially, no trend was noticed in R99p at any of the stations (Fig. 6(c)).

The Pitoa, Bere, Garoua, Madingring and Doukoula regions appear to have experienced a significant increase at a rate of > 0.5 mm/year with Rx1day (Fig. (6d)). whereas a significant increase of > 0.9 mm/year can be observed in Rx5day in the Hina-Marbak, Bere, Tchollire, Doukoula, Maroua and Lara regions, distributed over the central and southeastern parts of the study area (Fig. (6e)). Thus, the strong wetness of the Sahel is manifested both by more humid days but also by heavier extreme rainfall.

Pearson's product-moment correlation (CC) shows a positive correlation between annual PRCPTOT and other indices as shown in Table 5. The most extreme rainfall indices correlations except CDD and CWD were positive and significant at least 95 % confidence level. PRCPTOT is strongly correlated with R10mm, R20mm, R25mm, R95p, R99p, Rx1day and Rx5day values with CC of 0.94, 0.92, 0.89, 0.75, 0.62, 0.58, 0.64, respectively. These extreme precipitation indices translate the positive change in PRCPTOT while CDD and CWD negatively correlated; because CDD and CWD are an indicator of dry climate extremes. At the same time, all extreme maximum precipitation indices such as SDII are also significant among themselves. Globally, the CC values of extreme precipitation indices indicate that the study area with lower and higher mean annual precipitation can produce higher extreme precipitation values.

In accordance with the current findings, de Vondou et al. (2021) have also indicated that extreme rainfall indices represent patterns approximately similar to that of annual rainfall except CDD where the spatial south-north gradient is reversed. All extreme rainfall indices (except CWD), generally, increased in the sudano-Sahelian region of Cameroon during 1980-2012. Results are almost consistent with results obtained in previous studies at the regional level in West Africa (Barry et al., 2018; Sanogo et al., 2015), Central Africa (Aguilar et al., 2009) in the Sahelian region (Mouhamed Ly et al., 2013; Zhang et al., 2017), in some nearby areas, for example, Nigeria (Gbode et al., 2019). Several studies have justified the increasing rainfall trend over the last three decades by a recovery from the 1970-1980 droughts in West Africa in general (Druyan et al, et 2011; Chaney et al., 2014; Sanogo et al., 2015). In the same direction, Ibrahim et al (2014) in a further study reports both an increase in total annual rainfall and in the frequency of rainy days, which contributes to partial rainfall recovery in the Sahel. More recently, Globe et al. (2019) demonstrated that this recovery is summarized by a greater number of rainy days associated with a longer duration of the wet period and more extreme rainfall events. This was justified in the central-eastern Sahel in West Africa by the increase in vertical moisture flux, which is mainly driven by the increasing convergence of moisture from remote sources (Akinsanola and Zhou, 2018).

3.7 Standardized precipitation index

The Standardized Precipitation Index (SPI) is an index that indicates the standard deviations from the mean values for which an event occurs (Guenang et al, 2014). The fitted gamma distribution is used to calculate this index. The 3- and 12-month SPI were used to estimate the agricultural applications and groundwater storage variation (hydrological drought) of the Sudano-Sahelian of Cameroon based on long-term monthly precipitation data (1980-2019). Fig. 7 and 8 show the SPI values of 3- and 12-month time scales from 1980 to 2019. In addition, almost all stations exhibited the severe and

extreme droughts in the 1980s and 2010s while the 1990s were characterized by moderately wet moisture conditions. Thus, the analysis of SPI-3 and SPI-12 in this area present a severe hazard of drought for agriculture and groundwater storage. Njouenwet et al. (2021) have also concluded that the Sudano-Sahelian area of Cameroon exhibits the very high agricultural drought hazard zones, especially, where the maize and peanut grain crops are concerned. As found by Cheo et al (2013), variability results from an SPI-12 show that the wetter period surpasses the drier period in all regions. Mainly, the mid-1990s point out the climate shift in all stations as shown in Fig. 8. Following this, we observe similarities in the trends of SPI-12 at the different stations with the annual rainfall in the Sudano-Sahelian region, which corroborated those obtained by Sanogo et al, (2015) and Globe et al (2019).

4 Potential impacts of climate variability and extreme precipitation on agriculture and water management

Overall, the Sudano-Sahelian region of Cameroon from 1980 to 2012 recorded significant upward trends in annual rainfall and PRCPTOT index in our analysis, such as their interannual variability. They are related to the increase in extreme rainfall days. Rainfall during the rainy season is almost uniform, with low PCI levels and low risk of crop failure, but the amount and distribution of rainfall during this period with late rainfall onset dates have an impact on some crops and varieties, and thus on crop production and productivity. For instance, Sultan et al, (2009) found that the rainfall parameters (rainy season onset and length) are major drivers for the year-to-year and their variability impacts crop productivity. In addition, heavy rainfall can negatively impact crop yields and cause increased soil erosion. As mentioned in the introduction, the floods of September 2012 in Maga and Yagoua during which more than 14000 hectares of crops and 12375 fruit plants were destroyed (Ministry of Agriculture and Rural Development, 2012).

However, the study area is mainly drained by four streams which are Benue, Chari, Faro, and Logone. They extend to Chad, Nigeria, and RCA. Hence, the high value and increasing trends in annual PCI are observed over the same time period throughout the study area and could cause a challenge for water resource management. Increasing rainfall could favor hydropower production around the Lagdo dam and increase the supply of drinking water for industrial and domestic uses in the study area. Nevertheless, an increase in daily extreme precipitation (R1xday, R5xday, R95p, and R99p) indices could potentially lead to a greater probability of flooding. From 2010 to 2012, disastrous floods occurred in Yagoua and Guirvidig in the south-eastern part of the study area, as in many Sahelian countries, resulting in the destruction of the dyke, many deaths and material losses (Leumbe et al, 2015; Frédéric et al, 2020). On the other hand, as an indicator of lack of rainfall, an

increase in CDD and a decrease in CWD could create challenging situations for agricultural practices, food security, and runoff from major rivers.

