

Analysis of the Spatio-temporal Evolution of Extreme Precipitation Indices Over the Period 1980 - 2020 in the Cavally Watershed (West Africa)

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Abstract Heavy rainfall is recognized as the main factor in the flood risk occurrence. Analysis of daily meteorological data provides insight into the current situation and helps manage future extreme events with a view to preventing flood risks in a given region. This study aimed to determine the spatio-temporal evolution of 10 rainfall indices over the period 1983-2020 in order to highlight the risk of flooding in the Cavally watershed. The daily data used were processed and then integrated into the RCLimdex model to calculate the 10 rainfall indices, which are: PRCPTOT, CWD, RX1day, RX5day, RX10, RX20, RX25, R95p, R99p, and SDII. The Man-Kendall trend test and Sen's slope estimator were used in the analysis of meteorological data. Although not all trends are significant, the results show a general downward trend in total annual precipitation (PRCPTOT), the number of days with heavy and very heavy precipitation (R10 and R20), and the number of very wet days (R95p). On the other hand, maximum 1-day precipitation amount (RX1day), maximum 5-day precipitation amount (RX5day), and the number of extremely wet days (R99p) showed an upward trend. These positive trends are causing increasingly frequent flooding in the central and southern parts of the study area. It is therefore necessary to implement adaptation measures to protect this heavily agricultural area.

Keywords: Rainfall indices, climate change, flood, Cavally watershed

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1. Introduction

Natural disasters such as floods, droughts, and forest fires are a global problem and deserve to be examined at the global, regional, and even local levels [1] [2]. These natural disasters are exacerbated by climate change, which is now the greatest challenge facing humanity [1] [2] [3]. The frequency, magnitude, and seasonality of extreme events such as floods may increase as a result of climate change [4,5,6,7,8,9,10,11] rightly consider climate variations and changes in forest areas to be the main causes of the disturbances observed in the hydrological behavior of watersheds.

In Africa, the situation is likely to take a serious turn, as the Intergovernmental Panel on Climate Change (IPCC) predicts higher frequency and intensity of floods [12] on the continent due to climate change. Africa's vulnerability can be explained by the fact that its developing countries lack sufficient physical and financial resources and appropriate institutions to mitigate the adverse effects of

climate change [13,14]. The risk of flooding is closely linked to rainfall variability. Thus, an increase in the intensity or frequency of precipitation could lead to more severe flooding, hence the need to analyze meteorological variability in order to prevent flooding and mitigate its effects. The study of climate indices is a powerful tool for analyzing trends in meteorological data under current and future conditions and predicting extreme precipitation [1]. These indices provide a better understanding of the analysis of variations and trends in extreme weather events such as droughts and floods. They have been the subject of several studies around the world [1,2,15,16,17] [18,19,20,21,22,23]. Precipitation indices can be used to detect changes in the intensity, duration, and frequency of precipitation [24].

Increasingly deadly and devastating floods have been rocking Côte d'Ivoire, particularly the southern regions, for the past decade. The western region, home to the Cavally River Basin (CRB), has also experienced tragic events, specifically in the municipality of Danané, where torrential rains caused the deaths of 20 people and the destruction of several homes in September 2016 [25]. This

was also the case in the municipality of Man, where torrential rains in August 2014 caused flooding after the Kô River overflowed its banks in the Domoraud-extension neighborhood [26]. More recently, in June 2024, the town of Djouroutou, south of the CRB, was flooded following heavy rains that caused material damage and several days of work stoppages. However, analysis of daily meteorological data that would enable us to understand rainfall variability and climate extremes in Côte d'Ivoire, especially in the western region, is virtually non-existent [1]. Existing studies focus on determining breaks in time series based on annual and monthly precipitation and certain statistical methods such as the Pettit and Buishand tests, the application of Nicholson indices to highlight wet and dry periods in cases of precipitation variability and show the general trend, interannual behavior [27,28,29,30,31]. These approaches do not allow for a detailed understanding of weather trends or for establishing a link between climate change and increasingly frequent flooding.

This study, conducted in the Cavally watershed, aims to determine and analyze trends in 10 rainfall indices over the period 1983-2020 using the RClindex model.

2. Material and methods

2.1. Study area

Located in West Africa between latitudes $4^{\circ}19'34''$ and $7^{\circ}57'22''$ North and longitudes $6^{\circ}48'00''$ and $8^{\circ}36'00''$ West, the Cavally River watershed is shared by three countries: Côte d'Ivoire (53.93%), Liberia (41.39%) and Guinea (4.68%) (Figure 1). Its main watercourse originates at the foot of the Nimba Mountains in Guinea and crosses Côte d'Ivoire. The Cavally basin crosses Côte d'Ivoire, as well as the Zwedru region in Liberia; then its main watercourse forms the border between Côte d'Ivoire and Liberia from the town of Toulepleu. It flows into the Gulf of Guinea 21 km east of the town of Harper. The main river is 515 km long and its watershed covers 30,600 km². Its name comes from that of certain fish "caval carps or cavally fishes" given by Portuguese explorers because of the abundance of this species of fish at its mouth [32].

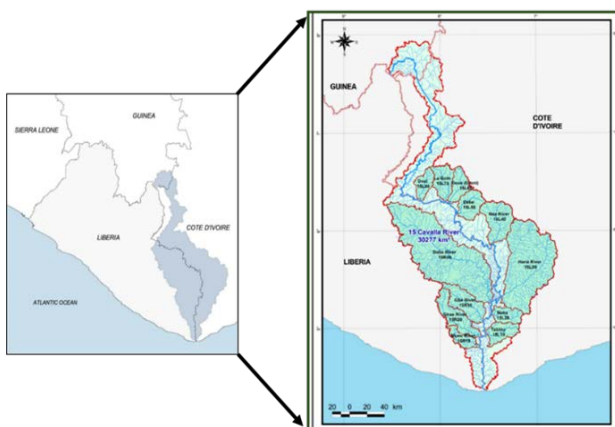


Figure 1. Geographic location of the Cavally watershed [32]

2.2. Data

Data of daily precipitation and temperature for 37 years from 1983 to 2020 for 9 meteorological stations, located across the Cavally watershed were used for spatial distribution analysis of precipitation and its extreme events over the study area. Given the numerous gaps in the data from SODEXAM's physical stations, due to the long period of military and political crisis (2002-2011), NASA satellite data downloaded free of charge from the link <https://power.larc.nasa.gov/data-access-viewer/> was used.

The nine virtual stations cover three different climate types: mountain climate in the north, attenuated transitional equatorial climate in the center, and transitional equatorial climate in the south (Table 1).

The RClindex 1.1 Software was used to check strict quality on the daily precipitation and temperature data. The RClindex 1.1 Software was developed by the ETCCDI and is available freely at the ETCCDI website <http://etccdi.pacificclimate.org/indices.shtml> [33]. Erroneous data, such as missing data, and negative precipitation were replaced with -99.9, which is recognized by RClindex. In order to avoid erroneous computation, homogeneity tests were also performed employing RHtests version 4 software package on the whole data set.

Table 1. Meteorological stations and their geographical location

Stations	Type of climate	UTM	
		X	Y
Danané	Mountain climate (north)	593836	801473
Toulepleu		566331	725889
Toweh town		537107	751239
Zagné	Attenuated transitional equatorial climate (center)	667788	692929
Balura town		624065	639903
Taï		670488	650174
Leopard town	Transitional equatorial climate (south)	663920	591166
Graobo		668173	543647
Harper		644146	483810

2.3. Methods

Climate trends, in particular, rainfall trends between 1983 and 2020 were determined in order to highlight the spatio-temporal variability of precipitation in the Cavally watershed. For this purpose, the RClindex model was used. It allows the efficient calculation of 27 meteorological indices for the detection of climate change. The calculation of these climate indices is done in three main steps [1,2].

2.3.1. Quality control

The purpose of this step is to detect and correct erroneous values in the data series. These errors may involve recording errors or gaps in a data series. Data quality control consists of:

- Replace missing or erroneous values with -99.9, which is the code recognized by RClindex for missing or erroneous data;
- Ensure that there are no more than 365 or 366 daily observations per year;

- Ensure that the month of February does not contain more than 28 observations, regardless of the year considered;
- Detect sudden jumps in the time series;
- Detect outliers, defined as a value outside the known climatic range in the area.

2.3.2. Homogenization

Homogenization consists of correcting all data presenting artificial discontinuities due to changes in the observation networks (movement of a station, change of measuring instrument, change in the immediate vicinity of a station, change of observer, etc.). These artificial discontinuities are present in most climate records and can interfere with current climate variations [1]. The advantage of the homogeneity test is to correct the data series so that they become homogeneous climate data series and to systematically involve a diagnosis on the average analysis of extremes.

2.3.3. Choice and Calculation of Climate Indices

Table 2. Description of the 10 indices used in the analysis of extreme climatic events in Cavally

Identification	Indicators name	Definitions	Units
PRCPTOT	Annual total wet-day precipitation	Annual total PRCP in wet days (PRCP ≥ 1 mm)	mm
RX1 day	Max 1-day precipitation amount	Monthly maximum 1-day precipitation	mm
RX5 day	Max 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	mm
R10	Number of heavy precipitation days	Annual count of days when PRCP ≥ 10 mm	Days
R20	Number of very heavy precipitation days	Annual count of days when PRCP ≥ 20 mm	Days
Rnn*	Number of days above nn mm days	Annual count of days when PRCP $\geq$ nn mm, nn is user defined threshold	Days
CWD	Consecutive wet days	Maximum number of consecutive days with PRCP ≥ 1 mm	Days
R95p	Very wet days	Annual total PRCP when PRCP $>$ 95th percentile	mm
R99p	Extremely wet days	Annual total PRCP when PRCP $>$ 99th percentile	mm
SDII	Simple daily intensity index	Annual total precipitation divided by number of wet days (defined as PRCP ≥ 10 mm) in the year	mm/day

Rnn*: Annual count of days when PRCP $\geq$ nn mm, nn is user defined threshold. Here, the defined threshold was 25 mm as recommended by [1].

Calculating indices involves determining the frequency, quantity, and duration of extreme events over a given period based on daily time series. The Expert Team on Climate Change Detection and Indices (ETCCDI) has

defined 27 basic indices, calculated daily by RClimDex, to characterize extreme rainfall events. Among these 27 indices, 10 are considered to be the most relevant by several authors [1,2,34]. These 10 indices were retained in this study. They are summarized in Table 2 with their meanings.

