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Extreme Precipitation Indices Trend Assessment over the Upper Oueme River Valley-(Benin)

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Abstract: This study analyzed trends in extreme precipitation based on daily rainfall data provided by Bénin Méteo Agency for the Upper Ouémé valley in Benin over the period 1951–2014. Eleven indices divided into two groups were considered. The first group consists of frequency indices: number of heavy rainfall days, very heavy rainfall days and extremely heavy rainfall days; and maximum number of Consecutive dry days and wet days. The second group concerns intensity: daily maximum rainfall (RX1day), maximum five-day rainfall (RX5day), annual total wet-day rainfall (PRCPTOT), simple daily intensity index (SDII), very wet day (R95P) and extremely wet day rainfall (R99P). The non-parametric Mann-Kendall test was used to assess trends in those indices. The results show that only 30% of the stations experienced decreasing trends for the number of heavy rainfall days (R10mm) and daily maximum rainfall (RX1day). For the annual total wet-day rainfall (PRCPTOT), the simple daily intensity index (SDII) and the very wet day rainfall (R95P), 20% of stations faced significant negative trends. In addition, the decreasing trends are observed for 10% stations considering the number of very heavy rainfall days (R20mm), the maximum five-day rainfall (RX5day) and the extremely wet day rainfall (R99P). About the increasing trend, 10% stations are identified for the number of consecutive dry days (CDD), very heavy rainfall days (R20mm), the daily maximum rainfall (RX1day), the simple daily intensity index, and the extremely wet day rainfall (R99P). These results show the absence of clear trend of climate indices evolution in almost all stations. Consequently, uncertainties in the evolution of rainfall indices must be taken into account in the definition of adaptation strategies for flood or drought risks. Similarly, these results show a slight drop in the dry sequences of the 1970s and 1980s revealed in the region by previous studies.

Keywords: rainfall; rainfall indices; frequency; intensity; upper Ouémé river valley; Benin

1. Introduction

In recent decades, the accentuation of climate variability has sometimes induced catastrophic floods in many countries over the world, and longer or shorter droughts. The consequences of changes in the frequency and intensity of extreme rainfall and atmospheric electrical activity have been violent winds, lightning and floods. These phenomena seriously impede the socio-economic development of nations and especially poor countries. Indeed, many extreme events influence policy-making in several vital sectors of economic and social development, including agriculture, infrastructure, drinking water supply and transport [1].

In Africa, the last decade has been characterized by frequent floods (notably in the west), which have not even spared the Sahelian countries, such as Senegal, Mali, Burkina Faso, and Niger. Indeed, the African continent was particularly hit in 2007 by floods which affected more than two million lives in the Central and Eastern parts in January, and 2.6 million victims in a large region from west to east in July and August of the same year [2]. West Africa is therefore one of the most vulnerable regions of the continent, often subject to the adverse effects of climate change.

Like many other countries of the West Africa sub-region, Benin is exposed to devastating natural hazards, resulting in loss of life, loss of economic wealth, and environmental damage. These risks are most often floods, violent precipitation, late rains and drought. From 1984 to 2010, severe floods resulting from heavy rains or river overflow origin affected most regions of the country [3].

According to the IPCC report [4], global warming will cause increase of extreme weather events in many parts of the world. This will increase the vulnerability of low income people. Therefore, it is important to know more about how extremes will be fluctuating at several spatial and temporal scales [5]. Most often, extremes are studied by considering their characteristics indices, mainly frequency indices and intensity indices. However, precipitation is the flux of water that governs the partitioning of water on land into runoff and evapotranspiration. As such, a trend/change in time in precipitation partitions is transformed into a change in evapotranspiration and a change in runoff. This has important implications for calculations of development of human water consumption (as change in evapotranspiration) and water availability (as change in runoff) [6,7].

Thus, according to precipitation, the analysis of extreme rainfall is prominent in understanding their previous evolution, current and future trends. This can help in strategies conception to mitigate the effects of climate change. As result, the events have received increased attention in recent years. Many studies have been devoted to trends in extreme weather events in several parts of the world, including Asia [1,8,9], Africa [10–12], Europe [13], America [14] and Australia [15].

The results of those studies vary from one region to another, from country to country and even from one local area to another within the same country. In general, several studies showed that while on some stations, there are clearly decreasing or negative trends in extreme rainfall indices, some other stations showed no statistically significant trends or increasing trends. In fact, historical data from 27 rainfall stations in the Iberian Peninsula in Portugal have presented, over the period 1903–2003, an increasing trend, except in the west and in the Gulf of Cadiz where the stations have provided a decreasing trend [13]. Similarly, in eastern and central Iran (Asia) the seasonal variations in rainfall have significantly decreased whereas in west and north of that country, they have increased over the period 1975–2014 [16].

At small time scale of 15 min to 240 min, increasing trend and decreasing trend in rainfall are also observable in Ivory Coast: [10].

In West Africa, considering the trend analysis of climatic indices, more precisely of extreme rainfall, many studies [10,11,17–19] indicated that there is no uniform trend in all the localities of the region. For example, in Ghana over the period 1960–2011, positive and negative rainfall trends are observed in different localities [11]. Similarly, in Ivory Coast, even at minute scale, trends depend on localities [10]. These results clearly demonstrate the need to continue analyzing the extreme rainfall indices trends because of all uncertainties that the climate change could induce.

In Benin, few studies exist on rainfall indices trends. Considering the daily rains of 21 stations over the period 1960–2000, the annual total rainfall, the annual rainy days as well as the maximal rainfall recorded for 30 days exhibited a decreasing trend [20]. However, there was no trend for the simple daily intensity index, maximum daily rainfall, maximum five-day rainfall, the annual total rainfall of very wet day and extremely wet day indices. This previous work also showed that there is no trend clearly exhibited by the annual number of days with rainfall $\geq$95th percentile and the annual number of days with rainfall $\geq$99th percentile as well as the percentage of annual total rainfall from days with rainfall $\geq$95th percentile and the percentage of annual total rainfall from days with rainfall $\geq$99th percentile.

At the mesoscale of the upper Ouémé river valley, there is a lack of information on the extreme rainfall indices trend because, even though the study by [20] took into account some stations of this region, all the stations were not considered. Moreover, this previous study used data ending at the year 2000. Considering increase in floods events in upper Ouémé river valley, which is an area of large agricultural production and shelters the source of the Ouémé river of which flooding often causes floods in southern Benin, it is suitable to extend the analysis to other parameters of the rainfall regime. To achieve this objective, the work carried out in this research aims to identify climate change in the western central part of Benin using rain gauge data, which provide valuable information due to their direct operational mode. The objective of this study is therefore to provide knowledge and more details about extreme rainfall indices trends to contribute to flood and drought management.

2. Materials and Methods

2.1. Materials

Benin is a West African country with estimated population of 9,983,884 inhabitants [21], situated (Figure 1) between longitudes 1° E and 3°40′ E and latitudes 6°30′ N and 12°30′ N. It borders the Atlantic Ocean in the south; the Federal Republic of Nigeria in the east; Togo in the west; Burkina Faso in northwest; and Niger in the north. The only one mountain chain's height is no more than 600 m and located in western north of the country. The climate is characterized by a bimodal precipitation regime in the south and unimodal rainfall regime in the north while the central part of the country is under a transitional precipitation regime. The mean maximum temperature for the whole country varies between 28 °C and 33.5 °C while the mean of minimum temperature fluctuates between 24.5 °C and 27.5 °C. In the southern part of the country, the mean annual precipitation varies from 1500 mm in the east to 900 mm in the west while in the northern region its varies from 700 mm in the far north to 1200 mm in the middle north. The main important rivers are Mekrou, Alibori and Sota in the north, and Ouémé (the major river of the country), Mono and Couffo in the middle and southern part of the country.

The upper Oueme valley, which is the study area, is located between 9° N and 10° N latitude and 1.5° E and 2.8° E longitude. Its climate is characterized by the alternation of a unique rainy season and a dry season of approximately equivalent duration. The dry period ranges from November to March. All the rivers of this basin are characterized by an intermittent regime.

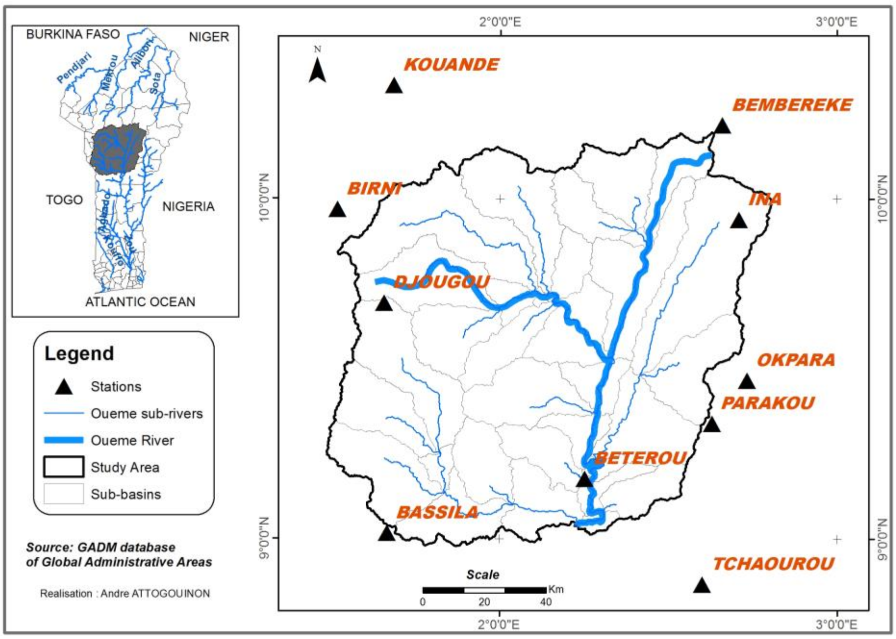

Figure 1. Location of the study area.

