Cheikh Diop et Yaya Mansour Diédhiou
Analyzing Annual Rainfall from three Centennial Observing Stations in Senegal and the Gambia
International Journal Water Sciences and Environment Technologies
Vol. (ix), Issue. 3, November 2024, pp. 6-14
ISSN Online: 1737-9350; ISSN Print: 1737-6688, Open Access
www.jiste.org
Scientific Press International Limited
Received: March 2024 / Revised: April 2024 / Accepted: July 2024 / Published: November2024

Analyzing Annual Rainfall from three Centennial Observing Stations in Senegal and the Gambia

Cheikh Diop[1], Yaya Mansour Diédhiou[1]

Département de Géographie, Université Cheikh Anta Diop, Dakar, Sénégal,

Abstract

Senegal and the Gambia are under the influence of a highly variable climate. Therefore, farming and human settlements have to find ways to adapt to new climate conditions and interannual changes. Climate information plays a crucial role in the adaptation process of public and private organizations. With the need to better understand the changing mode of climate patters, indices are used to describe the changes in the evolution of climate parameters. This paper aims at replacing the recent increase in rainfall in a broader context of long-term variations of annual precipitation totals. To this end, a long time series (120 years) of ground-based rainfall data has been collected. Three synoptic stations are chosen to analyze the rainfall series of centennial observing stations. The 10-year moving average and the 10-year averages are applied to the rainfall series to determine the trend over more than a century. With the calculation of the Percent Normal Precipitation (PNP), the comparison of phases has been done to distinguish between the wet and dry periods. Subsequently, the series has been divided into deciles to analyze the distribution of the highest and lowest annual precipitation totals. The results show that the trend is decreasing in all stations. The 1920s are the wettest years in Saint-Louis and Banjul, while the 1950s recorded the greatest rainfall amounts in Dakar. Two wet periods are separated by the dry period of the 1970s and 1980s in Saint-Louis and Dakar. In the last couple of decades, with the increase in rainfall, the PNP reached 150% some years. Furthermore, the highest rainfall amounts belong to the period before 1969. They did not appear in the second wet period. Conversely, the lowest rainfall amounts are well represented in the last couple of decades, showing that the recent years share some of the traits of the dry period of the 1970s and 1980s. The peculiarity of the annual precipitation totals since the early 2000s is a piece of climate information that can improve adjustments to year-to-year variations of precipitation.

Keywords: centennial observing station, rainfall, drought, Percent of Normal Precipitation, decile, Senegal, the Gambia

Analyse de la pluviométrie de trois stations d'observation centenaires du Sénégal et de la Gambie

Résumé

Rainfall over one watershed will be distributed on intercepted water, evaporated, infiltrated and flowed. Water flow at the surface depends on rainfall intensity and soil previous conditions. The year 2023 represent an exceptionnel dry year. The frequency is studied for the hydrological 22/23 and 23/24 years. Runoff coefficient calculated for registered floods over the three watersheds of Siliana, Nebhana and Lebna are very low from 1 to 2%. This is rarely registered over these watersheds. It shows the weakness of the surface flow and he very lowof water volume stocked in the dams. Dam siltation represents a threat to all dams and in particular to these three dams. Siliana dam in particular is a critical situation in that the siltation rate exceeds 50%.
We discuss also the importance of soil conservation measures in the three watersheds. These measures play an important role in soil protection and sediment decrease which increases dam's life. The adaptation measures to these conditions have to be undertaken at the field scale and water bodies.

Mots clés : : station d'observation centenaire, pluviométrie, sécheresse, Pourcentage de Précipitations Normales, décile, Sénégal, Gambie..

[1] Corresponding author: 1cheikh83.diop@ucad.edu.sn

INTRODUCTION

The highly variable character of the climate in West Africa makes it challenging to predict yields and flooding. In fact, human settlements are exposed to a variable rainfall in West Africa [1]. The first step in preparedness is the assessment of changes in the temporal distribution of rainfall. This is possible with long-time rainfall series recorded in Senegal and the Gambia. In fact, a historical perspective in rainfall variations is needed to better understand the recent trend in the climate evolution.