3. Results and Discussion

3.1. Results

3.1.1. Temporal trend of precipitation and its extreme

✓ Evolution of Annual Total Wet-Day Precipitation (PRCPTOT)

Figure 2 shows the evolution of annual precipitation totals (PRCPTOT) in the northern sector of the study area over the period 1983 - 2020. The negative slopes of -20.27 in Danané; -7.65 in Toulepleu and -11.20 in Towetown indicate a downward trend in total rainfall. These results show that rainfall decreases per decade by 202.7 mm in Danané; 76.5 mm in Toulepleu and 112 mm in Towetown. Thus, in 37 years, rainfall has decreased by 750 mm in Danané, 283.05 mm in Toulepleu and 414.4 mm in Towetown. This trend is not significant at p-value $<$ 0.05 except for Danané where the p-value = 0.02. The lowest cumulative rainfall was recorded in 2002 except for the Danané station where the lowest cumulative rainfall occurred in 2004 with 884.4 mm.

Figure 3 shows the variations in total annual rainfall in the central zone of the CRB. Analysis of this figure shows a downward trend in Zagné (-0.42) and Balura town (-6.96) while in Taï, an upward trend is observed (3.33). Thus, per decade, rainfall increases in Taï by 33.3 mm while it decreases by 4.2 and 69.6 mm respectively in Zagné and Balura town. All these trends are not significant at p-value $<$ 0.05 (0.53 in Taï; 0.94 in Zagné and 0.30 in Balura town).

The evolution of total annual rainfall in the south of the study area is illustrated in Figure 4. This figure shows an upward trend. Indeed, the stations of Leopard town, Grabo and Harper all display positive slopes, synonymous with an increase in rainfall south of the Cavally watershed. The ten-year variation in rainfall totals is 0.1; 33.4; 34.5 mm respectively in Leopard town, Harper and Grabo.

✓ Consecutive Wet Days (CWD)

Figure 5 illustrates the evolution of the number of consecutive wet days (CWD) in the northern part of the CRB. The linear trend line, with a slope of -0.84 in Danané and Zouan-Hounien; -0.24 in Toulepleu; -0.44 in Toetown and -1.01 in Towehtown, indicates a decrease in the number of wet days across the entire northern area. Thus, the regression per decade of CWD varies from 2.4 (in Toulepleu) to 10.1 days (in Towetown). In 37 years of observation, a decrease in CWD of just over one month (37.4 days) was recorded in the northern part of the CRB. The lowest values of the number of wet days were recorded in 2001 in Danané (33 days) and in 2007 in Towetown (27 days).

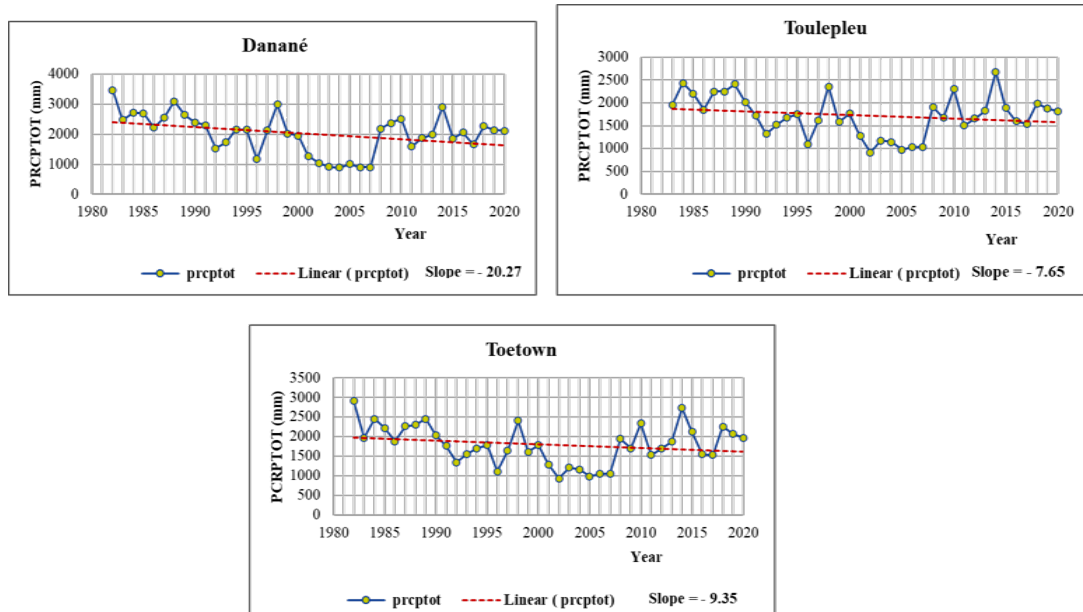


Figure 2. Annual total wet-day precipitation in the mountain climate (north)

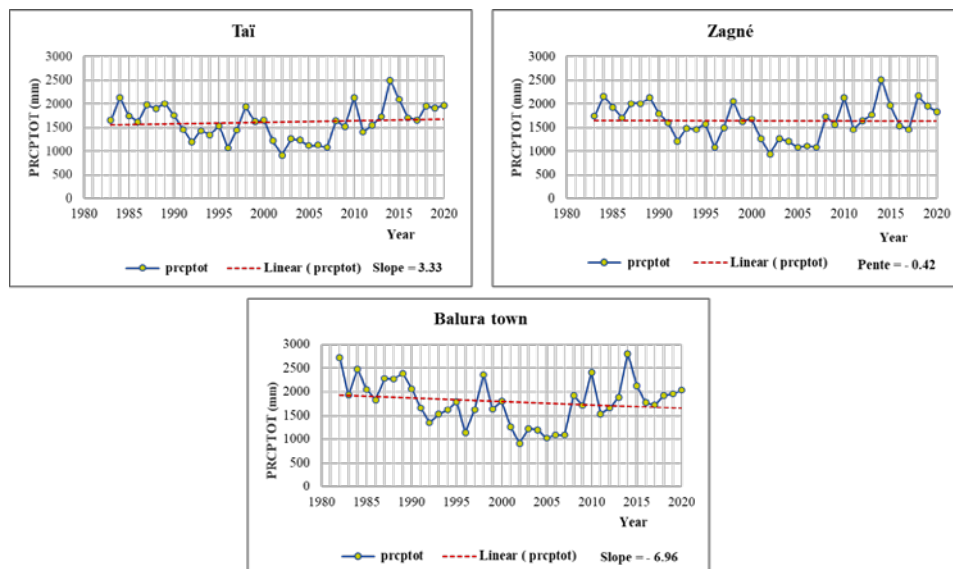


Figure 3. Annual total wet-day precipitation in Attenuated transitional equatorial climate (center)

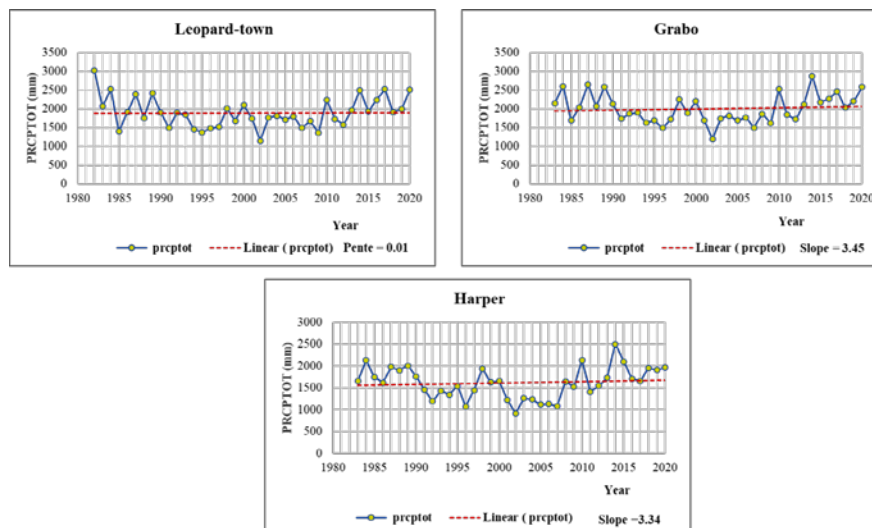


Figure 4. Annual total wet-day precipitation in transitional equatorial climate (south)

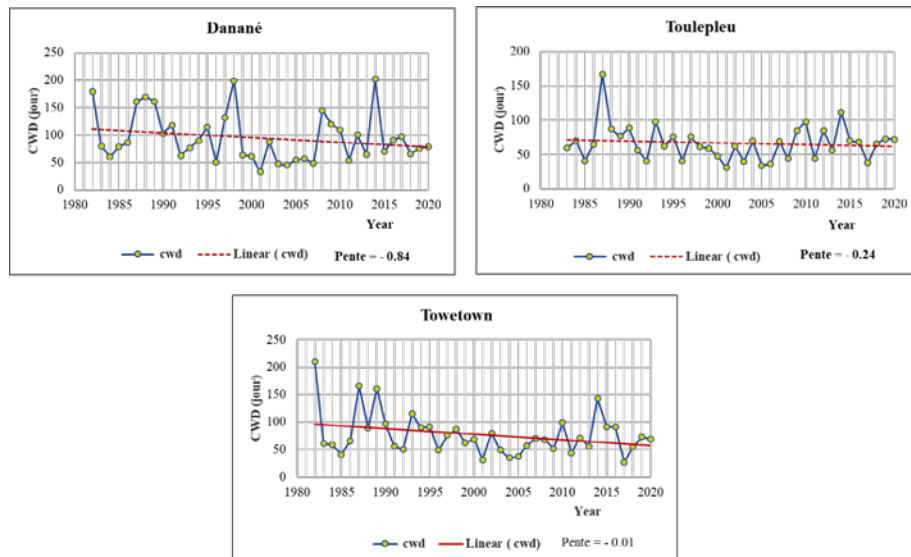


Figure 5. Consecutive wet days (north)