The upper Oueme valley basin has about twenty rain gauges. However, due to missing data and lack of large period of observation including temporal homogeneity aspects, we selected for this work only ten daily rain gauges (Table 1) from the whole provided by the Benin Meteo Agency. The graph on the right hand side of Figure 1 shows the spatial distribution of these ten stations. The daily rainfall data are considered over the period 1951–2014.

Table 1. List of selected stations in the Upper Oueme valley.

Stations	Benin Meteo Agency Code	Long (Degree)	Lat (Degree)	Elevation (m)
Bassila	D037	1.667	9.017	384
Bembereke	D024	2.662	10.223	491
Beterou	D036	2.267	9.200	252
Birni	D026	1.517	9.983	430
Djougou	D030	1.662	9.692	439
Ina	D027	2.727	9.969	358
Kouande	D019	1.683	10.333	442
Okpara	D033	2.733	9.467	295
Parakou	D034	2.612	9.357	392
Tchaourou	D038	2.600	325	325

2.2. Methods

2.2.1. Extreme Rainfall Indices

Several extreme rainfall indices are established by the World Meteorology Organization (WMO) [22] and widely used throughout the world [1,8,10,20,23,24]. In this study, eleven of these WMO indices were adopted. These indices, calculated on an annual basis, are defined and summarized in Table 2.

Table 2. Definition of indices.

Indices	Name	Indices Calculation	Definition	Unit
		Frequency Indices (adapted from WMO 2009)		
R10mm	Number of heavy rainfall days	$RR_{ij} \geq 10$ mm	Annual count of days when days rainfall ≥ 10 mm	Days
R20mm	Number of very heavy rainfall days	$RR_{ij} \geq 20$ mm	Annual count of days when days rainfall ≥ 20 mm	Days
R25mm	Number of extremely heavy rainfall days	$RR_{ij} \geq 25$ mm	Annual count of days when days rainfall ≥ 25 mm	Days
CDD	Consecutive dry days	$RR_{ij} < 1$ mm	Maximum number of consecutive days with RR < 1 mm	Days
CWD	Consecutive wet days	$RR_{ij} \geq 1$ mm	Maximum number of consecutive days with RR ≥ 1 mm	Days
		Intensity Indices (adapted from WMO 2009)		
RX1day	maximum Daily rainfall	$Rx1day_j = \max(RR_{ij})$	Maximum 1-day Rainfall	mm
RX5day	maximum 5-days rainfall	$Rx5day_j = \max(RR_{ij})$	Maximum 5-days rainfall	mm
PRCPTOT	Annual wet day rainfall total	$PRCPTOT_j = \sum_{i=1}^{I} RR_{ij}$	Annual total rainfall in wet day (RR > 1 mm)	mm
SDII	Simple daily intensity index	$SDII_j = \frac{\sum_{w=1}^{W} RR_{ij}}{W}$	Annual mean rainfall when PRCP ≥ 1 mm	mm/day
R95p	Very wet day	$R95P_j = \sum_{w=1}^{W} RR_{wj}$	Annual total rainfall when RR > 95 percentile	mm
R99p	Extremely wet day	$R99P_J = \sum_{w=1}^{W} RR_{wj}$	Annual total rainfall when RR > 99 percentile	mm

2.2.2. Trends Detection

The non-parametric Mann-Kendall test is commonly employed to detect monotonic trends in series of environmental data, climate data or hydrological data. One benefit of this test is that the data do not need to conform to any particular distribution. Moreover, data reported as non-detects can be included by assigning them a common value that is smaller than the smallest measured value in the data set. The null hypothesis (H0) is that the data come from a population with independent realizations and are identically distributed. The alternative hypothesis (H1) is that the data follow a monotonic trend. The test compares the relative magnitudes of sample data rather than the data values. The procedure of Mann–Kendall test is based on the calculation of the statistics S defined as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{Sgn}(X_j - X_i) \tag{1}$$

with

$$\mathrm{Sgn}(X_j - X_i) = \begin{cases} +1 \rightarrow \text{if } X_j - X_i > 0 \\ 0 \rightarrow \text{if } X_j - X_i = 0 \\ -1 \rightarrow \text{if } X_j - X_i < 0 \end{cases} \tag{2}$$

where X_j and X_i are the annual values in years j and i, j > i, respectively. If n < 10, the value of $|S|$ is directly compared to the theoretical distribution of S derived by Mann and Kendall. The two tailed test is used. At a certain probability level, H0 is rejected in favor of H1 if the absolute value of S equals or exceeds a specified value $S_{\frac{\alpha}{2}}$, where $S_{\frac{\alpha}{2}}$, is the smallest S which has the probability less than $\frac{\alpha}{2}$ to appear in case of no trend. A positive (negative) value of S indicates an upward (downward) trend.

For $n \geq 10$, the statistic S is approximately normally distributed with the average (E) and variance (Var) as follows:

$$E[S] = 0 \tag{3}$$

$$\mathrm{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{j=1}^{m} t_j (t_j - 1)(2t_j + 5)}{18} \tag{4}$$

where m is the number of the tied groups in the data set and t_j denotes the number of ties to extent j. The summation term in the numerator is used only if the data series contains tied values. If the sample size $n > 10$, the values of S and Var(S) are used to calculate the statistics of standard test Z as follows:

$$Z_s = \begin{cases} \frac{S-1}{\sqrt{\mathrm{Var}(S)}} \rightarrow \text{if } S > 0 \\ 0 \rightarrow \text{if } S = 0 \\ \frac{S+1}{\sqrt{\mathrm{Var}(S)}} \rightarrow \text{if } S < 0 \end{cases} \tag{5}$$

In the same way, the statistics tau (τ) of Kendall are calculated by:

$$\tau = \frac{S}{D} \tag{6}$$

where

$$D = \left[\frac{1}{2}n(n-1) - \frac{1}{2}\sum_{j=1}^{m} t_j (t_j - 1)\right]^{\frac{1}{2}} \left[\frac{1}{2}n(n-1)\right]^{\frac{1}{2}} \tag{7}$$

The statistic Z test is used to measure the importance of the trend. In fact, Z is used to test the null hypothesis H0. If $|Z|$ is greater than $Z_{\frac{\alpha}{2}}$, where α represents the chosen significance level (for example, 5% with $Z_{0.025}$ = 1.96), then the null hypothesis is invalid, implying that the trend is significant.

The trends of the extreme indices of precipitations were calculated using Mann-Kendall test with R.

The analysis of trend is carried out to identify the possible temporal changes of the frequency and the intensity of the extreme precipitations. This study used 5% as significance threshold. If the value (*p*-value) is lower than this threshold, H0 is rejected. By rejecting the null assumption, the result indicates an increasing (decreasing) trend when Z value is positive (negative).

When a monotonic trend is detected, its magnitude is calculated by the Sen's slope method [25]. The Sen's slope β corresponds to the calculation of the median of the slopes calculated on each peer of points in the time series where each measurement is performed at regular intervals. β is calculated as follows:

$$\beta = Median\left(\frac{X_i - X_j}{i - j}\right) \forall j < i \tag{8}$$

where X_i and X_j are data values at time t_i and t_j ($i > j$), respectively.

3. Results

3.1. Trends in Frequency Indices

The results for the frequency indices are summarized in Table 3. These results show that, at 5% significance threshold, no clear trend at annual time scale is detected over the study period for all the frequency indices in most stations except R10mm, R20mm and CDD index, respectively, in three, two and one of the stations.

The number of R10mm presents a decreasing trend at 30% of the stations (Table 4). For the number of R20mm, decreasing and increasing trends were detected, respectively, for 10% of the stations. On the other hand, there is an increasing trend for CDD only for 10% of the stations. The absence of trend, especially for R25mm, CWD and CDD except in Bassila indicates a stability of these indices evolution in the study area. Even if there is absence of trends for the frequency indices, the values of Z(S) reflect no statically significant negative trends in approximately 70% of the stations for each index R10mm, R20mm and R25mm (Table 4). This situation indicates the scarcity of such extreme precipitations in the area. Nevertheless, Z(S) presents more positive values than negative values for CWD and CDD. Moreover, in most cases, at each station if Z(S) is negative for CWD, then its value is positive for CDD and vice versa. Furthermore, the magnitude of frequency indices trends is low. Indeed, as shown by Table 3, the absolute value of the Sen's slope for each of these indices is close to zero. The evolution of frequency indices and that of their trends with their magnitude are shown in Appendix A.

