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Characterization of Precipitation Indices in the Republic of Guinea Using *In-Situ* Data

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Abstract

The Republic of Guinea experiences a tropical climate marked by a dry season influenced by the Harmattan winds and a rainy season driven by the West African monsoon, with a mean annual rainfall of approximately 1835 mm. This study examines precipitation trends using meteorological data from twelve synoptic stations over the period 1983-2013. Twelve precipitation indices, classified into four categories: hydrological, agro-hydrological, agronomic, and extreme precipitation indices, were analyzed to assess spatiotemporal variability. Trends were evaluated using the Mann-Kendall test at significance levels of 90%. Results reveal a pronounced north-south gradient in rainfall distribution, with the south receiving more abundant and intense precipitation. Agro-hydrological indices indicate that the rainy season begins around mid-January in southern regions, while the monsoon onset occurs nationwide by May 1st. Seven-day wet spells are frequent in the south, whereas dry spells predominate in northern areas. Conakry exhibits a high frequency of extreme wet events, in contrast to northern regions, which are more susceptible to severe dry conditions. Trend analysis shows a significant increase in wet-day indices, while indices related to dry days and extreme rainfall events display a statistically significant decrease.

Keywords

Precipitation, Climate Indices, *In-Situ* Data, Climate Extremes, Temporal

Trends

1. Introduction

In recent decades, West Africa has experienced a significant increase in extreme hydroclimatic events, including devastating floods and severe droughts [1] [2]. These phenomena result from the intensification of exceptional rainfall episodes and persistent precipitation deficits, respectively [3] [4]. Such events severely have severe socio-economic and ecological impacts [5]-[7]. Notable examples include the devastating 2009 floods in Ouagadougou, Burkina Faso, where 300 mm of rainfall was recorded within ten hours [8] [9], as well as the prolonged and severe droughts of the 1970s and 1980s in the Sahel [10]-[12].

To date, numerous studies have focused on analyzing the evolution of extreme precipitation in Africa, particularly north of the equator. Notable contributions include the works of [2] [13]-[17] which provide essential insights into climate trends and the potential impacts of climate change in this region. [18] analyzed data from six daily weather stations in West Africa (two in The Gambia and four in Nigeria) over the 1961-2000 period. They observed statistically significant increases in annual maximum daily rainfall at one Nigerian station.

However, in countries such as Senegal, the Republic of Guinea, and Guinea-Bissau, water management remains a major challenge. The water demand continues to rise, while climate change effects increasingly limit its availability [15] [19]. In Guinea-Conakry, [20] reported a decreasing trend in extreme rainfall events over the 1955-2006 period. [21] also highlighted a decline in precipitation since the late 1960s. Moreover, the spatial distribution of rainfall exhibits a positive latitudinal gradient from north to south [15] [21] [22]. Nevertheless, precipitation remains particularly high in the coastal and southeastern regions of Guinea. The northern half and southern regions of Guinea experience the most significant warming, followed by the coastal region, which is influenced by oceanic proximity, topography, and urbanization effects.

Beyond earlier studies that analyzed trends in total precipitation indices (total precipitation) in Guinea, this study introduces a classification of precipitation indices into four categories: hydrological, agro-hydrological, agronomic, and extreme precipitation indices, covering the period from 1983 to 2013. This research provides a comprehensive and diversified perspective on climate dynamics, fostering a better understanding of their impacts on water resources, agriculture, and extreme climate events. This innovative and ambitious study represents a pioneering effort, not only for the Republic of Guinea but also on an international scale.

It is, therefore, essential to prioritize studies that highlight spatiotemporal variations in precipitation. The key research questions of this study are:

- What is the spatiotemporal evolution of precipitation indices in the Republic of Guinea?

- What are the trends in precipitation indices in Guinea from 1983 to 2013?

Using *in-situ* meteorological data, this study aims to documents significant trends in precipitation indices over Guinea, while the physical mechanisms and climate drivers-such as ocean-atmosphere interactions and teleconnection patterns-will be explored in detail in a forthcoming paper. Furthermore, by identifying trends in various rainfall indices, this research seeks to enhance the understanding of the specific climate challenges facing Guinea. The findings are expected to highlight potential implications for several critical sectors, including agriculture, sustainable water resource management, and disaster risk reduction in response to extreme rainfall events. This study is structured as follows: Section 2 describes the *in-situ* precipitation data and the adopted methodology. The results and discussions are presented in Section 3. Finally, Section 4 provides the general conclusion.