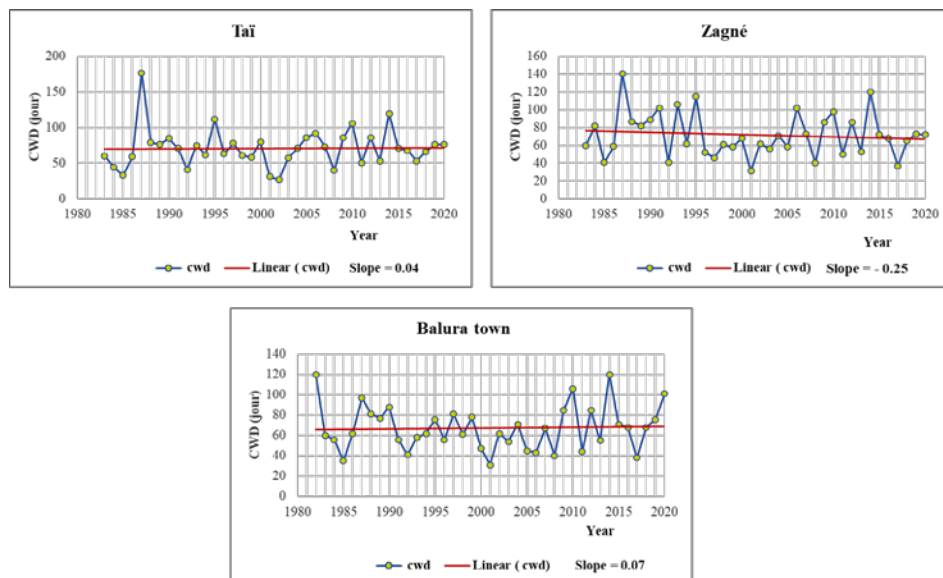


Figure 6. Consecutive wet days (center)

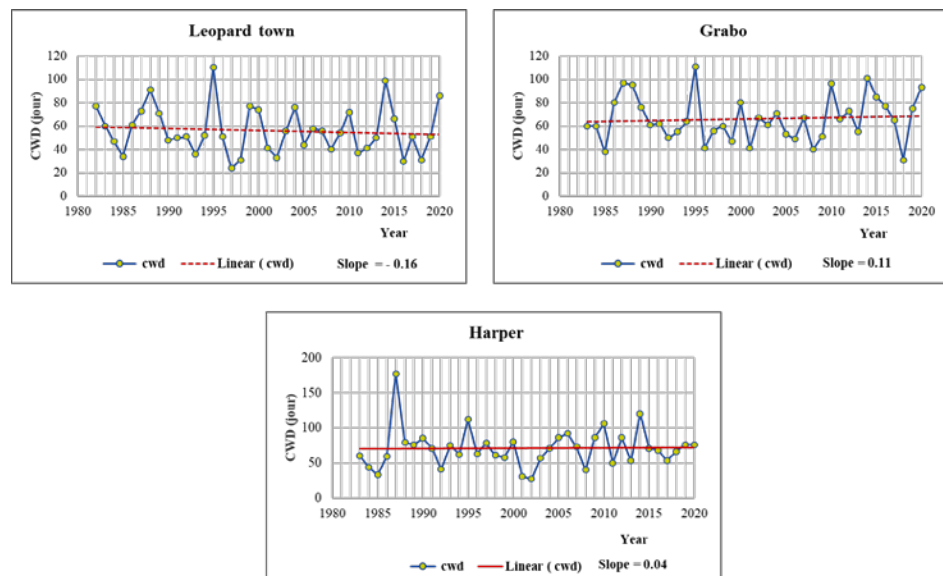


Figure 7. Consecutive wet days (south)

Figure 6 and Figure 7 show the situation in the center and north of the study area. There is a downward trend at Zagné (with a slope of -0.25) and a less pronounced upward trend at Taï and Balura town (with slopes of 0.04 and 0.07 respectively). In the southern zone, the situation is essentially the same with a downward trend at Leopard town with a slope of -0.16. As in the central zone, the upward trend observed at Grabo and Harper is less pronounced with respective slopes of 0.04 and 0.11, an increase of barely 1 day in 10 years. Ultimately, we can conclude that, in general, the Cavally watershed is characterized by a downward trend in the number of consecutive wet days. This trend is nevertheless limited since in 10 years the maximum decrease amounts to 10.1 days in Towetown.

✓ Number of Heavy Precipitation Days (R10)

The variation in the number of days of heavy precipitation (PRCP ≥ 10 mm) recorded at stations in the

north of the study area is shown in Figure 8. This figure shows that the period 1983 to 2020 is characterized by a downward trend with negative slopes of -0.59 in Toulepleu; -0.71 in Towetown and -0.93 in Danané. Thus, the number of days of heavy precipitation decreases each decade by about 6 days (5.9 in Toulepleu) to 9 days (9.3 in Danané) in the northern part of the CRB.

Analysis of Figure 9 and Figure 10 reveals an identical situation in the center and the south. Indeed, the trend is also downward in the center of the basin but to a lesser degree than in the north. The highest number of days of heavy rainfall is about 5 days (4.9 in Balura town) in 10 years compared to about 9 days in the north (9.3 in Danané). In the south of the basin, this decrease is barely 1 day (1.1 in Harper) in 10 years (Figure 10). Thus, there is a decrease in the number of days of heavy rainfall ranging from 1 to 9 days, per decade, across the entire study area.

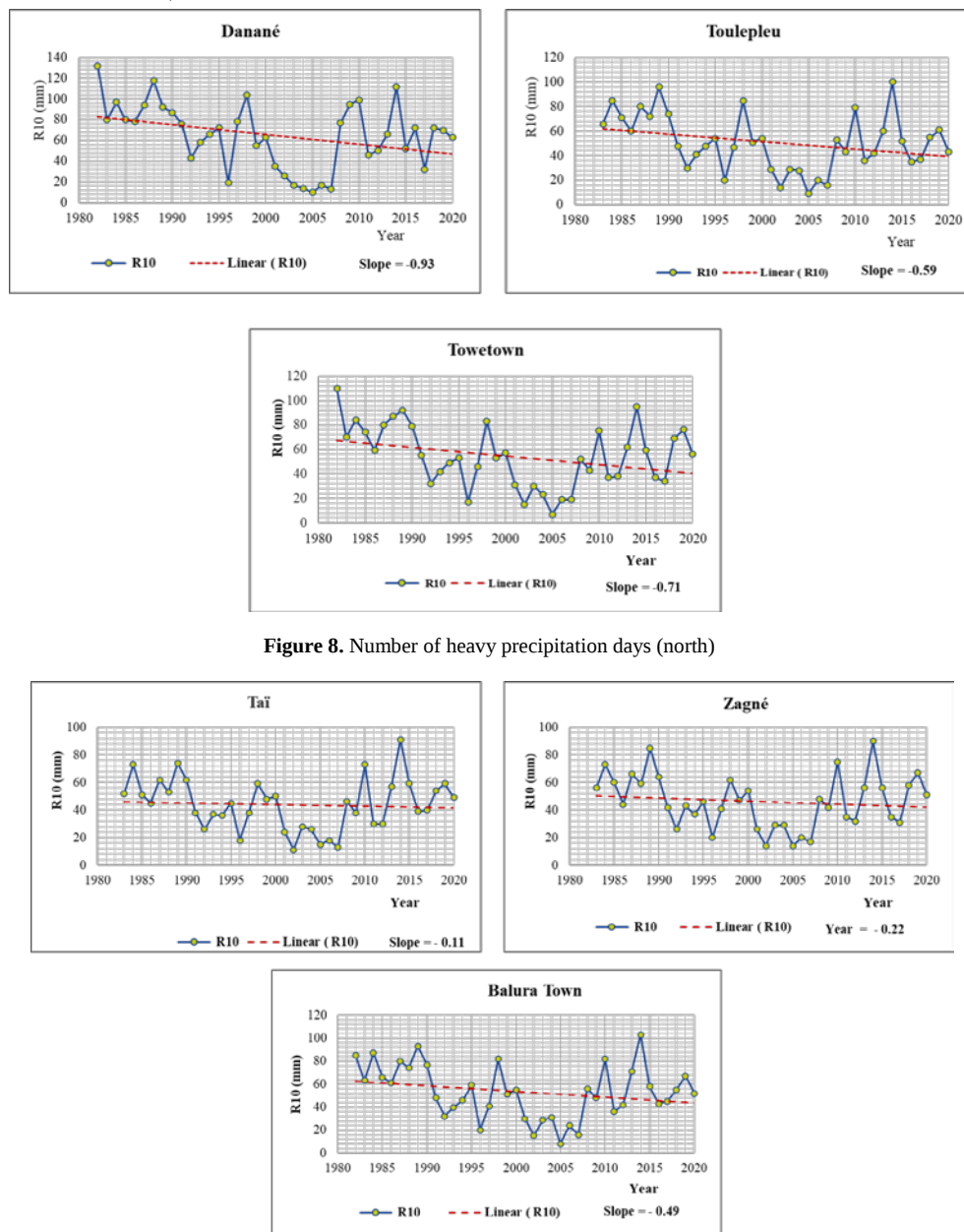


Figure 9. Number of heavy precipitation days (center)

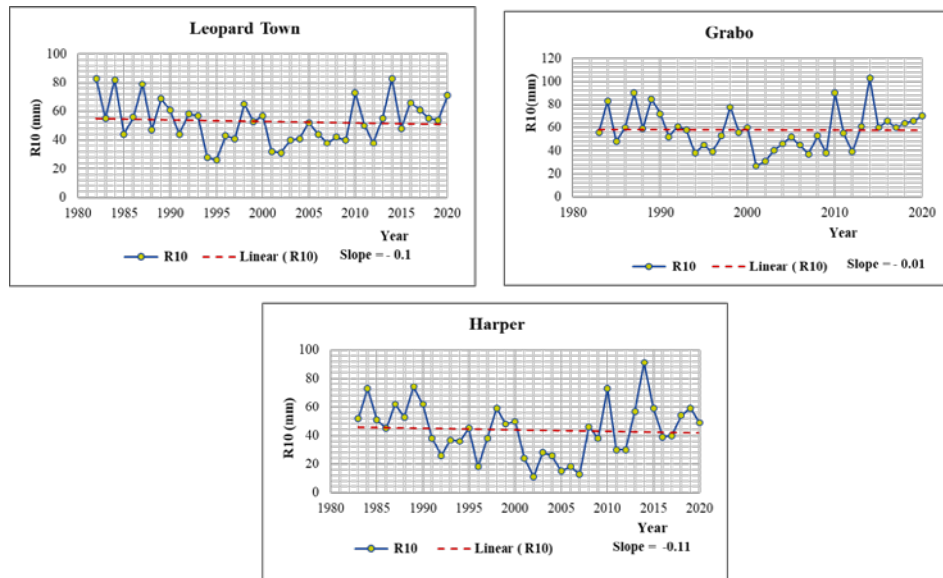


Figure 10. Number of heavy precipitation days (south)