5 Conclusions

This study analyzed spatio-temporal variability and changes in mean rainfall and extreme indices in the sudano-sahelian region of Cameroon based on daily synoptic rainfall datasets for the period from 1980 to 2012. A homogeneity test was performed on the data series using the standard normal homogeneity test (SNHT), the Pettitt test, the Buishand range test, and the Von Neumann ratio test. The ETCCDI (Expert Team on Climate Change Detection Indices) indices were calculated using RClimDex version 1.0 software. These climate indices were used to assess corresponding trends in the frequency and intensity of daily rainfall and changes in the length of the season. Based on the Sen slope and Modified Mann-Kendall (MMK) trend test, most of the rainfall stations showed a statistically insignificant upward trend for annual rainfall. The temporal and spatial variability of precipitation using the Precipitation Concentration Index (PCI) and Precipitation Concentration Period (PCP) showed a higher variability of precipitation on the annual and dry season scale than the wet seasons. Most stations show increasing trends in the number of very heavy rains and precipitation intensity indices, so very few are significant. In addition, non-significant increasing and decreasing trends were observed in the south and north, respectively, for consecutive dry days (CDD) in the study area while the opposite trends were observed for consecutive wet days (CWD). However, this study highlights further research on how the hydrological regime responds to climate change causing flooding, food insecurity, and affecting water resources in the Sudano-Sahelian zones. It is beneficial for the future social and economic planning of the country and the sub-region.

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Conflict of interest

The authors declare that they have no conflict of interest.

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Author's Contribution

All authors contributed to the study conception and design. Ibrahim Njouenwet, Lucie A. Djiotang Tchotchou, Brian Odhiambo Ayugi, Guy Merlin Guenang, Derbetini A. Vondou and Robert Nouayou contributed to the conceptualization of the study. The first draft of the manuscript was written by Ibrahim Njouenwet and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Table 1 Geographical descriptions of the data, altitude, period of measurement and percentage of missing data.

N°	Stations	Latitude(°N)	Longitude(°E)	Altitude(m)	Period	Missing(%)
1	Bidzar	9.9	14.12	470	1980-2019	1.8
2	Fignole	8.57	13.05	523	1980-2019	0
3	Guetale	10.07	13.91	490	1980-2019	2.8
4	Guider	9.03	13.95	356	1980-2019	2.8
5	Guidiguis	10.10	14.71	362	1980-2019	0.8
6	Hina-marbak	10.37	13.85	544	1980-2019	0.8
7	Kaélé	10.08	14.43	388	1980-2019	0
8	Pitoa	9.34	13.53	274	1980-2019	0
9	Tchatibili	10.05	14.91	815	1980-2019	0
10	Touboro	7.67	15.37	500	1980-2019	0.6
11	Yagoua	10.35	15.23	325	1980-2019	0
12	Bere	9.01	14.23	238	1980-2018	0
13	Garoua	8.56	13.05	213	1980-2018	0.8
14	Madingring	8.45	15.00	430	1980-2018	0
15	Tchollire	8.4	14.16	392	1980-2018	1.7
16	Maroua	10.58	14.30	428	1980-2015	0
17	Doukoula	10.12	14.97	340	1980-2012	3
18	Gawar	10.51	13.85	420	1980-2012	0.4
19	Lara	10.17	14.51	416	1980-2012	0.4
20	Mokolo	10.73	13.82	795	1980-2012	0
21	Mora	11.05	14.15	438	1980-2012	0

22	Ndock	7.96	14.67	489	1980-2012	0
23	Sanguere	9.08	13.52	418	1980-2012	0
24	Waza	11.40	14.57	311	1980-2012	0
25	Soudounkou	9.85	13.88	358	1980-2011	0

692

693 **Table 2** Definition of ETCCDI indices based on daily precipitation and units.

Variables	Description	Definitions	Units
cdd	Consecutive dry days	Maximum number of consecutive dry days	days
cwd	Consecutive wet days	Maximum number of consecutive wet days	days
r10	Number of heavy precipitation days	Annual count of days when RR > = 10 mm	Days
r20	Number of very heavy precipitation days	Annual count of days when RR > = 20 mm	Days
r25	Number of very heavy precipitation days	Annual count of days when RR > = 25 mm	Days
ptot	Annual precipitation	Annual total precipitation when RR > =1 mm	mm
r95p	Very wet days	Annual total precipitation when RR > 95th percentile	mm
r99p	Extremely wet days	Annual total precipitation when RR > 99th percentile	mm
rx1day	Maximum 1 day precipitation	Annual highest daily precipitation	mm

rx5day	Maximum 5-day precipitation	Annual highest 5 consecutive days precipitation	mm
sdii	Simple daily intensity index	Annual precipitation divided by number of wet days	mm/day

694

695

696 **Table 3** Statistical test of homogeneity applied to the annual rainfall count series of main climate
697 stations in the sudano-sahelian region of Cameroon.

N°	Stations	SNHT	Pettitt's test	Buishand's test	Von Neumann's test	decision
1	Bidzar	36	8	30	1.74	Useful
2	Fignole	38*	30*	30*	1.58	Doubtful
3	Guetale	39*	11	11	1.40*	Doubtful
4	Guider	36*	27	27	1.70	Useful
5	Guidiguis	6	6	6	2.06	Useful
6	Hina-marbak	39*	13	32	1.40*	Doubtful
7	Kaélé	38*	11	11	1.31	Useful
8	Pitoa	31*	31	31	1.37	Useful
9	Tchatibili	6	14	11	1.56	Useful
10	Touboro	10*	15*	15*	1.96	Doubtful
11	Yagoua	38	14	36	1.78	Useful
12	Bere	17	17	17	1.32	Useful
13	Garoua	8	31	8	1.68	Useful