2. Data and Methods

2.1. Study Area

Figure 1 presents the study area. The Republic of Guinea is divided into four (4) natural regions, each with distinct microclimatic characteristics.

1) Lower Guinea (Maritime Guinea)

Lower Guinea (LG) includes the synoptic stations of Boké, Conakry, and Kindia. This region is also known as Maritime Guinea due to its coastal location. It experiences a humid tropical climate, with peak rainfall occurring in August, reaching up to 4000 mm annually in Conakry [23].

2) Middle Guinea (Fouta Djallon)

Middle Guinea (MG) comprises the synoptic stations of Koundara, Labé, and Mamou. This is the most mountainous region of the country, dominated by the Fouta Djallon massif, which covers approximately 80,000 km^2, with its highest peak being Mount Loura (1532 m). The rainy season lasts between 5 and 8 months, depending on the location, with annual rainfall below 1300 mm in the northern areas [23].

3) Upper Guinea

Upper Guinea (UG) includes the synoptic stations of Faranah, Kankan, and Siguiri. It lies between Forest Guinea and Fouta Djallon, at the western edge of the vast Niger Basin. Climatically, this is the driest region in Guinea, characterized by a Sudanian climate. Annual precipitation ranges between 1200 and 1800 mm, with the longest dry season (7 - 8 months). Average temperatures remain relatively high throughout the year, reaching up to 40˚C between March and April [24].

4) Forest Guinea

Forest Guinea (FG) encompasses the synoptic stations of Kissidougou, Macenta, and N'zérékoré. It features a sub-equatorial climate, with abundant and nearly continuous rainfall for 8 to 9 months each year. This region records a high number of rainy days [25]. The average annual rainfall ranges from 1800 to 2300 mm [23]. Temperatures are mild throughout the year, fluctuating around 25˚C.

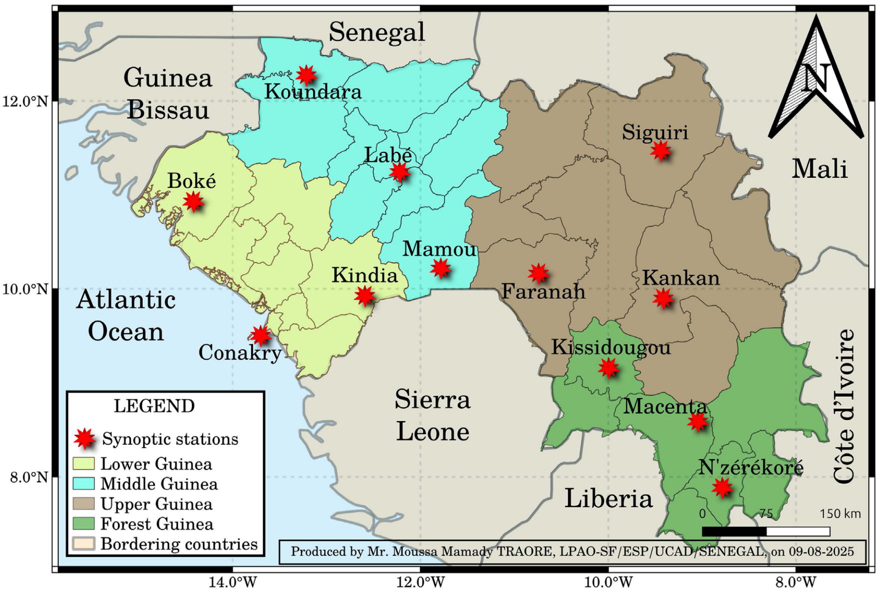

Figure 1. Map of the study area with the geographic locations (red stars) of the synoptic stations used (created by the authors of this manuscript using QGIS software. The source of the map is clearly indicated at the bottom: "Produced by Mr. Moussa Mamady TRAORÉ, LPAO-SF/ESP/UCAD/SENEGAL, on 09-08-2025").