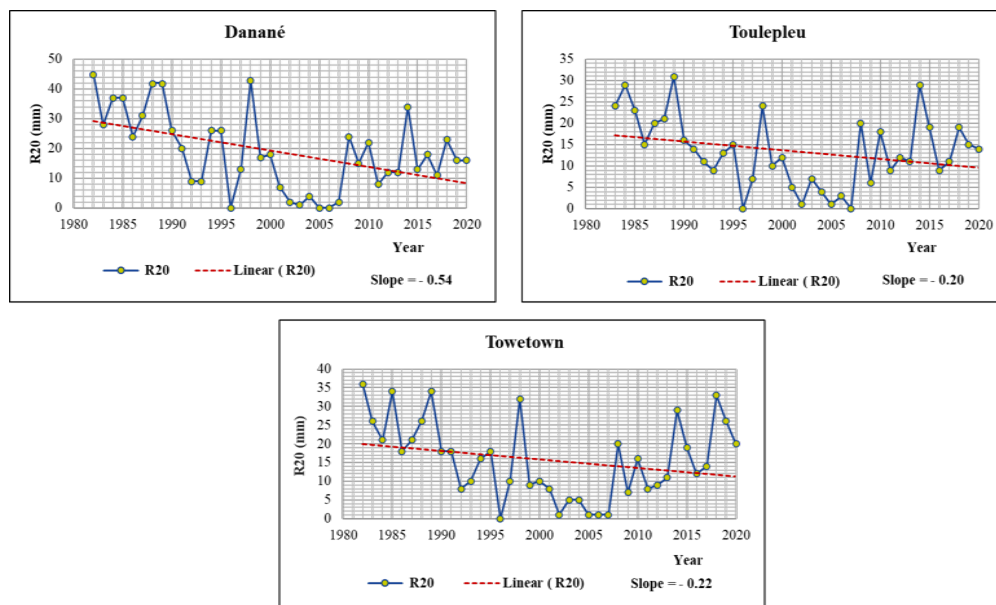


Figure 11. Number of Very Heavy Precipitation Days (north)

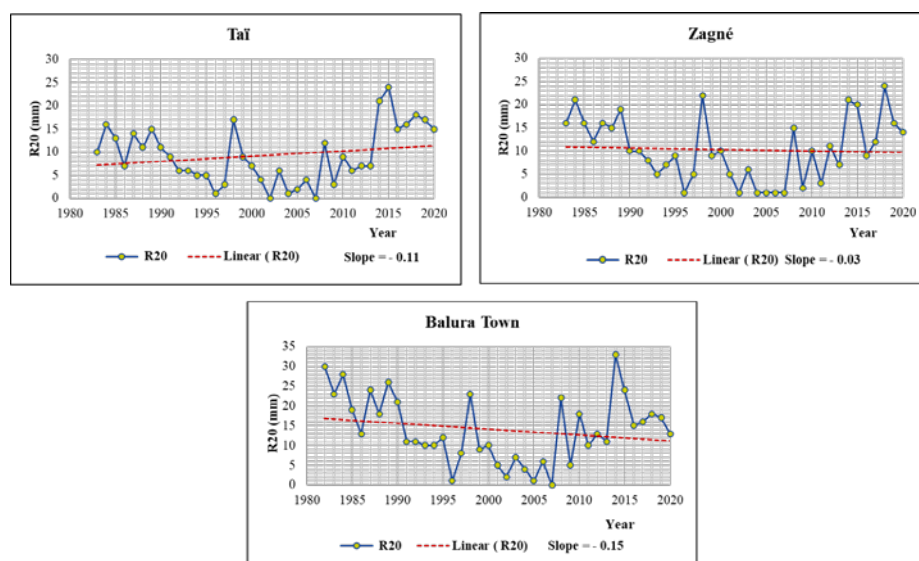


Figure 12. Number of Very Heavy Precipitation Days (center)

✓ Number of Very Heavy Precipitation Days (R20)

Over the period 1983 - 2020, the R20 rainfall index is also characterized by a downward trend across the entire watershed (north, center and south) with the exception of the Harper station, the southernmost, where a positive slope of 0.11 was recorded (Figure 11, Figure 12 and Figure 13). The regression per decade amounts to 5.4 days in the north (Danané station), 1.5 days in the center (Taï station) and about 2 days (1.9 days in Pleebo). Thus, the decrease in the number of days with precipitation greater than 20 mm is less pronounced in the south than in the north of the basin.

✓ Very Wet Days (R95p)

The evolution of the number of very wet days (R95p) over the period 1983 - 2020 is presented in Figure 14, Figure 15 and Figure 16. The analysis of Figure 14 shows a downward trend north of the CRB. This decrease varies from 4 mm/year (Toulepleu) to 13.23 mm/year (Danané), or 40 mm to 132.3 mm in 10 years (Figure 14). However, in the center the trend is upward in Taï (3.86 mm/year) and Zagné (1.44 mm/year). At the Balura town station, a downward trend of 3.39 mm/year was recorded, a decrease of 33.9 mm in 10 years (Figure 15).

In the south of the basin, the annual cumulative precipitation of very wet days is also decreasing with the exception of the Harper station where an increase of 3.36

mm/year was observed. The annual regression is 1.15 mm in Leopard town; 1.43 mm in Grabo (Figure 16). Thus, the decrease in the annual cumulative precipitation of very wet days is a little more than 9 times less pronounced in the south than in the north (14.3 mm in Grabo compared to 132.3 mm in 10 years in Danané).

✓ Number of Days above 25 mm (Rnn)

The index of the number of days with rainfall above 25 mm is characterized by a general downward trend with the exception of some stations in the center and south (Figures 17 to 19). However, some stations in the center and south show an upward trend. This is the case of Taï, Zagné and Harper with respective slopes of 3.86; 1.44 and 3.86.

✓ Extremely Wet Days (R99p)

The index of the number of extremely rainy days (R99p) is marked by a general upward trend with almost all positive slopes (Figure 20 to Figure 22). However, negative slopes, reflecting a slight downward trend, were recorded in Danané, Balura town with respective slopes of 1.62 and 0.53.

✓ Maximum 1-Day Precipitation Amount (RX1day)

The 1-day maximum precipitation amount index (RX1) is characterized by a slight upward trend throughout the CRB (Figure 23 to Figure 25). This increase increases from north to south, from 3.8 mm (Towetown) to 8.4 mm (Grabo) per decade.

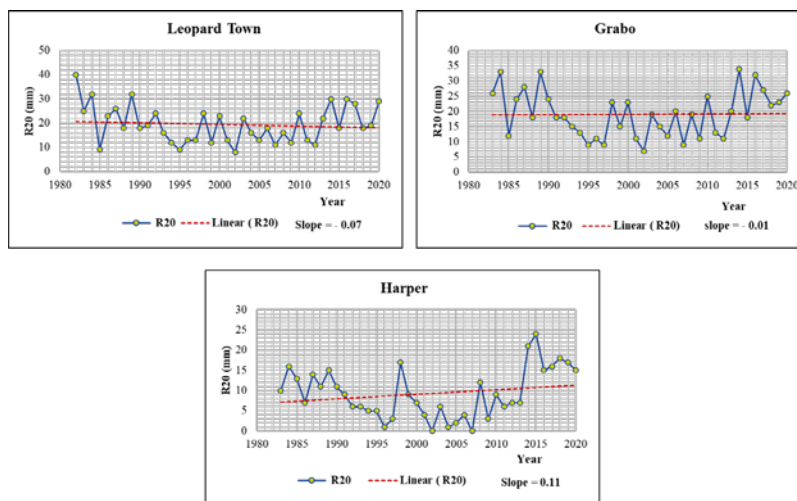


Figure 13. Number of Very Heavy Precipitation Days (south)

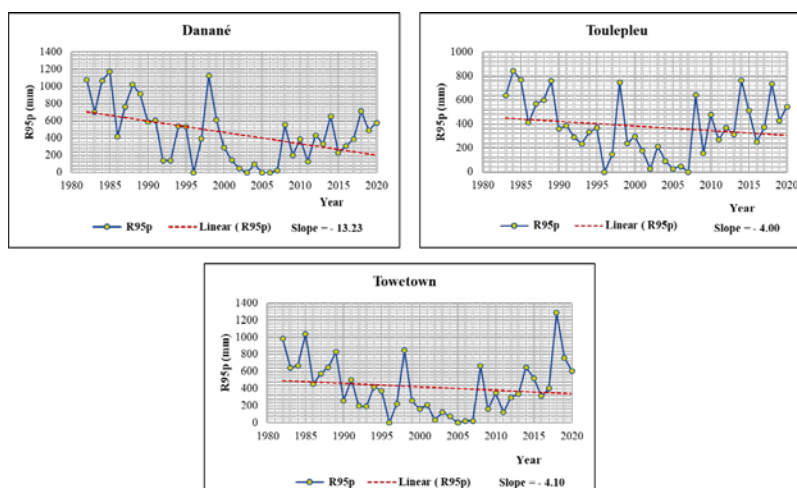


Figure 14. Number of Very Wet Days (north)

