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ANALYSIS OF EXTREME RAINS THROUGH CLIMATE INDICATORS IN THE CONTEXT OF CLIMATE CHANGE IN SOUTHERN BENIN

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ABSTRACT:

The recurrence of flooding in recent years in West Africa is dramatically affecting the socio-economic system of most countries in the region. This work is devoted to the analysis of the heavy rains of its last years in the context of global warming in subequatorial Benin through eight rainfall indicators. For this purpose, the daily rains collected at seventeen stations in the south of Benin between 1960 and 2018, the maximum and minimum daily temperatures of the two synoptic stations in the study area between 1970 and 2015 are used. Analysis of the results shows a non-uniform trend in rainfall indicators over the entire study period. The monthly trend is in accordance with the bimodal rain regime of southern Benin for each of the climatic indicators studied. After the break in the downward trend in rainfall in the 1980s or 1990s at the various stations, the last three decades have been marked above all by ten-year averages of the various indicators that are higher than those obtained over the entire study period. Despite the low proportion of extreme rains, their frequency has increased since the resumption of rainfall in the 1980s or 1990s, especially compared to the 1970s and 1980s. The highest heights are observed for the most part in the towns close to the Atlantic Ocean. Global warming in southern Benin is characterized above all by high decadal temperature variation rates in the 1990s. This significant global warming in this pivotal decade is accompanied by relatively large growth in all indicators in southern Benin.

Résumé

La récurrence des inondations de ces dernières années en Afrique de l'Ouest, affecte dramatiquement le système socio-économique de la plupart des pays de la région. Le présent travail est consacré à l'analyse des fortes pluies de ses dernières années dans le contexte du réchauffement climatique dans le Bénin subéquatorial à travers huit indicateurs pluviométriques. A cet effet, les pluies journalières recueillies sur dix-sept stations au sud du Bénin entre 1960 et 2018 les températures quotidiennes maximales et minimales des deux stations synoptiques de la zone d'étude entre 1970 et 2015 sont utilisées. L'analyse des résultats montre, une tendance non uniforme des indicateurs pluviométriques sur toute la période d'étude. La tendance mensuelle est en accord avec le régime de pluie bimodal du sud Bénin pour chacun des indicateurs climatiques étudiés. Après la rupture de la tendance à la baisse de la pluviométrie dans les années 80 ou 90 sur les différentes stations, les trois dernières décennies sont marquées surtout par des moyennes décennales des différents indicateurs supérieurs à celles obtenues sur toute la période d'étude. Malgré la faible proportion des pluies extrêmes, leur fréquence a augmenté depuis la reprise de la pluviométrie dans les années 80 ou 90, surtout par rapport aux décennies 70 et 80. Les plus fortes hauteurs sont observées pour la plupart dans les villes proches de l'océan Atlantique. Le réchauffement climatique au sud du Bénin est caractérisé surtout par des taux de variation décennale élevés des températures dans les années 90. Cet important réchauffement climatique dans cette décennie charnière est accompagné d'une croissance relativement importante de tous les indicateurs au sud du Bénin.

I. INTRODUCTION

The increase in the concentration of carbon dioxide, due in large part to human activities and above all to the use of fossil fuels, increases the natural greenhouse effect and consequently an increase in the temperature of the globe (Goubanova, 2007). This climate change has affected several natural systems following observations on all continents and in most oceans (IPCC, 2007). The warming of the climate is mainly revealed by changes in sea level, snow cover, glacier area and precipitation. In this context, the sensitivity to climate variations and changes in several regions of the world is manifested by extreme climatic phenomena which further affect the ecosystem and society.

West Africa belongs to the tropical zone, hydrologically very contrasted and which remains linked to the complexity of the ocean-atmosphere system that generates precipitation. This complexity is due to the position of the zone which straddles the two hemispheres (Mahé, 1993; Muhindo et al., 2012). West Africa is one of the regions of the world which are dramatically affected by hydro-climatic extremes because of the high variability of its climate and the high vulnerability of its population to climatic extremes (Tschakert, 2007; Pauleit et al. al., 2015). The specific nature of the various prevention and protection measures requires a good understanding of the hazard (Panthou, 2013). The documentation of hydro-climatic hazards in this part of the world is of particular importance because of the vulnerability of the population, who rarely has an operational management framework to deal with the associated risks. The recurrent droughts of the 2070s and 2080s imprinted in the collective mind the notion that the major climatic hazard in the region is drought, which made it possible to improve the resilience and adaptive capacities of the populations with the drought hazard (Tschakert et al., 2010). On the other hand, the recurrence of floods in recent decades shows a very high vulnerability of populations to floods (Di-Baldassarre et al., 2010). This hazard should therefore be considered with a view to improving the associated adaptation measures (Panthou, 2013).

Benin, like all the countries of the tropical zone, has experienced several heavy rains, perhaps having their share of responsibility in the floods of recent years in the various cities of the country. For example, in 2010, the floods caused, above all in southern Benin, significant damage to goods and services (Benin post-disaster needs assessment report, 2011). The constant increase in damage from torrential rains and floods in this part of the country, worries and requires careful analysis of the seasonal cycle of rainfall through the variability of extreme rains. Extreme rains are often studied by statistical modeling and / or by analysis of climate indicators.

Statistical modeling is based on the frequency analysis of annual maxima or the method of values above a threshold. It consists in studying past events in order to define the probabilities of future appearance. Several studies around the world (Gellens, 2002; Crisci, et al., 2002; Neppel, 2003; Zhai et al., 2006; Goubanova, 2006; Chu et al., 2008; Sene, 2002; Li et al, 2013a; Zheng et al., 2016) and in Africa (Zahar and Laborde, 2007; Habibi et al. 2012; Panthou, 2012; Karimou et al. 2015; Ague and Afouda, 2015; Soro et al., 2016) are devoted to the study of extreme precipitation with statistical modeling.

As for climatic indicators, they make it possible to describe the empirical annual or seasonal distribution of precipitation. The definitions and mathematical formulas of these indicators have been proposed by several authors (Jones et al., 1999; Frich et al. 2002; Tank and Können, 2003; Kiktev et al., 2003; Alexander et al., 2006; Goubanova, 2006). These climate indicators or indices are used by several authors around the world (Manton et al., 2001; Griffiths et al., 2003, Haylock et al., 2004; Mohymont and Démaréé, 2006; New et al., 2006; Aguilar et al., 2009; Hountondji et al. 2011; Sahani et al., 2012; Ibrahim et al. (2012); Habibi et al., 2013; Saidi et al., 2013; Panthou et al., 2014; Abatan et al. al., 2015 and 2017a; Ta et al., 2016; Attogouinon et al., 2017; Adeyeria et al., 2020). In Benin, very few extreme precipitation trend studies based on daily rainfall data are carried out.

Hountondji et al. (2011) studied through twelve indicators, this trend at the national level with daily rains of twenty-one (21) stations from 1960 to 2000. The results show that only the annual total of precipitation, the annual total of days of rainfall and the maximum precipitation recorded for thirty (30) days show a decreasing trend while the other nine rainfall indicators appear to remain stable. Attogouinon et al. (2017) worked particularly on the upper Ouémé valley with eleven (11) indices over the period 1951-2014. The Mann-Kendall nonparametric test was used to assess trends in these indices. The results show the absence of a clear trend in the evolution of climate indices at almost all stations. The authors even called for new research on this subject in West Africa because water management is a major tool for sustainable development and poverty reduction. Ahokpossi (2020) examined the temporal variation and trends in the annual distribution of precipitation in Benin using rainfall data from 1940 to 2015 at nine stations nationwide. Following the analysis of the time series through several climate indicators and trend tests, no significant trend is detected. Most stations (six of nine) show sharp change points, corresponding to the alternation between wet (before 1968 and after 1990) and dry (1969–1990) periods.

Like the rest of the world, global warming is a reality in Benin. Indeed, the IPCC report (IPCC, 2007) highlighted an increase in temperature of 0.17 ° C per decade between 1970 and 2004 in West Africa. Recently, several works have been devoted to the study of temperatures evoking global warming in recent decades in Benin (Gnanglè et al, 2012; Houngninou et al. 2017).

In the present work, the trend of extreme rains through eight (08) indicators is studied taking into account the global warming of recent years in subequatorial Benin. This work is essential since changes in the intensity and frequency of climate extremes, especially rainfall, have sometimes dramatic environmental and socio-economic consequences.

II. DATA AND METHODS

2.1. Data

Extending from Cotonou (to the south), on the Atlantic coast, to the latitude of Bohicon (to the north) on the Dahomean base, subequatorial Benin is located between 1 ° 37 'and 2 ° 44' E and 6 ° 14 'and 7 ° 22' N. It covers an area of 14,111.0811 km2. Southern Benin is subject to a bimodal rainfall regime. The main season is from March to July and the small one from September to November (Boko, 1992; Adewi et al, 2010).

The data used in this study are chronological series of daily precipitation collected on seventeen (17) stations (figure 1) of Meteo Bénin. These stations are made up of two (02) synoptics, four (04) agro-climatic and eleven (11) meteorological. These daily rainfall amounts are collected between 1980 and 2018 for four (04) stations (Aplahoue, Allada, Dogbo and Lokossa) and from 1960 and 2018 on the thirteen (13) others. Missing data does not exceed 5% in the series. As for the daily minimum and maximum temperature data, they are collected between 1970 and 2015 on only the two synoptic stations (Cotonou and Bohicon). In terms of observation data, there are only these two stations in southern Benin.

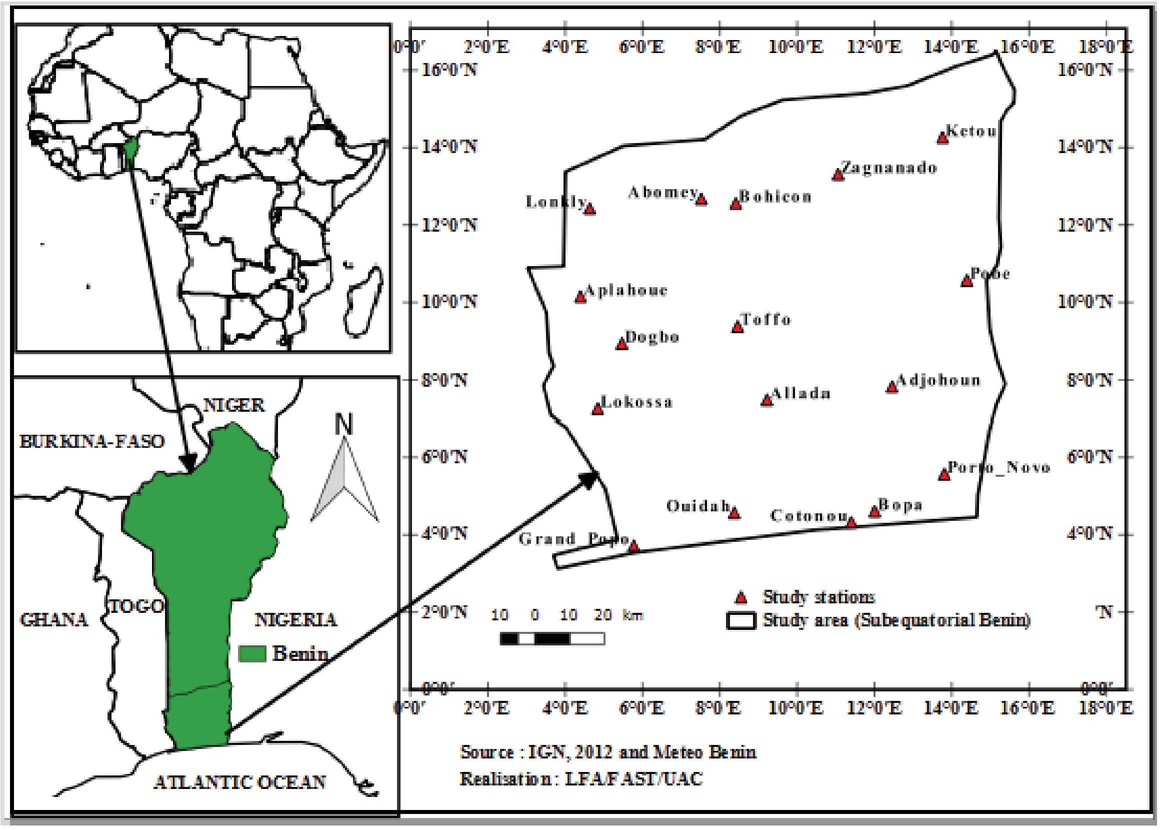


Fig 1: Geographical location of the study area.

2.2. Methods

To analyze and describe the different aspects of climate extremes, several indicators derived from the empirical distribution of daily temperature and precipitation data are often used (Wmo, 2009; Sahani et al., 2012; Attogouinon et al., 2017) such as d others can be defined for particular needs. But among the 27 indices considered as basic indices, a small number can be assumed to follow a distribution of extreme values (Diallo and Foamouhoue, 2014). In our study, eight (08) trend indicators (Table 1) are retained. These indices are mainly used to characterize the frequency and intensity of heavy rains in the daily series of subequatorial Benin. Percentiles are calculated from daily data over a period of at least thirty years, to comply with the standards of the World Meteorological Organization (WMO). The 95th percentile corresponds to an intense rainfall event. The 99th percentile corresponds to an extreme rainfall event while the 99.5th percentile represents a very extreme rainfall event. The frequency of these intense (P95p), extreme (P99p) and very extreme (P99.5p) rainfall events is expressed in days per year.

As the start and end of the two rainy seasons are variable (Lawin et al., 2013), the calculation of the percentiles P95P, P99P and P99.5P is made over the period March-July and September-November covering the two rainy seasons of the year. This period is considered not only to take into account most of the rains of the year but also not to have very low percentiles as in the case where the calculation would be made over the whole year.

Table 1: *The eight (08) trend criteria selected.*

Acronyms	Indicators name	Definition	Unit
JP	Rainy days	Total number of wet days (≥ 1 mm)	[days]
P20	rain frequency ≥ 20 mm	Number of days with rainfall ≥ 20 mm	[days]
PTOT	Total precipitation	Total annual precipitation	[mm]
P×1J	Maximum daily rain	Maximum daily precipitation	[mm]
P×3J	Maximum rain in three days	Maximum precipitation over three days	[mm]
P95P	Intensity of very intense rain	Number of rainy days ≥ 95th percentile	[%]
P99P	Exceptional rain intensity	Number of rainy days ≥ 99th percentile	[%]
P99.5P	Very exceptional rain intensity	Number of rainy days ≥ 99.5th percentile	[%]

The interannual variability of the rainfall regime is analyzed from the data on each station. The normalized rainfall index (Lawin et al., 2012) is determined over the study period by: $I(i) = (P(i) - P) / \sigma$, with $P(i)$, the indicator concerned on each of the stations in the study area for year i, P and σ correspond respectively to the mean and the standard deviation of the series. The moving average was used to look for the upward or downward trend in the rainfall indicators. To see the trend of indicators or temperatures at different stations, the linear regression line is also used. It represents the linear link between two variables x and y. The ten-year average is calculated by considering the minimum or maximum daily temperatures for the decade considered. The rate of temperature change per decade is calculated from the normalized index for each of the ten years considered. The test of the slope of the simple linear regression line is applied to the significance level of 5% is applied to show the significance of the trends of the rainfall indicators between 1960 and 2018.

III. RESULTS AND DISCUSSION

Subequatorial Benin like the rest of the world has warmed steadily (Figure 2) since the 1970s with non-uniform decadal rates of change (Figure 3). The ten-year average maximum temperatures of the 1990s are greater than those of the 1970s and 1980s. It is thus the pivotal decade with greater warming than the other decades with relatively high growth rates of minimum and maximum temperatures. In the cities of Cotonou and Bohicon annual average maximum temperatures have steadily increased since 1970 by at least 0.02 °C per year (Figure 4). These experienced an attenuation towards the end of the study period, especially from 2008 in Cotonou. This last part is not taken into account in the linear regression because it does not allow us to highlight the almost uniform growth of maximum temperatures on the two stations. As for minimum temperatures, the growth of annual averages is lower in Bohicon while it is relatively high in Cotonou. In the late 1970s and 1980s, the climate in southern Benin was generally mild with below average temperatures. But by the early 1990s, this part of Benin warmed with above average maxima, followed by easing towards the end of the study period.

The analysis of the daily rains (see appendices) of subequatorial Benin, does not reveal any significant generalizable trend in the frequency and intensity indices in the rainfall series (Table 2). This confirms the work of Hountondji et al. (2016), for most stations in Benin over the period 1960-2000. These results also corroborate those of Attogouinon et al. (2017) in the Ouémé valley between 1951-2014 and those of Ahokpossi (2020) nationally between 1940 and 2015 with only three stations in southern Benin. Nevertheless, a downward trend in all climatic indices is observed until the 1980s or the beginning of the 1990s. This downward trend is due to the severe drought in the Sahel which has spread towards the Gulf of Guinea to a lesser extent (Le Barbé et al. 2002; Lawin et al. 2011). This result corroborates the conclusions of Nicholson et al. (1993) in the Sahel and those of Lawin et al. (2011) in the Ouémé valley. The results mainly alluded to the reduction in negative precipitation anomalies during the period 1961-1990, with a resumption of precipitation during the 1990s.

After the drop in rainfall in the 1980s or 1990s, all the rainfall indices experienced a relatively significant increase (appendices) even if at the decadal scale on 92% of the stations, the indices experienced a second relatively large drop towards the end of the following decade. The various indicators over the last three decades are marked above all by ten-year averages higher than those obtained over the entire study period. This confirms the work of Amoussou et al (2014) in the Mono basin where the maximum daily rainfall intensities between 1988 and 2010 experienced a significant increase which could lead to flooding. Most of the linear regression coefficients calculated in this statistical trend study are positive and relatively large for all indicators in the 1990s.