Table 3. Results of Mann–Kendall and Sen tests for the frequency indices.

Stations	R10m			R20m			R25m			CDD			CWD		
	Z	*p*-Value	β	Z	*p*-Value	β	Z	*p*-Value	β	Z	*p*-Value	β	Z	*p*-Value	β
Bassila	−2.5	0.013	−0.1467	−1.6	0.105	−0.0769	−0.7	0.497	−0.0217	4.9	7.59×10^{-7}	0.1398	−1.5	0.133	−0.183
Bembereke	−2.4	0.016	−0.1079	−2.3	0.023	−0.075	−1.7	0.089	−0.0465	−1	0.303	−0.0253	−1.8	0.066	−0.126
Beterou	−0.5	0.626	−0.0294	0.6	0.535	0.0278	0.7	0.510	0	−1.1	0.270	−0.0182	0.7	0.496	0.048
Birni	1.8	0.071	0.0769	2.4	0.018	0.1111	1.6	0.120	0.0588	0.8	0.418	0.0171	−1.5	0.124	−0.138
Djougou	−0.2	0.825	0	−1.2	0.241	−0.0533	−1.9	0.058	−0.069	−0.5	0.624	0	0.6	0.582	0.052
Ina	0.1	0.949	0	−0.3	0.05	0	−0.4	0.718	0	−0.5	0.605	0	0.9	0.391	0.071
Kouande	−2	0.044	−0.0909	−1.8	0.05	−0.0625	−1.4	0.156	−0.0333	0.7	0.511	0	−0.5	0.618	−0.033
Okpara	−1.8	0.079	−0.1042	−1.1	0.276	−0.0385	−0.8	0.437	0	0.8	0.423	0.02	−1.4	0.165	−0.111
Parakou	−4	0.150	−0.0682	0	0.963	0	−0.7	0.485	0	0.1	0.926	0	1.1	0.291	0.075
Tchaourou	−0.7	0.497	−0.031	−0.6	0.558	−0.0235	−0.4	0.693	0	−0.3	0.771	0	0	0.972	0

Trends statistically significant at 5% level.

Table 4. Percentage of significant and no significant trend frequency index.

Indices	Significant Positive Trend (%)	No Significant Positive Trend (%)	Significant Negative Trend (%)	No Significant Negative Trend (%)
R10mm	0	20	30	50
R20mm	10	10	10	70
R25mm	0	20	0	80
CWD	0	40	0	60
CDD	10	40	0	50

3.2. Trends in Intensity Indices

The intensity indices trends results are presented from Table 5. The analysis of these results shows that there is no uniform trend over the entire study period for all stations and for all indices. However, the null assumption is rejected for 20%, 30%, 40%, 10%, 20% and 20% of stations, respectively, for PRCPTOT, SDII, RX1day, RX5day, R95P and R99P indices (Table 6). For RX1day, three stations showed a decreasing trend and one station an increasing trend (Table 5). About RX5day, only one station showed a decreasing trend (Table 5). As for SDII, two stations showed a decreasing trend and one station an increasing trend (Table 5). Finally, PRCPTOT and R95P showed decreasing trend at two stations, while R99P shows decreasing and increasing trends respectively at one station (Table 5).

The intensity indices present more trend than the frequency indices. As well as the frequency indices R10mm, R20mm and R25mm, Z(S) values reflect the negative trend in roughly 80% of the stations for each intensity indices PRCPTOT and SDII. Thus, PRCPTOT index evolution depends not only on SDII but also on R10mm, R20mm and R25mm. As for frequency indices, the magnitude of intensity index trends is low except for the PRCPTOT and R95P in some stations. The value of Sen's slope is near to zero for PRCPTOT at Bassia, Bembereke, Birni, Djougou, kouande and Okpara and for R95P in Bassila and Bembereke. The evolution of intensity indices and that of their trends with their magnitude are shown in Appendix B.

The figures in Appendixs A and B show that the distribution of frequency and intensity indices presents their low values between 1970 and 1990 and their high values between 1951 and 1970 then between 1990 and 2014 except for the CDD which presents the opposite situation. They are especially the PRCPTOT high values of 1951–1970 and 1990–2014 periods, which weakened the downward trends caused by the dryness of the 1970s and 1980s.

Table 5. Results of Mann–Kendall and Sen tests for the intensity indices.

Stations	RX1day			RX5day			PRCPTOT			SDII			R95P			R99P		
	Z	*p*-Value	β	Z	*p*-Value	β	Z	*p*-Value	β	Z	*p*-Value	β	Z	*p*-Value	β	Z	*p*-Value	β
Bassila	−2.7	0.008	−0349	−1.7	0.083	−0.288	−2.5	0.012	−4.24	0,3	0.741	0.011	−3.8	0.0001	−1.268	−1.8	0.072	−0.257
Bembereke	−2	0.044	−0.277	−1.4	0.169	−0.281	−2.5	0.013	−3.89	−1.4	0.159	−0.025	−2.4	0.016	−1.195	−2	0.044	−0.277
Beterou	0.4	0.662	0.083	0.5	0.627	0.107	0.4	0.715	0.775	−0.1	0.932	−0.0007	0.6	0.535	0.344	0.7	0.508	0.106
Birni	−0.5	0.634	−0.045	0.1	0.954	0	0.6	0.574	1.039	2.3	0.021	0.053	−0.07	0.397	−0.208	0	0.972	0
Djougou	−0.2	0.876	−0.012	−0.3	0.749	−0.067	−0.7	0.513	−1.04	−2	0.044	−0.030	0.3	0.772	0.105	1.1	0.263	0.167
Ina	−3.5	0.0005	−0.483	−2.2	0.028	−0.39	−0.3	0.754	−0.46	−2.2	0.025	−0.031	−1.6	0.103	−0.601	−1.2	0.246	−0.138
Kouande	0.1	0.958	0.006	0.9	0.382	0.209	−1.6	0.119	−2.38	−1.2	0.224	−0.016	0.3	0.749	0.116	−0.2	0.830	−0.021
Okpara	1	0.323	0.180	−0.6	0.522	−0.15	−1.3	0.209	−2.37	−0.3	0.768	−0.004	−0.4	0.671	−0.189	0.7	0.509	0.1412
Parakou	2.1	0.039	0.326	0.4	0.694	0.0672	−0.4	0.715	−0.45	−0.4	0.668	−0.008	1.7	0.082	0.827	2.2	0.026	0.3544
Tchaourou	−0.1	0.903	−0.018	−0.3	0.754	−0.065	−0.5	0.647	−0.75	−0.6	0.524	−0.013	−0.8	0.404	−0.436	0.5	0.626	0.064

Trends statistically significant at 5% level.

Table 6. Significant and no significant trend percent of intensity index.

Indices	Significant Positive Trend (%)	No Significant Positive Trend (%)	Significant Negative Trend (%)	No Significant Negative Trend (%)
RX1day	10	30	30	30
RX5day	0	40	10	50
PRCPTOT	0	20	20	60
SDII	10	10	20	60
R95P	0	40	20	40
R99P	10	40	10	40

4. Discussion

The climatic analysis carried out on the daily rainfall series did not detect a generalized change in the frequency and intensity indices. The analysis showed an almost total absence of statistically significant trends for all the studied variables.

The results show, for almost all the indices of frequency, an absence of trend. For stations that experienced some frequency indices (R10mm, R20mm and CDD) trends, the extents are less significant. These findings confirm those of Hountondji [13] for most stations in Benin over the period 1960–2000. For intensity indices, many more trends are observed than the case of frequency indices. Nevertheless, the extent of these trends remains also weak except PRCPTOT. This situation could be explained on one hand by the great variability of the precipitations and the random behavior of convective processes which influence the PRCPTOT. Trend absence noted can also be explained by the test of Kendall which supposes a single trend in the data while several changes of the direction of trend can occur. The trend of CDD and CWD that is not clear, indicates the resumption of precipitations in the study area. This result corroborates the findings of Nicholson [26] which reported the reduction of the negative anomalies of precipitation compared to the reference period 1961–1990, with a certain resumption of the precipitations during the decade 1990. In spite of the negative evolution of PRCPTOT and CWD respectively for 80% and 60% of the stations, the number of consecutive dry days does not present positive trend. Thus, the dry sequences seem to have undergone weak changes. That means that the onset and cessation of the rainy season did not experience any modification over the period 1951–2014. PRCPTOT and CWD indices evolution is the consequence of dry sequences attenuation after the 1980s. This result confirms the "rainfall recovery" during the 1990s noted by Ozer [27] for the Sahelian area and Lawin [28] for the study area.

The negative SDII evolution (80% stations) indicates that the changes in intensity of precipitation do not depend necessarily on CWD evolution. However, CWD and PRCPTOT trends are similar on 50% of stations.

Nevertheless, R10mm, R20mm, R25mm, RX1day, RX5day, R95P and R99P indices presented the same trend with PRCPTOT over the period 1951–2014 in almost all the stations. These results show that the annual total precipitation depends on extreme precipitation observed for the period 1951–2014. Thus, the floods recorded in the upper Ouémé river valley during these last decades result from the strong precipitations that occur in zone.