2.2. Data

The climatic data used in this study consist of time series of precipitation from twelve (12) synoptic stations covering the Guinean territory, where observations are conducted 24 hours a day. These data were obtained from the National Meteorology Directorate (DNM) of Guinea, which manages the observation stations represented in **Figure 1**. The precipitation data correspond to daily averages over a 31-year period (1983-2013) for all twelve (12) synoptic stations. These stations are distributed across Guinea's four (4) natural regions, with three (3) stations per region (**Table 1**).

The original dataset covered the period from 1981 to 2021. After applying quality control procedures, years with missing data were detected at four stations. Consequently, a complete and continuous period from 1983 to 2013 was selected for the analysis [26]. The completeness rate is then calculated by dividing the number of valid values by the total number of expected observations [27]. Finally, the results are summarized in a comprehensive table (**Table 1**), providing a clear overview of the quality for all data stations used. This procedure follows the recommendations of the National Weather Service (NWS) regarding quality control, which includes the detection of missing values and the reconstruction of absent data-essential elements for ensuring the reliability and consistency of meteorological time series.

The set of pluviometric stations used exhibits a data completeness rate of 99.929%, reflecting an almost full coverage of the observational series for the period 1983-2013 (**Table 1**). Specifically, less than 0.1% of the expected observations are missing, indicating that the datasets are practically complete and homogeneous. This very high level of availability enhances the reliability of climatological and statistical analyses by minimizing biases associated with data gaps, providing a robust foundation for the study of rainfall variability and climatic trends in Guinea.

Table 1. The twelve (12) synoptic weather stations of Guinea (1983-2013) and their coordinates. From left to right we have the Guinean regions, weather stations, the coordinates (lattitude, longitude, altitude) and the completeness rate (%).

Region	Stations	Latitude	Longitude	Altitude (m)	Completeness (%)
Lower Guinea	Boké	10˚56'	−14˚18'	69	99.929
	Conakry	09˚64'	−13˚58'	46	99.929
	Kindia	10˚04'	−12˚86'	458	99.929
Middle Guinea	Koundara	12˚34'	−13˚31'	90	99.929
	Labé	11˚19'	−12˚29'	1050	99.929
	Mamou	10˚38'	−10˚80'	782	99.929
Upper Guinea	Faranah	10˚26'	−10˚80'	358	99.929
	Kankan	10˚12'	−09˚55'	376	99.929
	Siguiri	11˚74'	−09˚37'	361	99.929
Forest Guinea	Kissidougou	09˚19'	−10˚11'	524	99.929
	Macenta	08˚32'	−09˚28'	542	99.929
	N'Zérékoré	07˚75'	−08˚83'	467	99.929

2.3. Methodology

In this study, our approach is based on the calculation of precipitation indices, which are grouped in **Table 2**. The precipitation indices are computed following the definitions provided by the Expert Team on Climate Change Detection and Indices (ETCCDI). A detailed description of these indices is available at https://rdrr.io/cran/climdex.pcic/man/climdex.prcptot.html.

The calculation of the total precipitation index (RPTOT) is based on the annual accumulation of rainfall. The frequency index (R1mm) represents the total number of rainy days (days with precipitation ≥ 1 mm) per year, while the dry day index (DD) refers to the number of non-rainy days (precipitation < 1 mm). The intensity index (SDII) is calculated as the mean precipitation on rainy days. The dry spell (CDD, consecutive dry days) and wet spell (CWD, consecutive wet days) indices are based on a threshold of seven (7) consecutive dry and wet days, respectively. The Max_CDD and Max_CWD indices represent the longest annual sequences of consecutive dry and wet days, respectively [28] [29].

For extreme rainfall event indices (ERE_R99p), considering that in regions where the number of rainy days is very high (which may be the case in this study), the calculation is not solely based on rainy days (above 1 mm) but rather on all days, as recommended by [30]. In such cases, these authors used a percentile-based approach considering all days. Accordingly, we define the ERE_R99p index as the number of days with precipitation exceeding the 99th percentile threshold, computed over the entire period (1983-2013) and considering the rainy season from February to December.

The calculation of the onset and length of the rainy season indices is based on the method of [31]. In this study, the onset of the rainy season (ORS) is defined as the first date after January 1st when cumulative precipitation over three consecutive days reaches at least 20 mm, provided that no dry spell exceeding seven days occurs within the following 30 days to avoid false onsets. Similarly, the end of the rainy season is defined as the first date after September 1st when 20 consecutive dry days are recorded. The length of the rainy season (LRS) is then calculated as the difference between the end and onset dates.