In some cases, there is a succession of wet and dry periods without abrupt changes. By analyzing a 500-long historical rainfall data, Rodrigo et al. [2] showed different phases in the evolution of the rainfall in southern Spain. In connection with the North Atlantic Oscillation, the annual precipitation totals statistically decreased from 1900 to 2010 in most of the Mediterranean regions [3]. In Thailand, Limsakul and Singhruck [4] showed an increase in rainfall in the early 2000s by analyzing a 1955-2014 series. The variations on interannual-to-interdecadal time scales in annual precipitation totals are in relation with large-scale phenomena in the Pacific Ocean.

To better understand the evolutionary pattern of the rainfall, gridded data are developed to provide longer time-series. Funk et al. [5], in 2015, acquired a centennial trend for the Horn of Africa. The gridded data showed a significant decline in rainfall since the 1990s. Century-long station data showed that the recent positive trend seen in Argentina in the second half of the century is still true when placed in a longer time series [6]. In the Sahel region, where Nouaceur and Murarescu [7] analyzed the rainfall data of 27 stations between 1947 and 2014 in Burkina Faso, Mauritania and Senegal, the annual rainfall increased in recent years following the dry period of the 1970s and 1980s and the intermediate period of the 1990s and early 2000s. Descroix et al. [8] highlighted the breaks in a century-long series. The dry period from 1968 continued until 1998 in Senegal and the Gambia. It followed a 1950-1967 wet period. The recovery in rainfall is accompanied by an increase in the interannual variability with abnormally wet years following abnormally dry years. Such a high interannual variability is comparable to what was observed during the wet period before the 1950s [8].

The high variability in rainfall affects both arid and humid regions. In the Northern Territory of Australia, by analyzing rainfall data of 230 stations from 1910 to 2017, He et al. pointed out the abrupt change in rainfall between 1966 and 1975 [9]. They found that the increasing trend in annual precipitation is associated with a greater variability in recent decades. Reconstructed rainfall data show decreases in areas of the Horn of Africa where rain gauges are scarce [5].

As above-mentioned, multidecadal rainfall series display phases in the evolution of annual precipitation totals. In addition, significant breaks appeared as the start of dry periods or wet periods. In the Sahel, recent studies place the beginning of the increase in annual amounts of rainfall in the late 1990s or early 2000s. To better understand the significance of the recent increase in rainfall in the Sahel region and in Banjul, this study focuses on coastal ground-based observations to describe the characteristics of the last phase in the evolution of the annual precipitation totals on the coast of Senegal and the Gambia.

2. METHODS

2.1 *Description of the study area*

Th weather stations chosen for this study are located in the oldest cities of Senegal and the Gambia (Fig. 1). The city of Saint-Louis in Senegal was founded by Europeans from a ship anchored off the coast. In 1633, the Cape Verde Company established the first trading post for the slave trade on an island at the mouth of the river. Ten years later, the trading post was transferred by Louis Caullier to a less flood-prone area, the island of N'Dar, which then took the name of Saint-Louis, in homage to the King of France [10]. This city was the starting point of all kinds of expeditions across black Africa, Saint-Louis was at that time the heart of the colony of Senegal and its dependencies, capital of the colony of Senegal and finally in 1895 capital of French West Africa: Senegal, Sudan (Mali), Guinea and Côte d'Ivoire. The region of Saint-Louis covers an area of 19,034 km², or about 10% of the national territory. It is bordered to the north by the Senegal River and Mauritania. Located 270 km from Dakar, Saint-Louis is part of the Sahel region and is located at 16°14'04" north latitude and 16°29'22" west longitude. The rainfall measurements began in Saint-Louis in 1892 [11].