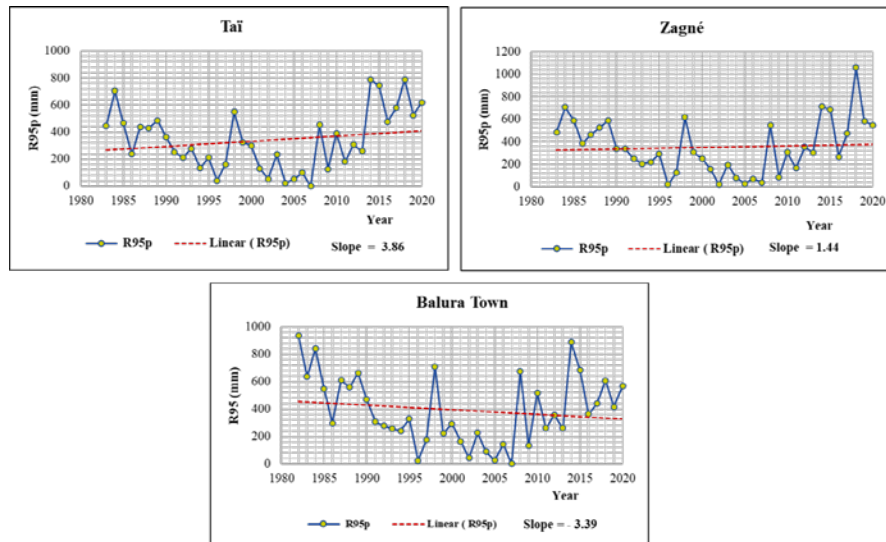


Figure 15. Number of Very Wet Days (center)

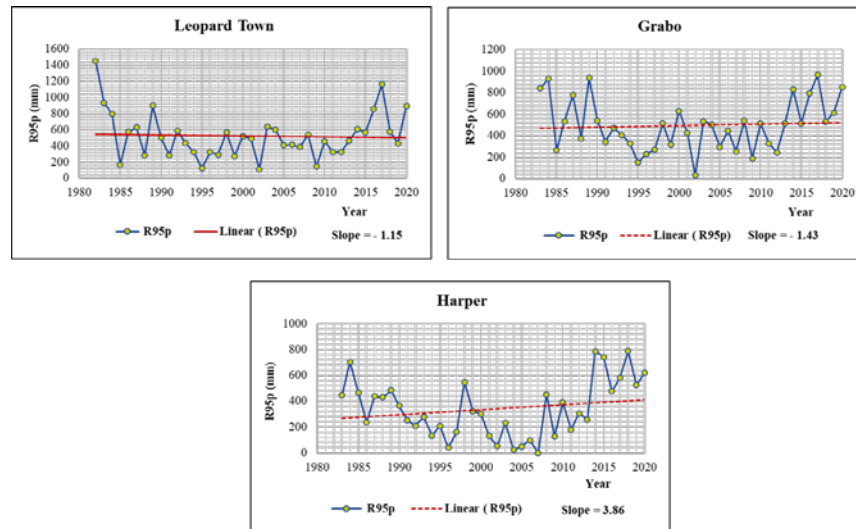


Figure 16. Number of Very Wet Days (south)

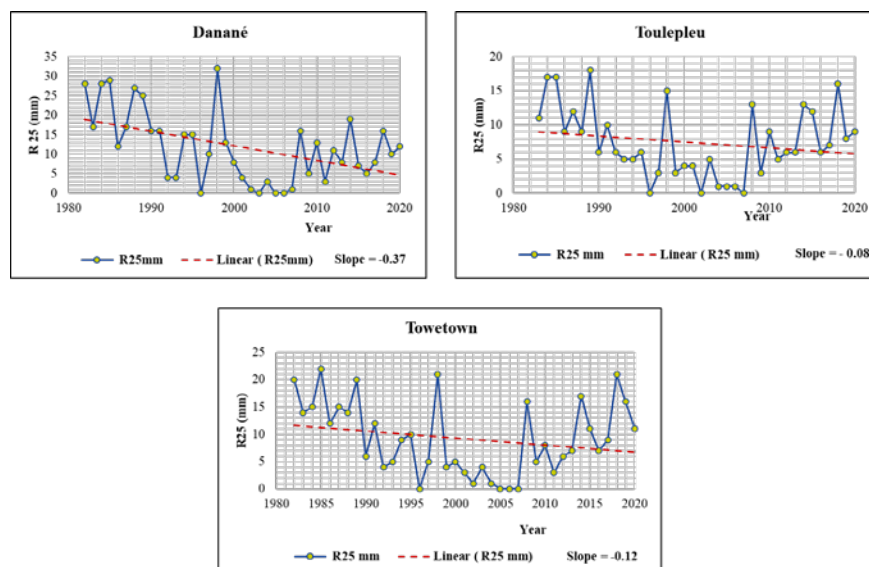


Figure 17. Number of days above 25 mm (north)

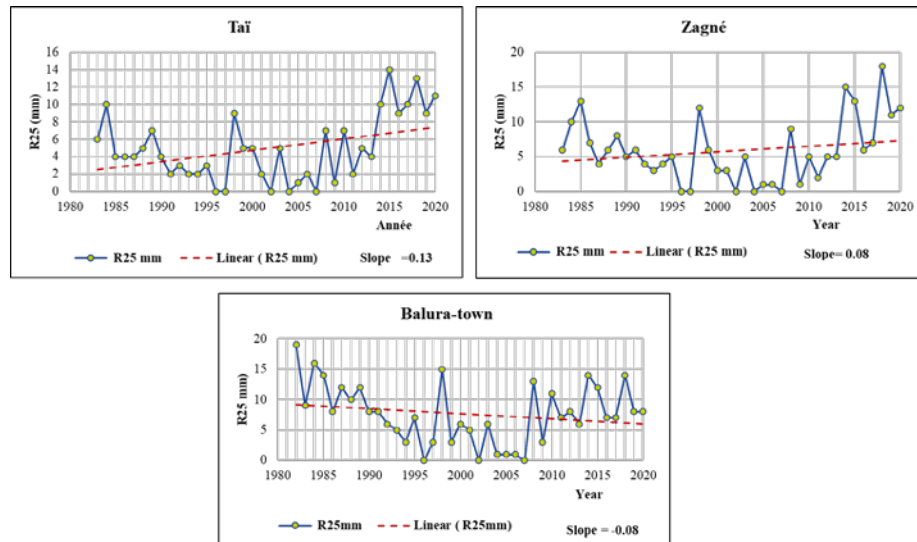


Figure 18. Number of days above 25 mm (center)

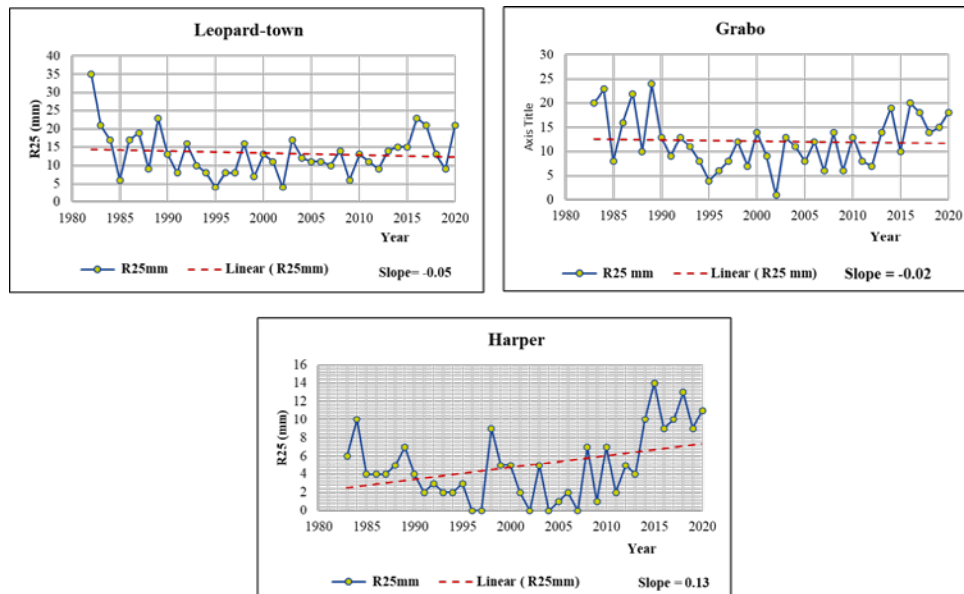


Figure 19. Number of days above 25 mm (south)

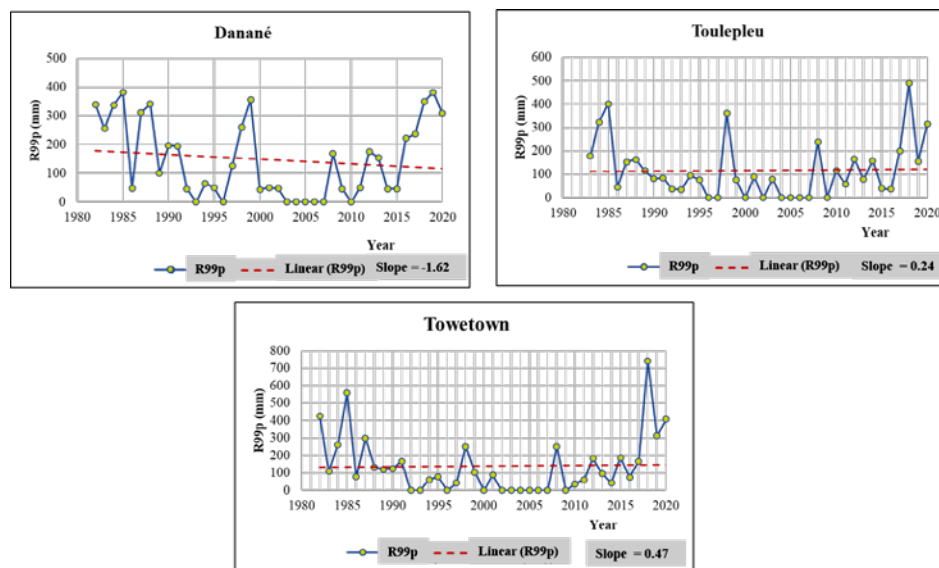


Figure 20. Extremely wet days (R99p) (north)