14	Madingring	31	31	23*	1.57	Useful
15	Tchollire	8	8	8	1.97	Useful
16	Maroua	23*	23*	23	1.53	Doubtful
17	Doukoula	14	14	14	1.89	Useful
18	**Gawar**	**23***	**23***	**23***	**1.61**	**Suspect**
19	Lara	8	8	8	1.76	Useful
20	Mokolo	20	10	20	2.11	Useful
21	**Mora**	**11***	**11***	**11***	**1.19**	**Suspect**
22	Ndock	23	23	23*	1.70	Useful
23	Sanguere	21	21	21	1.73	Useful
24	Waza	11	11*	11	1.79	Useful
25	Soudounkou	30	12	22	2.00	Useful

698 (*) indicate that the test rejects the null hypothesis at the 1% level and the annual data series is

699 not homogenous

700 **Table 4** Summary (minimum, maximum and natural variability) and Modified Mann-Kendall trend
701 statistics for total annual precipitation. Significant changes (i.e. Z greater than 1.96) are indicated in
702 bold. The abbreviations are NT = no trend, P = positive trend, SP = significant positive trend, N =
703 negative trend, and SN = significant negative trend.

704

Stations	Annual Max (mm)	Annual Min (mm)	Standard deviation	Z-statistics	Sen's slope (mm)	Trend
Bidzar	1319	534.9	183.5	0.36	1	P
Fignole	1654	688	221.6	-0.46	-3.0	N

Guetale	1013	436	135.2	1.39	5.16	P
Guider	1212	557	171.9	-0.54	-1.53	N
Guidiguis	1077	597	138.2	1.08	2.58	P
Hina-marbak	1260	554.2	168.1	**2.25**	**7.04**	**SP**
Kaélé	1080	604.7	151.7	**2.27**	**6.34**	**SP**
Pitoa	1304	387	182.2	0.45	6.22	P
Tchatibili	1162	491	169.1	0.70	2.18	P
Touboro	1539	830	195.9	0.91	9.47	P
Yagoua	1044	110	170.3	1.05	1.40	P
Bere	1258	554	176.3	**2.58**	**3.52**	**SP**
Garoua	1258	554	194.8	**2.48**	**3.82**	**SP**
Madingring	1336	660	170.1	1.05	3.15	P
Tchollire	1670	736	208.9	**2.59**	**10**	**SP**
Maroua	1333	530.1	218.6	**2.48**	**10**	**SP**
Doukoula	1162	491	179.3	1.16	4	P
Lara	1244	462	162	1.08	2.62	P
Mokolo	1458	721.7	172.8	1.42	3.46	P
Ndock	1708	845	225.8	-0.33	-1.23	N
Sanguere	1393	670	161.8	-1.04	-3.88	N
Waza	954.6	441.8	115.2	1.61	2.67	P
Soudounkou	1575	561	202.2	-0.18	-0.68	N

705

706 **Table 5** Correlation coefficients of annual extreme precipitation indices for baseline precipitation
707 data from 1980 to 2012 in the sub-humid region of Cameroon.

708

Indices	CDD	CWD	PTOT	R10	R20	R25	R95p	R99p	Rx1day	Rx5day	SDII
CDD	1*										
CWD	-0.33	1*									
PTOT	-0.35	0.40*	1*								
R10	-0.47	0.34*	0.94*	1*							
R20	-0.23	0.28	0.92*	0.83*	1*						
R25	-0.12	0.24	0.88*	0.77*	0.95*	1*					
R95p	-0.09	0.45*	0.74*	0.56*	0.68*	0.71*	1*				
R99p	0.01	0.37*	0.62*	0.45*	0.45*	0.49*	0.85*	1*			
Rx1day	0.01	0.31*	0.58*	0.39*	0.41*	0.47*	0.80*	0.91*	1*		
Rx5day	0.01	0.42*	0.64*	0.49*	0.56*	0.59*	0.82*	0.75*	0.81*	1*	
SDII	0.23	0.02	0.30*	0.13	0.42*	0.53*	0.65*	0.46*	0.43*	0.52*	1*