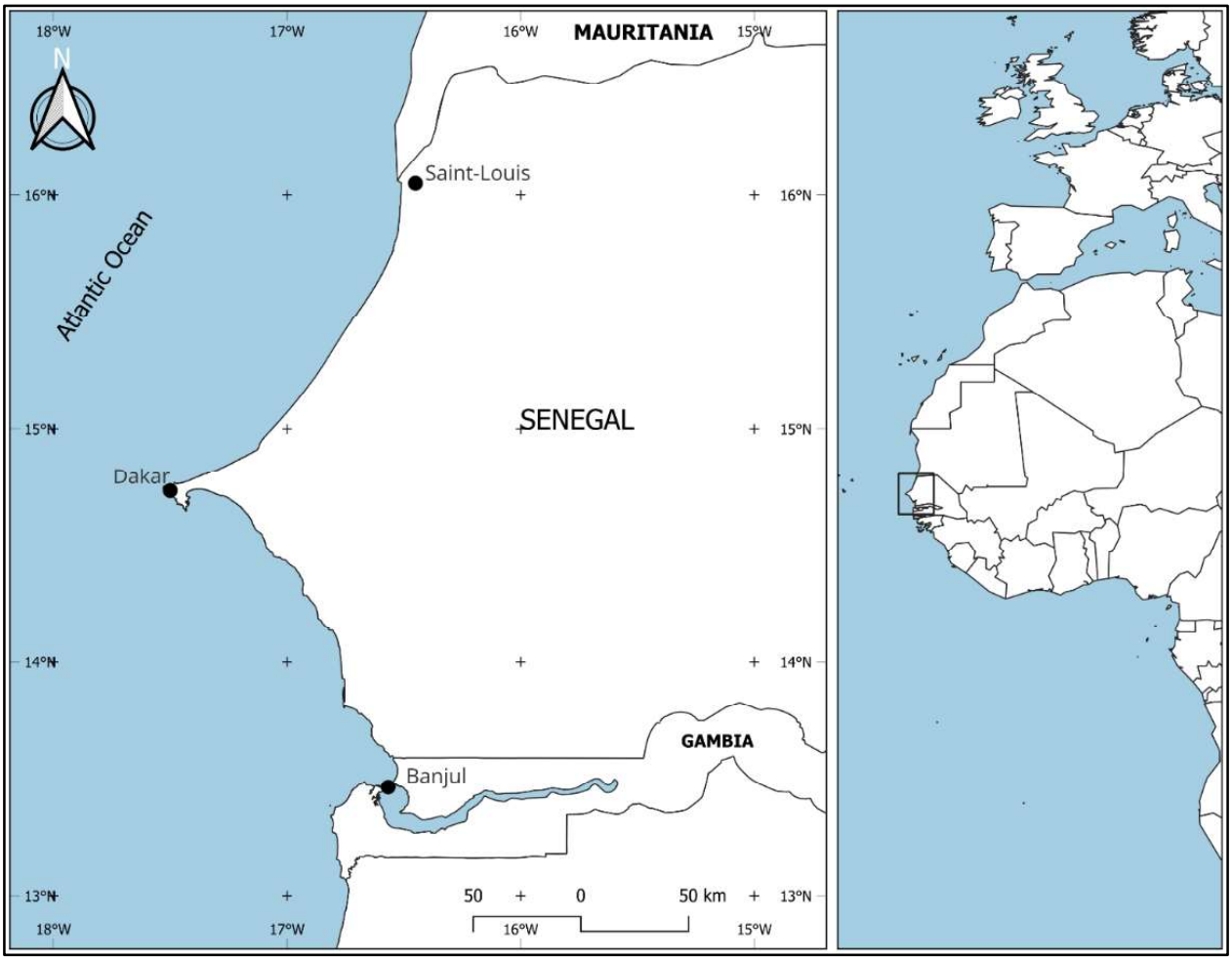

Fig. 1 – Location of the chosen centennial observing stations

Dakar was founded in 1857. In 1875, the administration was transferred from Gorée island, off the coast of Dakar, to Dakar. Nevertheless, it was the construction of the railway in 1883 that gave Dakar its importance. It was erected in 1887 as a commune for its 8,700 inhabitants. The Dakar region is located in the Cape Verde peninsula. It covers an area of 550 km², or 0.28% of the national territory. Dakar is located at 17°30'00' west longitude and 14°43'00" north latitude. The Dakar region is bordered by the Atlantic Ocean in its northern, western and southern parts (12). From a climatic point of view, Dakar belongs to the Sahel region. The first rain gauge was installed in 1896 [11].