The monsoon onset index (IoM) for each year is determined as the difference between the onset dates at different stations and the station with the earliest onset date, which is considered the reference station.

Table 2. The twelve (12) precipitation indices.

No	Acronym	Description	Unit
1	RPTOT	Total precipitation index	mm
2	SDII	Precipitation intensity	mm/days
3	R1mm	Precipitation frequency	days
4	DD	Number of Dry Days	days
5	ORS	Onset of the Rainy Season	date
6	LRS	Length of the Rainy Season	days
7	IoM	Monsoon of installation	days
8	ERE_R99p	Extreme Rainfall Event	event
9	CDD	Seven consecutive dry days	event
10	CWD	Seven consecutive wet days	event
11	Max_CDD	Maximum number of consecutive dry days	days
12	Max_CWD	Maximum number of consecutive wet days	days

To quantify the trends associated with the temporal evolution of each index, we applied the Mann-Kendall statistical test with a significance level of 90%. A 90% significance level was selected for the Mann-Kendall test during this period in order to detect moderate trends while limiting the risk of Type I error (incorrect rejection of the null hypothesis). Considering the natural characteristics of precipitation over the 31-year study period, this threshold represents a reasonable compromise between sensitivity to trend detection and statistical reliability. It thus allows for a cautious quantification of both the magnitude and the uncertainty of the observed trends in the analyzed rainfall series.

In this study, the indices are classified into four categories based on their characteristics:

- **Hydrological indices:** RPTOT, SDII, R1mm [32] [33].
- **Agro-hydrological indices:** ORS, LRS, IoM [34].
- **Agronomic indices:** DD, CDD, CWD [35].
- **Extreme indices:** ERE_R99p, Max_CDD, Max_CWD [36].

3. Results

3.1. Spatiotemporal Evolution of Precipitation Indices

1) Hydrological Indices

Figure 2 illustrates the spatiotemporal evolution of hydrological indices (RPTOT, R1mm, and SDII) in the Republic of Guinea from 1983 to 2013. The total precipitation (RPTOT) is characterized by high rainfall amounts ranging from 1000 mm in Koundara to 4500 mm in Conakry, with a well-defined meridional precipitation gradient (**Figure 2**), consistent with the findings of [37].

Figure 2(b) shows a decrease in precipitation frequency towards the north, with a maximum observed in the southern forest region (Macenta), which may be attributed to the influence of vegetation cover [38]. This result aligns with the work of [25] on the spatiotemporal distribution of precipitation in Guinea. A similar spatial distribution is observed for precipitation intensity (**Figure 2(c)**), with the highest values recorded in the coastal (Conakry and Boké) and forest (Macenta) stations.

It is noteworthy that the high rainfall amounts recorded in Conakry are primarily driven by precipitation intensity rather than frequency. According to [37], this spatial distribution of precipitation can be explained by moisture transport, precipitable water, and humidity divergence patterns. However, in other stations, total precipitation is influenced by both frequency and intensity. With hydrological indices, the observed decrease in precipitation frequency towards the north, with a maximum in the south in the forest region, aligns with the work of [25].

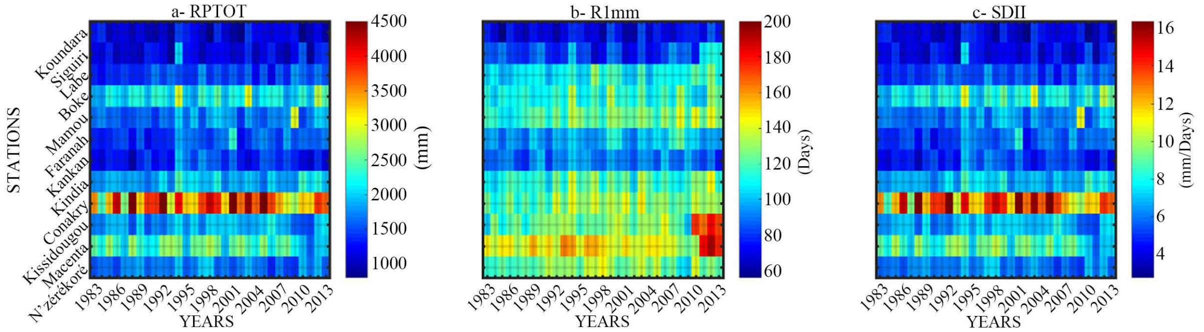

Figure 2. Spatiotemporal evolution of hydrological precipitation indices (RPTOT, R1mm, and SDII) in the Republic of Guinea from 1983 to 2013.