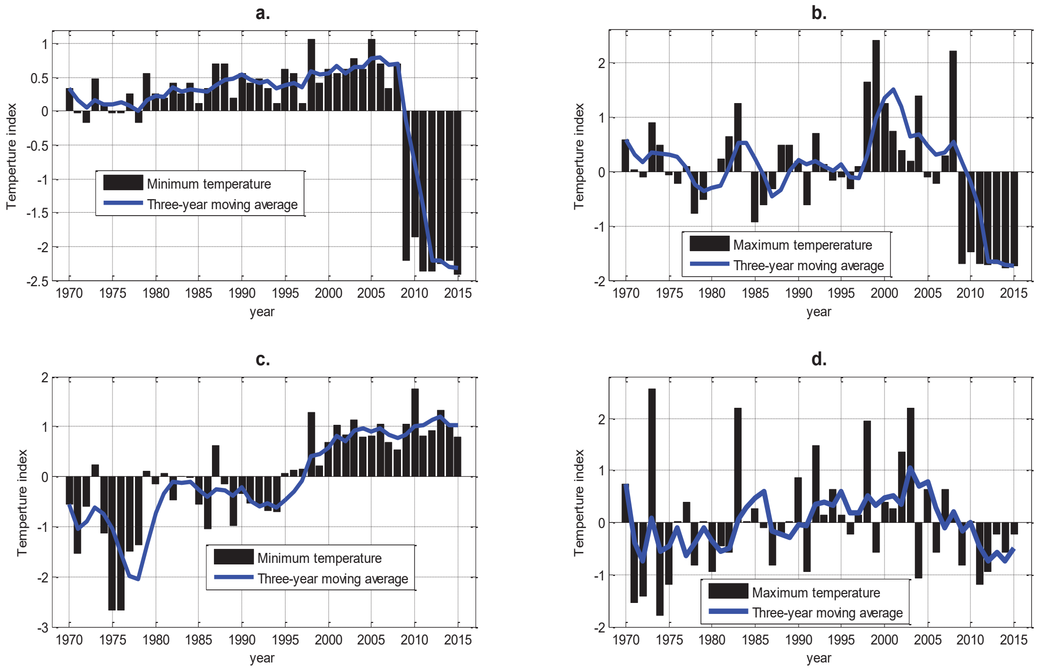


Fig 2: *Interannual variability of minimum and maximum average temperatures in Cotonou (a and b) and in Bohicon (c and d).*

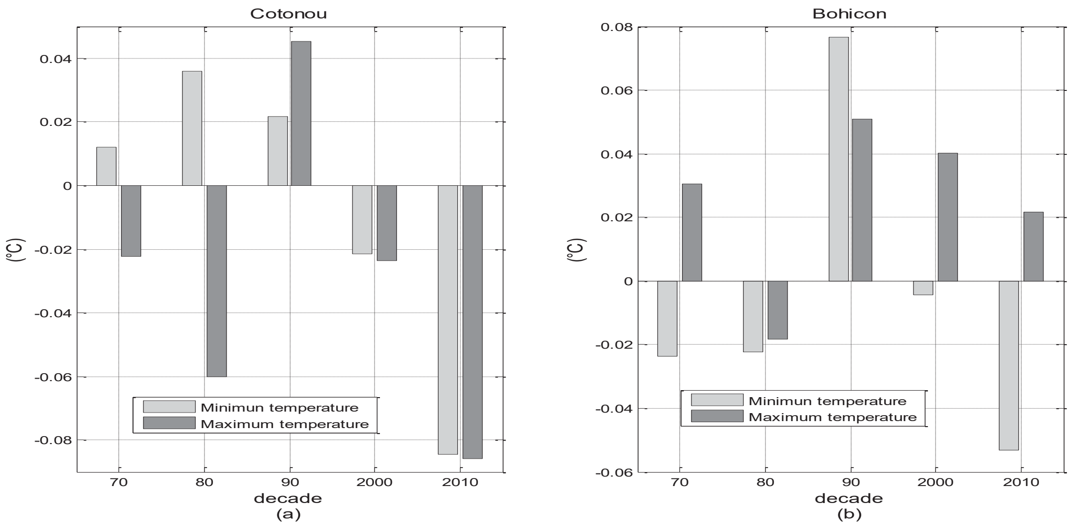


Fig 3: *Rate of change of the average minimum and maximum temperatures per year in Cotonou (a) and Bohicon (b).*

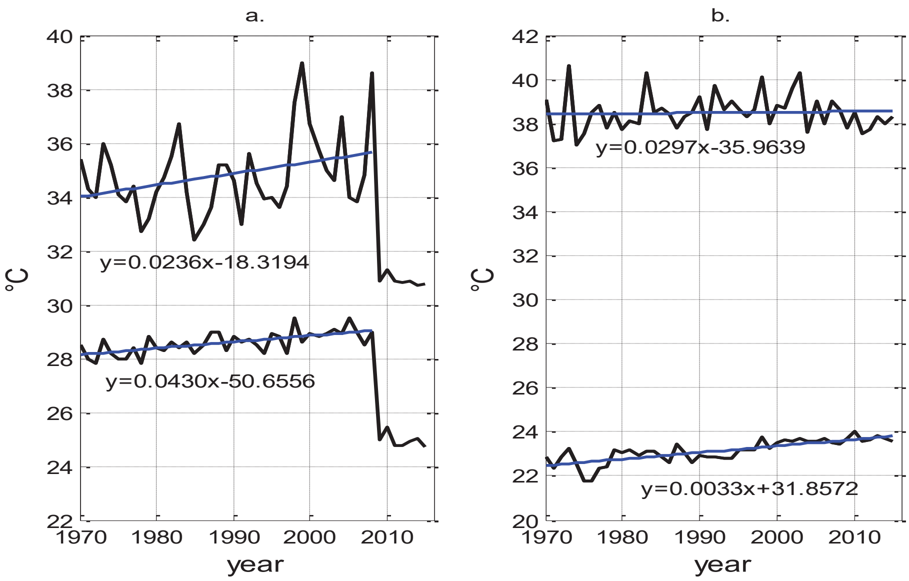


Fig 4: Annual average of minimum and maximum temperatures in Cotonou (a) and Bohicon (b).

An attenuation of the indicators is observed towards the end of several decades after the resumption of the indicators on a good number of stations. This highlights the uncertainties in the evolution of rainfall indices and which must be taken into account when defining strategies for adapting to the risks of flooding or drought (Hountondji et al. 2011). The increase in precipitation indices of its last years (90 until 2018) corroborates with the fourth report of the IPCC (2007) which indicates that extreme precipitation is projected to increase more than the average precipitation.

The spatial analysis of the indicators shows a non-uniform distribution of 75% of the latter in southern Benin. Only the daily annual maxima (Figure 5a) and in three consecutive days (Figure 5b) show a semblance of a gradient as a function of the latitude both at the level of the minimum, average and maximum values. The lowest values observed north of the study area. The high values of these two indicators are observed in cities near the Atlantic Ocean. The maximum values for the number of rainy days vary between 129 days in Cotonou and 85 days in Grand-Popo. The minimum values observed can go below 30 days in Bopa, Grand-Popo and Zagnanado. Average values (Figure 6a) per year can reach 70 days in Lonkly, Porto-Novo and Abomey. As for the annual totals (Figure 7a), like most indicators, there is no clearly identifiable spatial consistency. The annual totals vary between 139 mm and 2874.70 mm. The highest values are observed in Porto-Novo, Cotonou, Ouidah and Lonkly with values greater than 2400mm. The lowest values are observed at Bopa, Grand-Popo and Toffo. Most of the different values of the calculated percentiles (Figures 7a and 8) are all greater than 30 mm (Table 3) which is the threshold for intense rains (Panthou, 2013) that can cause flooding. Several large values of these percentiles are observed in cities near the Atlantic Ocean. This confirms the work of Age and Afouda (2015) concerning the rainfall quantiles estimated with the laws at the national level.

Table 2: *Different values of the regression slope (b) and the test statistic (T) calculated on the stations of the period 1960-2018. The test is significant when the absolute value of T is greater than 1.96 (value only read from the table of Student's law)*

Stations		JP	P20	PTOT	P*1J	P*3J	P95P	P99P	P99.5P
TONOU	b	-0.0539	0.1132	-1.0797	-0.2656	-0.3938	0.0034	0.0023	-0.0043
	T	-0.4034	1.2152	-8.0869	-2.0151	-2.9855	0.0267	0.0185	-0.0331
ZAGNANAD	b	0.0497	0.1102	1.6103	0.2137	0.4343	0.0004	0.0050	0.0050
O	T	0.3886	1.2754	11.9125	1.6266	3.2983	0.0333	0.0359	0.0508
BOHICON	b	-01842	0.0286	-07532	0.1363	0.2200	0.0164	0.0065	0.0015
	T	-1.4006	0.2097	-5.6822	1.0352	1.7023	0.1238	0.0529	0.0122
OUIDAH	b	-0.3309	0.0585	-3.9468	-0.1057	-0.4679	-0.0477	-0.0036	0.0015
	T	-2.4528	0.4207	-29.0538	-0.8105	-3.5577	-0.3568	-0.0242	0.0122
POBE	b	-0.1866	0.0271	-1.2598	0.1123	-0.1211	0.0181	0.0077	$4.0912.\ 10^{-4}$
	T	-1.4246	0.2003	-9.6393	0.8595	-0.9258	0.1429	0.0558	0.0034
LONKLY	b	-0.1797	0.2131	6.5386	0.5208	0.9514	0.1079	0.0272	0.0040
	T	-1.3936	1.5128	47.0682	3.8418	6.9108	0.7508	0.2220	0.0474
TOFFO	b	-0.1483	0.1390	3.0203	-0.0489	0.0096	0.0458	0.0227	- $1.1689.\ 10^{-4}$
	T	-1.3936	1.0253	22.7202	-0.3836	0.0756	0.3413	0.1852	-0001
BOPA	b	-0.0600	0.0368	-0.6543	-0.0228	0.1509	0.0021	0.0095	- $1.7534.\ 10^{-4}$
	T	-0.4468	0.2672	-4.8508	-0.1693	1.1346	0.0157	0.0645	-0.0011
KETOU	b	-0.0788	0.0780	-2.4915	-0.2672	-0.3160	0.0071	$6.4290.\ 10^{-4}$	-0.0022
	T	-0.5995	0.5735	-18.6342	-2.0127	-2.3871	0.0524	-0.0039	-0.0363
ADJOHOUN	b	-0.0151	0.0513	0.1216	-0.2540	-0.2454	-0.0120	0.0110	-0.0041
	T	-0.1148	0.3768	0.9076	-1.9156	-1.8032	-0.0884	0.0805	-0.0456
ABOMEY	b	-0.3006	-0.0018	-2.7497	0.2996	0.4165	-0.0174	0.0109	-0.0238
	T	-2.2620	-0.0137	-20.7712	2.2452	3.0993	-0.1341	0.0787	-0.1831
GRAND-	b	-0.2118	0.0627	-4.6640	0.2546	-0.0876	-0.0417	0.0122	0.0069
POPO	T	-1.6365	0.5486	-35.0011	1.9603	-0.6703	-0.3072	0.0902	0.0614
PORT0-NOVO	b	-0.7149	0.0751	-7.4154	-0.1755	-0.5157	-0.0208	-0.0077	-0.0099
	T	-5.4183	0.6452	-54.7665	-1.3162	-3.8812	-01400	-0.0549	-0.0730

Table 3: *Values of the rainfall quantiles calculated on the different stations.*

Stations	Percentile		
	95th (mm)	99th (mm)	99.5th (mm)
ABOMEY	38.8000	95.3460	136.7385
ADJOHOUN	43.5600	84.7080	134.0460
BOHICON	40.6400	88.4080	100.9090
BOPA	40.1000	100.8360	121.8900
COTONOU	61.7000	121.4960	138.2050
GRAND-POPO	47.3200	99.5840	153.6310
KETOU	41.6000	126.7230	140.5305
LONKLY	44.3200	95.4600	126.8320
OUIDAH	51.5200	120.3560	157.6900
POBE	43.5400	86.4840	109.1010
PORTO-NOVO	63.3400	124.5000	139.4860
TOFFO	40.0000	82.1650	140.3270
ZAGNANADO	50.6600	86.5800	111.3350
APLAHOUE	38.3200	82.0480	100.5720
ALLADA	18,0800	44,3350	108,3350
DOGBO	25.8200	84.7880	102.0450
LOKOSSA	28.0200	81.6760	105.0200

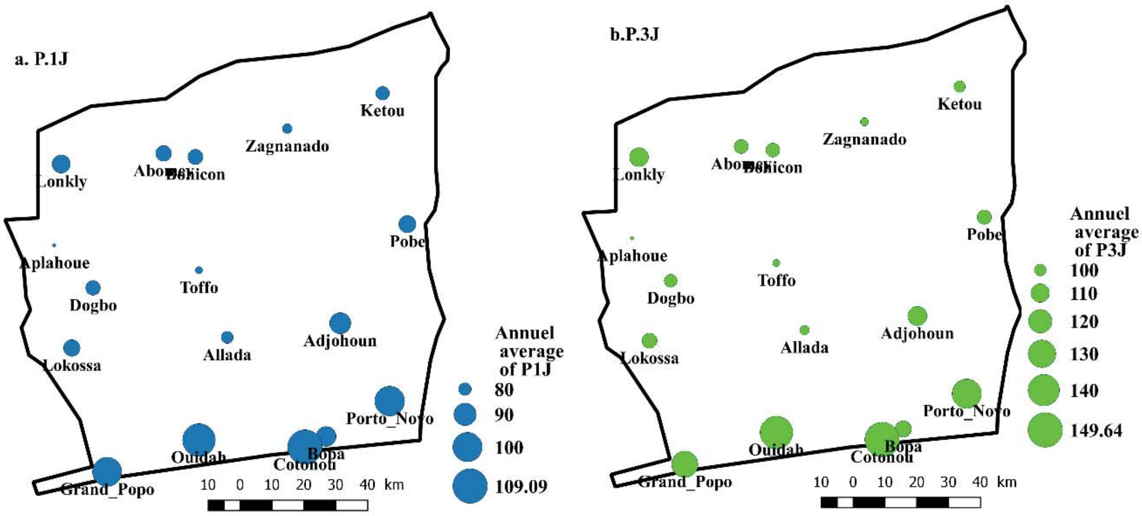


Fig 5: *Spatial distribution map of the means of the daily annual maxima in mm (a) and of the annual maxima over three consecutive days (b).*

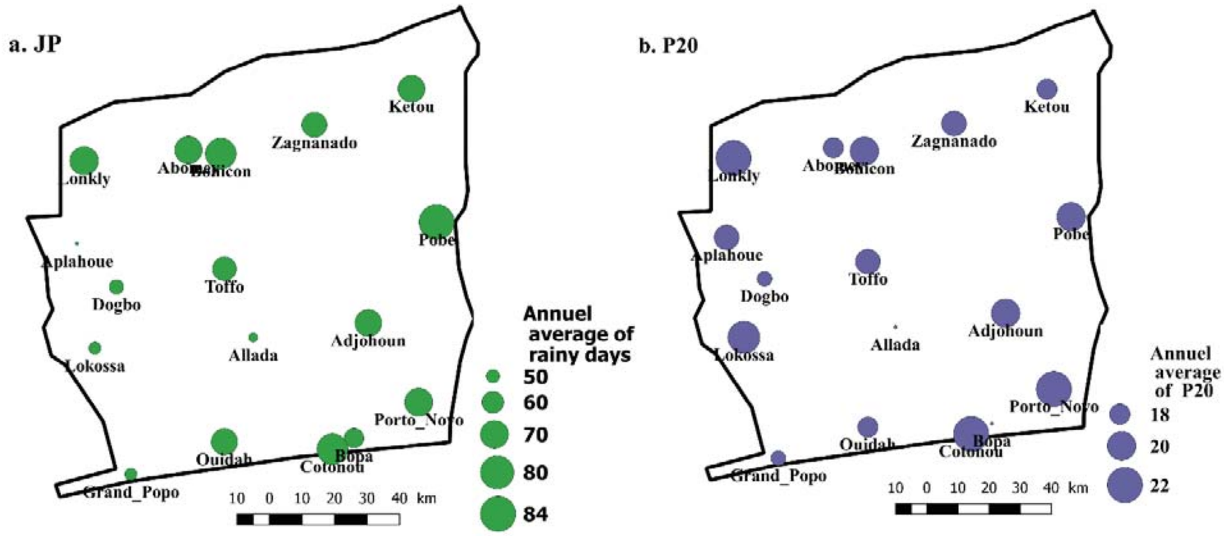


Fig 6: Spatial distribution of the annual averages of the number of rainy days (a) and days of rain greater than 20 mm (b) in southern Benin.

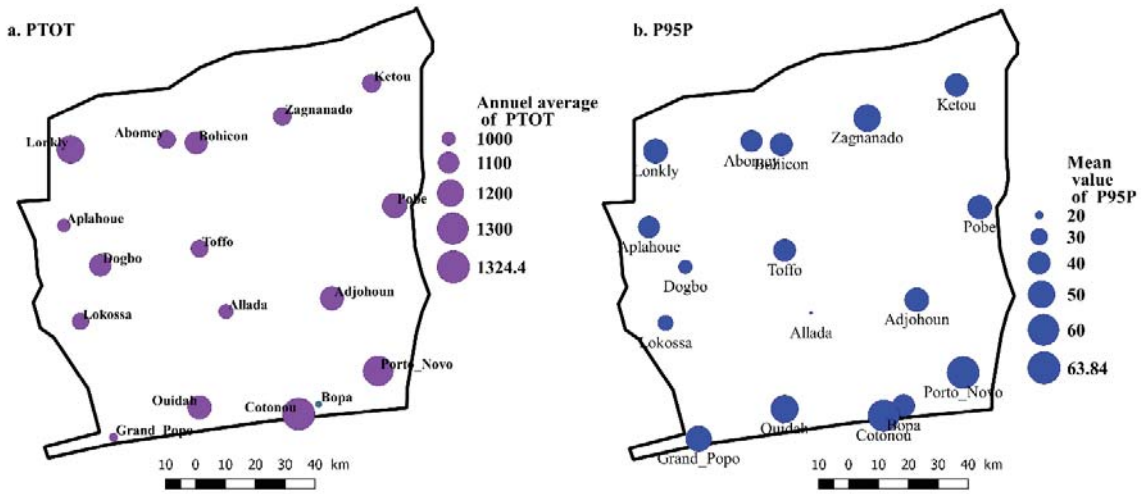


Fig 7: Spatial distribution of the annual totals (a) and of the 95th percentiles (b) calculated on the different stations in the south of Benin.

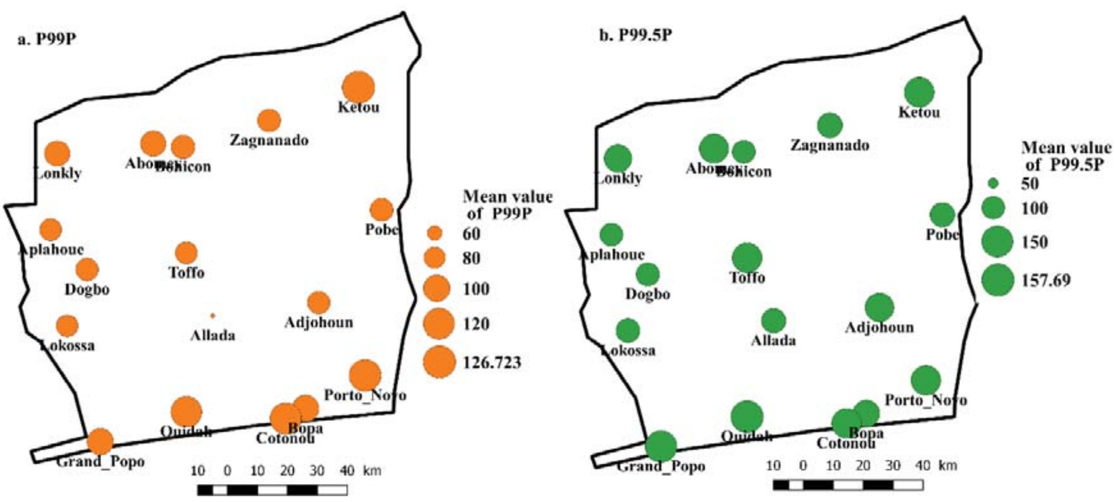


Fig 8: Spatial distribution of the upper quantiles of rainfall calculated on the different stations in the south of Benin. 99th percentile (a) and 99.5th percentile (b).

The temporal evolution (Figures 9, 10, 11, 12 and 13) of the intense (95th percentile) and extreme (99th and 99.5th percentiles) rains on the various stations, highlights the inhomogeneity of the annual number of rainy days above the percentiles since the beginning of the 60s. Thus, southern Benin, in the 90s and 2000s, suffered from several rains of height greater than, for example, 126 mm in Porto-Novo; 129.0140 mm in Kétou and 101.8230 mm in Abomey since the 1970s. The analysis also shows the rarity (less than 1% of the number of rainy days during the study period) of rains above the 99.5th percentile at south Benin. Cities like Porto-Novo, Adjohoun, Pobe and Ouidah experienced approximately 25, 6, 9 and 4 rains respectively above the 99.5th percentile compared to 4137, 4050, 4933 and 3928 rainy days. This area of the country therefore rarely experiences rains exceeding, for example, 153.6310 mm in Grand-Popo, 140.3270 mm in Toffo and 136.3200 mm in Abomey. This characterizes the non-linear behavior of precipitation (Sighoumnou, 2004; Kouakou et al, 2007). There has also been relatively significant growth in these majority years since 1994, but a little more pronounced from the beginning of the 2000s on most of the resorts with peaks around 2010.