709 (*) significant at the 95% confidence level

710

711

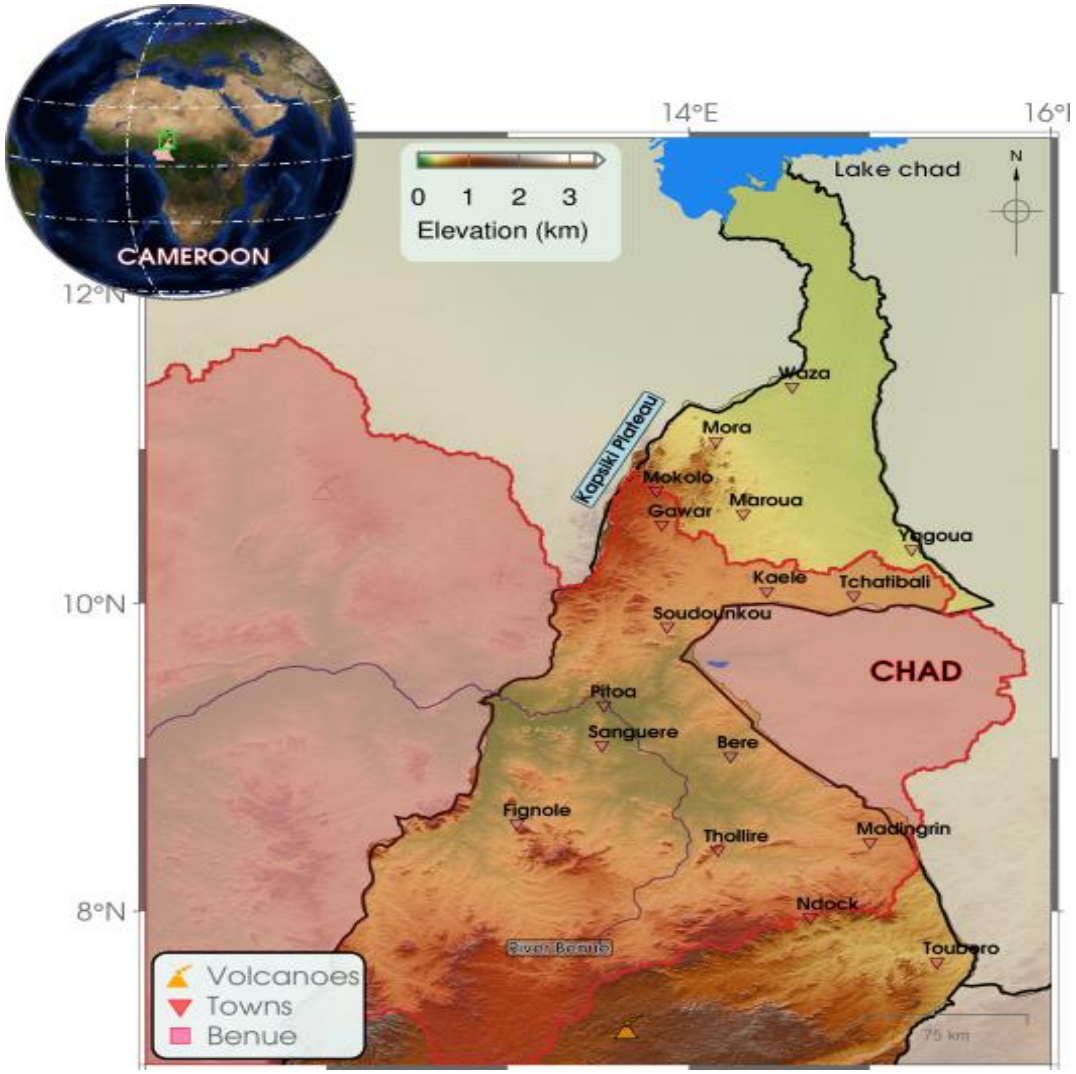

Fig. 1 Map of the study area with the Sudano-Sahelian political border of Cameroon, topography and selected rainfall stations. Red line delineates the water catchment boundary.

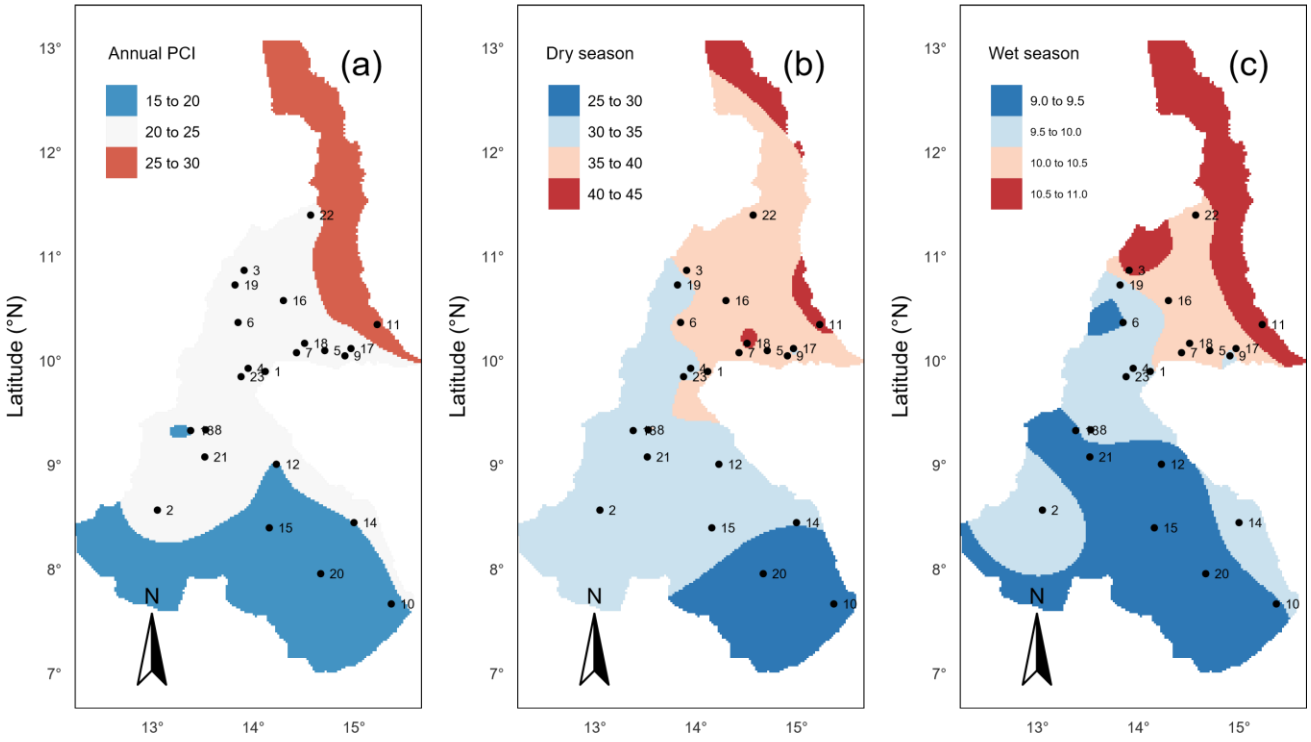

Fig. 2 Spatial map of mean value of (a) annual precipitation concentration index (PCI), (b) dry season PCI, and (c) rainy season PCI over in the Sudano-Sahelian region of Cameroon.