5. Conclusions

The results obtained in this work showed an almost total absence of trend in the frequency indices. Only R10m showed a decreasing trend at Bassila, Bembereke and Kouande; R20m a decreasing trend at Bembereke and an increasing trend at Birni; and CDD showed an increasing trend in Bassila.

As for the intensity indices, they showed more trends than the frequency indices. Decreasing trends are more observed than increasing trends for RX1day, RX5day, PRCPTOT, SDII, R95P, and R10mm, at 30%, 10%, 20%, 20%, 20%, and 30% of stations, respectively. For increasing trend, only CDD faced it, at 10% of stations. About R20mm and R99P decreasing and increasing trends were detected respectively for 10% of the stations.

This study revealed that the upper Ouémé river valley is dominated by non-significant trends.

Bassila, Bembereke, Kouande and Okpara stations exhibited a decrease (negative Z values) in the PRCPTOT and CWD indices, while Beterou station showed an increase for these two parameters (positive Z values). At Birni, a growth of the SDII index is identified. This increase of SDII index is due to the increase in PRCPTOT index and a reduction in the number of wet days. On the other hand, a reduction in the SDII index is recorded at Djougou, Ina, Parakou and Tchaourou stations where the PRCPTOT decreases and the number of wet days increases. Furthermore, Bassila, Bembereke, Birni and Ina experienced a decrease of R95P and R99P while Beterou, Djougou and Parakou showed a slight decrease for these two parameters.

More globally, the analysis of the evolution of the rainfall indices over the period 1951–2014 underlined the non-significant decreasing of the PRCPTOT index, indicating a rainfall recovery in the study region. This trend is partially due to an insignificant reduction of the number of consecutive dry days caused mainly by the wet period 1990–2014. Furthermore, at local scale, the annual rainfall trend seems to be correlated both to the number of heavy, very heavy and extremely heavy rainfall days as well as the simple rainfall intensity indices. Thus, if water consumption and availability have indeed changed in the study area during this period, it must be due to other drivers such as human activities.

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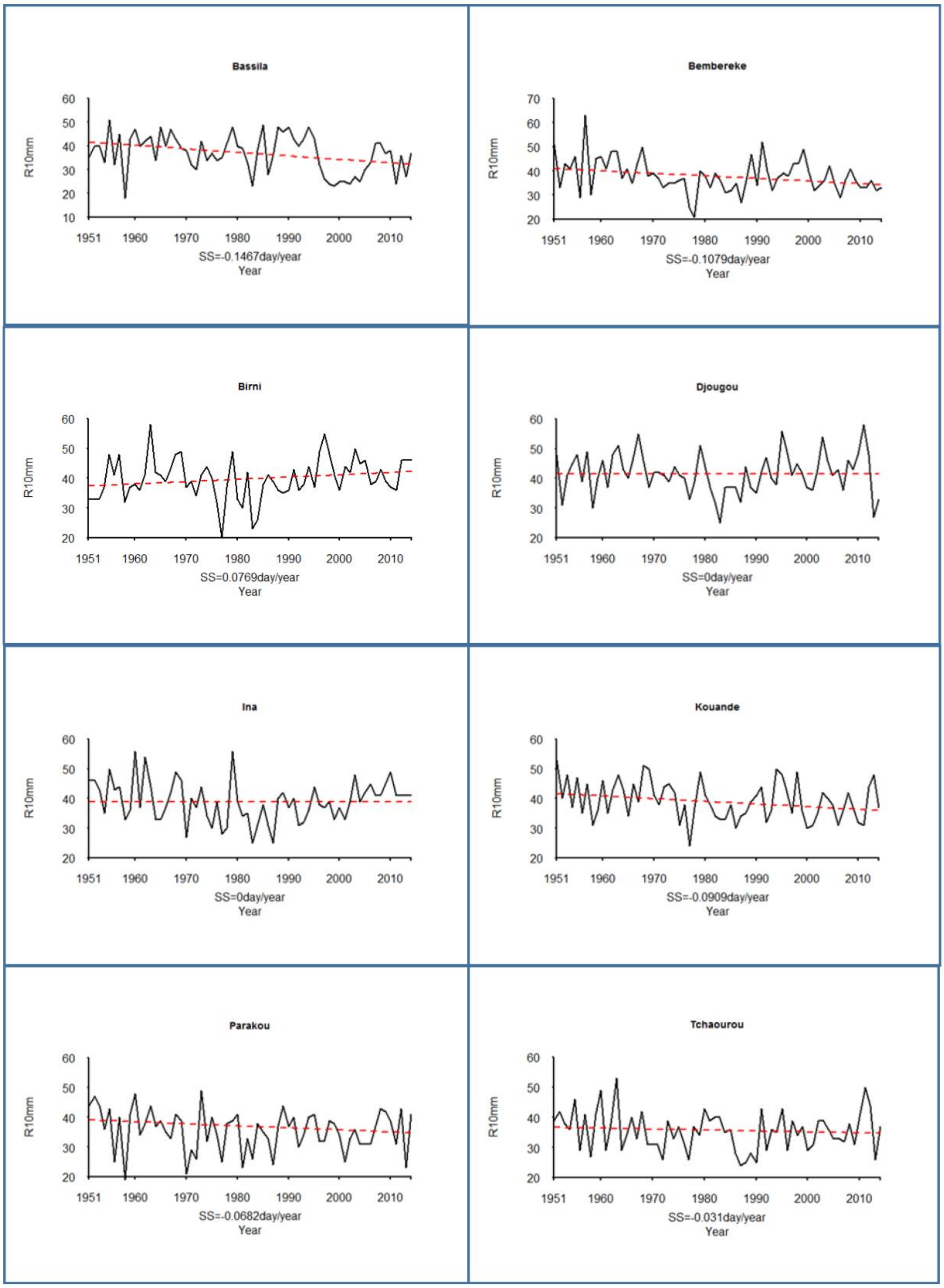
Author Contributions: André Attogouinon and Emmanuel Agnidé Lawin conceived the study, collected and analyzed data, while Yèkambèssoun N'Tcha M'Po and Rita Houngue contributed appreciably to the interpretation of the results and the writing of manuscript.

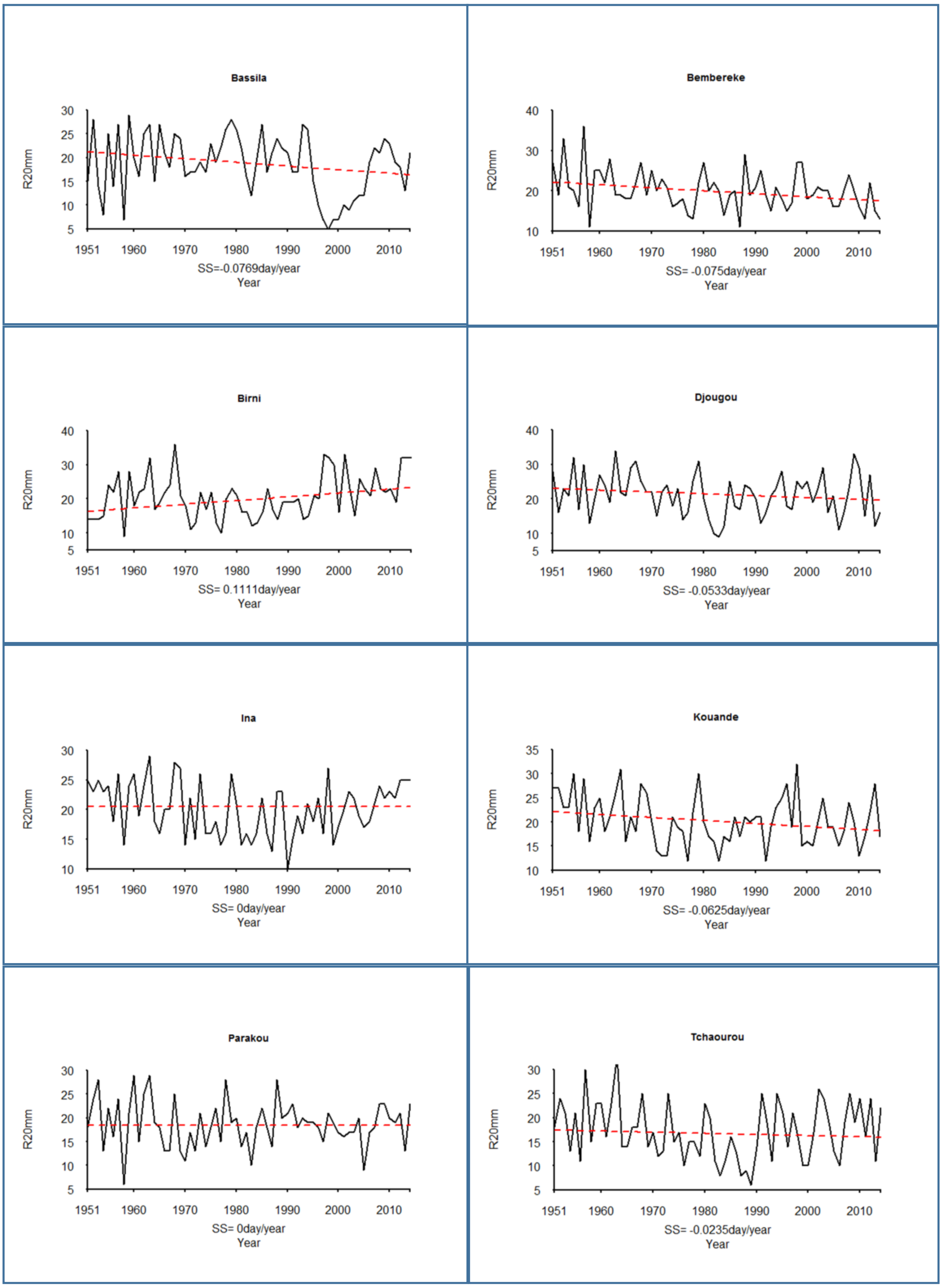
Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A