On a decadal scale, despite the rarity of extreme rains, the distribution of the percentiles shows not only a relative increase in their number but also that this growth is observed on all the stations of the region for the 95th and 99th percentiles and almost as much for the 99.5th percentiles. Even if it is once or twice a decade on some stations, cities like Cotonou (Figure 9) and Porto-Novo (Figure 10) experienced extreme rain during the different decades of the study period. The different decades of the study period did not experience extreme rains on the different study stations. This is the case with Kétou for example in the 1980s and 1990s (Figure 11); Grand-Popo (Figure 12) which did not experience any rainfall greater than the 99.5th in the 1960s; Zagnanado (Figure 13) did not experience rains above the 99th in the 1960s, 80s and 90s. The last two decades are characterized by the resumption with a slight increase in the number of extreme rains.

The monthly trend is in good agreement with the bimodal rainfall regime in southern Benin for each of the climatic indicators studied except for the high percentiles for which the monthly percentages are very low. The months of the year (January, February, August and December) which are known as dry months, with virtually no rain, experienced several days of heavy rain with sometimes rainfall heights above the 95th percentile at Aplahoué and Grand-Popo (Figure 13) as in other towns in the region. This is how, for example, the city of Abomey was sprayed with a 65mm rain on January 20, 2004; Cotonou suffered 85.3mm on January 02, 2003; Porto-Novo 62.5mm on February 06, 2005 and 62.8mm in Ouidah on December 04, 2008. The month of August which is the intermediate between the two rainy seasons experienced the high proportion compared to the aforementioned months with for example rains of 84.8mm on August 11, 2002 in Abomey and 88.3mm on August 26, 2005 in Grand-Popo. The frequency of these heavy rains in the months of normally dry periods partly explains the disruption or shift of the rainy seasons in recent years in southern Benin. This disturbance is mainly characterized by the early end of the short rainy season (Lawin et al., 2012). The disruption of the start of the rainy seasons and the arrival of water from the north of the Ouémé basin could explain the amplification of the floods in the city of Cotonou. Lake Nokoué, Cotonou's rainwater reservoir, thus reaches its maximum capacity during the same August-September period (Lawin et al., 2012).

Climate change in subequatorial Benin rhymes with climate warming accompanied by an increase in rainfall indicators. The frequency of heavy rains observed since the beginning of the 21st century is not generally exceptional (beyond the 99th percentile). However, on several occasions, extreme rains have accompanied the seasons with higher than normal rainfall in the 1960-2018 series, particularly in Cotonou, Grand-Popo, Ouidah and Zagnanado. This goes in the same direction as the projections of the IPCC (2013) according to which, the episodes of extreme precipitation will become more intense and frequent, in connection with the increase in the average temperature at the surface. This becomes more worrying in view of the vulnerability of our societies and the expected evolution of their frequency and intensity in the 21st century (IPCC, 2013). The continuous improvement of knowledge will therefore make it possible to specify the future impacts of climate change. The current uncertainties should not however prevent actions to prepare, now, for a global average temperature 2 ° C higher than that of the pre-industrial era, which corresponds to the long-term objective of the Paris while continuing to do the maximum not to exceed 1.5 ° C (ONERC, 2018). Socio-political acts of capital importance must therefore come into play to preserve the balance between demographic development and the natural resources of our dear planet

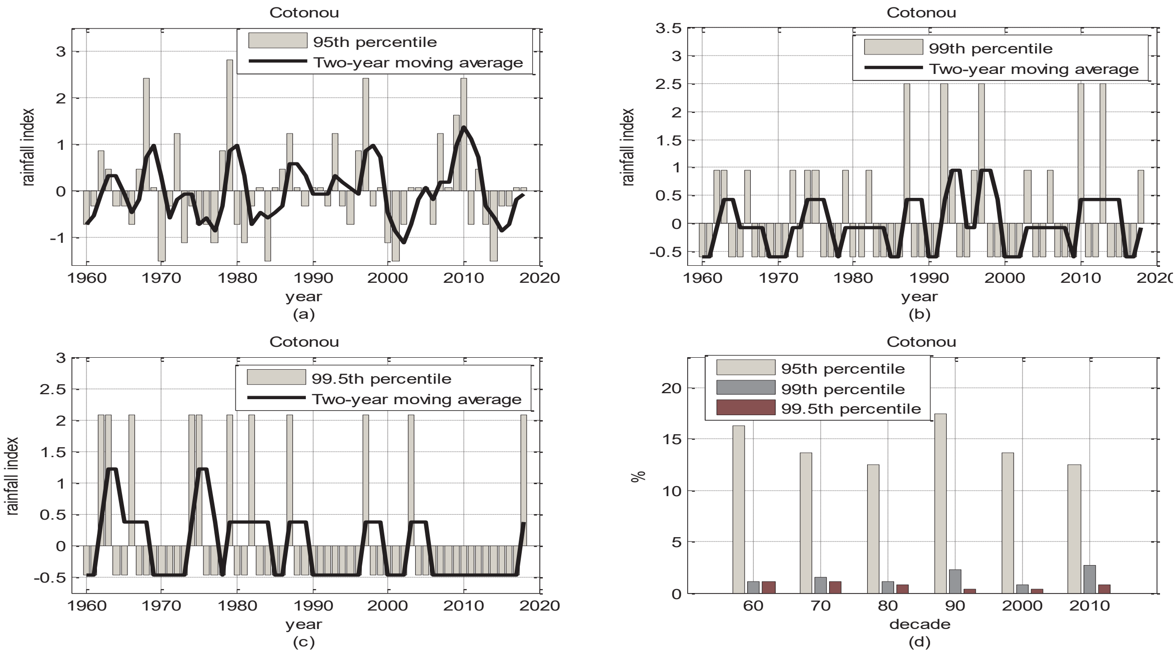


Fig 9: *Interannual and decadal variations of percentiles in Cotonou. The 95th percentiles (a); the 99th percentiles (b) and the 99.5th percentiles (c). Percentile change rates by decade (d).*

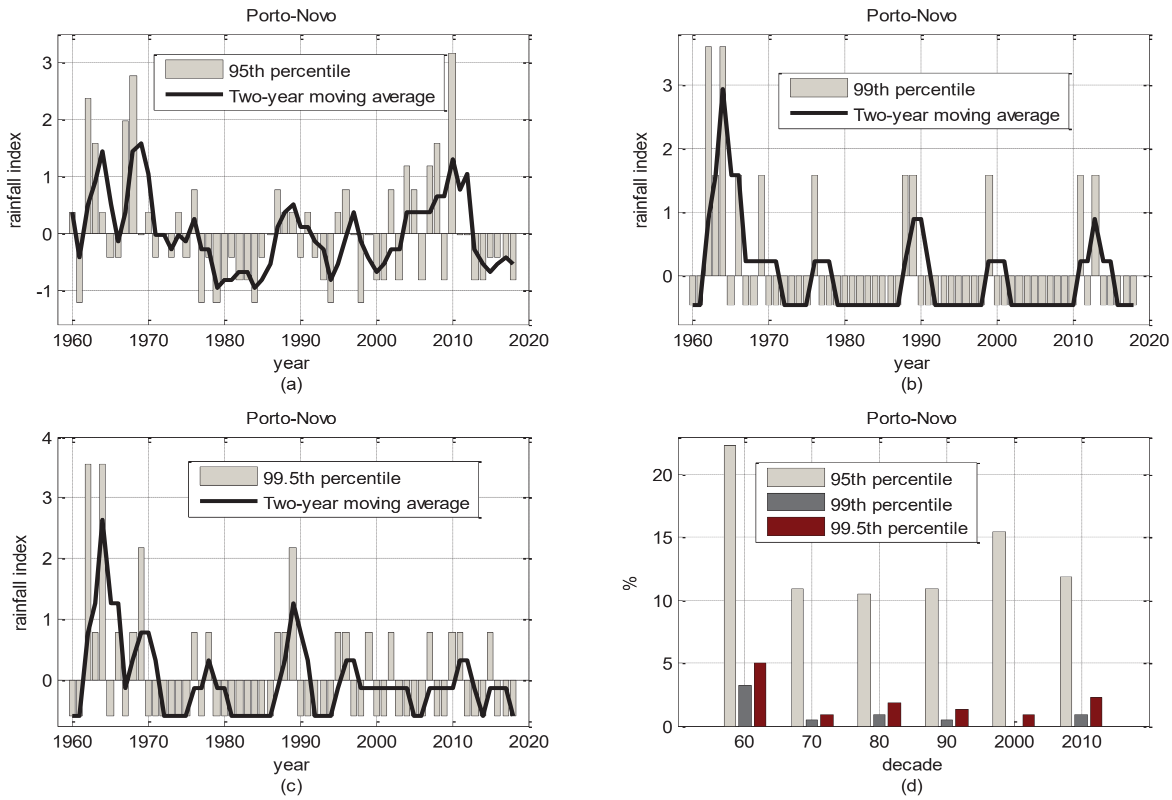


Fig 10: *Interannual and decadal variations of percentiles in Porto-Novo. The 95th percentiles (a); the 99th percentiles (b) and the 99.5th percentiles (c). Percentile change rates by decade (d).*

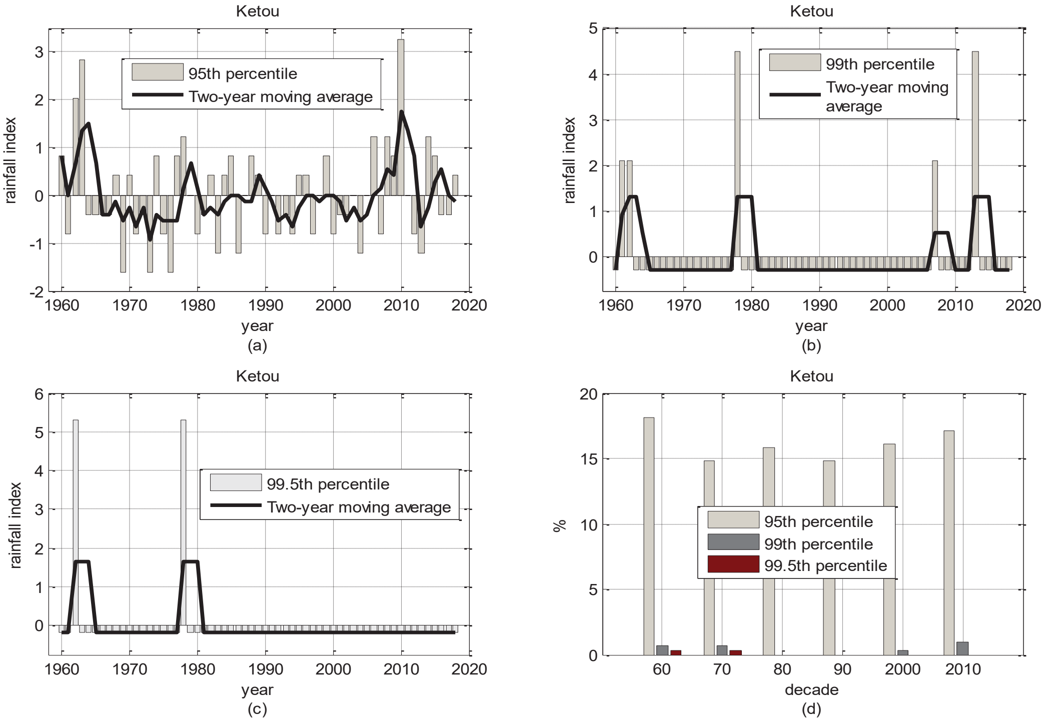


Fig 11: *Interannual and decadal variations of percentiles in Kétou. The 95th percentiles (a); the 99th percentiles (b) and the 99.5th percentiles (c). Percentile change rates by decade (d).*

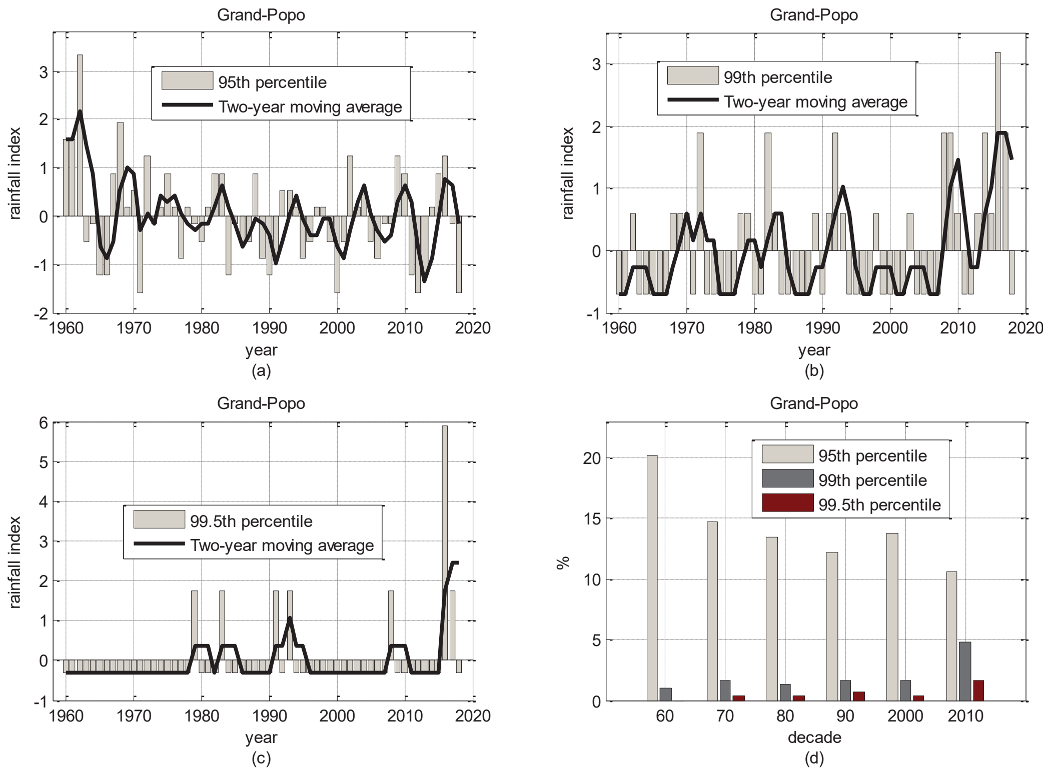


Fig 12: Interannual and decadal variations of percentiles at Grand-Popo. The 95th percentiles (a); the 99th percentiles (b) and the 99.5th percentiles (c). Percentile change rates by decade (d).

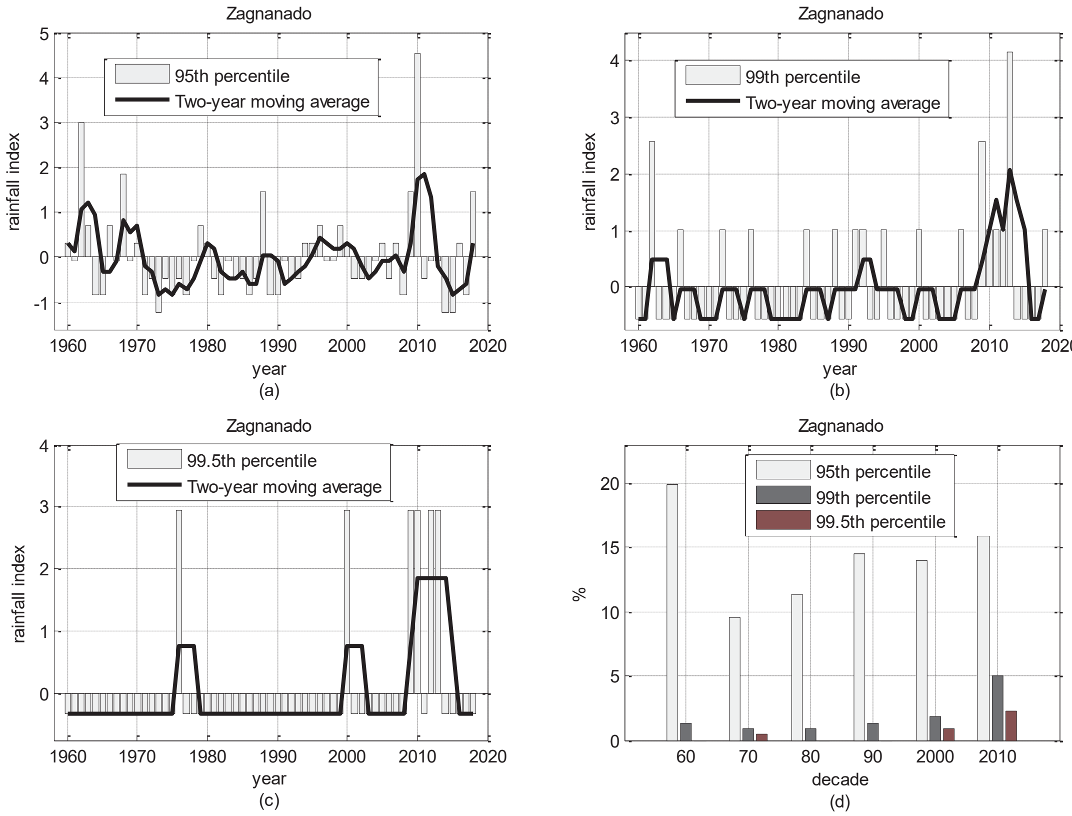


Fig13: Interannual and decadal variation of percentiles at Zagnanado. The 95th percentiles (a); the 99th percentiles (b) and the 99.5th percentiles (c). Percentile change rates by decade (d).

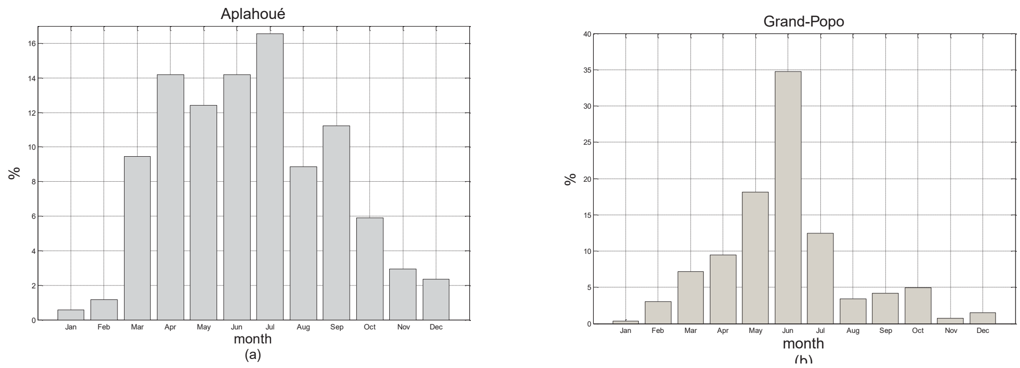


Fig 14: Monthly rainfall trend ≥ 95th percentile in Aplahoué (a) and Grand-Popo(b).

IV. CONCLUSION

The recent climatic variations in southern Benin are understood through precipitation and temperatures. Analysis of daily precipitation did not reveal any statistically significant trend over the entire study period. After the decrease in the frequency and intensity indicators in the 1970s and 1980s due to the drought of this period in West Africa, rainfall has resumed with relatively high growth rates of climate indicators. Regarding the evolution of the intensity and frequency of heavy rains, the amplitude of the heaviest daily rains in southern Benin has increased by around 10 to 25% since the beginning of the 21st century compared to the 1980s. An increase in extreme rains is thus highlighted in the current context of global warming characterized by an average increase in temperatures, especially maximum temperatures since the 1970s in southern Benin. This is in agreement with the results of studies carried out at the international level (IPCC, 2013). In the current context of climate change, the great unknown that remains is the future evolution of the intensity and frequency of these rainy events, especially since the work of the IPCC evokes the intensification of climatic parameters in the future in several regions of the world. It is therefore imperative to develop tools for forecasting and simulating extreme climatic events. Our decision-makers must therefore take climate risk into account in the development and implementation of expansion plans for our cities through appropriate prevention and adaptation measures.