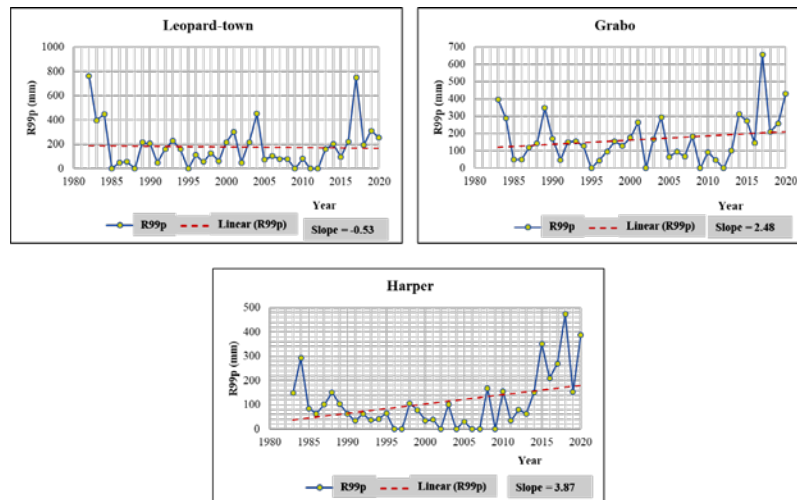


Figure 21. Extremely wet days (R99p) (center)

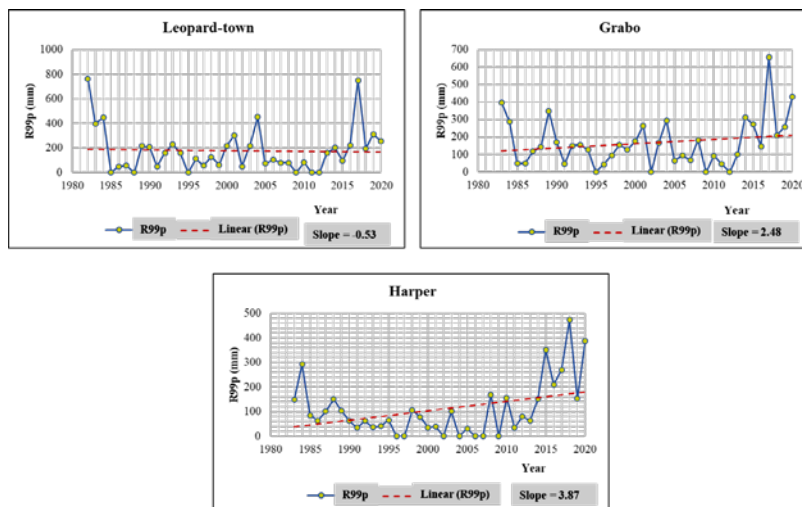


Figure 22. Extremely wet days (R99p) (south)

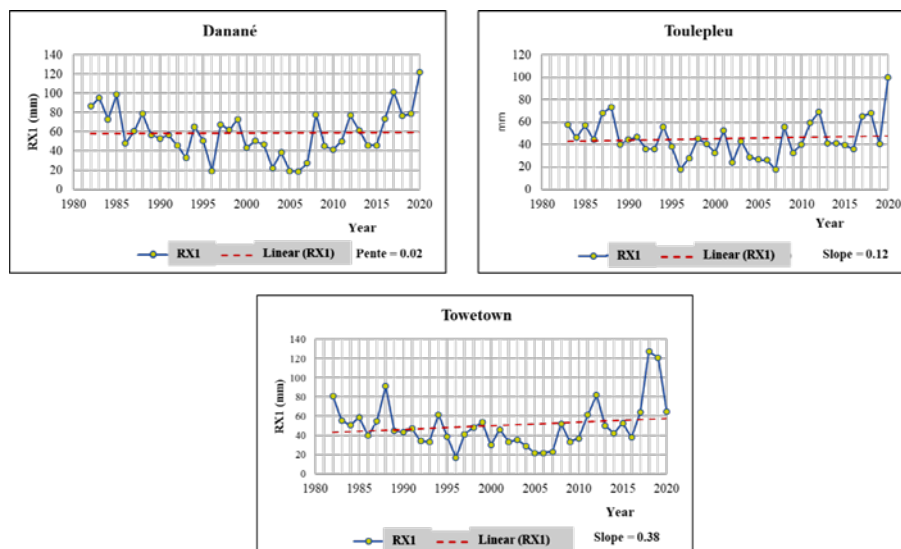


Figure 23. Maximum 1-day precipitation amount (north)

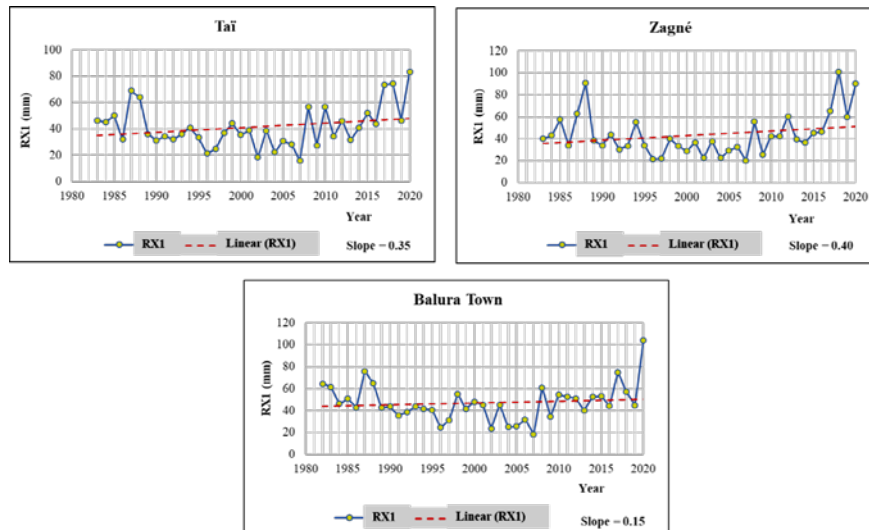


Figure 24. Maximum 1-day precipitation amount (center)

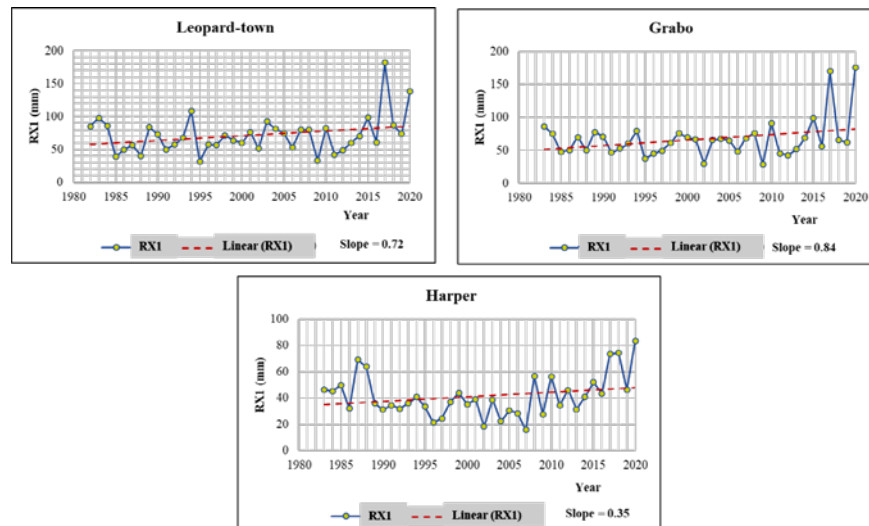


Figure 25. Maximum 1-day precipitation amount (south)

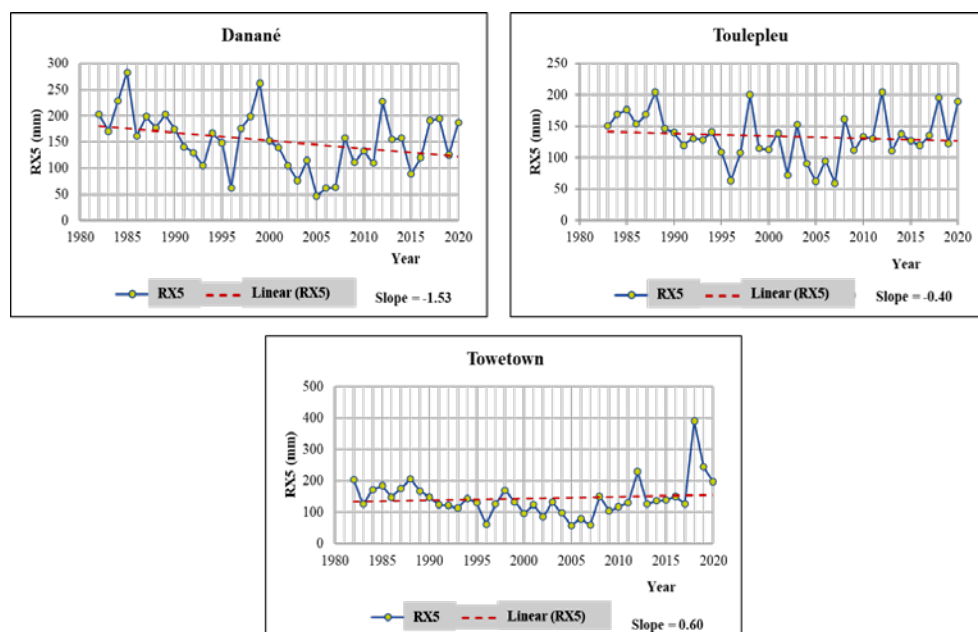


Figure 26. Maximum 5-day precipitation amount (north)

✓ Maximum 5-Day Precipitation Amount (RX5day)

The maximum precipitation index over 5 consecutive wet days (RX5) is marked by a downward trend in the north with the exception of Towerown where the slope is positive (0.60 mm) (Figure 26). In the center and south of the basin, upward trends were recorded in all stations except Balura town (-0.82 mm) (Figure 27). In the south, the upward trend is generalized with respective slopes of 0.08; 0.38 and 0.22 in Leopard town, Grabo and Harper (Figure 28).

✓ Simple Daily Intensity Index (SDII)

The simple daily precipitation intensity index (SDII) shows a general trend which is either stationary or with a very slight decrease (Figure 29 to Figure 31).

These ten indices (PRCPTOT, CWD, RX1, RX5, R10, R20, R25, SDII, R95p and R99p) made it possible to study the temporal variability of rainfall in the CRB. Generally, between 1983 and 2020, a slight downward trend was observed in the study area, although more pronounced in the north than in the south. However, it is important to note that the maximum 1-day rainfall index (RX1) suggests an upward trend across the entire basin for the period 1983 - 2020. Also, the maximum precipitation index over 5 consecutive rainy days (RX5) and the index of the number of extremely rainy days (R99p) showed an upward trend in almost all stations. Finally, note the few slight upward trends recorded in Taï, Leopard town, Grabo or even Harper for both PRCPTOT, CWD, R25 and R95p.