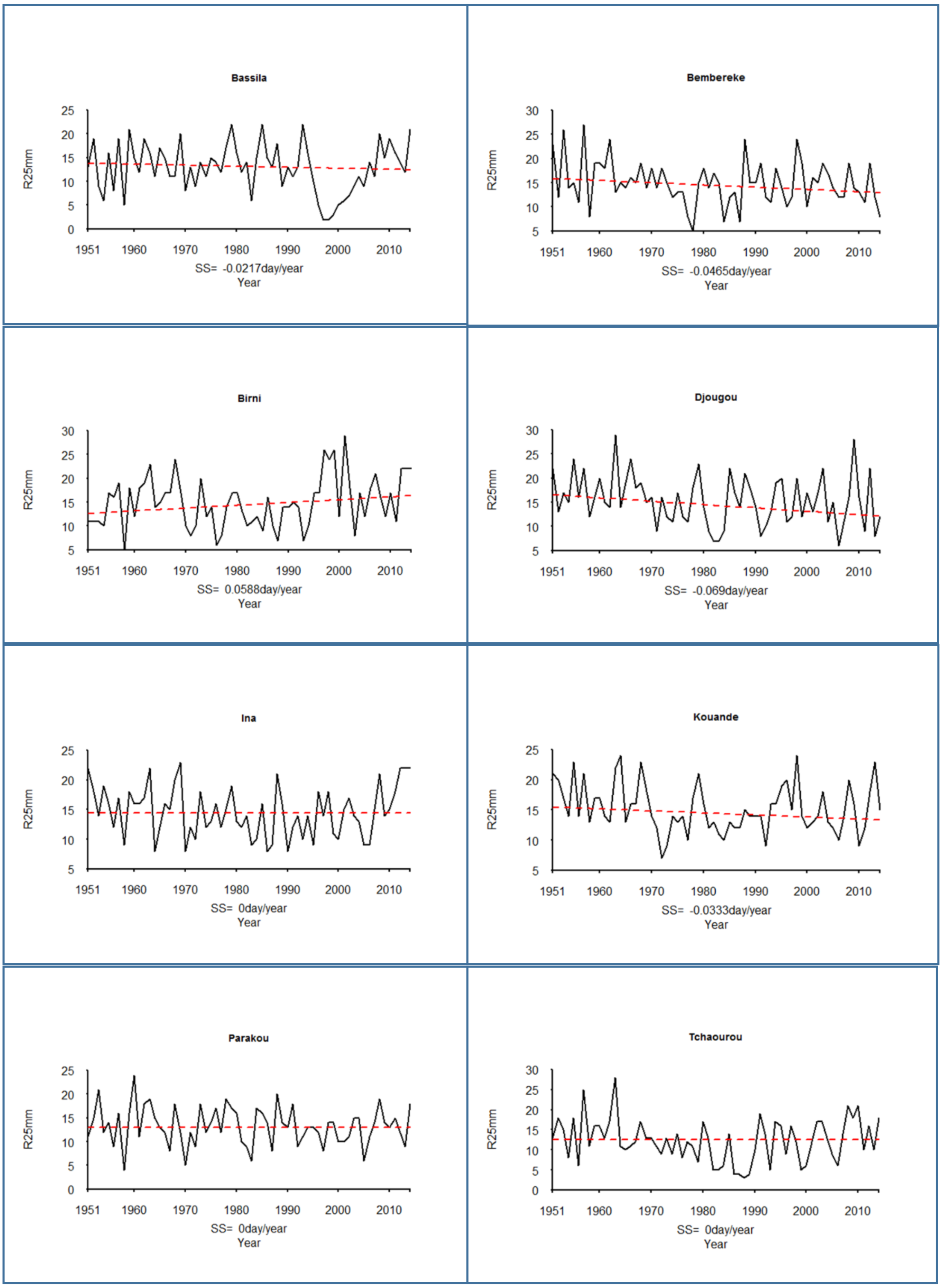
(**a**)

Figure A1. *Cont.*



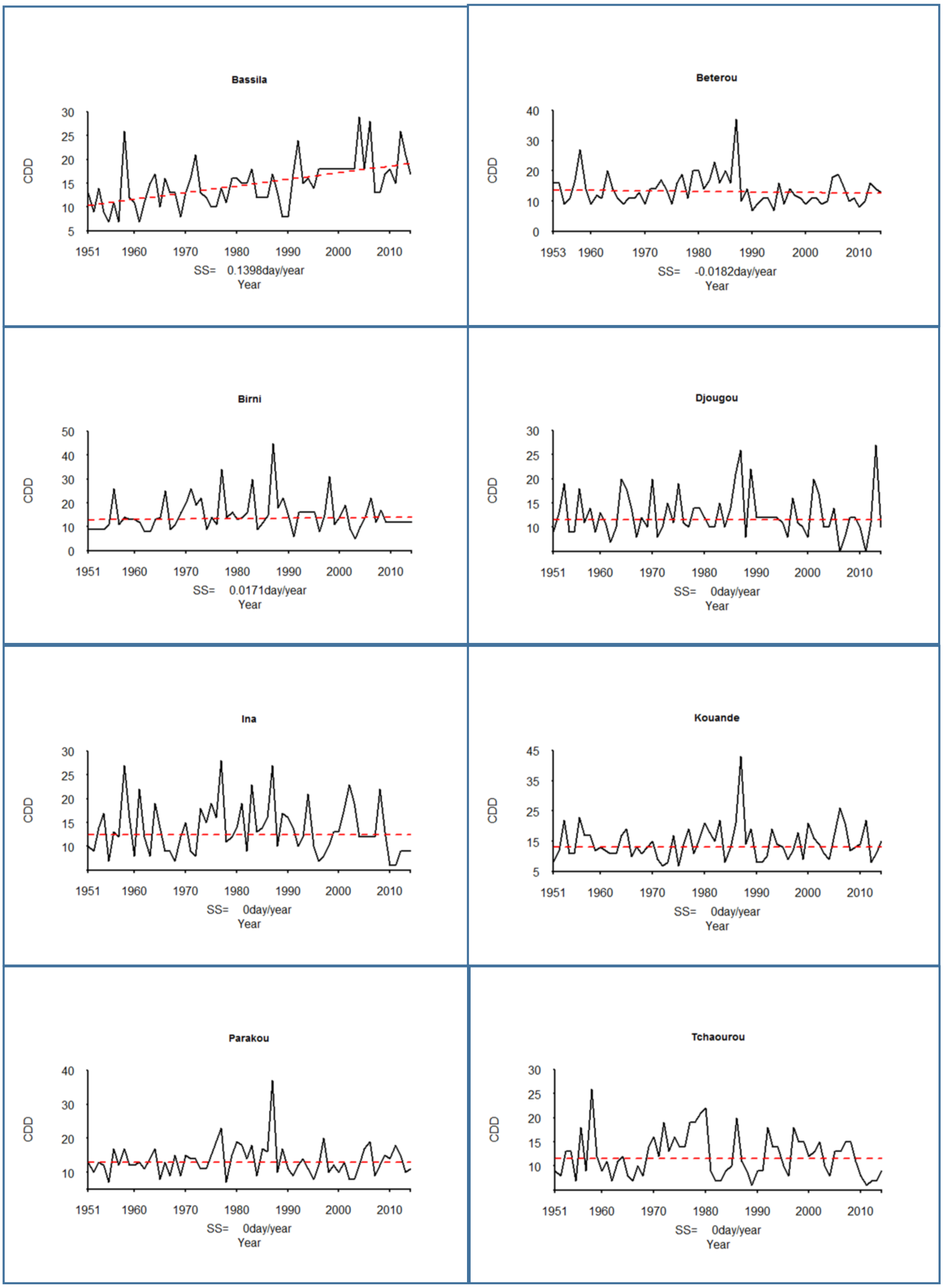
(**b**)