REFERENCES

Adewi E., K. M. S. Badameli et V. Dubreuil, 2010. Evolution des saisons des pluies potentiellement utiles au Togo de 1950 à 2000. Climatologie, 7, 92-94.

Aguilar, E., Aziz Barry, A., Brunet, M., Ekang, L., Fernandes, A., Massoukina, M., Mbah, J., Mhanda, A., Do Nascimento, D., Peterson, T., 2009. Changes in temperature and precipitation extremes in western central Africa, Guinea Conakry, and Zimbabwe, 1955–2006. Journal of Geophysical Research: Atmospheres, 114, D02115, 11p.

Aguilar, E., Peterson, T., Obando, P.R., Frutos, R., Retana, J., Solera, M., Soley, J., García, I.G., Araujo, R., Santos, A.R., 2005. Changes in precipitation and temperature extremes in Central America and northern South America, 1961–2003. Journal of Geophysical Research: Atmospheres, 110, D23107, 15p.

Akaike, H., 1974. A new look at statistical model identification. IEEE Trans. Auto. Control, 20:716–722.

Alexander, L., Zhang, X., Peterson, T., Caesar, J., Gleason, B., Klein Tank, A., Haylock, M., Collins, D., Trewin, B., Rahimzadeh, F., Tagipour, A., Ambenje, P., Rupa Kumar, K., Revadekar, J., Grifiths, G., Vincent, L., Stephenson, D., Burn, J., Aguilar, E., Brunet, M., Taylor, M., New, M., Zhai, P., Rusticucci, M., and Vazquez-Aguirre, J., 2006. Global observed changes in daily climate extremes of temperature and precipitation. Journal of Geophysical Research, 111: DO5109: doi: 10.1029/2005JD006290.

Amoussou E., Camberlin P., Totin Vodounon S. H., Tramblay Y., Houndénou C., Mahé G., Paturel J.-E., Boko M., 2014. Evolution des précipitations extrêmes dans le bassin versant du mono (Bénin-Togo) en contexte de variabilité / changement climatique. XXVIIe Colloque de l'Association Internationale de Climatologie 2-5 juillet 2014 – Dijon (France).

Anadia Niger, 2014. Manuel de la base de données des inondations.

Alain I. AGUE et Abel Afouda, 2015. Analyse fréquentielle et nouvelle cartographie des maxima annuels de pluies journalières au Bénin. International Formulae Group. All rights reserved. DOI: http://dx.doi.org/10.4314/ijbcs.v9i1.12

André Attogouinon, Agnidé E. Lawin, Yèkambèssoun N'Tcha M'Po, and Rita Houngue, 2017. Extreme Precipitation Indices Trend Assessment over the Upper Oueme River Valley-(Benin). Hydrology 2017, 4, 36 ; doi :10.3390/hydrology4030036.

Benkhaled A. 2007. Distributions statistiques des pluies maximales annuelles dans la région du Cheliff : comparaison des techniques et des résultats. Courrier du Savoir, 8 : 83 - 91.

Boko M., 1988. Climats et communautés rurales au Bénin : rythmes climatiques et rythmes du développement. Thèse de Doctorat d'État. 2 tonnes, CRC, URA 909 CNRS, Université de Bourgogne, Dijon 601 p.

Boko M., 1992. Saisons et types de temps au Bénin : analyse objective et perceptions populaires.: Espace géographique, tome 21, n°4, pp. 321-332; doi : 10.3406/spgeo.2092.3106

Coles, S., 2001. An Introduction to Statistical Modeling of Extreme Values. Bristol, UK: Springer, 221 p.

Crisci A., B. Gozzini, F. Meneguzzo, S. Pagliara and G. Maracchi., 2002. Extreme rainfall in a changing climate: regional analysis and hydrological implications in Tuscany. Hydrological Processes Hydrol. Process. 16, 1261–1274 (2002). Published online in Wiley Inter Science (www.interscience.wiley.com). DOI: 10.1002/hyp.1061

Daniel Gellens, 2002. Combining regional approach and data extension procedure forassessing GEV distribution of extreme precipitation in Belgium. Journal of Hydrology 268 (2002) 113–126.

Demarée, G., 1990. An indication of climatic change as seen from the rainfall data of a Mauritanian station. Theoretical and Applied climatology 42, 139–147.

Diallo Ahmadou Aliou et Andre Kamga Foamouhoue, 2014. Changement climatique : Evaluation des sorties de Modèles/Analyse des observations-simulations-projections et Production de Scénarios en Guinée. Séjour Scientifique, Rapport ETAPE 3. African Center for Meteorological Applications for Development (ACMAD) /85 Avenue des ministères, BP : 13184 Niamey Niger.

Di Baldassarre, G., Montanari, A., Lins, H., Koutsoyiannis, D., Brandimarte, L., Blöschl, G., 2010. Flood fatalities in Africa: from diagnosis to mitigation. Geophysical Research Letters 37, L22402, 5p.

E. W. Vissin, 2007. Impact de la variabilité climatique et de la dynamique des états de surface sur les écoulements du bassin béninois du fleuve Niger. Thèse de Doctorat, Université de Bourgogne, 310 p.

Brahim Habibi et al. 2012. Analyse fréquentielle des pluies journalières maximales Cas du Bassin Chott-Chergui. Nature & Technologie, 41-48.

Frich, P., Alexander, L., Della-Marta, P., Gleason, B., Haylock, M., Klein Tank, A., and Peterson, T., 2002. Observed coherent changes in climatic extremes during the second half of the 20th century. Climate Research, 20:203.212.

Fischer E.M., Schar C. 2010. Consistent geographical patterns of changes in high-impact European heatwaves. Nature Geosciences, 3 (6): 398-403.

GIEC, 2013, Climate Change 2013.The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change", [Stocker T.F., Qin D., Plattner G.-K., Tignor M., Allen S.K., Boschung J., Nauels A., Xia Y., Bex V. and Midgley P.M. (eds.)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 p.

GIEC, 2014, Climate Change 2014.Impacts, Adaptation, and Vulnerability, Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, [Field C.B., Barros V.R., Dokken D.J., Mach K.J., Mastrandrea M.D., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P. R., et White L.L. (eds.)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1132 p.

Griffiths G.M., Salinger M. J. & Leleu I., 2003. Trends in extreme daily rainfall across the South Pacific and relationship to the South Pacific Convergence Zone. International Journal of Climatology. 23, 8, 847-869.

Gnanglè Césaire P., Romain Glèlè Kakaï, Achille E. Assogbadjo, Samuel Vodounnon, Jacob Afouda Yabi et Nestor Sokpon., 2011. Tendances climatiques passées, modélisation, perceptions et adaptations locales au Benin. Climatologie, vol. 8.

Goubanova Katerina, 2006. Une étude des événements climatiques extrêmes sur l'Europe et le bassin Méditerranéen et de leur évolution future. Thèse de Doctorat, Université de Paris 6, 120P.

Goula, B. T. A., Soro, E. G., Kouassi, W., & Srohourou, B., 2012. Tendances et ruptures au niveau des pluies journalières extrêmes en Côte D'ivoire (Afrique de l'Ouest). Hydrological Sciences Journal, 57(6), 1067–1080.

Haylock, M. and Goodess, C., 2004. Interannual variability of European extreme winter rainfall and links with mean large-scale circulation. Int. Journal of Climatology, 24:759.776.

Houngninou B. Etienne, Allé C. S. Ulrich, Kougbéagbédè Hilaire and Guédjé K. François., 2017. Changes in daily temperature extremes over Benin between 1970 and 2015. International Journal of Advanced Research. 108 http://dx.doi.org/10.21474/IJAR01/5944.

Hangnon, H., de Longueville, F., Ozer, P., 2015. Précipitations "extrêmes" et inondations à Ouagadougou; quand le développement urbain est mal maîtrisé... Presented at the Actes du 28e Colloque.

Hountondji, Y., De Longueville, F., Ozer, P., 2011. Trends in extreme rainfall events in Benin (West Africa), 1960-2000. Presented at the Proceedings of the 1st International Conference on Energy, Environment and Climate Change. hdl.handle.net/2268/96112.

Hubert, P., Carbonnel, J. P., & Chaouche, A., 1989. Segmentation des séries hydrométéorologiques. Application à des séries de précipitations et de débits de l'Afrique de l'Ouest. Journal of Hydrology, 110, 349–367.

IPCC 2001. Climate change, 2001: The Scientific Basis, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. In Houghton, J., Ding, Y., Griggs, D., Noguer, M., van der Linden, P., and Xiaosu, D., editors, „ Cambridge, United Kingdom. Cambridge University Press, 944 pp.

IPCC, 2007. Climate change, 2007: The Scientific Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K., Tignor, M., and Miller, H., editors, Cambridge, United Kingdom and New York, NY, USA. Cambridge University Press, 996 pp.

Jean HOUNKPE, 2016. Assessing the climate and land use changes impact on flood hazard in Ouémé river basin, Benin (West Africa). Thèse de doctorat. Université d'Abomey Calavi, Bénin, 149p.

Johnson, N.L., S. Kotz, and N. Balakrishnan, 1994. Continuous Univariate Distributions, Volume 1, Wiley-Interscience, page 15, Eqn 12.33

Kendall M., 1938. A new measure of rank correlation, Biometrika, 30 (1–2): 81–89.

Karimou Barké M. et al., 2015. Analyse des phénomènes climatiques extrêmes dans le sud-est du Niger. XXVIIIe Colloque de l'Association Internationale de Climatologie, Liège 2015.

Kiktev, D., Sexton, D., Alexander, L., and Folland, C., 2003. Comparison of modeled and observed trends in indices of daily climate extremes. Journal of Climate, 16:3560.3571.

Klein Tank, A. and Können, G., 2003. Trends in indices of daily temperature and precipitation extremes in Europe, 1946-99. Journal of Climate, 16:3665.3680.

K.E. Kouakou., B.T.A. Goula and I. Savane, 2007. Impacts de la variabilité climatique sur les ressources en eau de surface en zone tropicale humide : Cas du bassin versant transfrontalier de la Comoé (Côte D'ivoire - Burkina Faso). European Journal of Scientific Research, 16(1) (2007) 31-43.

Koutsoyiannis D, Baloutsos G., 2000. Analysis of a long record of annual maximum rainfall in Athens, Greece and design rainfall inferences. Natural Hazards (Dordrecht), **22**(1): 29-48.

Koutsoyiannis D., 2004a. Statistics of estimation of extreme rainfall: I. Theoretical of investigation. Journal des Sciences Hydrologiques, 49(4): 575–590.

Koutsoyiannis D., 2004b. Statistics of estimation of extreme rainfall: II. Theoretical of investigation. Empirical investigation of long rainfall record. Journal des Sciences Hydrologiques, 49(4): 591–610.

Lanokou C. M., Ogouwalé E. et Afouda F., 2012. Contraintes pédoclimatiques et stratégies d'adaptation paysannes dans la Dépression Médiane d'Issaba au Bénin (Afrique de l'Ouest.). Actes du XXV ème Colloque de l'Association International de la Climatologie, 395-400.

Observatoire national sur les effets du réchauffement climatique (ONERC), 2018. Les événements météorologiques extrêmes dans un contexte de changement climatique. Rapport au Premier ministre et au Parlement. La documentation Française.

Lawin A. E., 2007. Analyse climatologique et statistique du régime pluviométrique de la haute vallée de l'Ouémé à partir des données pluviométriques Amma-CATCH Bénin, thèse de Doctorat, Institut Nationale Polytechnique de Grenoble et l'Université d'Abomey-Calavi.

Lawin, A. E., Afouda, A., & Lebel, T., 2011. Analyse de la variabilité du régime pluviométrique dans la région agricole d'Ina au Benin. European Journal of Scientific Research, 50(3), 425-439.

Lawin, E. A., Afouda, A., Oguntunde, P. G., Lebel, T. and Gosset, M., 2012. Rainfall Variability at Regional and Local Scales in the Oueme Upper Valley in Benin. International Journal of Science and Advanced Technology. 2 (6): p. 46–55.

Lawin E.A., Moumouni S., Akponikpe P.B.I., Kiki C. et Afouda A., 2013. Variabilité des dates de début, de fin et de la durée de la petite saison des pluies à Cotonou, Bénin. XXVIème colloque de l'Association Internationale de Climatologie.

Le Barbé, L., Lebel, T., & Tapsoba, D. 2002. Rainfall variability in West Africa during the years 1950–90. Journal of climate, 15(2), 187-202.

Li, J., R. Yu, and W. Sun, 2013a: Calculation and analysis of the thresholds of hourly extreme precipitation in mainland China (in Chinese), Torrential Rain and Disasters, **32**, 11–16, doi: 10.3969/j.issn.1004-9045.2013.01.002 .

Jones, P. D., Horton, E. B., Folland, C. K., Hulme, M., Parker, D. E., and Basnett, T. A., 1999. The Use of Indices to Identify Changes in Climatic Extremes. Clim. Change, 42 : 131.149.

Mahé, G., 1993. Les écoulements fluviaux sur la façade atlantique de l'Afrique. Etude des éléments du bilan hydrique et variabilité interannuelle, analyse de situations hydroclimatiques moyennes et extrêmes. ORSTOM, Coll. Etudes et Thèses, Paris.

Mahé, G. L'Hôte, Y., Olivry, J.C. & Wolting, G., 2001. Trends and discontinuities in regional rainfall of West and Central Africa – 1951-1989. Hydrological Sciences Journal, 46 : 211-226.

Mohymont, B. & Demarée, G.R., 2006. Courbes intensité-durée-fréquence des précipitations à Yangambi, Congo, au moyen de différents modèles de type Montana. Hydrological Sciences Journal, 51 : 239-253.

Manton M.J., Della-Marta P.M., Haylock M.R., Hennessy K.J., Nicholls N., Chambers L.E., Collins D.A., Daw G., Finet A., Gunawan D., Inape K., Isobe H., Kestin T.S., Lefale P., Leyu C.H., Lwin T., Maitrepierre L., Ouprasitwong N., Page C.M., Pahalad J., Plummer N., Salinger M.J., Suppiah R., Tran V.L., Trewin B., Tibig I. & Yee D., 2001. Trends in extreme daily rainfall and temperature in Southeast Asia and the South Pacific: 1961-1998. International Journal of Climatology, 21, 3, 269-284.

Naveau, P., Nogaj, M., Ammann, C., Yiou, P., Cooley, D. & Jomelli, V., 2005. Statistical methods for the analysis of climate extremes. C.R. Geosciences, 337 : 1013-1022.

Neppel L., Bouvier C., Vinet F., Desbordes M., 2003. Sur l'origine de l'augmentation apparente des inondations en région méditerranéenne, Revue des Sciences de l'Eau, 16, 475-493.

New, M., Hewiston, B., David, B., Tsiga, S.A., Kruger, A., Manhinsue, A., Gomez, B., Coelho, C.A.S., Masisi, D.N., Kalulanga, E., Bulane, E., Fortunata, L., Mdoka, M.L. & Lajoie, R., 2006. Evidence of trends in daily climate extremes over southern and West Africa. Journal of Geophysical Research, 111, D14102, doi: 10.1029/2005JD006289.

Nicholson S.E., 1993: An overview of African rainfall fluctuations of the last decade. Journal of Climate, 6, 1463-1466.

Ogouwalé E., Afouda F. et Lanokou C. M., 2010 : Fondements climatiques des productions vivrières dans la dépression d'Issaba dans le département du Plateau (Bénin, Afrique de l'Ouest). In Publication Annales FLASH, Vol 2, 4 numéros, pp 126-138.

Ozer, P., 2012. Les risques naturels. Articuler risques, planification d'urgence et gestion de crise. Editions de Boeck, 135p.

Ozer, P., Hountondji, Y., Laminou Manzo, O., 2009. Evolution des caractéristiques pluviométriques dans l'est du Niger de 1940 à 2007. Geo-Eco-Trop 33, 11–30.

Ozer, P., Hountondji, Y.-C., Gassani, J., Djaby, B., De Longueville, F., 2014. Evolution récente des extrêmes pluviométriques en Mauritanie (1933-2010). Presented at the Actes du 27e Colloque International de l'Association Internationale de Climatologie, Université de Bourgogne, pp. 394–400.

Pao-Shin Chu, Xin Zhao, Ying Ruan and Melodie Grubbs, 2008. Extreme Rainfall Events in the Hawaiian Islands. University of Hawaii-Manoa, Honolulu, Hawaii 96822. 44p.

Pauleit S., Coly A., Fohlmeister S., Gasparini P., Jorgensen G., Kabisch S., Kombe W.J., Lindley S., Simonis I. and Yeshitela K., 2015. Urban vulnerability and climate change in Africa. Springer, 4.

PANA, 2007. Programme d'action national d'adaptation à la variabilité et aux changements climatiques (PANA du Burkina Faso), 76p.

Panthou, G., 2013. Analyse des extrêmes pluviométriques en Afrique de l'Ouest et de leur évolution au cours des 60 dernières années. Thèse de Doctorat, Université de Grenoble, France, 270p

Paturel, J.-E., Servat, E., Kouamé, B., Boyer, J.-F., Lubes Niel, H., Masson, J., 2096. Procédures d'identification de "ruptures" dans des séries chronologiques– modification du régime pluviométrique.

Philip G. Oguntunde, Babatunde J. Abiodun, Gunnar Lischeid 2011. Rainfall trends in Nigeria, 2001–2000. Journal of Hydrology 411 (2011) 207–218.

Sahani, M., Moeyersons, J., Vandecasteele, I., Trefois, P., Ozer, P., 2012. Evolution des caractéristiques pluviométriques dans la zone urbaine de Butembo (RDC) de 1957 à 2010. Geo-Eco-Trop : Revue Internationale de Géologie, de Géographie et d'Ecologie Tropicales 36, 121–136.

Rapport d'évaluation des Besoins Post Catastrophe, 2011. Inondation au Bénin. Préparé par le Gouvernement de la République du Bénin avec l'appui de la Banque Mondiale et du Système des Nations Unies. Rapport Final Avril, 2011.

Sene, S. & Ozer, P., 2002. Evolution pluviométrique et relation inondations-événements pluvieux au Sénégal. Bulletin de la société géographique de Liège, 42 : 27-43.

Sighomnou, D., 2004. Analyse et redéfinition des régimes climatiques et hydrologiques du Cameroun : perspectives d'évolution des ressources en eau. Yaoundé : Université de Yaoundé 1, multigr. Th. : Sci.de l'Eau, Université de Yaoundé 1. 289 p.

Soro G. E., Goula Bi TA, Kouassi FW, Koffi K, Kamagate B, Doumouya I, Savane I, Srohorou B., 2008. Courbes Intensité-Durée-Fréquence des précipitations En climat Tropical Humide : Cas de la Région d'Abidjan (Côte D'Ivoire). European Journal of Scientific Research, **21**(3): 394-405.

Tschakert, P., 2007. Views from the vulnérable: Understanding climatic and other stressors in the Sahel". Global Environmental Change. Vol. 17. n°: 3-4, p. 381-396.

Tschakert, P., Sagoe, R., Ofori-Darko, G. & Codjoe, S.N. 2010. Floods in the Sahel: an analysis of anomalies, memory, and anticipatory learning. Climatic Change. Vol. 103. N°. 3-4, p. 471-502.

Vandiepenbeeck, M., 1995. Détection pratique de changement de climat dans le cas d'une alternative au caractère aléatoire. Publications de l'Association Internationale de Climatologie 8, 116–124.

Wang, X.L., 2008. Accounting for autocorrelation in detecting mean shifts in climate data series using the penalized maximal t or F test. Journal of Applied Meteorology and Climatology 47, 2423–2444.

WMO, 2009. Guidelines on analysis of extremes in a changing climate in support of informed decisions for adaptation. World Meteorological Organization, Genève, 52p.