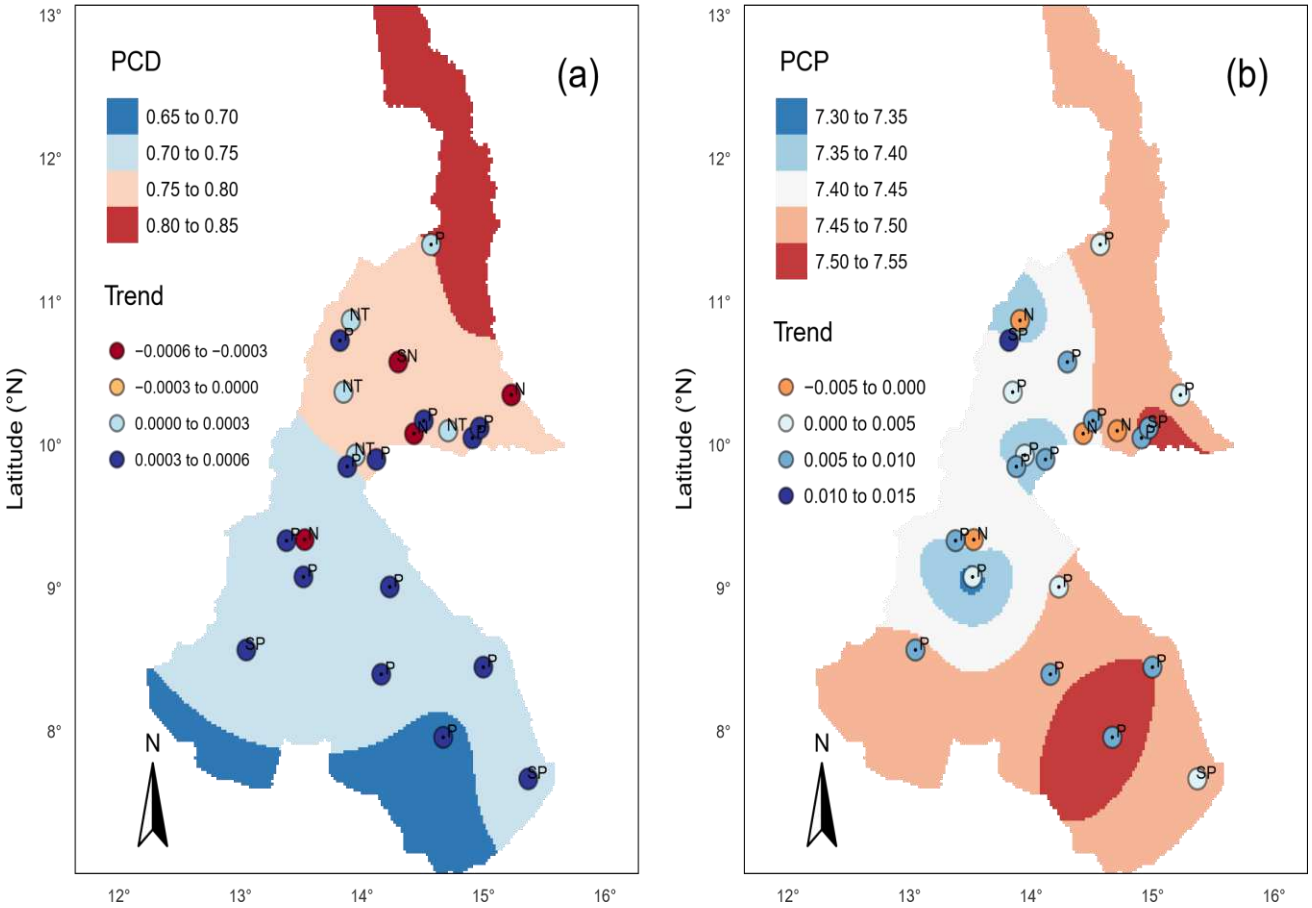

Fig. 3 Spatial distribution of mean annual values and trends for variability parameters from 1980 to 2012 **a** Precipitation Concentration Degree (PCD), and **b** Precipitation Concentration Period (PCP). The abbreviations are NT = no trend, P = positive trend, SP = significant positive trend, N = negative trend, and SN = significant negative trend.