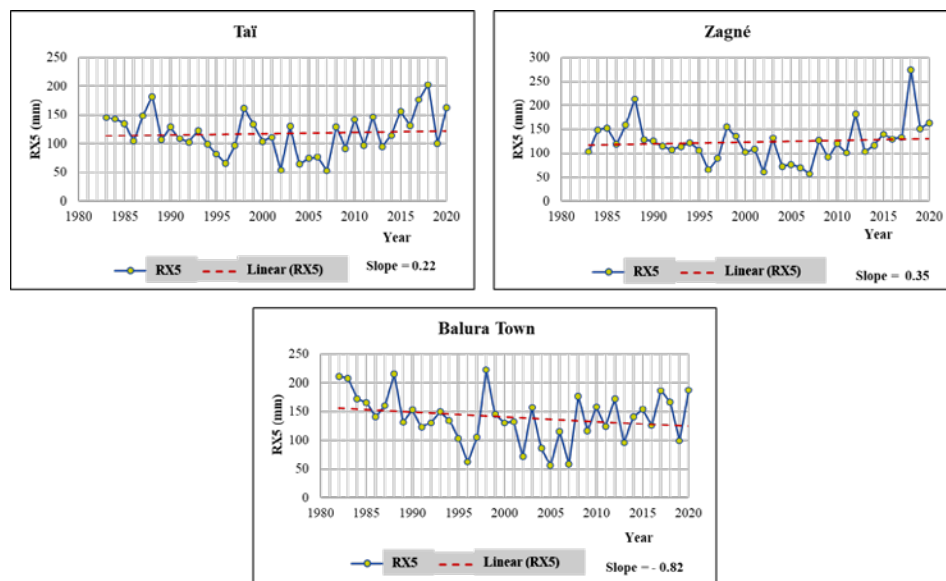


Figure 27. Maximum 5-day precipitation amount (center)

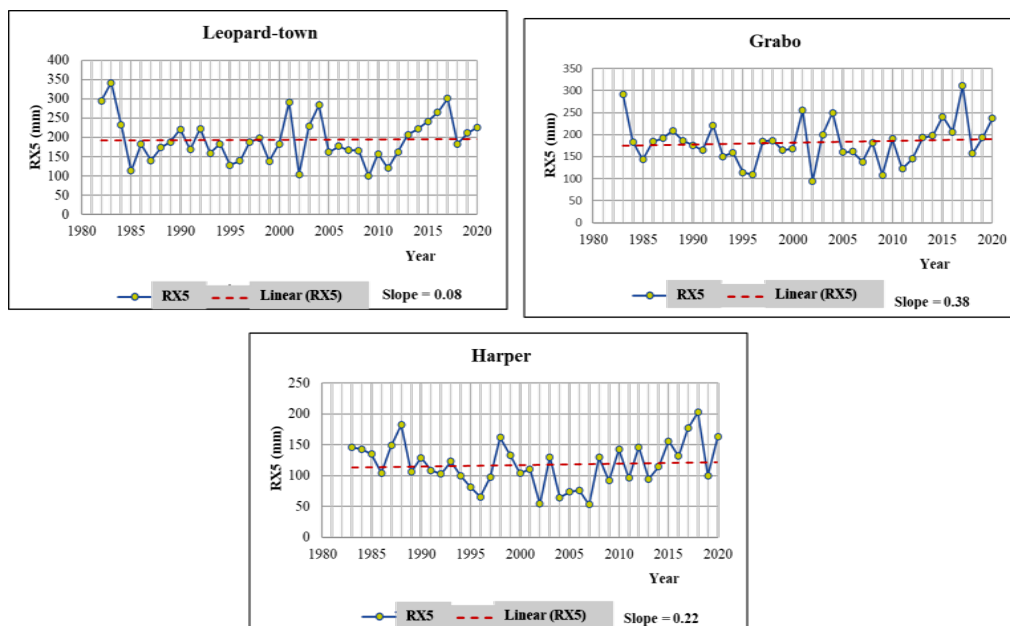


Figure 28. Maximum 5-day precipitation amount (north)

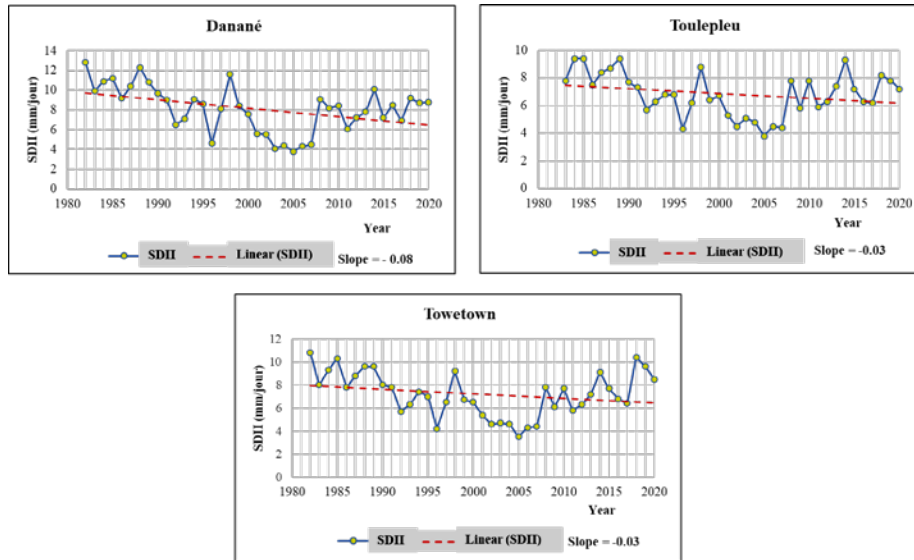


Figure 29. Simple daily intensity index (north)

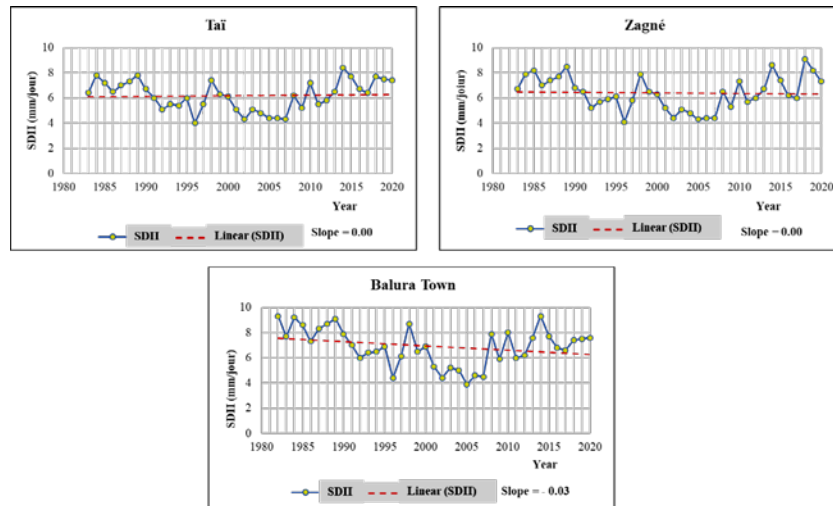


Figure 30. Simple daily intensity index (center)

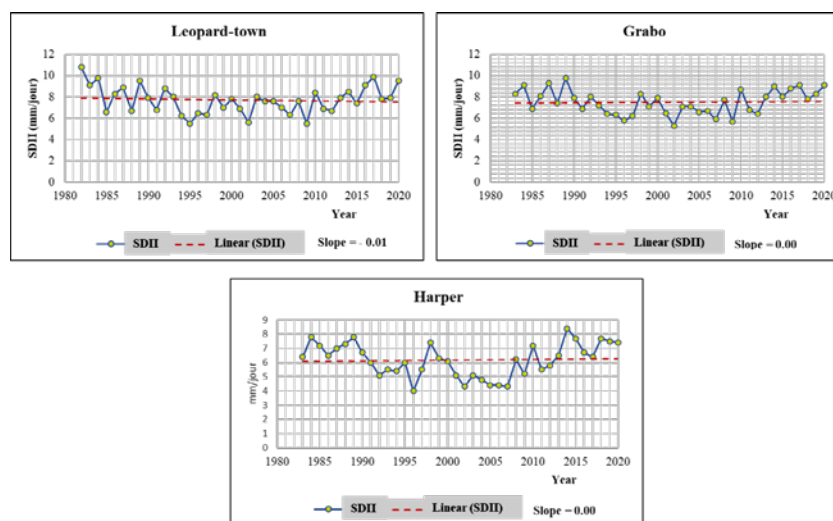


Figure 31. Simple daily intensity index (south)

3.1.2. Spatial distribution of precipitation indices

The spatial dynamics of the maximum 1-day and 5-day precipitation (RX1day and RX5day) over the period 1983-2020 are highlighted in Figure 32. The RX1day index

ranges from 40 to 71 mm/day (Figure 32a). The highest values (51 to 71 mm) were recorded in the south and north. The lowest values are found in the center, in the Taï and Zagné area, while the average values (47 to 51 mm) cover the entire center up to the south of Ity. As for the

maximum 5-day precipitation (Figure 32b), it oscillates between 118 and 195 mm. Its spatial distribution almost follows that of the RX1day index. However, the highest values (151 to 195 mm) are no longer distributed in the north, but are confined to the south in the regions of Niébé, Nékaounié and Grabo.