2) Agro-hydrological Indices

The spatiotemporal evolution of agro-hydrological indices (ORS, LRS, and IoM) is illustrated in **Figure 3**. This figure highlights the northward shift of the Intertropical Convergence Zone (ITCZ) during the rainy season. This meridional displacement of the ITCZ largely explains the variability of West African precipitation, particularly in Guinea.

Specifically, the rainy season typically begins around January 15 in N'zérékoré (south) and July 2 in Koundara (north), representing a six-month difference between the southernmost and northernmost stations in the country (**Figure 3(a)**). The stations of Kissidougou, N'zérékoré, and Macenta are characterized by a season length of up to 330 days, indicating that daily precipitation frequency is higher in the southern region, covering almost the entire year (**Figure 3(b)**). In contrast, northern stations (Siguiri and Koundara) experience shorter rainy seasons, ranging from 120 to 150 days. However, a decline in the length of the rainy season has been observed since 2003 in these regions, with durations varying between 110 and 150 days.

Similar to the onset of the rainy season, the monsoon onset index (**Figure 3(c)**) exhibits the same spatial distribution, with an earlier onset in the south and a progressive northward evolution.

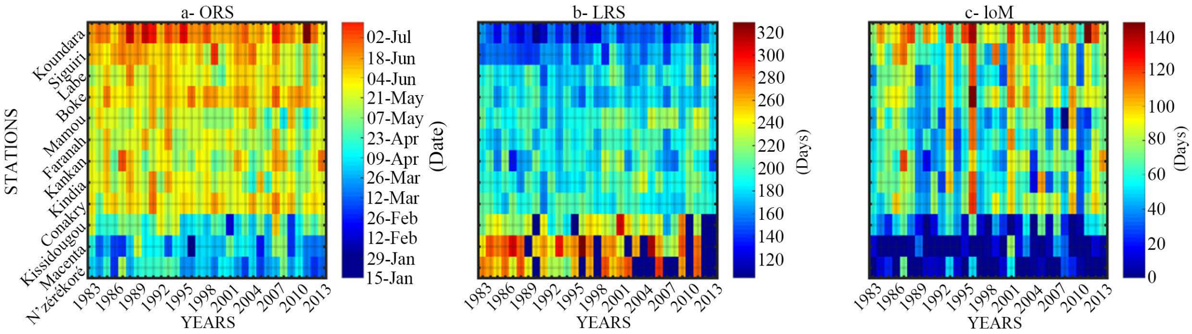

Figure 3. Same as **Figure 2**, but for the agro-hydrological indices (ORS, LRS, and IoM).

3) Agronomic Indices

Figure 4 illustrates the spatiotemporal evolution of agronomic indices, specifically the number of dry days (DD), seven (7) consecutive dry days (CDD), and seven (7) consecutive wet days (CWD).

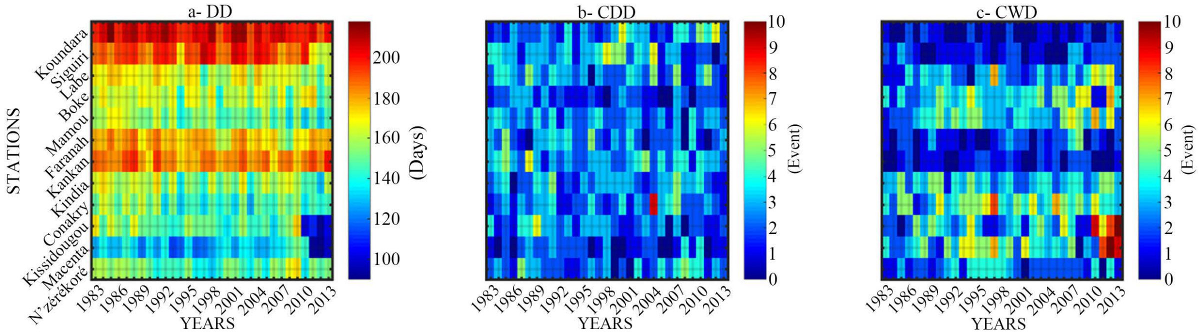

Figure 4. Same as **Figure 2**, but for the agronomic indices (DD, CDD, and CWD).