Yédjinnavènan Ahokpossi (2020): Analysis of the rainfall variability and change in the Republic of Benin (West Africa). Hydrological Sciences Journal, DOI: 10.1080/02626667.2018.1554286.

Yongguang Zheng, Ming Xue, Bo Li, Jiong Chen, and Zuyu Tao, 2016. Climatology of Extreme Rainfall over China with Hourly through 24-Hour Accumulation Periods Based on National-Level Hourly Rain Gauge Data. Journal of Applied Meteorology and Climatology.

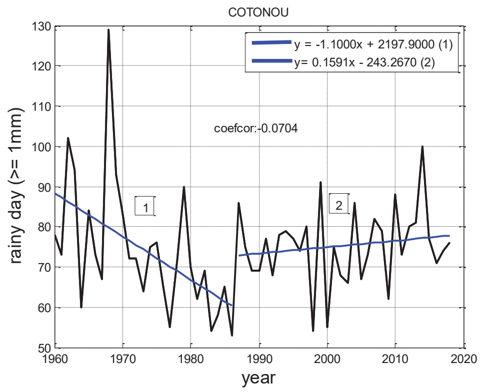
Zahar Y, Laborde JP., 2007. Modélisation statistique et synthèse cartographique des pluies journalières extrêmes de Tunisie. Rev. Sci. Eau, 20: 409-424.

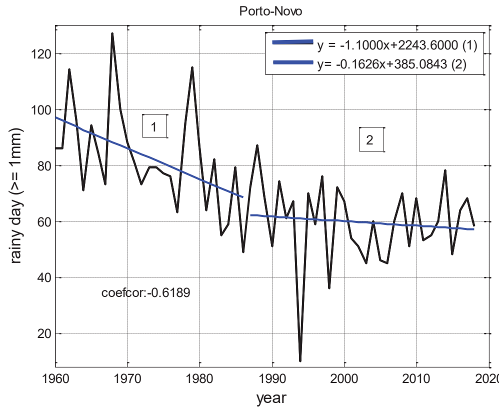
Zhai, P., Rusticucci, M., and Vazquez- Aguirre, J., 2006. Global observed changes in daily climate extremes of temperature and precipitation. Journal of Geophysical Research, 111: DO5109: doi: 10.1029/2005JD006290.

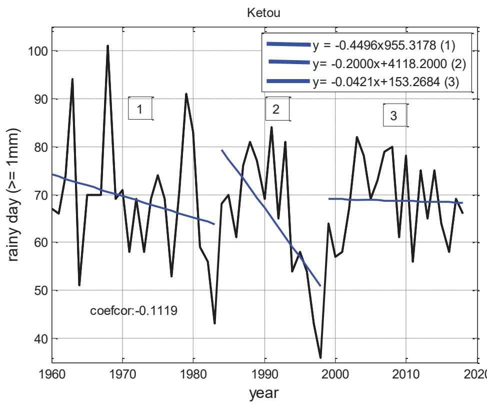
Zhang, X., Yang, F., 2004. RClimDex.

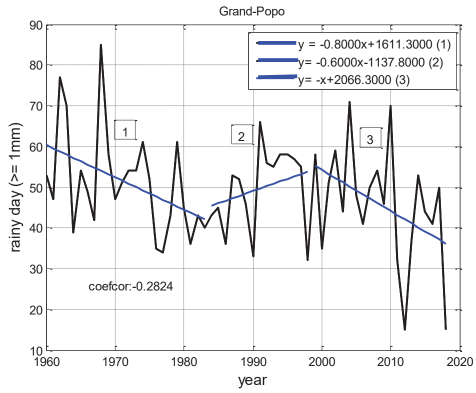
Appendices:

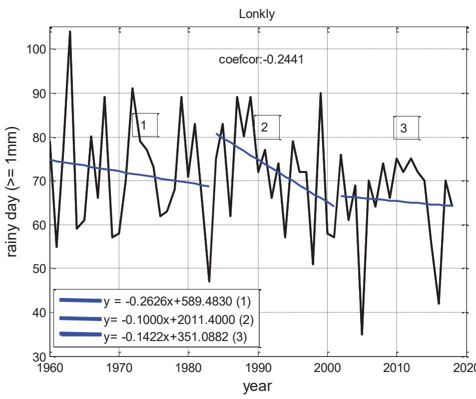
The number of rainy days (rain ≥1mm) at the different stations from 1960 to 2018.

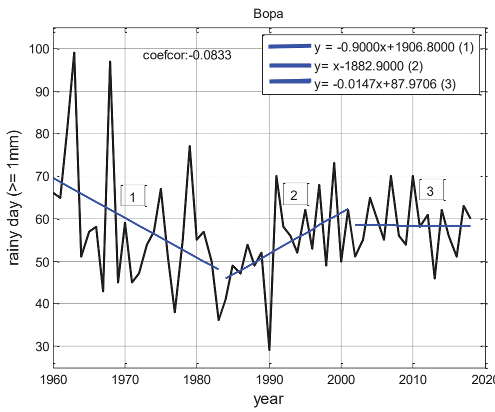


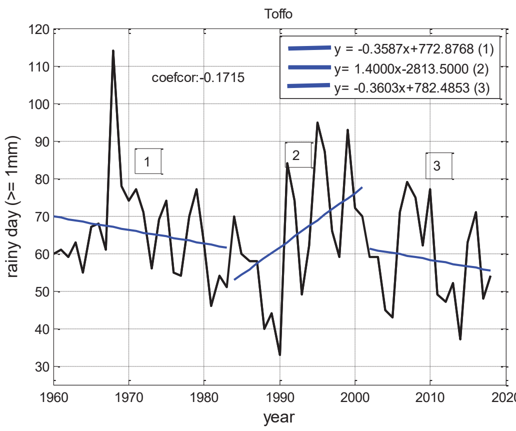


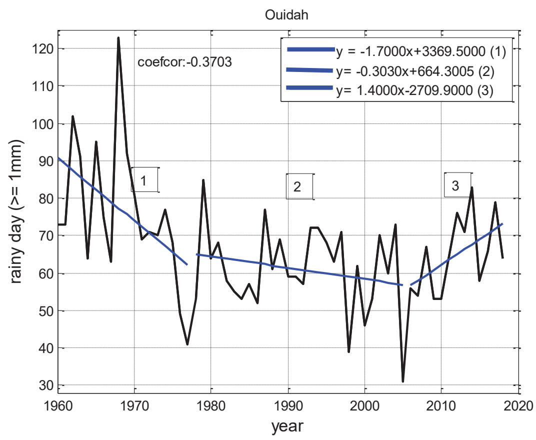


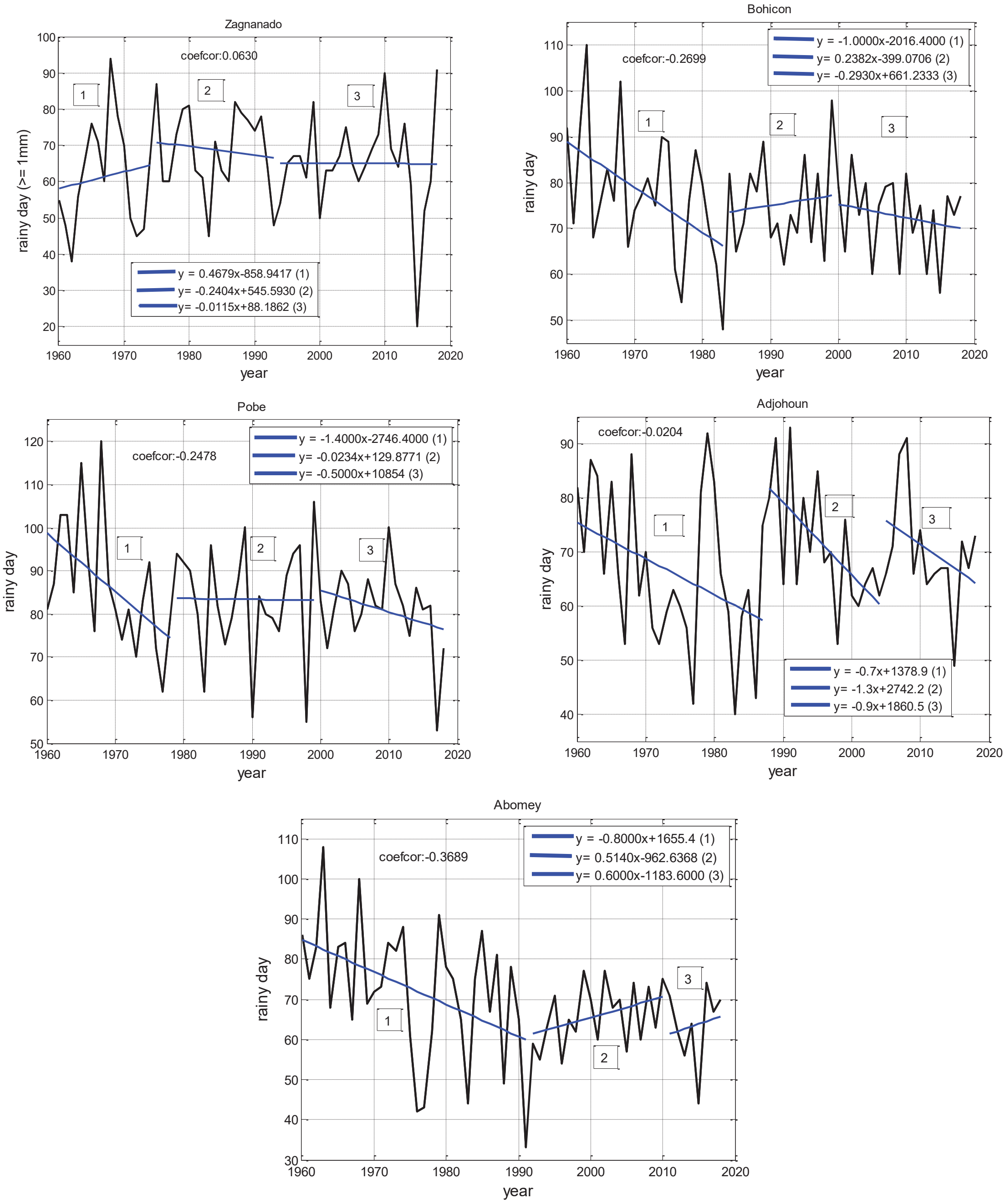




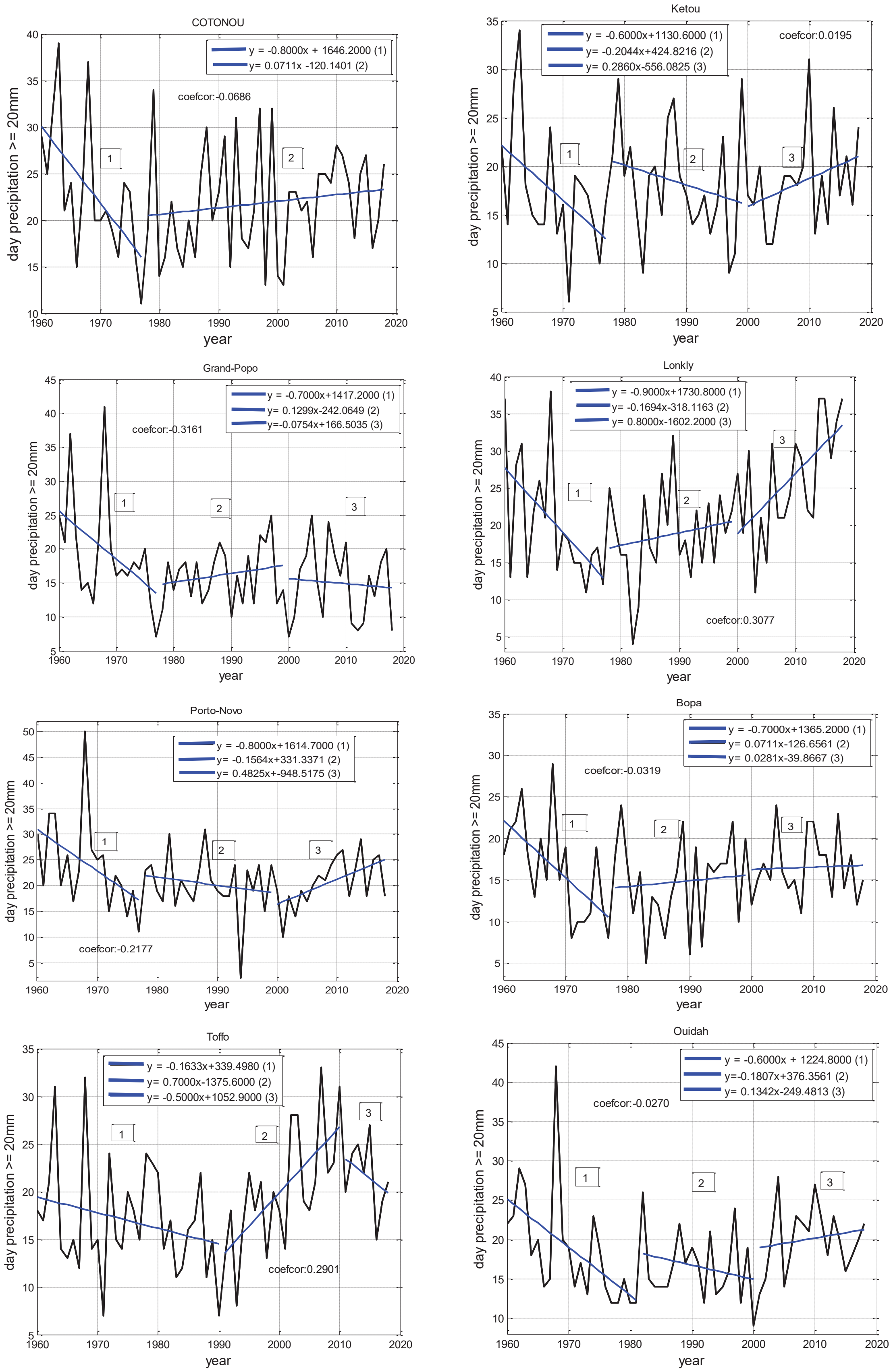


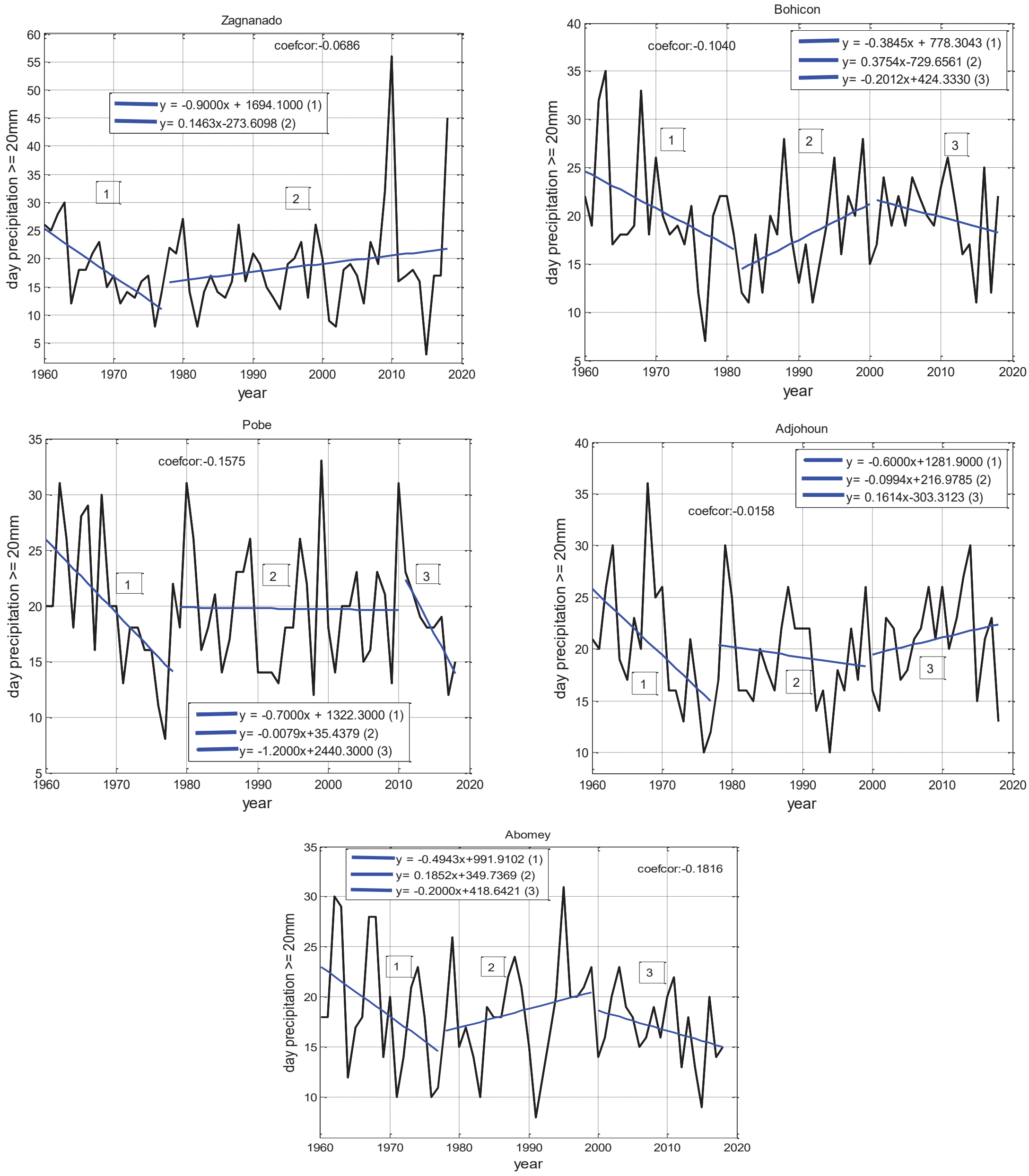




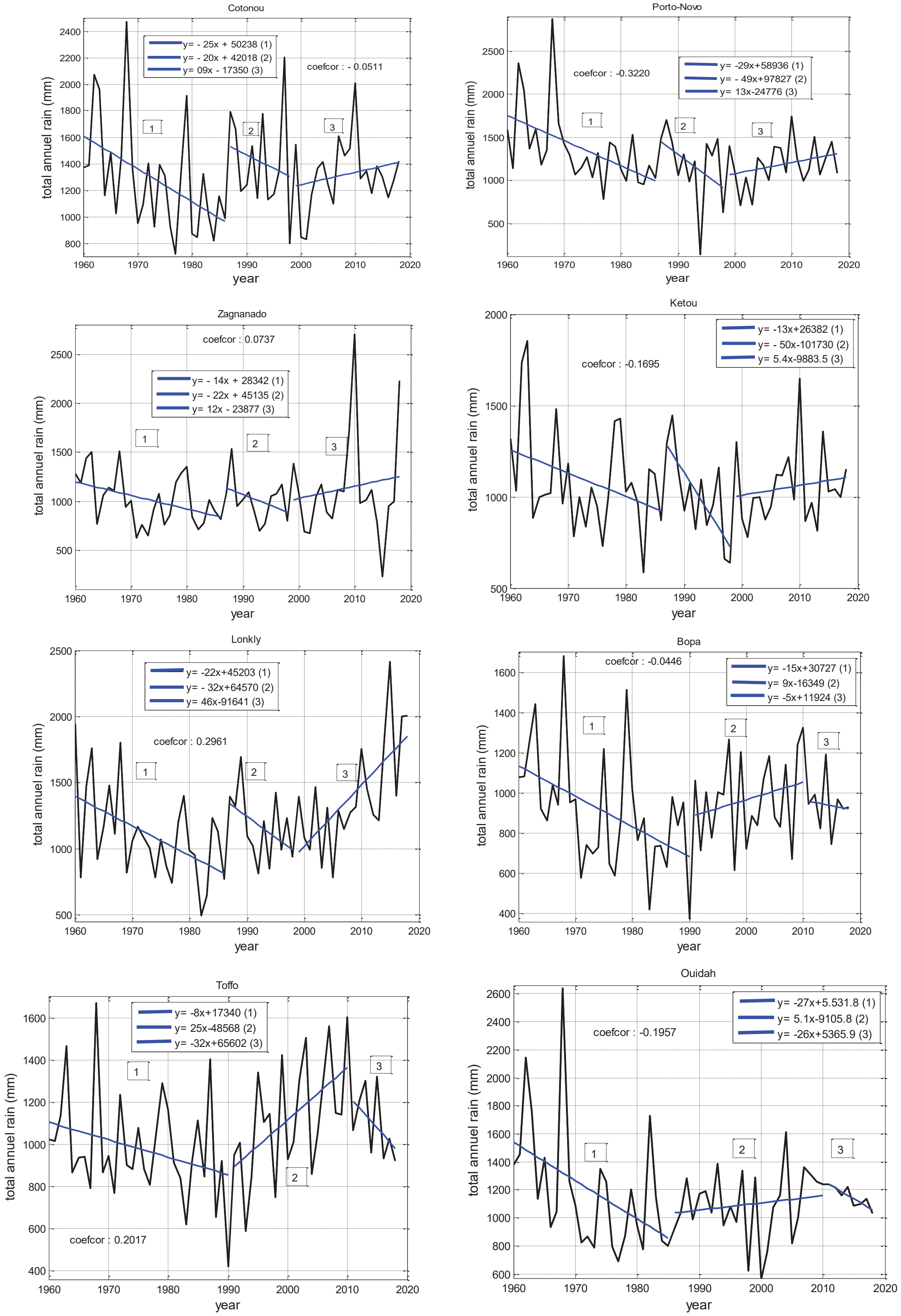

Zagnanado
coefcor:0.0630
rainy day (>= 1mm)
year
y = 0.4679x-858.9417 (1)
y= -0.2404x+545.5930 (2)
y= -0.0115x+88.1862 (3)
Bohicon
coefcor:-0.2699
rainy day
year
y = -1.0000x-2016.4000 (1)
y= 0.2382x-399.0706 (2)
y= -0.2930x+661.2333 (3)
Pobe
coefcor:-0.2478
rainy day
year
y = -1.4000x-2746.4000 (1)
y= -0.0234x+129.8771 (2)
y= -0.5000x+10854 (3)
Adjohoun
coefcor:-0.0204
rainy day
year
y = -0.7x+1378.9 (1)
y= -1.3x+2742.2 (2)
y= -0.9x+1860.5 (3)
Abomey
coefcor:-0.3689
rainy day
year
y = -0.8000x+1655.4 (1)
y= 0.5140x-962.6368 (2)
y= 0.6000x-1183.6000 (3)