Banjul, the capital city of the Gambia, is an island located near the mouth of the Gambia River. It was founded in 1816. Under the orders of the British Colonial Office a military post was established on the river in order to stop the illegal slave trade. It was also intended to be a commercial outlet for merchants sent back from Senegal to France. Banjul was named in honor of Henry Bathurst, then colonial secretary. It thus became the capital of the British colony and protectorate of the Gambia. Bathurst, as it was called then, became the country's capital and was renamed Banjul in 1973. Its geographical position makes it a coastal area. The first rainfall records were made in 1886 [11].

In all of the three areas, there is a distinction between a long dry season of seven to nine months. The duration of the rainy season increases from the north (Saint-Louis) to the south (Banjul). The daily average temperature slightly varies during the year between 20 and 30°C (Fig. 2). In those coastal areas, the temperature is moderate.

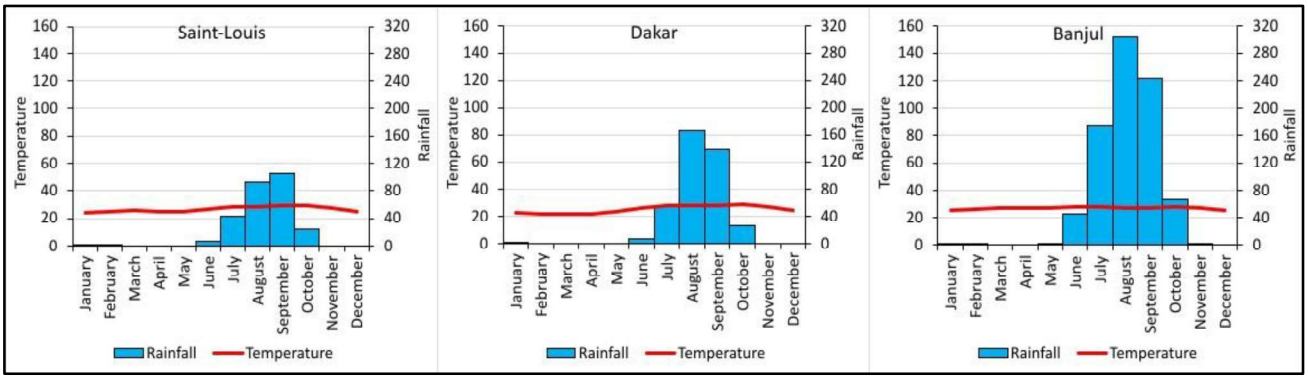

Fig. 2 - Climate diagrams of the study area

Saint-Louis and Dakar are cooler than Banjul, especially in the dry season. The rainfall increases from Saint-Louis to Banjul ranging between 272 mm, in Saint-Louis, and 839 mm, in Banjul. The latter station belongs to a much more rainier climate area. The rainfall is highly variable. From one year to another, the annual precipitation total can be the double. Furthermore, the time series of the rainfall is marked by significant changes showing different periods according to the average yearly rainfall [13, 14, 15, 16, 17]. In fact, the rainfall series in West Africa are characterized by abrupt increases or decreases starting new phases in the evolution of annual precipitation totals.

2.2 *Data and analysis*

To obtain a good representation of the territory covering Senegal and the Gambia, three synoptic stations have been selected (Tab. 1). Two of them are located in the Sahel region (Saint-Louis and Dakar). The station of Banjul represents the wetter area between the arid region and the equatorial climate. Among the nine centennial observing stations that exist in Senegal and the Gambia, these three of them (Saint-Louis, Dakar and the Gambia) offer the most complete rainfall series. They have been chosen to analyze the variability of the rainfall since the beginning of the twentieth century (1901). They are located on the coast of Senegal and the Gambia and differ in latitude (13 ° to 16 °). The time series of 120 years (1901-2020) makes it possible to analyze the evolution of annual precipitation totals in regions where decadal variations of the rainwater have significant consequences in farming and living conditions in cities during the rainy season. In fact, the chosen series include a number of phases among which the severe droughts of the 1970s and the 1980s as well as the noticeable increase in rainfall in the recent decades (1990s and 2000s).