Consistent with the distribution of the number of wet days index (R1mm, **Figure 2(b)**), **Figure 4(a)** shows that the number of dry days (DD) is higher in the north, particularly in the Fouta Djallon region (Koundara) and Upper Guinea (Siguiri), as well as in the central-eastern areas (Kankan and Faranah), which aligns with the findings of [39]. However, the CDD and CWD indices exhibit a highly heterogeneous spatial distribution across Guinea (Figure 4(b) and Figure 4(c)), with some stations recording up to 10 events of either CWD or CDD.

Figure 4(c) further reveals that northern and central-eastern stations are rarely associated with wet sequences lasting more than seven days. In contrast, coastal stations (Boké, Conakry, Kindia) and southern stations (Macenta) exhibit more frequent wet sequences.

4) Extreme Indices

Figure 5 illustrates the spatiotemporal evolution of extreme precipitation indices (ERE_R99p, Max_CWD, and Max_CDD) in the Republic of Guinea from 1983 to 2013.

Figure 5(a) shows that Conakry experiences the highest number of extreme rainfall events (ERE_R99p), with up to 14 events per year. In contrast, the rest of the country is less affected by these extreme rainfall events, with a maximum of only two events in certain years. This pattern can be attributed to the high precipitation intensity and totals recorded in Conakry (Figure 2(c)). Regarding the high rainfall amounts recorded in Conakry, explained by the intensity of precipitation, these are confirmed by [37] and [40], where maxima of moisture flux and precipitable water are observed in coastal areas.

Figure 5(b) highlights that the stations of Conakry and Kindia record the highest number of consecutive wet days (Max_CWD) in the country over the study period. The Max_CWD index is generally higher in the southern regions and decreases progressively towards the north.

Conversely, the maximum number of consecutive dry days (Max_CDD) is recorded in the northern part of the country, with peaks observed in the Boké and Labé stations. This Max_CDD index gradually decreases toward the south (Figure 5(c)).

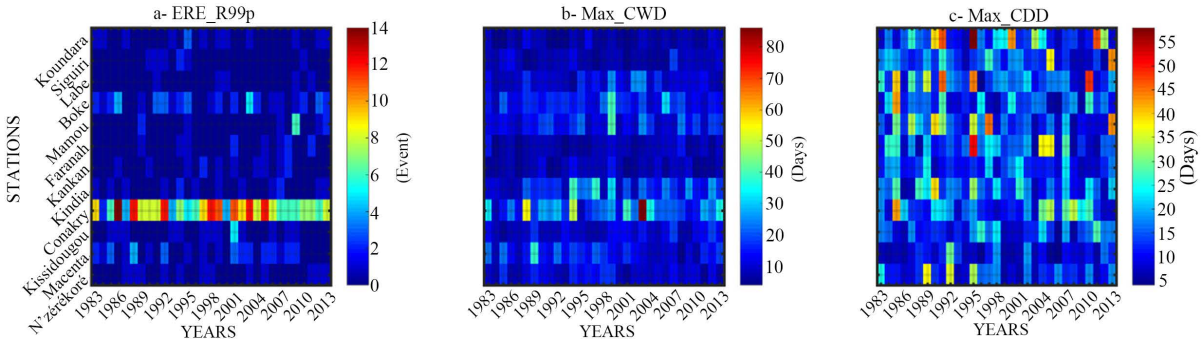

Figure 5. Same as Figure 2, but for the extreme indices (ERE_R99p, Max_CWD, and Max_CDD).

3.2. Trends in Precipitation Indices

The evolution of precipitation indices in Guinea indicates an increasing trend in hydrological indices (Figures 6(a)-(c)). Figure 6(a) shows a significant upward trend in RPTOT, with an increase of 3 mm/year. This increase is associated with a rise in both precipitation intensity (SDII, **Figure 6(b)**), which increases by 0.011 mm/day per year, and rainfall frequency (R1mm, **Figure 6(c)**), which increases by 0.6 days/year across the entire country. This result aligns with the findings of [21] and [41].