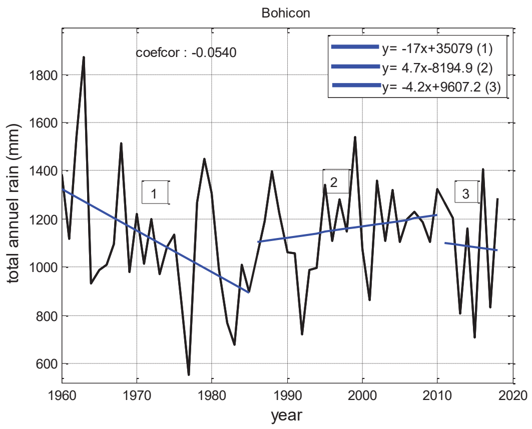
The number of rainy days ≥20mm at the different stations from 1960 to 2018.

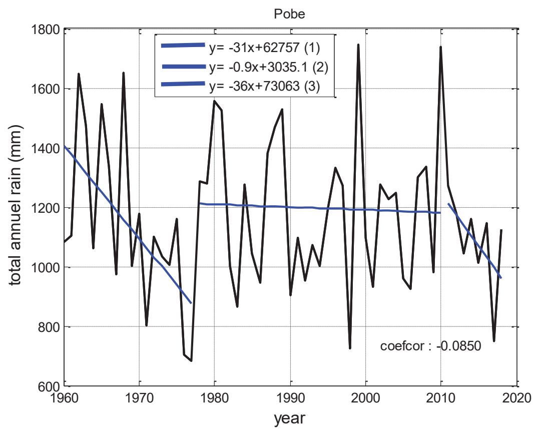


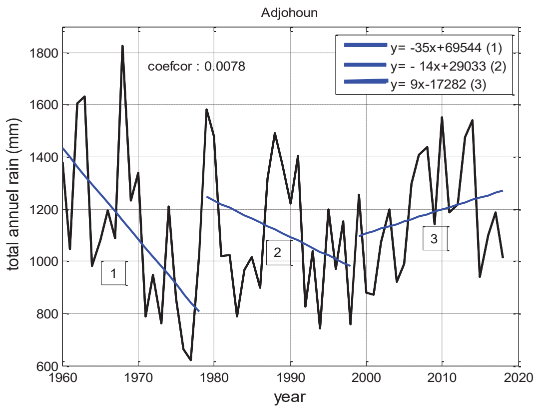

Zagnanado
coefcor:-0.0686
y = -0.9000x + 1694.1000 (1)
y= 0.1463x-273.6098 (2)
day precipitation >= 20mm
year
Bohicon
coefcor:-0.1040
y = -0.3845x + 778.3043 (1)
y= 0.3754x-729.6561 (2)
y= -0.2012x+424.3330 (3)
day precipitation >= 20mm
year
Pobe
coefcor:-0.1575
y = -0.7000x + 1322.3000 (1)
y= -0.0079x+35.4379 (2)
y= -1.2000x+2440.3000 (3)
day precipitation >= 20mm
year
Adjohoun
coefcor:-0.0158
y = -0.6000x+1281.9000 (1)
y= -0.0994x+216.9785 (2)
y= 0.1614x-303.3123 (3)
day precipitation >= 20mm
year
Abomey
coefcor:-0.1816
y = -0.4943x+991.9102 (1)
y= 0.1852x+349.7369 (2)
y= -0.2000x+418.6421 (3)
day precipitation >= 20mm
year

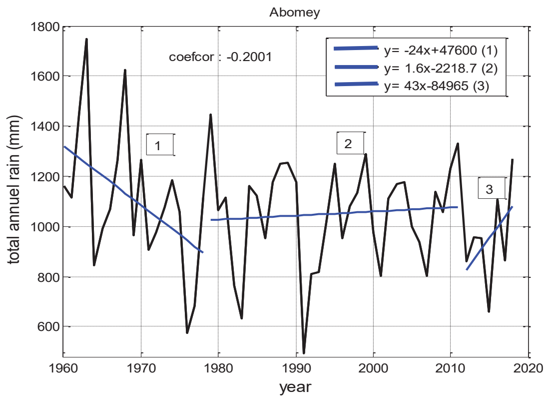
Total annual rainfall at the various stations from 2060 to 2018.

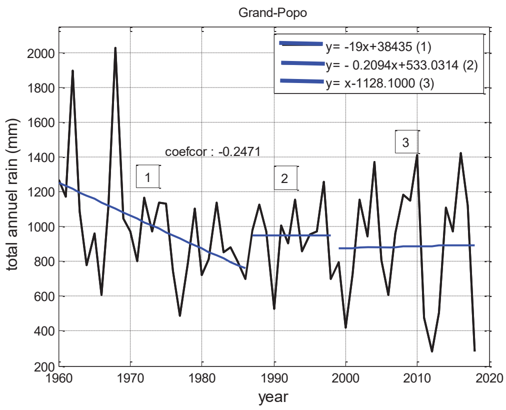



Bohicon
coefcor : -0.0540
y= -17x+35079 (1)
y= 4.7x-8194.9 (2)
y= -4.2x+9607.2 (3)
total annuel rain (mm)
year

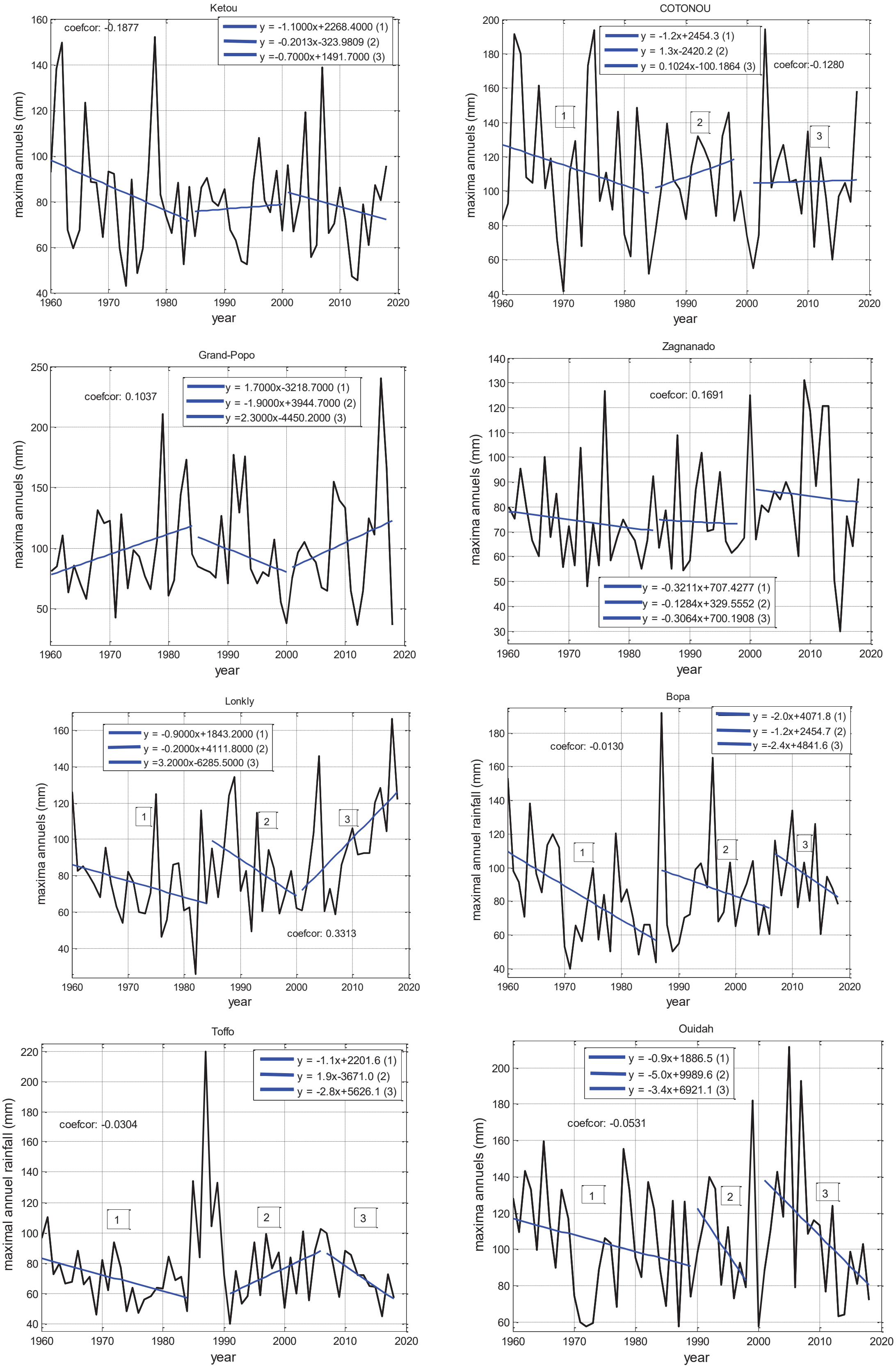

Pobe
y= -31x+62757 (1)
y= -0.9x+3035.1 (2)
y= -36x+73063 (3)
coefcor : -0.0850
total annuel rain (mm)
year

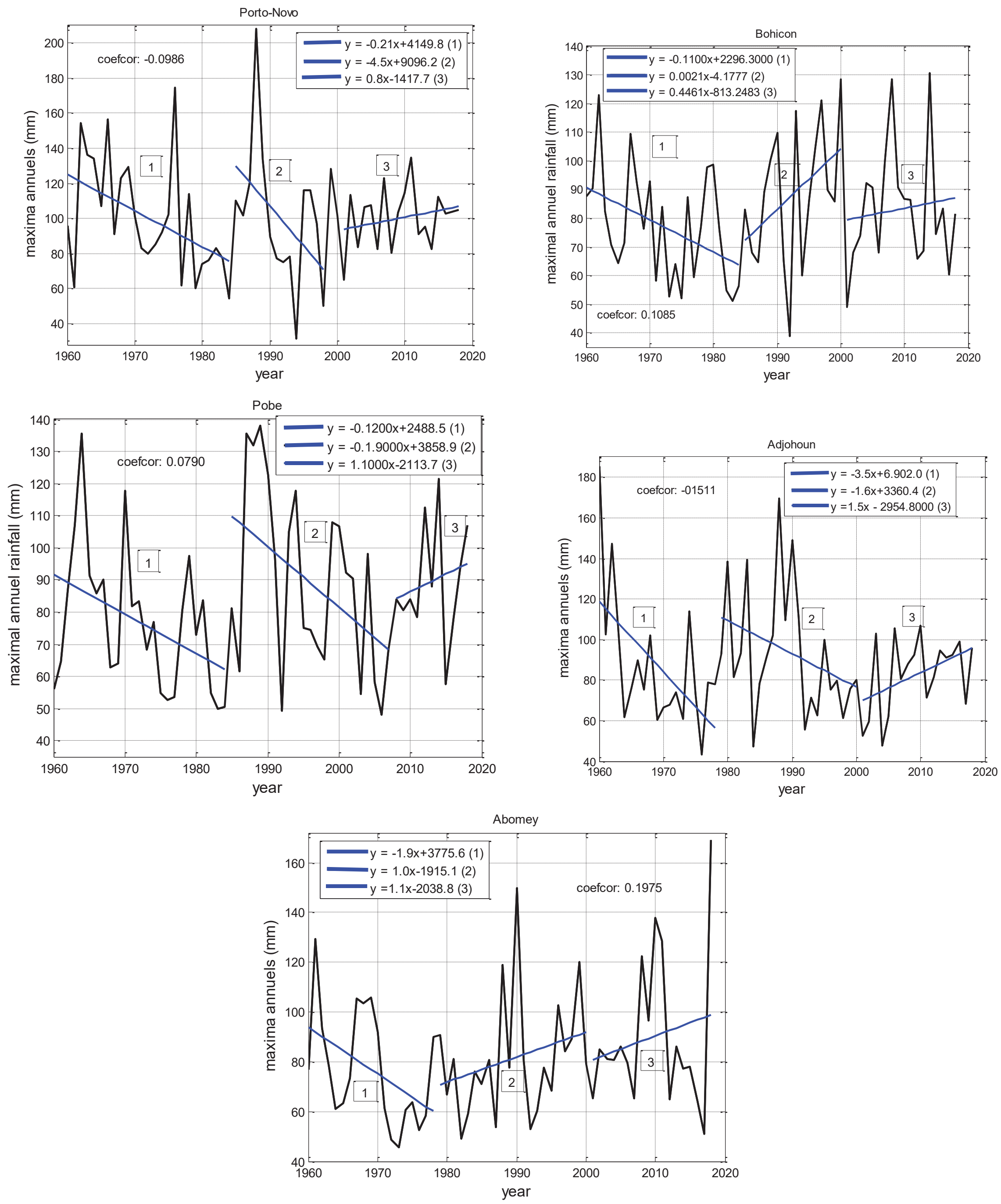

Adjohoun
coefcor : 0.0078
y= -35x+69544 (1)
y= - 14x+29033 (2)
y= 9x-17282 (3)
total annuel rain (mm)
year


Abomey
coefcor : -0.2001
y= -24x+47600 (1)
y= 1.6x-2218.7 (2)
y= 43x-84965 (3)
total annuel rain (mm)
year

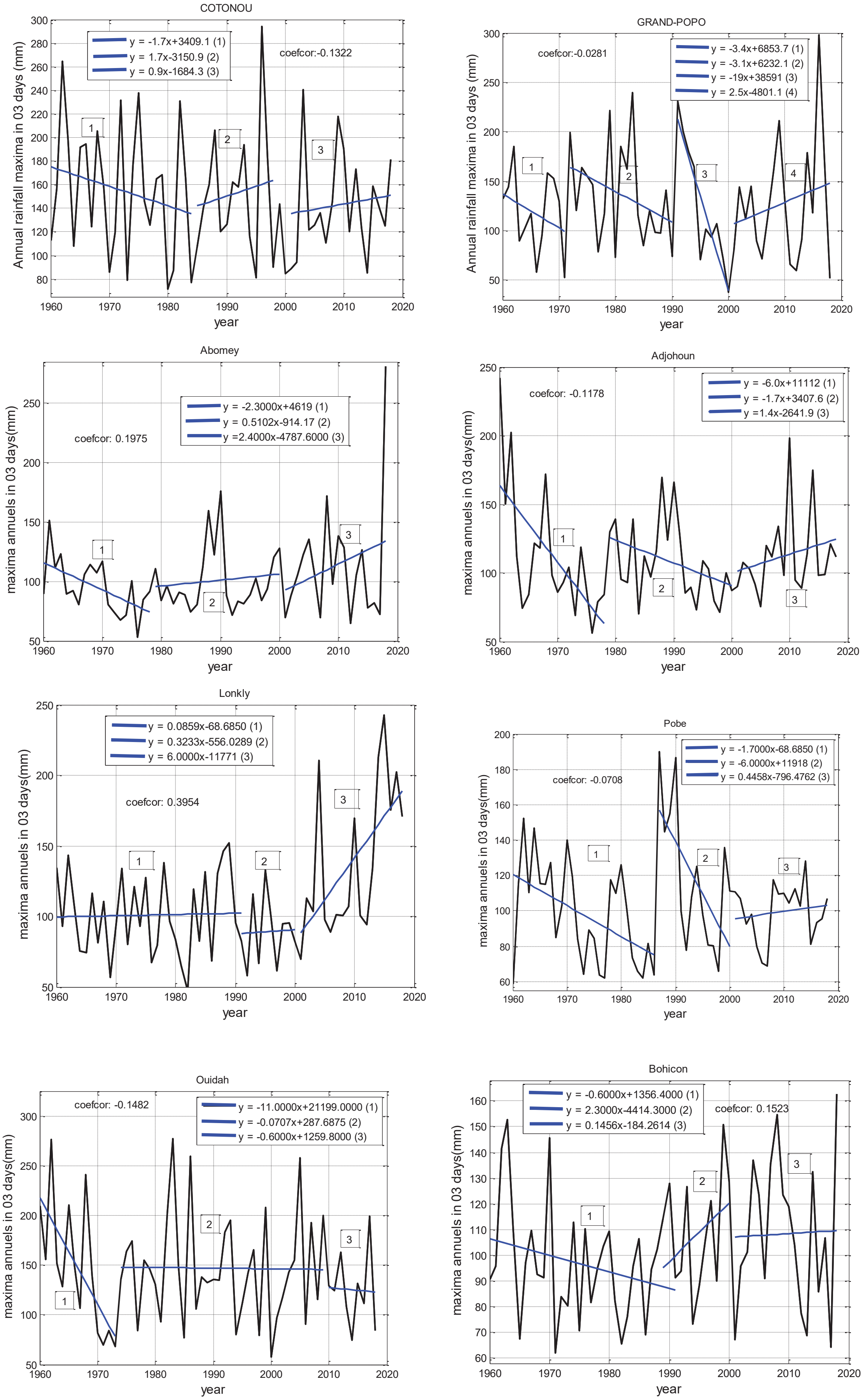

Grand-Popo
y= -19x+38435 (1)
y= - 0.2094x+533.0314 (2)
y= x-1128.1000 (3)
coefcor : -0.2471
total annuel rain (mm)
year