Figure A1. *Cont.*



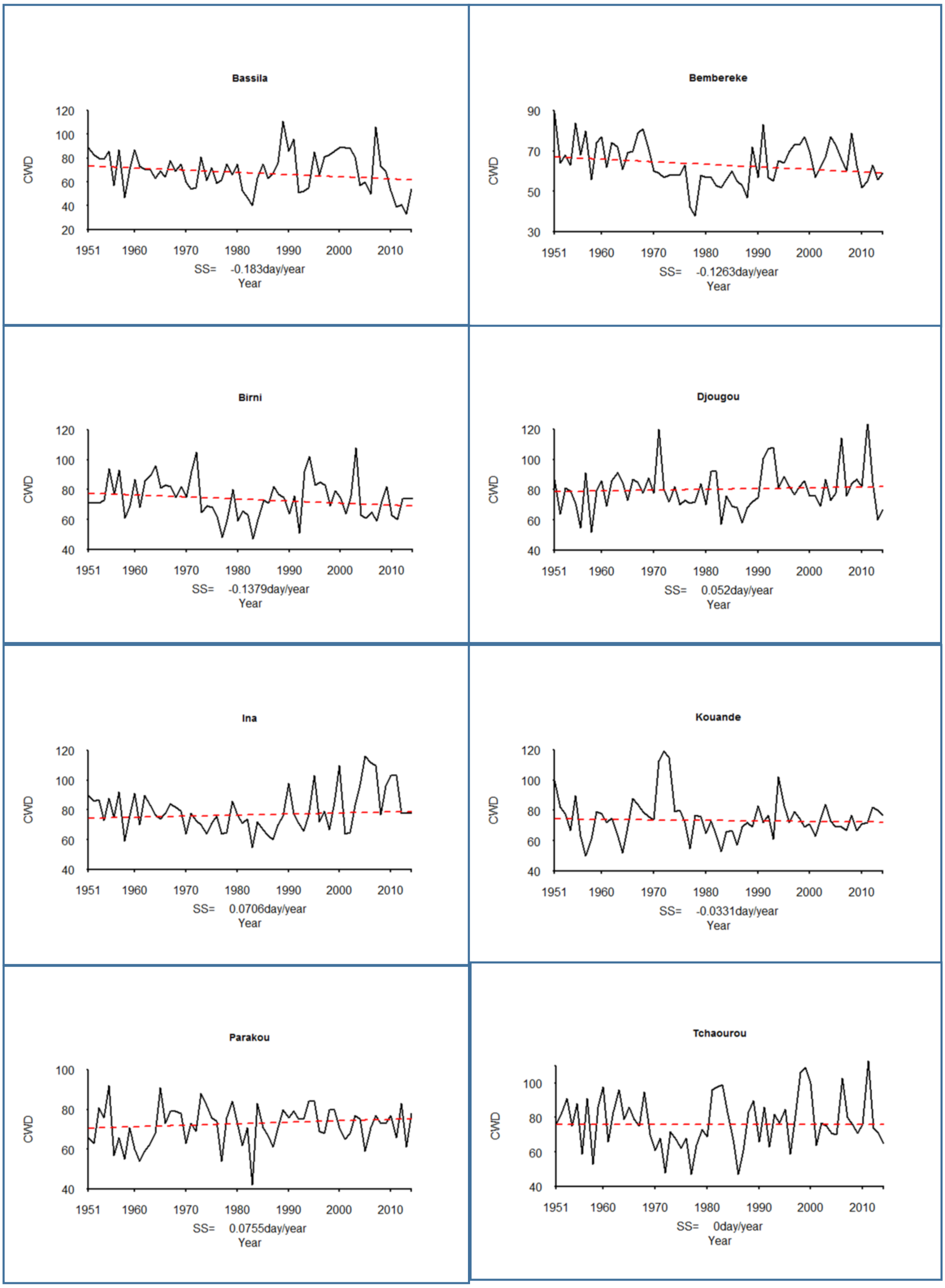
(**c**)

Figure A1. *Cont.*



(**d**)

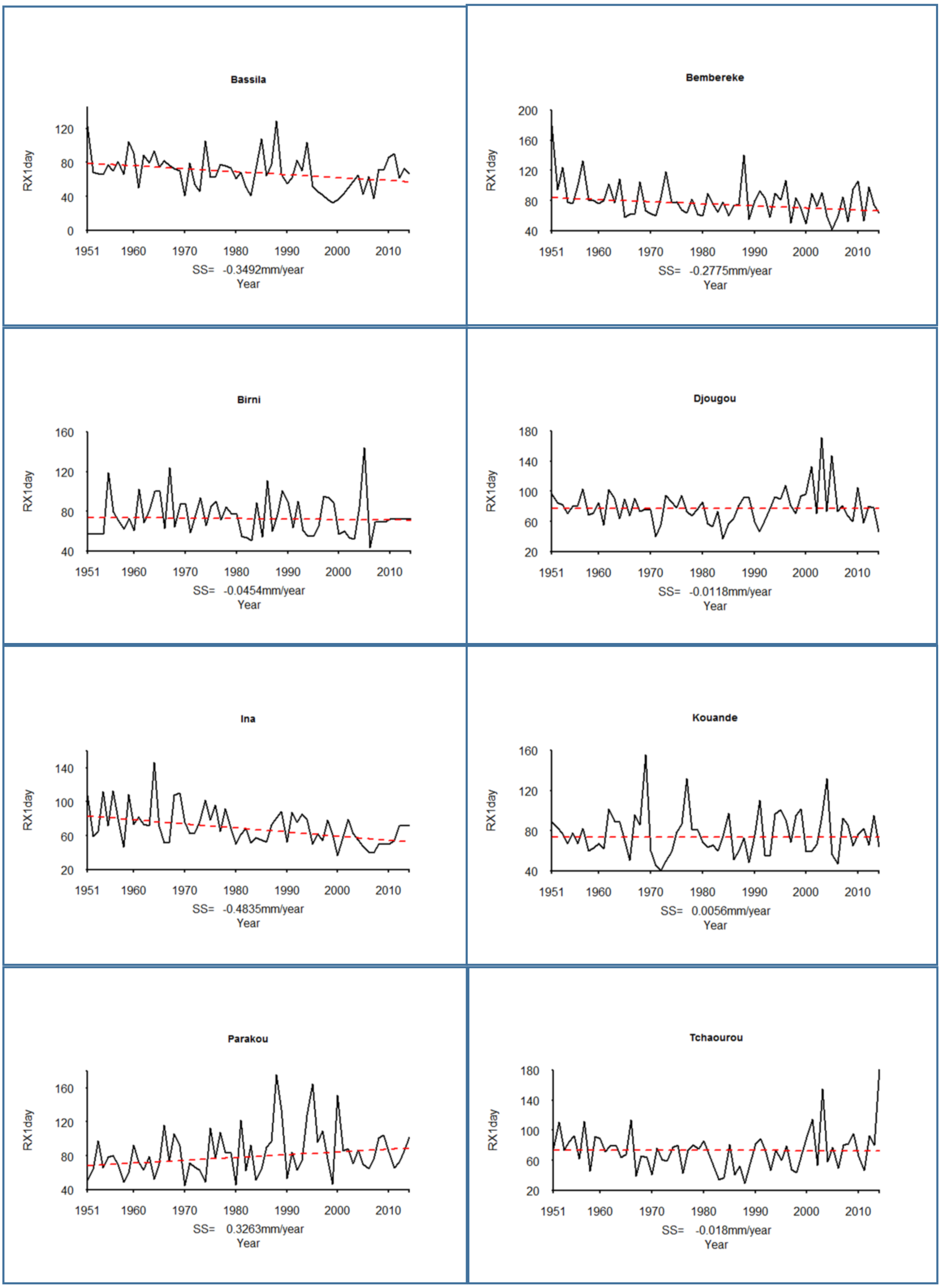
Figure A1. *Cont.*



(**e**)