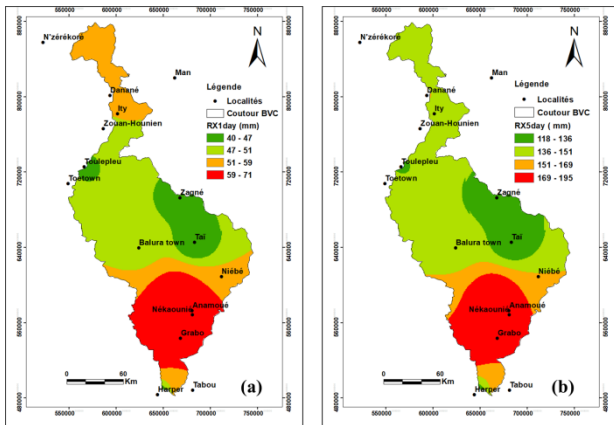


Figure 32. Spatial variation of indices (a) RX1day and (b) RX5day

Figure 33 shows the spatial distribution of total annual precipitation and consecutive wet days. The total annual precipitation between 1983 and 2020 ranges from 1630 to 2019 mm (Figure 33a). The very high values (1900 - 2014) are found in the north around Danané and in the south towards Grabo. Total precipitation between 1800 - 1900 mm is almost distributed across the entire CRB while the lowest values (1630 to 1800 mm) are found mainly in the center and around the Toulepleu area.

Figure 33b shows that the highest CWDs (85 to 98 days) are located in the extreme north of the CRB, at the foot of Mount Nimba to the south of Ity. The center and the south are characterized by indices ranging from 65 to 74 days and 57 to 65 days respectively. Thus, the number of consecutive wet days decreases as one moves away from the mountainous region.

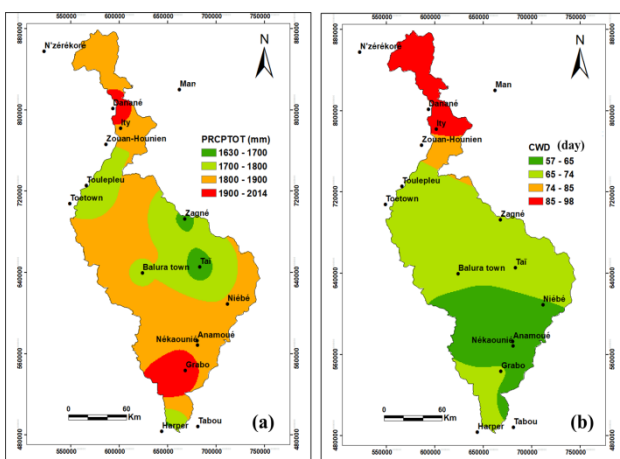


Figure 33. Spatial variation of indices. (a) PRCPTOT. (b) CWD

Figure 34 shows the variation in the number of days with heavy precipitation (rainfall ≥ 10 mm, (R10)) and very heavy precipitation (rainfall ≥ 20 mm, (R20)). It can be seen that the extreme north and south are dominated by the highest R10 values (between 60 and 68 days), while the lowest R10 values (47 to 54 days) are found in the center in the Niébé and Balura town sectors, up to

Toulepleu, passing through Taï and Zagné (Figure 34a). As for the number of heavy precipitation days, the number of very heavy precipitation days varies from 12 to 25 days (Figure 34b). Its distribution across the entire CRB is broadly similar to that of R10. The highest values, forming pockets, are found in the north, between Danané and Ity and in the south towards Grabo, while the lowest are located in the center, around Taï and Zagné and a little in the center-north (between Toulepleu and Toetown). However, R20s between 17 and 20 days cover practically the entire study area.

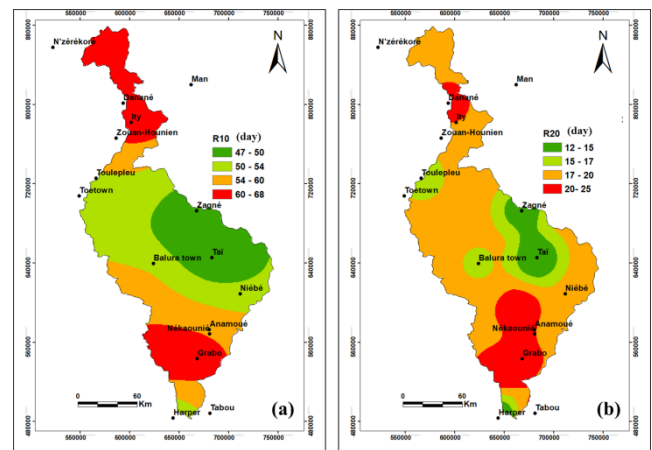


Figure 34. Spatial variation of indices (a) R10 and (b) R20

The same observation is made with the R25 and R95p indices, with the highest values of these indices being located in the north and south (Figure 35). The R25 index represents the number of days with precipitation ≥ 25 mm and the R95p index denotes the number of very wet days, i.e. days with precipitation above the 95th percentile. The number of days with precipitation ≥ 25 mm varies from 5 to 13 days (Figure 35a). Very wet days (R95p) record values ranging from 338 to 522 mm/year, the highest of which are concentrated in the south around Grabo (Figure 35b).

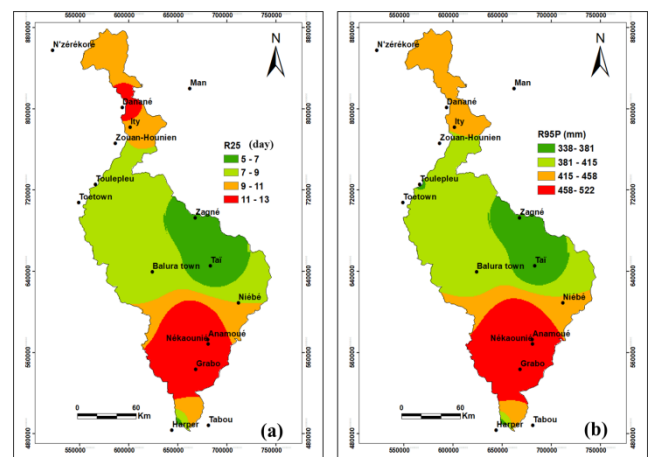


Figure 35. Spatial variation of indices (a) R25 and (b) R95p

The distribution of extremely wet days (R99p), i.e. days with precipitation above the 99th percentile, is shown in Figure 36a. The R99p index records values ranging from 118 to 186 mm/year, the highest of which (141 - 186 mm/year) are located throughout the southern CRB and in the high mountains north of Danané up to Mount Nimba. Low (118 - 128 mm/year) and medium (128 - 141

mm/year) values are found throughout the centre and slightly to the north, between Danané and Toetown.

Figure (36b) shows the distribution of the simple daily rainfall intensity index (SDII). Thus, we note that the lowest values (5 to 7 mm/day) are recorded in the Taï and Zagné sector while the highest (10 to 15 mm/day) are encountered in the south and north. The average values (7 to 10 mm/day) are mainly located in the center of the CRB, between Niébé, Balura town and Toulepleu. The study of the variation in the indices highlighted a spatial irregularity in rainfall in the CRB. The wettest areas are the far north and south of the study area. The central area, and more specifically the area surrounding the towns of Taï and Zagné, is marked by low rainfall, making it less humid. Although the center of the basin receives less rainfall than the far north and south, the amounts of rainfall that fall can still reach levels likely to trigger flooding. Therefore, a study of threshold rainfall capable of generating flooding was conducted.

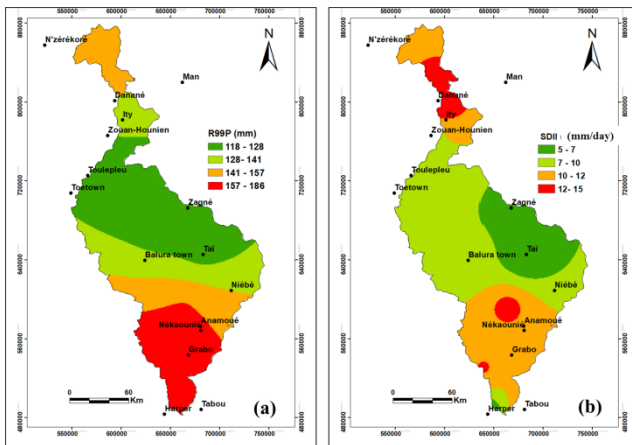


Figure 36. Spatial variation of indices (a) R99p and (b) SDII

3.2. Discussion

Rainfall variability was highlighted through ten precipitation indices (PRCPTOT, CWD, RX1, RX5, R10, R20, R25, SDII, R95p and R99p). The results of these rainfall indices calculated over the period 1983 - 2020 revealed variations between negative (decreasing) and positive (increasing) trends from one index to another on the one hand and from one station to another on the other hand. The indices of total annual precipitation (PRCPTOT), number of days of heavy and very heavy precipitation (R10 and R20), number of very wet or very rainy days (R95p) showed an overall downward trend over the period studied. These indices thus reflect a generally decreasing rainfall as demonstrated by [35,36] who highlighted a decrease in total annual rainfall in West Africa. Similarly, [21] indicated that West African countries were experiencing a decrease in total annual precipitation and the number of rainy days. Outside Africa, [37] observed a decreasing trend in total annual rainfall in Bangladesh. They obtained a decadal regression rate of about 84 mm. Over the period 1983 - 2020, the maximum 1-day precipitation amount index (RX1) showed an increasing trend across the entire Cavally watershed. The highest RX1s range from 0.38 mm/year in the north (Towetown) to 0.84 mm/year in the south (Grabou).

Reference [38] also showed an increasing trend in the RX1 index in the San-Pédro region. On the other hand, [1,39] highlighted decreasing trends in this index respectively in the northern regions of Côte d'Ivoire (Boundiali, Korhogo and Ferkessedougou) and in the district of Abidjan. The increasing trends in RX1, RX5 and R99 indices observed in the study area explain the frequency of flooding especially in the central and southern areas of the CRB as shown by [2] in Nigeria. Furthermore, [40] indicated that the RX1 index is often the cause of large amounts of flash rainfall that can lead to flooding and landslides.

4. Conclusion

The RCLIMDEX model was used to calculate ten rainfall indices to highlight the flood risk in the Cavally catchment area. The indices calculated after the data quality control and homogenization steps show a general downward trend in total annual rainfall (PRCPTOT), the number of days with heavy and very heavy rainfall (R10 and R20) and the number of very wet days (R95p). However, at the same time, the maximum amounts of precipitation over 1 day (RX1), the maximum precipitation over 5 consecutive rainy days (RX5) as well as the number of extremely rainy days (R99p) showed an upward trend. These positive trends confirm the extreme rainfall events observed in the Cavally watershed, which are manifested by increasingly frequent floods in the center and south of the study area. The results of this study constitute indicators that call for adaptation measures by the authorities to protect this highly agricultural area.

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