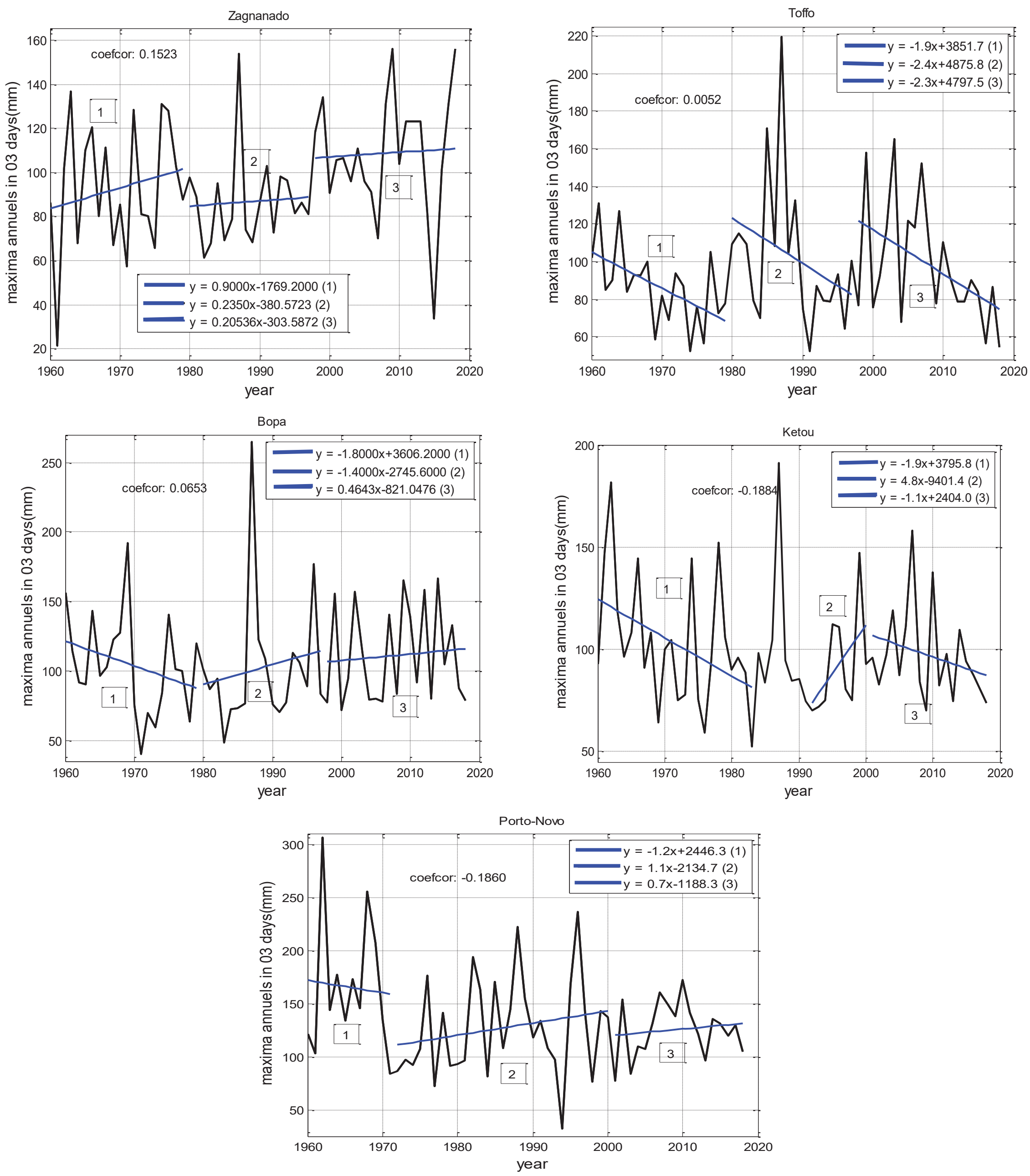
The annual rainfall maxima at the various stations from 1960 to 2018.



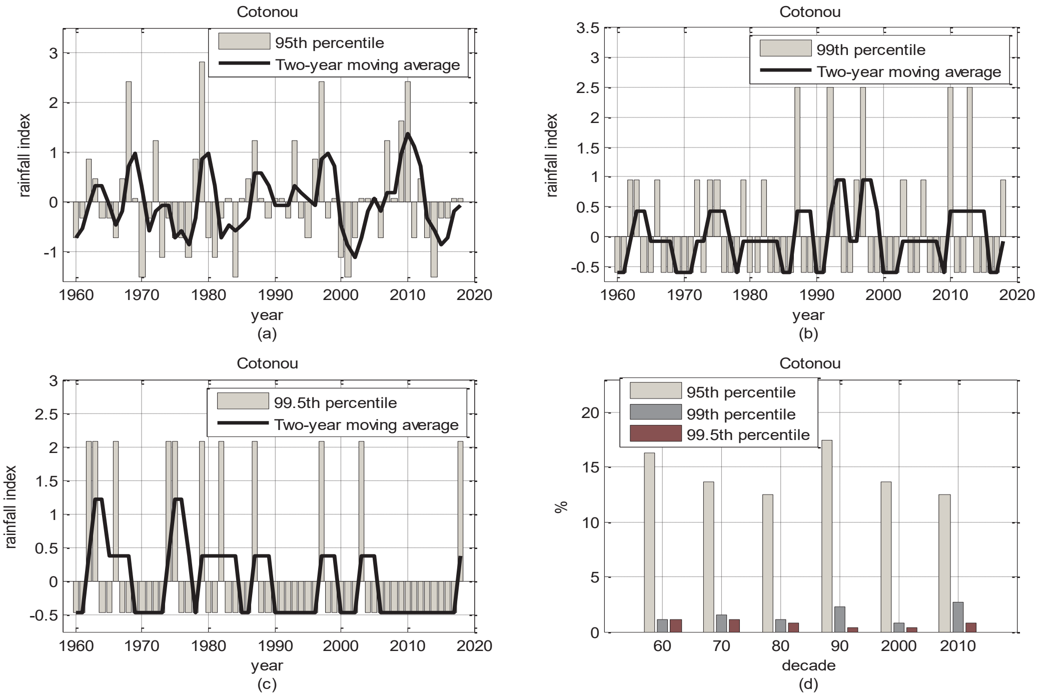

Porto-Novo
coefcor: -0.0986
y = -0.21x+4149.8 (1)
y = -4.5x+9096.2 (2)
y = 0.8x-1417.7 (3)
maxima annuels (mm)
year
Bohicon
y = -0.1100x+2296.3000 (1)
y = 0.0021x-4.1777 (2)
y = 0.4461x-813.2483 (3)
coefcor: 0.1085
maximal annuel rainfall (mm)
year
Pobe
coefcor: 0.0790
y = -0.1200x+2488.5 (1)
y = -0.1.9000x+3858.9 (2)
y = 1.1000x-2113.7 (3)
maximal annuel rainfall (mm)
year
Adjohoun
coefcor: -01511
y = -3.5x+6.902.0 (1)
y = -1.6x+3360.4 (2)
y =1.5x - 2954.8000 (3)
maxima annuels (mm)
year
Abomey
y = -1.9x+3775.6 (1)
y = 1.0x-1915.1 (2)
y =1.1x-2038.8 (3)
coefcor: 0.1975
maxima annuels (mm)
year

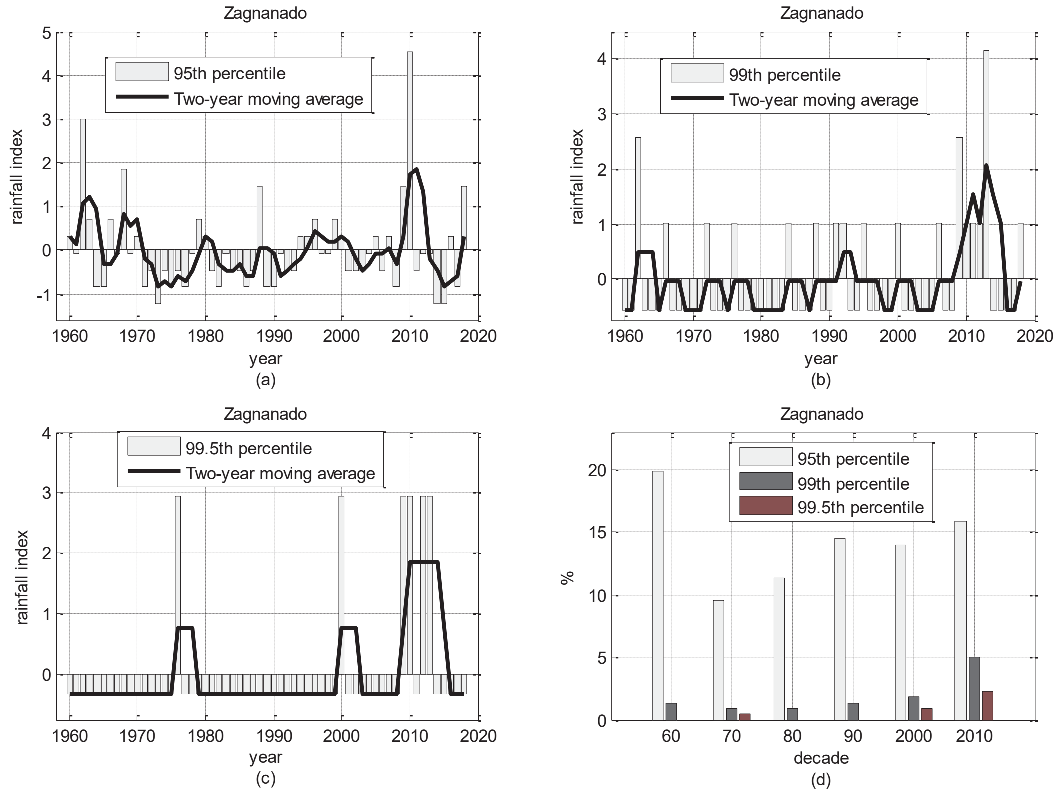
Maximum annual precipitation over three consecutive days at the various stations from 1960 to 2018.

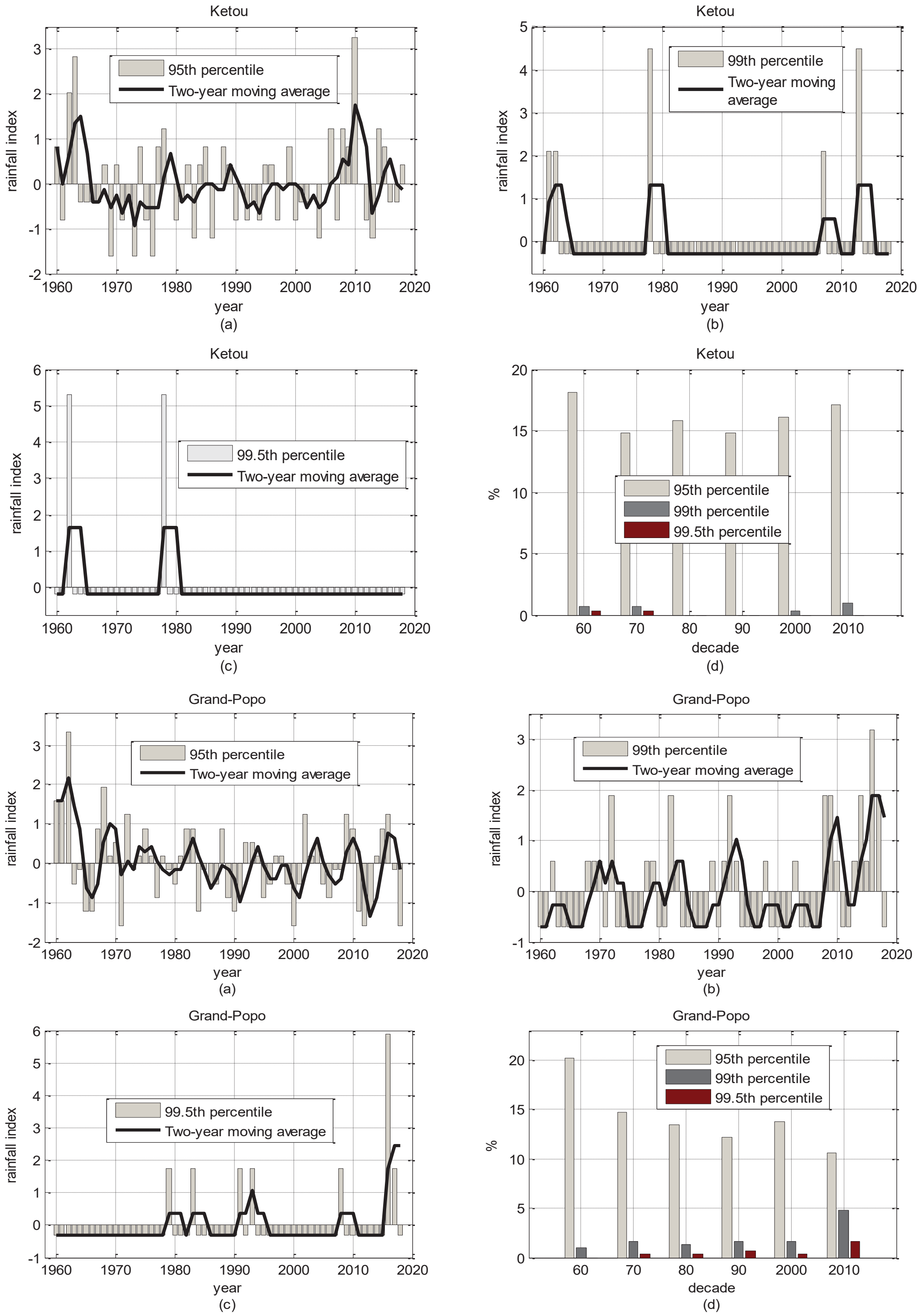


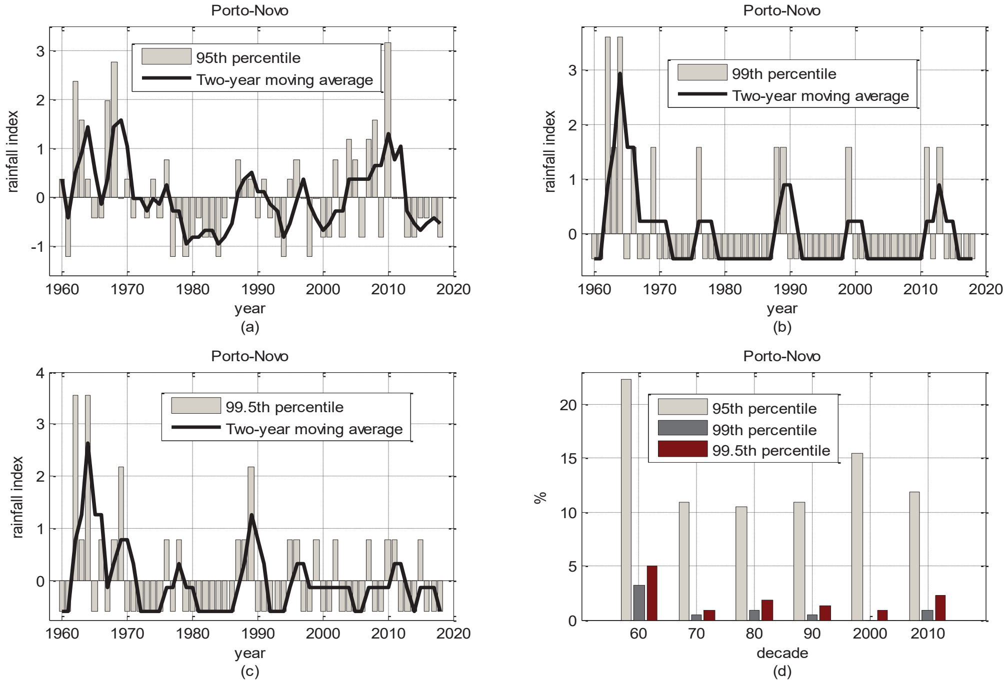

Zagnanado
coefcor: 0.1523
y = 0.9000x-1769.2000 (1)
y = 0.2350x-380.5723 (2)
y = 0.20536x-303.5872 (3)
maxima annuels in 03 days(mm)
year
Toffo
coefcor: 0.0052
y = -1.9x+3851.7 (1)
y = -2.4x+4875.8 (2)
y = -2.3x+4797.5 (3)
Bopa
coefcor: 0.0653
y = -1.8000x+3606.2000 (1)
y = -1.4000x-2745.6000 (2)
y = 0.4643x-821.0476 (3)
Ketou
coefcor: -0.1884
y = -1.9x+3795.8 (1)
y = 4.8x-9401.4 (2)
y = -1.1x+2404.0 (3)
Porto-Novo
coefcor: -0.1860
y = -1.2x+2446.3 (1)
y = 1.1x-2134.7 (2)
y = 0.7x-1188.3 (3)

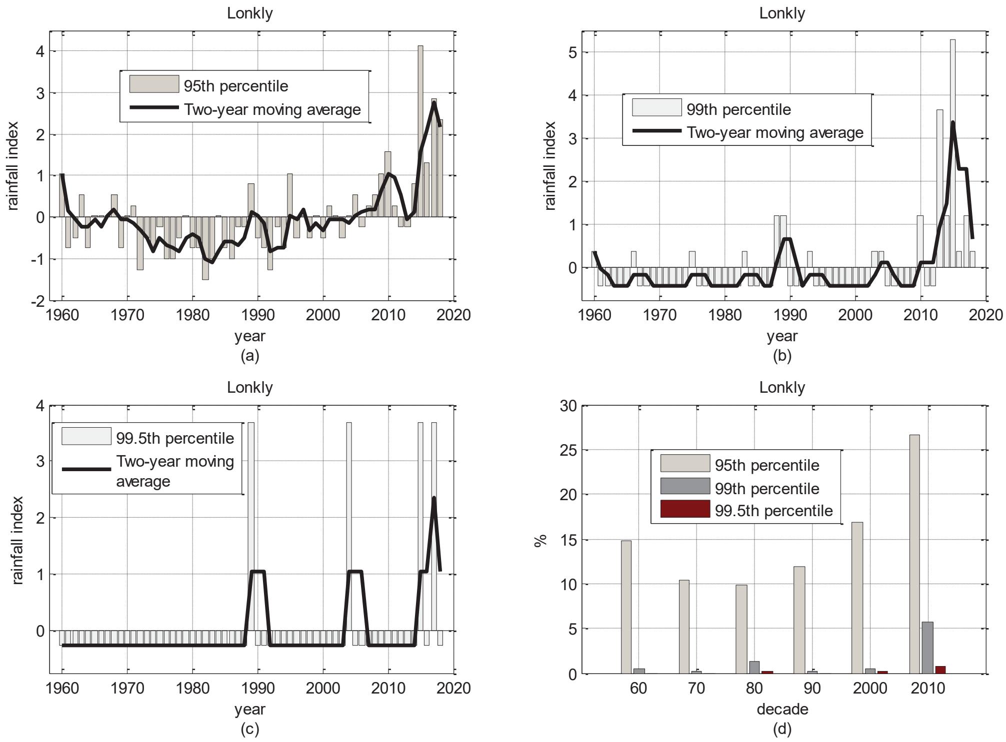
The percentiles at the various stations from 1960 to 2018.