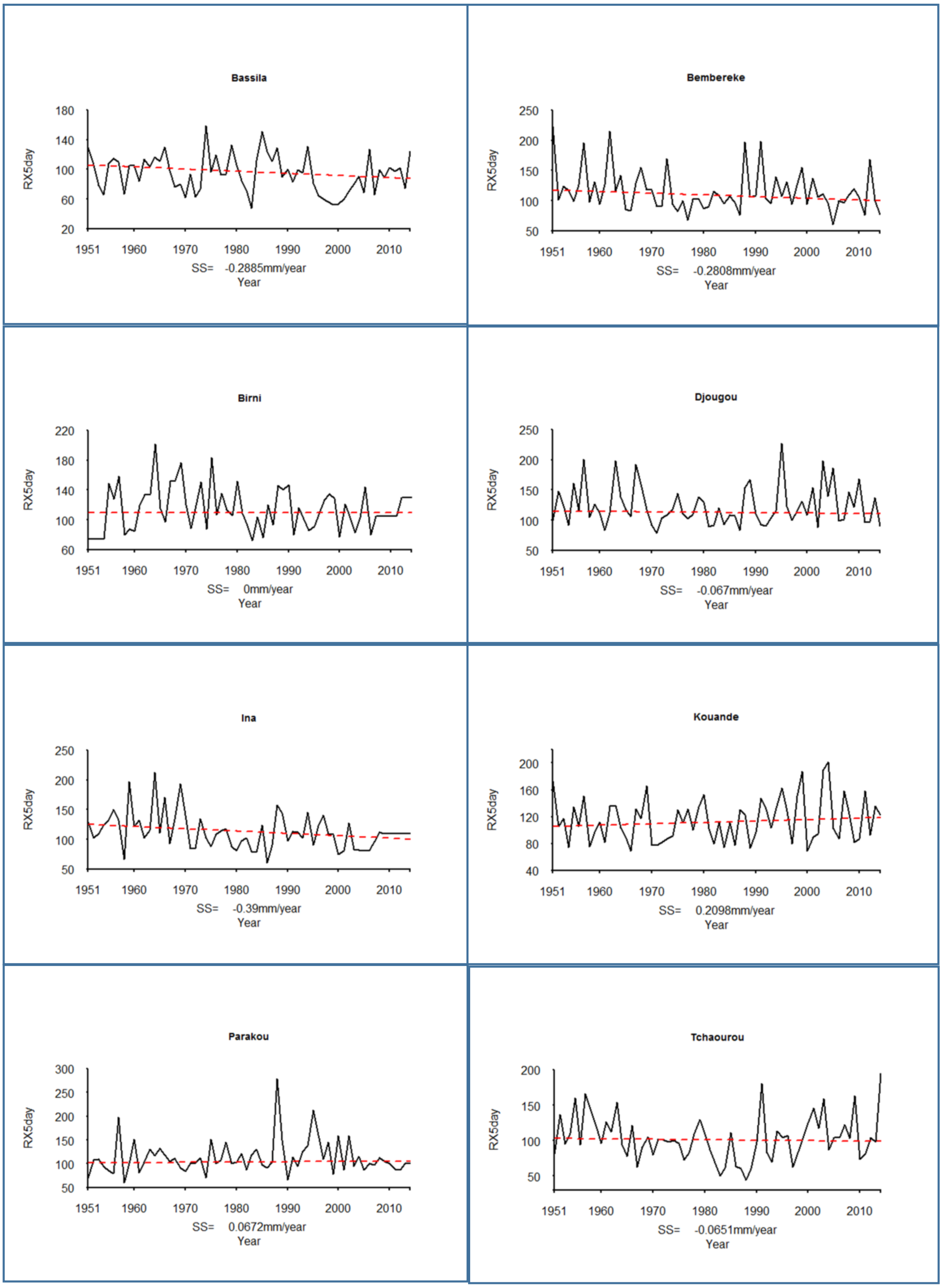
Figure A1. Frequency indices evolution and trends in some stations studied (SS = Sen's slope): (**a**) R10m; (**b**) R20m; (**c**) R25m; (**d**) CDD; and (**e**) CWD.

Appendix B



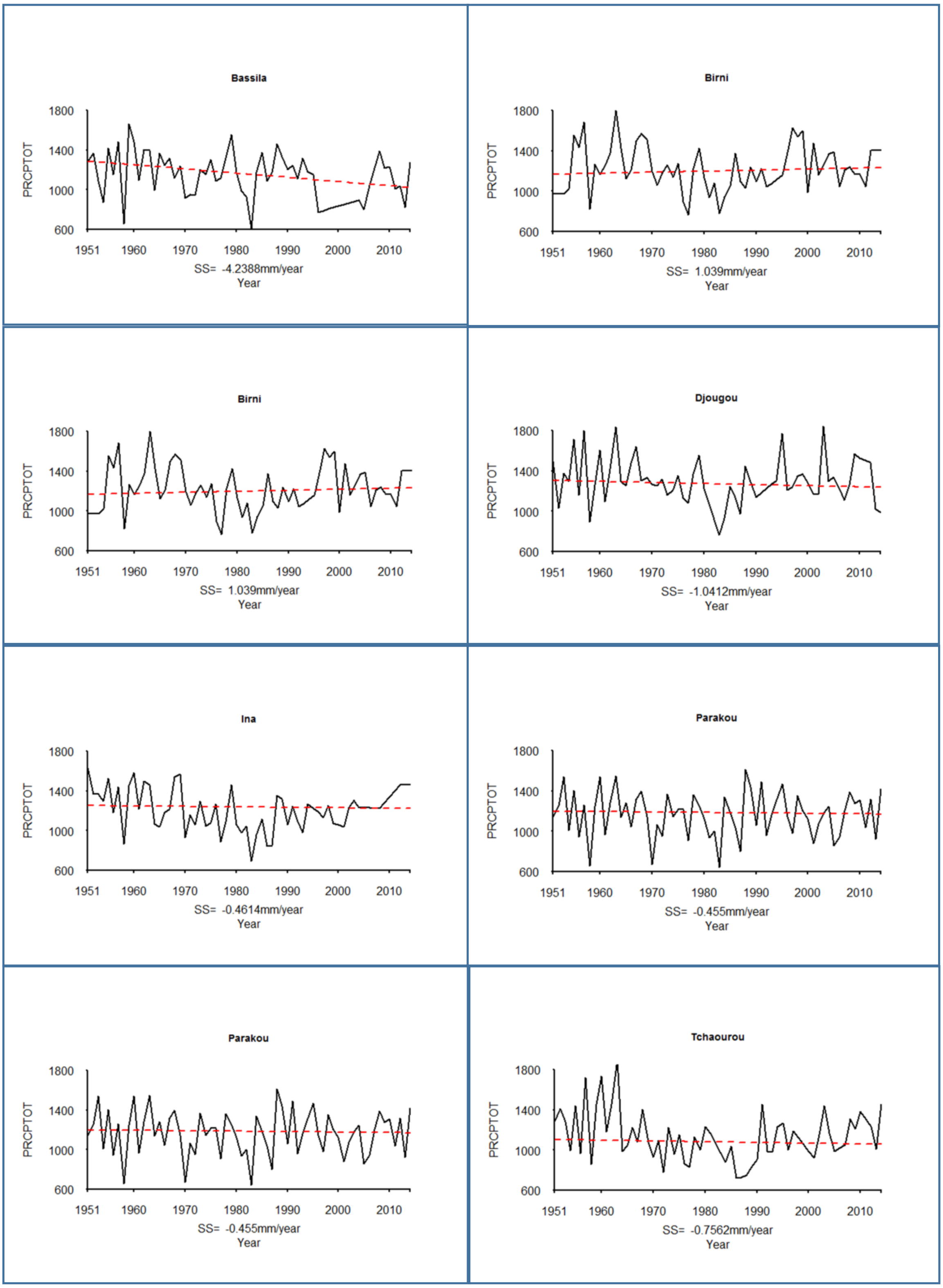
(**a**)

Figure A2. *Cont.*



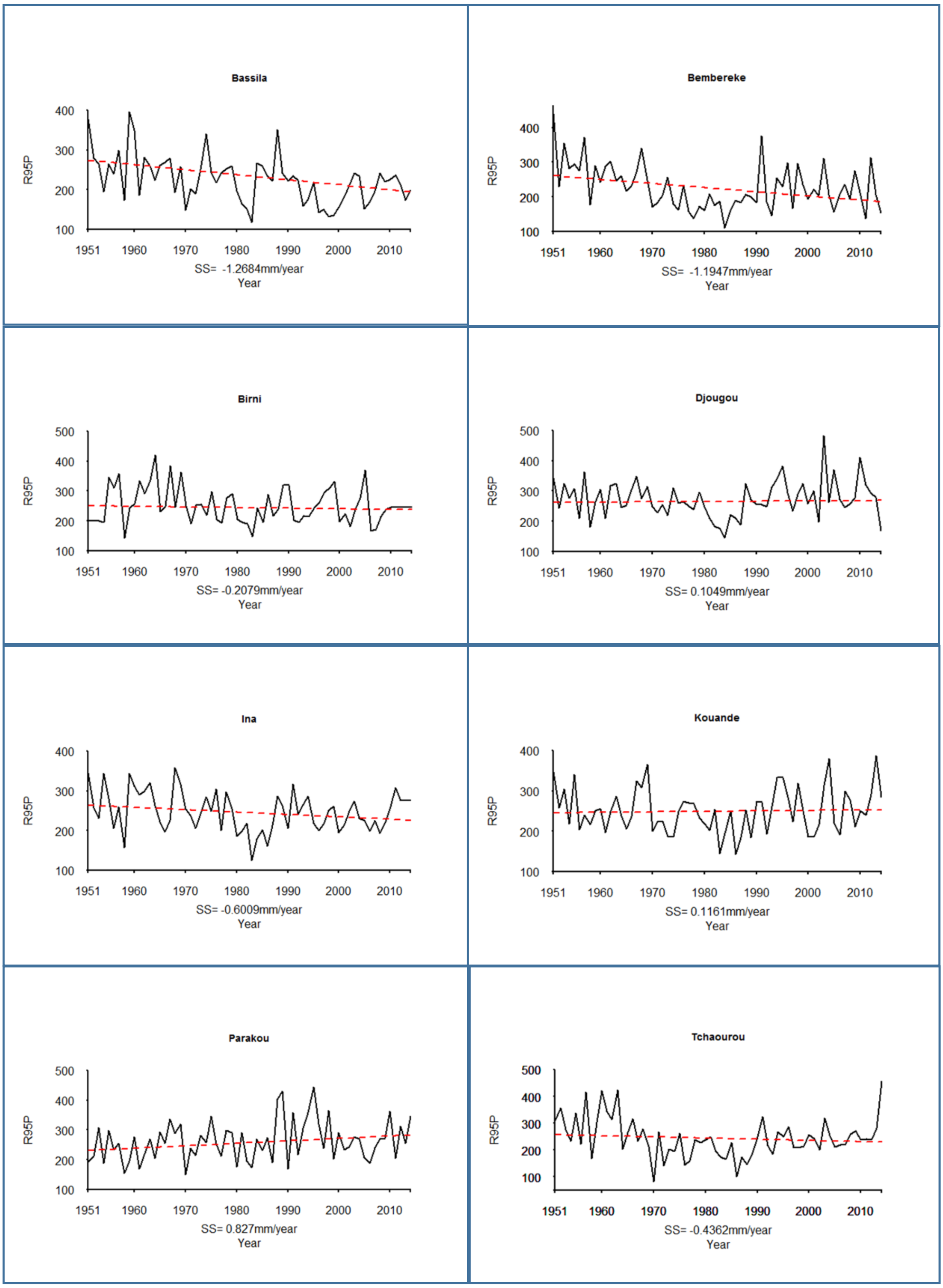
(**b**)