Similarly, agro-hydrological indices also exhibit increasing trends for ORS and IoM, while LRS shows a decreasing trend (**Figures 6(d)-(f)**). The declining trend in LRS (**Figure 6(e)**) can be explained by the increasing trends in ORS (0.2 days/year, **Figure 6(d)**) and IoM (0.2 days/year, **Figure 6(f)**), indicating a tendency toward a delayed onset of the rainy season in Guinea.

Regarding agronomic indices, we observe a decreasing trend in DD and CWD, in contrast to an increasing trend in CDD (**Figures 6(g)-(i)**). The most significant change is observed in the DD index, which shows a decreasing trend of 0.65 days/year (**Figure 6(g)**), while CWD exhibits a decline of 0.06 events/year (**Figure 6(i)**). In response to the decrease in CWD, the CDD index shows an increasing trend of 0.015 events/year (**Figure 6(h)**).

Finally, extreme precipitation indices (ERE_R99p, Max_CDD, and Max_CWD, **Figures 6(j)-(l)**) reveal a strong decreasing trend of 0.06 events/year for ERE_R99p (**Figure 6(j)**) and an increasing trend of 1.4 days/year for Max_CWD (**Figure 6(l)**). However, Max_CDD shows a very slight decreasing trend of 0.01 days/year (**Figure 6(k)**).

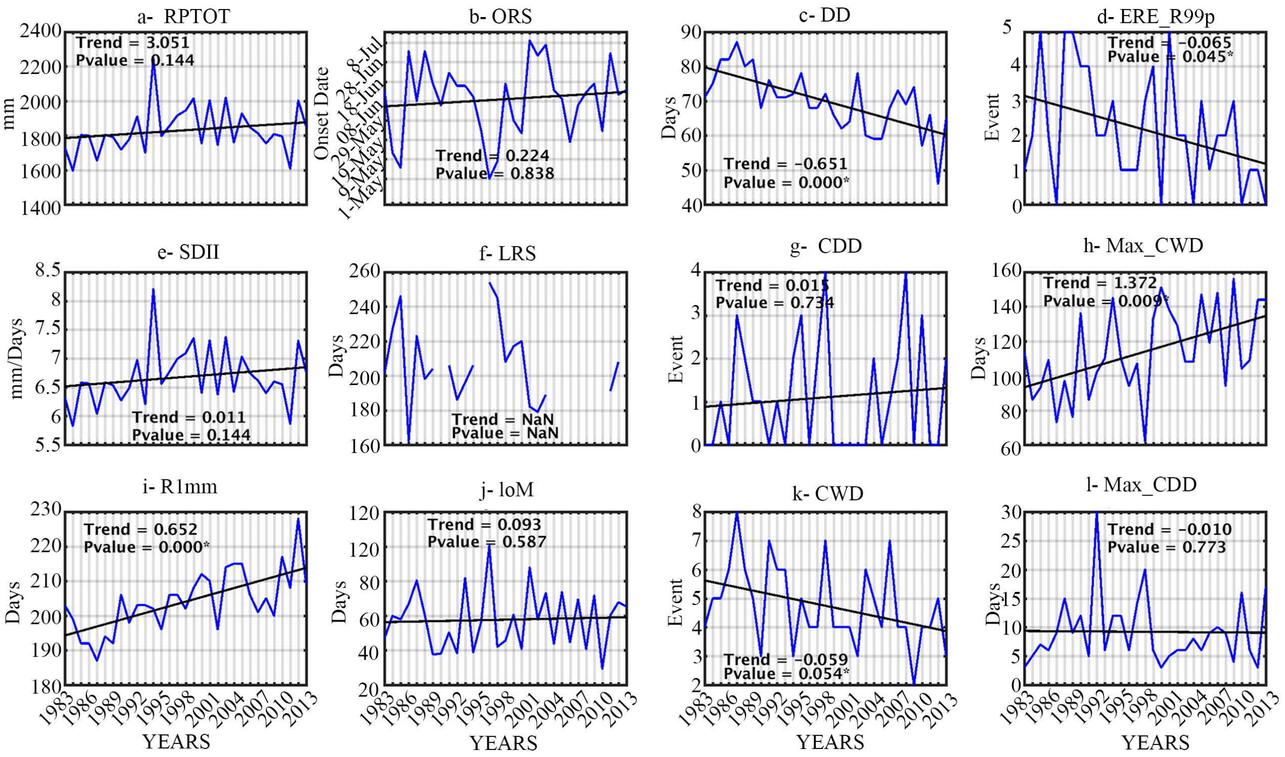

Figure 6. Temporal evolution of precipitation indices (blue curves) from 1983 to 2013 for: a) RPTOT, b) SDII, c) R1mm, d) ORS, e) LRS, f) IoM, g) DD, h) CDD, i) CWD, j) ERE_R99p, k) Max_CDD, and l) Max_CWD. For each index, the associated linear trend based on a Mann-Kendall test with a significance level of 90% is superimposed (black line).