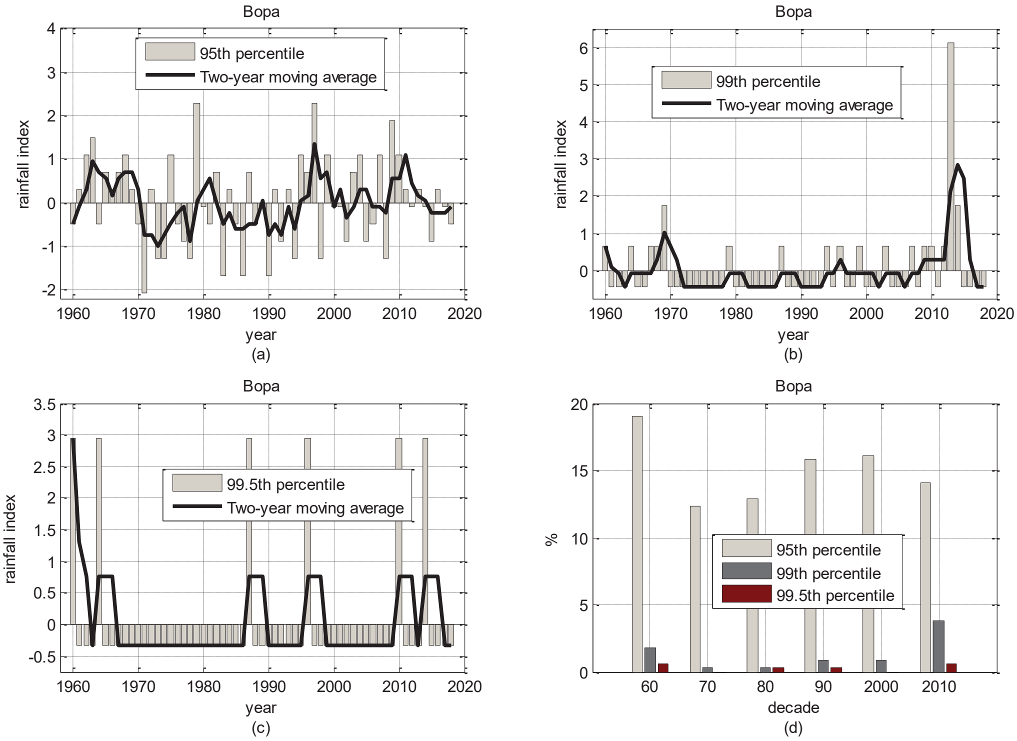


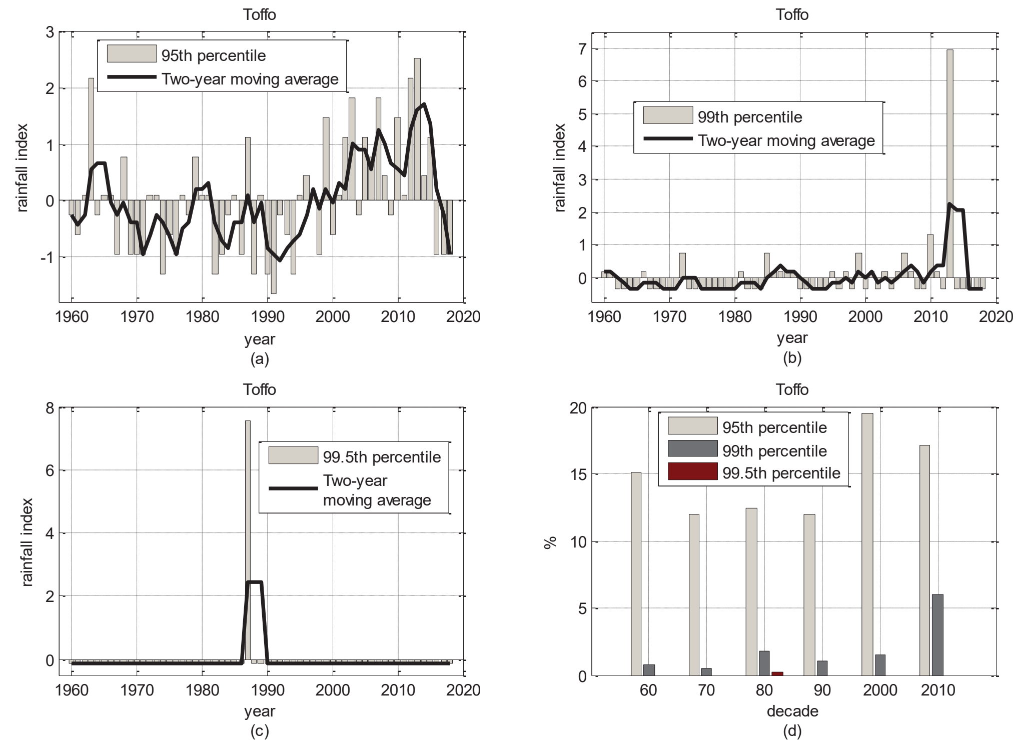


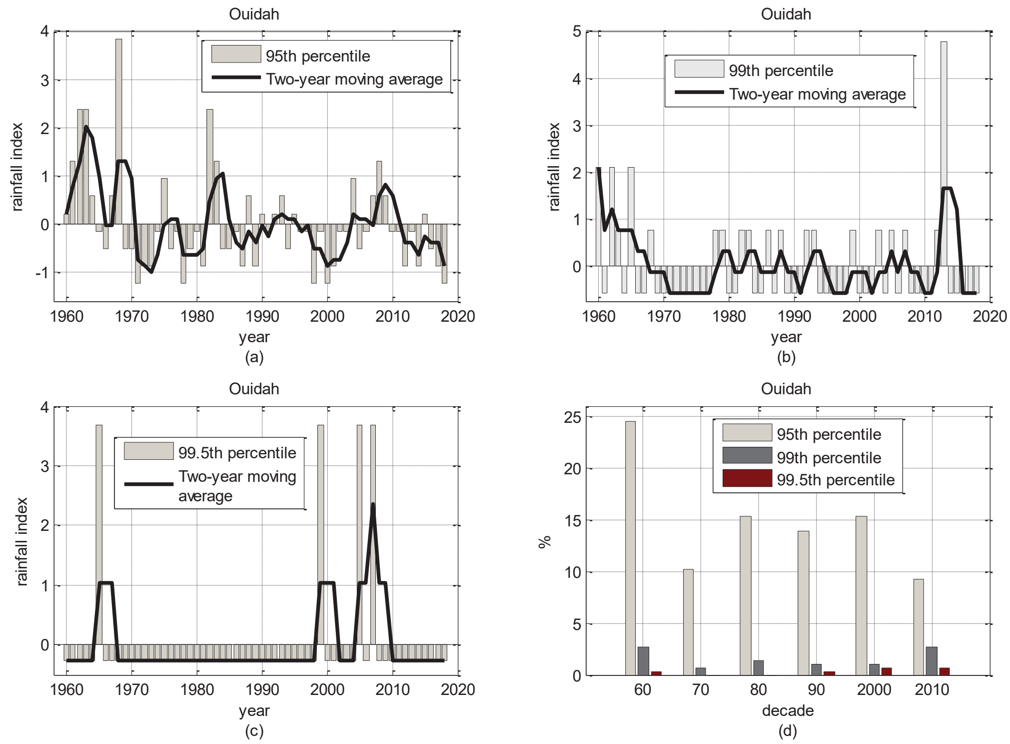

Ketou
95th percentile
Two-year moving average
rainfall index
year
(a)
Ketou
99th percentile
Two-year moving average
rainfall index
year
(b)
Ketou
99.5th percentile
Two-year moving average
rainfall index
year
(c)
Ketou
95th percentile
99th percentile
99.5th percentile
%
decade
(d)
Grand-Popo
95th percentile
Two-year moving average
rainfall index
year
(a)
Grand-Popo
99th percentile
Two-year moving average
rainfall index
year
(b)
Grand-Popo
99.5th percentile
Two-year moving average
rainfall index
year
(c)
Grand-Popo
95th percentile
99th percentile
99.5th percentile
%
decade
(d)

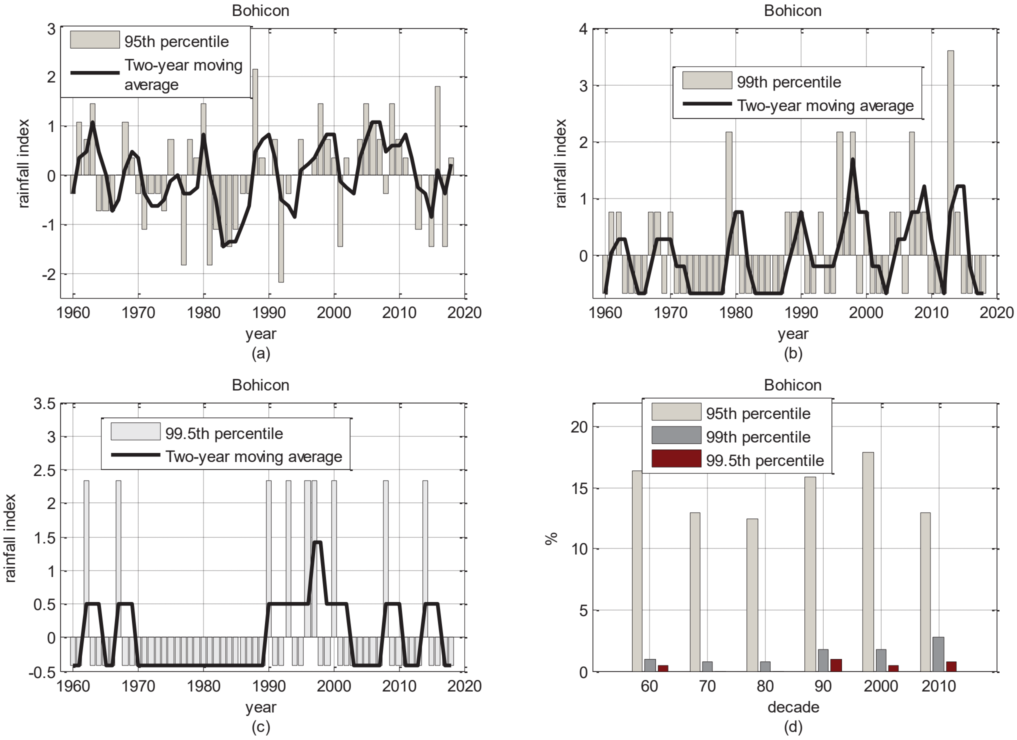

Porto-Novo
95th percentile
Two-year moving average
rainfall index
year
(a)
99th percentile
(b)
99.5th percentile
(c)
99.5th percentile
%
decade
(d)

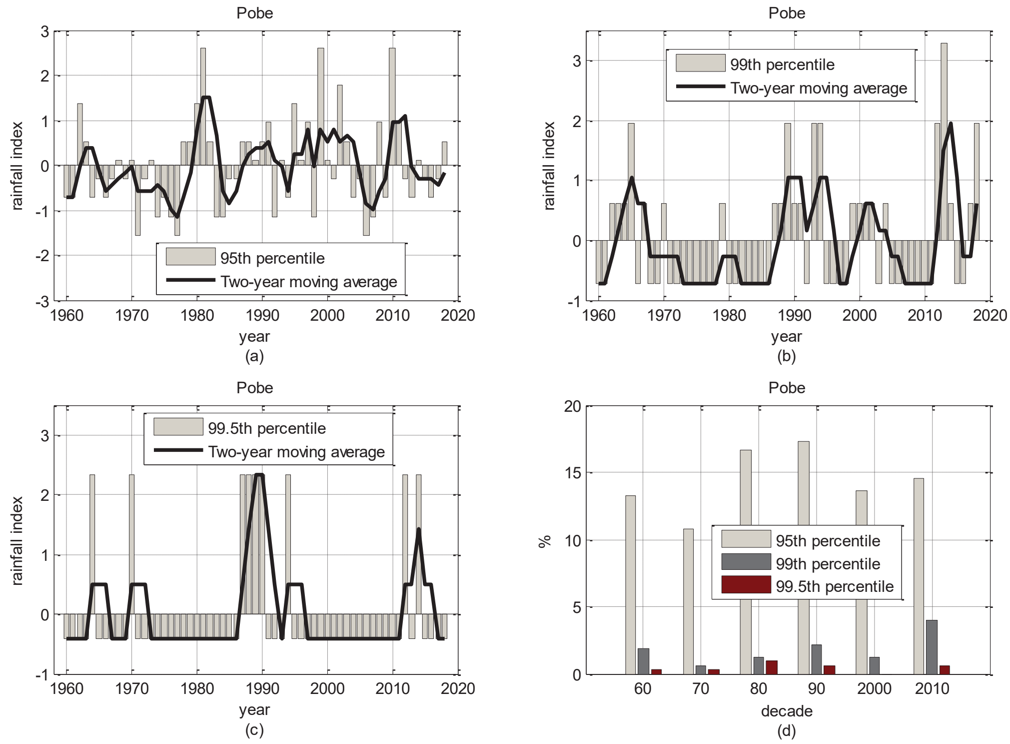

Lonkly
95th percentile
Two-year moving average
rainfall index
year
(a)
99th percentile
(b)
99.5th percentile
Two-year moving average
(c)
%
decade
(d)

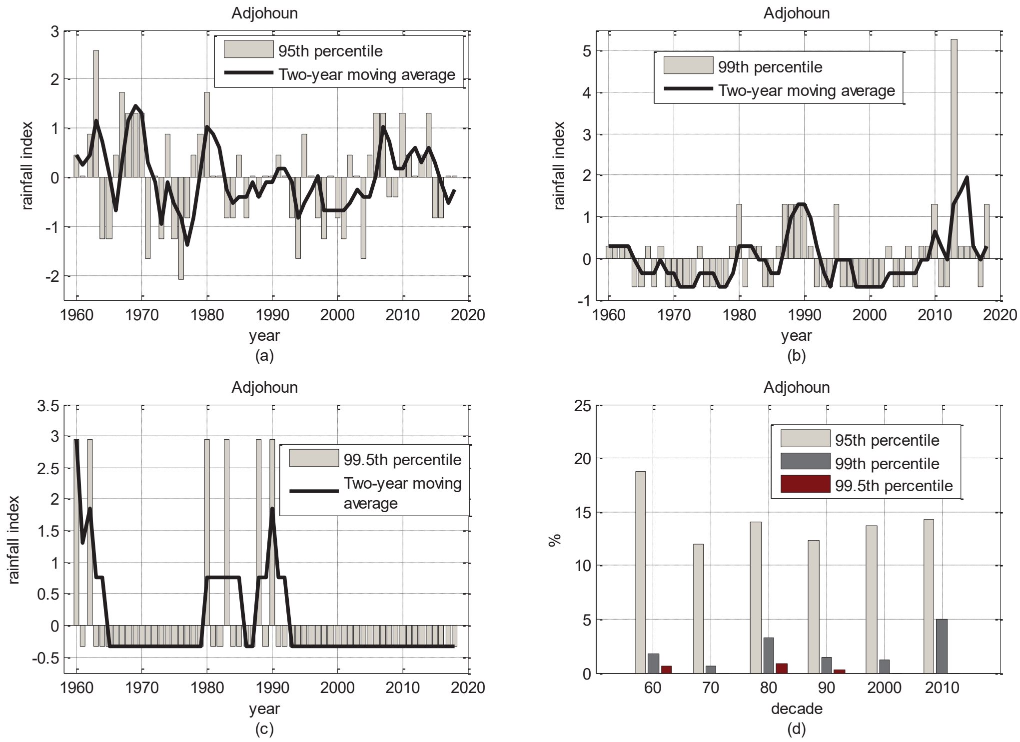

Bopa
95th percentile
Two-year moving average
rainfall index
year
(a)
Bopa
99th percentile
Two-year moving average
rainfall index
year
(b)
Bopa
99.5th percentile
Two-year moving average
rainfall index
year
(c)
Bopa
95th percentile
99th percentile
99.5th percentile
%
decade
(d)

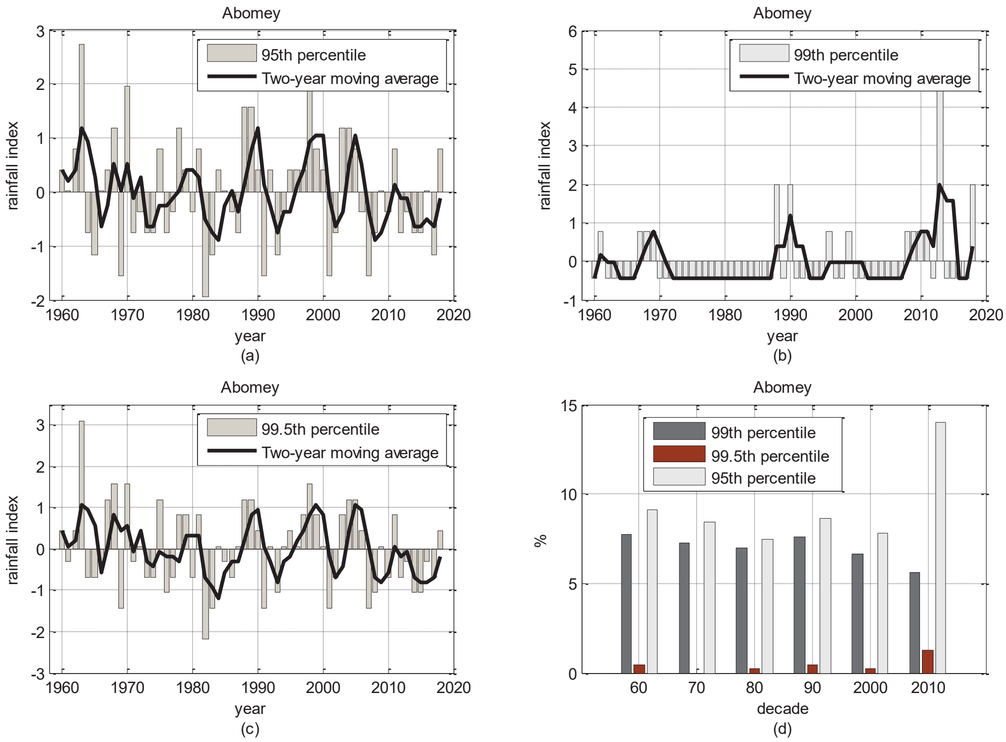

Toffo
95th percentile
Two-year moving average
rainfall index
year
(a)
Toffo
99th percentile
Two-year moving average
rainfall index
year
(b)
Toffo
99.5th percentile
Two-year moving average
rainfall index
year
(c)
Toffo
95th percentile
99th percentile
99.5th percentile
%
decade
(d)


Ouidah
95th percentile
Two-year moving average
rainfall index
year
(a)
Ouidah
99th percentile
Two-year moving average
rainfall index
year
(b)
Ouidah
99.5th percentile
Two-year moving average
rainfall index
year
(c)
Ouidah
95th percentile
99th percentile
99.5th percentile
%
decade
(d)


Bohicon
95th percentile
Two-year moving average
rainfall index
year
(a)
Bohicon
99th percentile
Two-year moving average
rainfall index
year
(b)
Bohicon
99.5th percentile
Two-year moving average
rainfall index
year
(c)
Bohicon
95th percentile
99th percentile
99.5th percentile
%
decade
(d)


Pobe
rainfall index
95th percentile
Two-year moving average
year
(a)
99th percentile
Two-year moving average
(b)
99.5th percentile
Two-year moving average
(c)
%
95th percentile
99th percentile
99.5th percentile
decade
(d)


Adjohoun
rainfall index
95th percentile
Two-year moving average
year
(a)
99th percentile
Two-year moving average
(b)
99.5th percentile
Two-year moving average
(c)
%
95th percentile
99th percentile
99.5th percentile
decade
(d)


Abomey
95th percentile
Two-year moving average
rainfall index
year
(a)
Abomey
99th percentile
Two-year moving average
rainfall index
year
(b)
Abomey
99.5th percentile
Two-year moving average
rainfall index
year
(c)
Abomey
99th percentile
99.5th percentile
95th percentile
%
decade
(d)

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