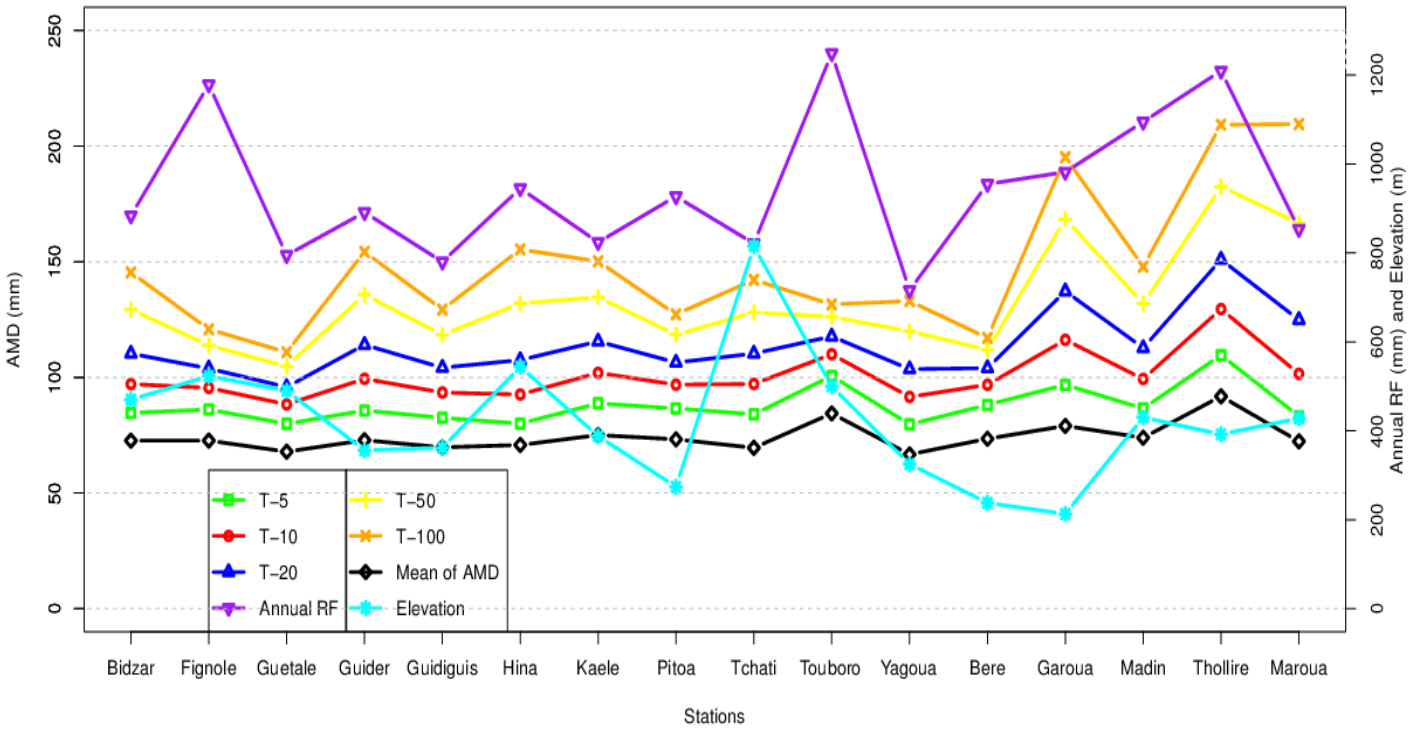

Fig. 4 Annual maximum daily (AMD) rainfall (mm) for different return periods in year (T-100yr, T-50yr, T-20yr, T-10yr, and T-5yr), mean of AMD rainfall and precipitation, and elevation for baseline precipitation data from 1980 to 2019.

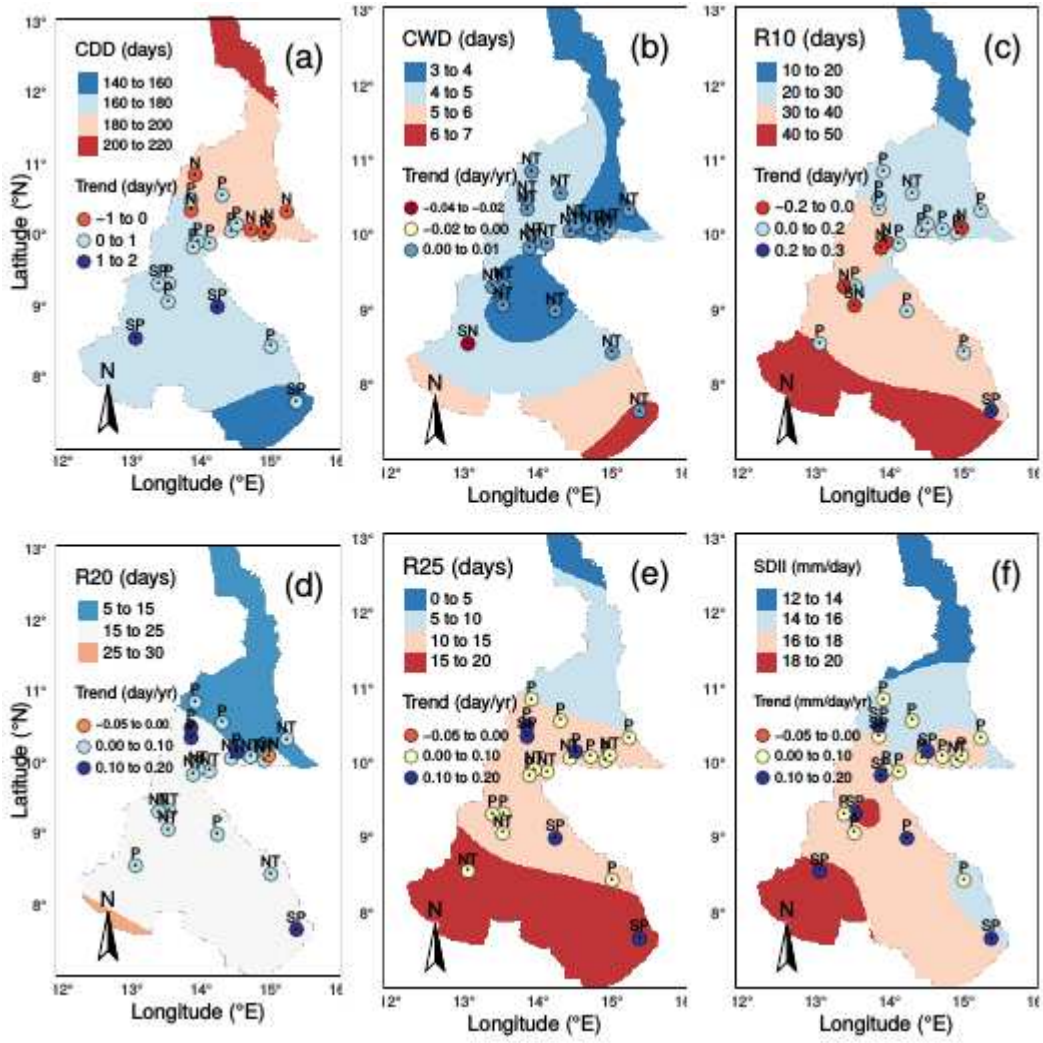

Fig. 5 Spatial distribution of average and trends for extreme precipitation indices from 1980 to 2012 **(a)** CDD, **(b)** CWD, **(c)** R10, **(d)** R20, **(e)** R25, and **(f)** SDII. The abbreviations are NT = no trend, P = positive trend, SP = significant positive trend, N = negative trend, and SN = significant negative trend.