4. Conclusions

This study focuses on the characterization of precipitation in the Republic of Guinea using daily *in-situ* observation data from twelve (12) synoptic stations over the period 1983-2013. The characterization is based on 12 climatic indices defined by the expert team on the detection and indices of climate change (ETCCDI). These indices are divided into four categories: hydrological indices (RPTOT, R1mm, SDII), agro-hydrological indices (ORS, LRS, IoM), agronomic indices (DD, CDD, CWD), and extreme indices (ERE_R99p, Max_CDD, Max_CWD).

The spatiotemporal analysis of the hydrological indices reveals a meridional gradient of precipitation, with the highest rainfall amounts (RPTOT) recorded in the south, peaking at Conakry. This maximum is explained by the high rainfall intensities (SDII) observed at this station. For the remaining stations by both the intensity and rainy day (R1mm) frequency (R1mm). Furthermore, trend analysis shows an increase of 3 mm/year in RPTOT (3 mm/year), R1mm (0.6 days/year), and SDII (0.011 mm/day/year). Concerning the agro-hydrological indices, they indicate the onset of the rainy season starting between January 15 in the south (N'zérékoré) and July 2 in the north (Koundara), with a six (6)-month delay between the southern and northern regions of the country. The southern stations are characterized by a longer rainy season (330 days, up to a maximum of 365 days), while the northern stations record a rainy season of 120 to 150 days.

Similar to the hydrological indices, ORS and IoM show an upward trend of 0.2 days/year, indicating a trend toward a delayed start to the season, resulting in a decrease in LRS.

In accordance with the distribution of the wet-day index (R1mm), the number of dry days (DD) is higher in the north, particularly at Koundara and Siguiri, as well as in the central-east regions of Kankan and Faranah. However, the consecutive dry days (CDD) and consecutive wet days (CWD) indices show a highly heterogeneous spatial distribution across Guinea, with stations recording up to 10 events of CWD or CDD. Trend analysis of these extreme precipitation indices reveals a significant decrease in dry days (DD) by 0.65 day/year and a significant reduction in the number of 7-day consecutive wet days (CWD) by 0.06 event/year. Meanwhile, the number of 7 CDD shows an increase of 0.015 event/year.

Our results show that Conakry is more associated with extreme rainfall events (ERE_R99p), which can reach up to 14 events per year. In contrast, other stations are less affected by extreme rainfall events (maximum of 2 per year). Furthermore, Max_CWD is higher in the south of the country and decreases progressively towards the north, in contrast to Max_CDD. We also found a significant decrease of 0.06 event/year for ERE_R99p and 0.01 day/year for Max_CDD, while Max_CWD shows a significant increasing trend of 1.4 days/year.

It is important to note that the spatial coverage of twelve synoptic stations, while representing the best available long-term data, is insufficient to fully resolve Guinea's complex spatial climate patterns. This is particularly true for localized, high-intensity convective events influenced by topography, which may be undersampled. Consequently, our findings are more representative of broad-scale regional trends rather than fine-scale spatial variability. Despite the constraint posed by the number of stations, this study has successfully characterized the spatiotemporal evolution of precipitation indices across Guinea and identified their trends. The results provide valuable climate information at the national level, which can inform policy decisions and support strategic planning. Moreover, these findings are critical for impact assessments in key sectors such as agriculture and water resource management.

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The dataset used in this study originates from synoptic stations across Guinea and was provided by the DNM. It consists of daily rainfall averages recorded over a 31-year period (1983-2013) at twelve (12) synoptic stations distributed nationwide. These data were analyzed as part of a scientific collaboration aimed at enhancing the understanding of precipitation variability in Guinea.

Conflicts of Interest

The authors declare no conflict of interest.

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