Figure A2. *Cont.*



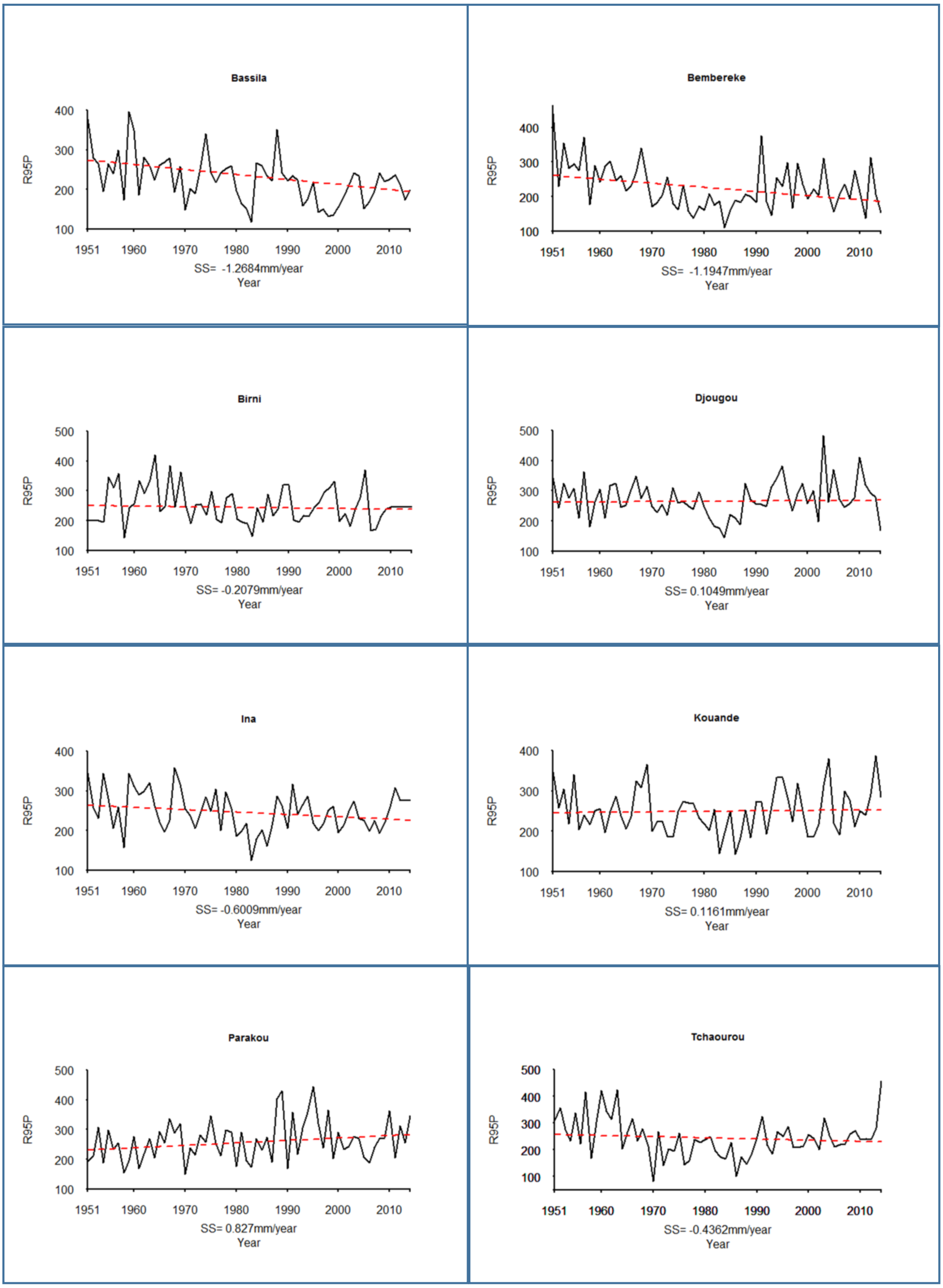
(**c**)

Figure A2. *Cont.*



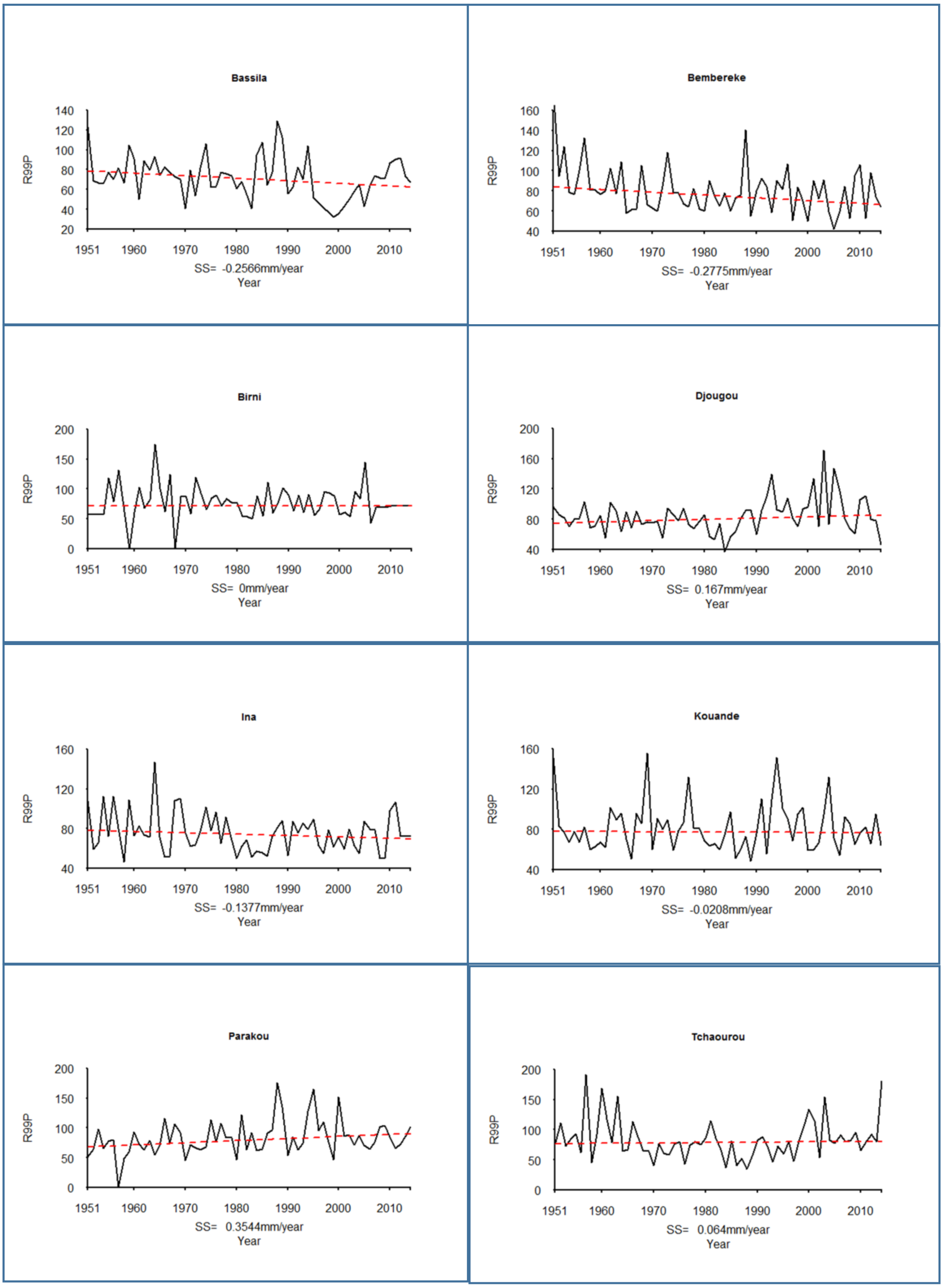
(**e**)

Figure A2. *Cont.*



(e)

Figure A2. *Cont.*



(**f**)

Figure A2. Intensity indices evolution and trends in some stations studied (SS = Sen's slope): (**a**) RX1day; (**b**) RX5day; (**c**) PRCPTOT; (**d**) SDII; (**e**) R95P; and (**f**) R99P.

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