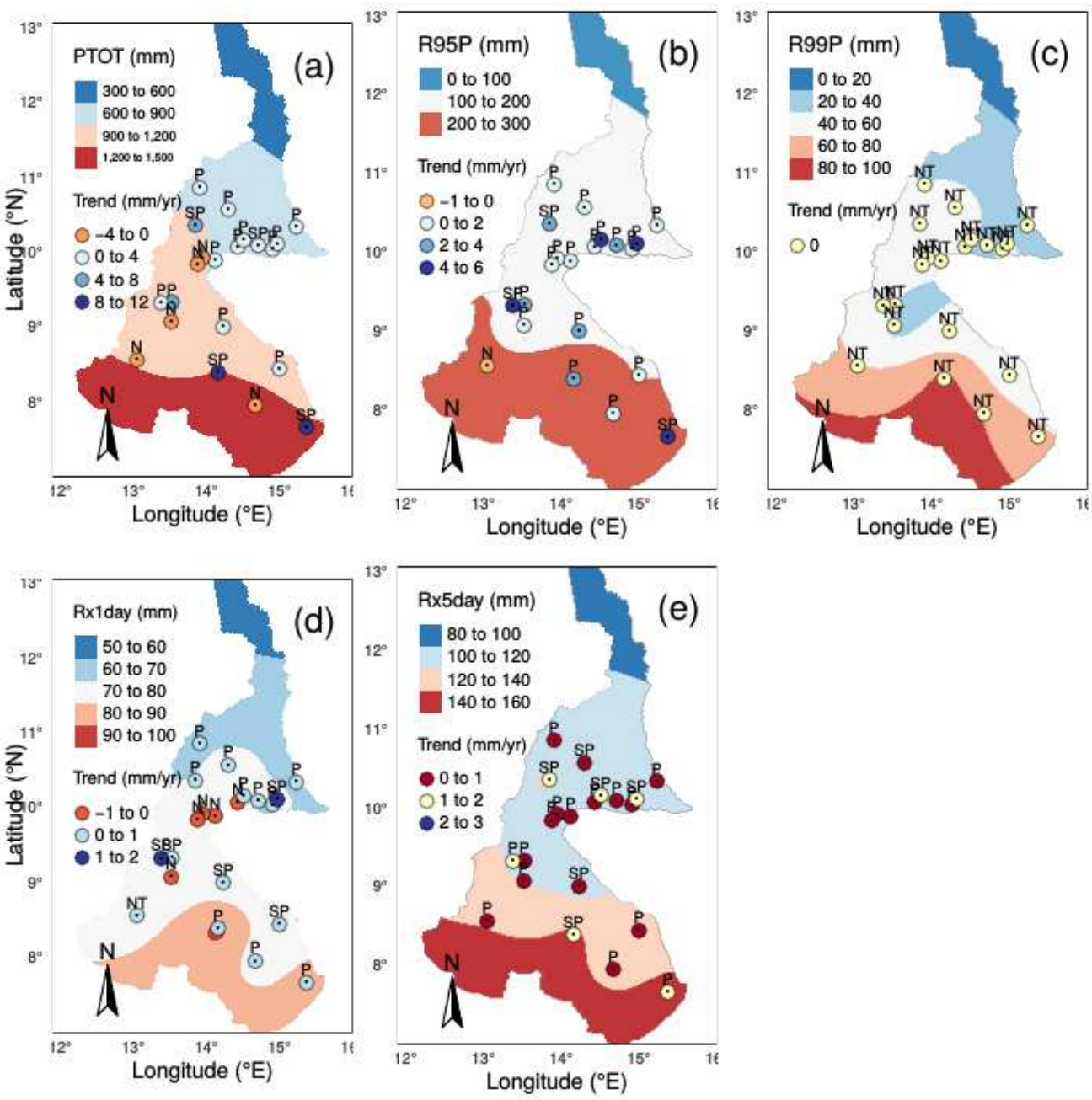

Fig. 6 Spatial distribution of average annual values and trends for extreme precipitation amount/intensity/days indices from 1980 to 2012 **(a)** PTOT, **(b)** R95p, **(c)** R99p, **(d)** Rx1day, and **(e)** Rx5day.

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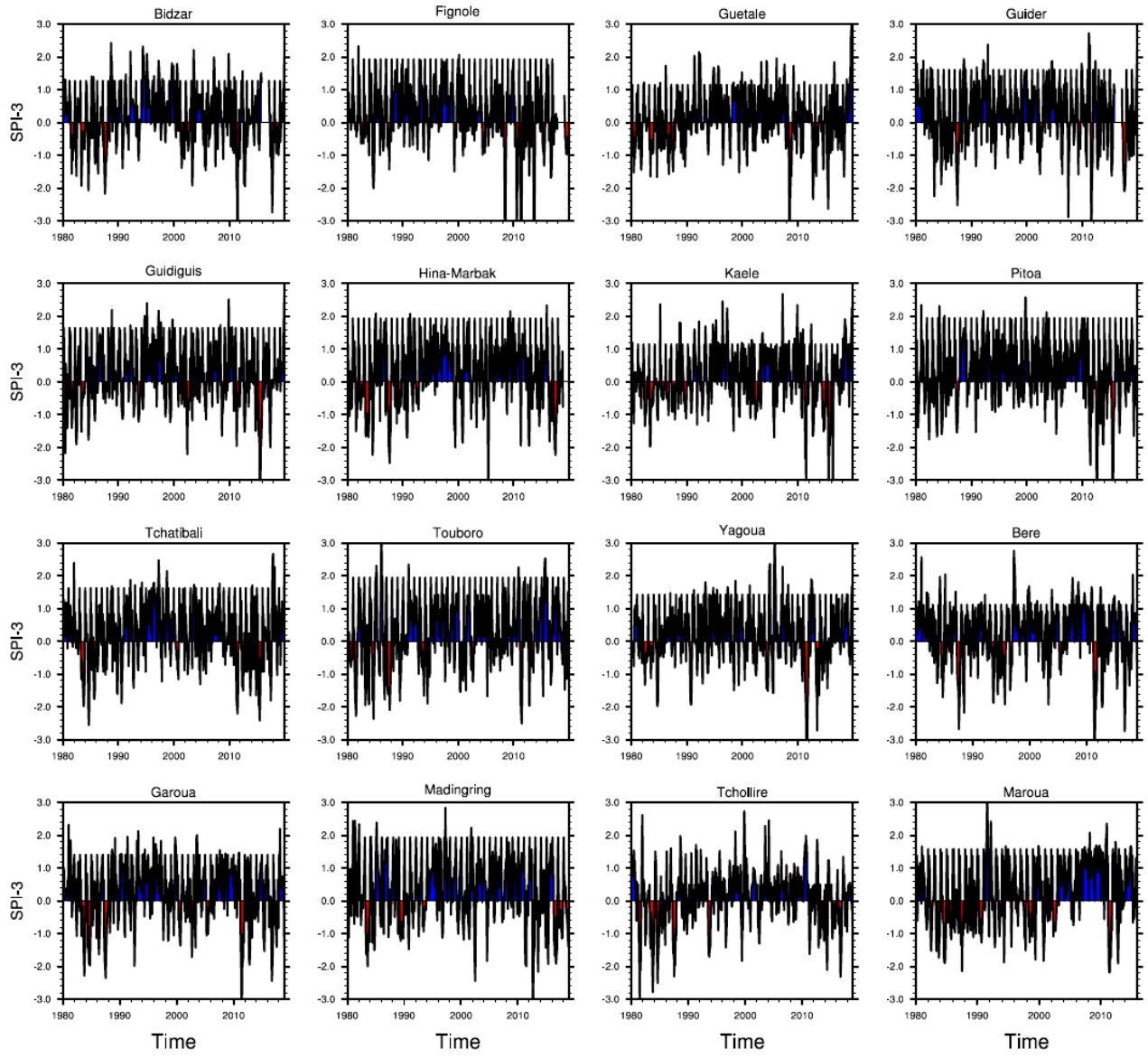

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805

806 **Fig. 7** The 3-month-scale Standardized precipitation index (SPI) time series for selected stations
807 from 1980 to 2019 in the Sudano-Sahelian region of Cameroon for wet conditions (blue) and drought
808 conditions (red).

809

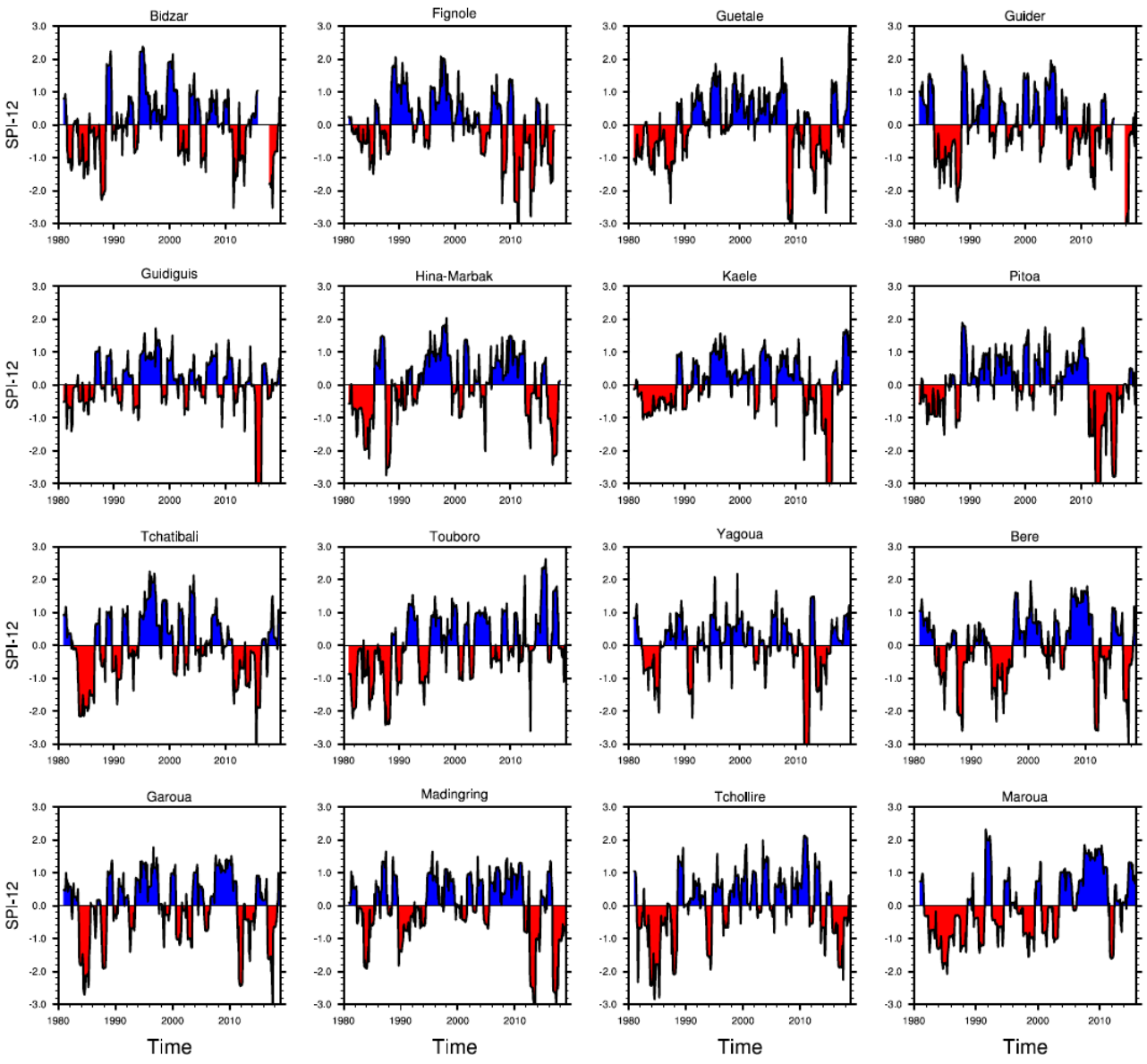

Fig. 8 The 12-month-scale Standardized precipitation index (SPI) time series for selected stations from 1980 to 2019 in the Sudano-Sahelian region of Cameroon for wet conditions (blue) and drought conditions (red).