Table 1 – Selected centennial stations

Station	Latitude	Longitude	Elevation (m)	Average annual rainfall in mm (1991-2020)
Saint-Louis	16° 03' 00" N	16° 27' 00" W	4	272
Dakar	14° 43' 48" N	17° 30' 00" W	24	393
Banjul	13° 27' 00" N	16° 34' 48" W	5	835

World Meteorological Organization/Agence Nationale de l'Aviation Civile et de la Météorologie du Sénégal

As it is shown on the map (Fig. 1), the three stations are approximatively equally positioned from one another -178 km from Saint-Louis to Dakar and 171 km from Dakar to Banjul. While Saint-Louis and Dakar share a Sahel climate with low rainfall and highly variable annual precipitation totals, Banjul displays a much wetter climate with rainfall amounts that are more than the double of the average total of Dakar.

The10-year moving average, the Percent of Normal Precipitation (PNP) and the deciles have been utilized in analyzing the data. The moving average gave a general trend of the series when applied to annual values [18]. It makes it possible to easily display the trend by removing the extreme numbers that are frequently recorded in the Sahel. It has been displayed alongside the ten-year average of every decade. The PNP gives a measure of the departure between the rainfall of a given year and the 1991-2020 rainfall. The deciles provided insight into the distribution of annual precipitation totals in the series. They are used as indicators of drought or extremely high rainfall. Deciles give a distribution of rainfall in a time series [19, 20]. In this analysis, the 1st decile (lowest 10 percent) and the 10th decile (highest 10 percent) have been determined to show how the last 20 years (2000-2020) – described as wet - differ from the previous years of the series.

3. FINDINGS

3.1 *Evolution of the annual precipitation totals from 1901 to 2020*

The lines in Fig. 3 show the ten-year moving average of the rainfall in Saint-Louis, Dakar and Banjul from 1901 to 2020. The downward evolution of the trendlines indicate a decreasing trend over the period under consideration.

In Saint-Louis, the first decade (1901-1910) had an average of 341.4 mm. Only the years 1901, 1905, 1906 and 1910 received above-average amounts of rainfall. The second decade (1911-1920) has an average of 439.5 mm. The average for the third decade (1921-1930) was 473 mm. It was in that decade that the rainiest year of the series (1922) has been recorded with its 769.5 mm. The fourth decade recorded an average of 374.7 mm with 1935 as the wettest year with 521.6 mm. From 1941 to 2020 the decadal averages are less than 350 mm. The 1970s, 1980s, and 1990s have averages of no more than 250 mm.

In Dakar, the decadal averages show a fluctuation until the 1950s when the highest annual values were recorded. In fact, the decade 1951-1960, with an average of 613.4 mm, was the rainiest. It was in the first decade, especially in 1906, that the largest quantity of the series was recorded (957.5 mm). From the 1970s to the 1990s, the annual precipitation totals were below 370 mm. There was an increase in the 2000s and 2010s with respectively an average of 424.4 mm and 432,0 mm.

For Banjul, a drop of 235.7 mm has been recorded in the 1910s – from 1215,13 mm to 979,4 mm. In the next decade, the decadal average reached its highest value (1269.2 mm) in the series before decreasing until the 1940s. Two times during the 1920s, annual precipitation totals greater than 1,500 mm have been recorded (in 1923 and 1927). The 1950s showed the second highest amounts with an average of 1221,7 mm. From the 1960s to the 1980s, a steady decline led to the lowest amounts in the 1980s. Since the 1960s, the decadal average of the annual precipitation totals has been below 1000 mm. The rise in the 1990s and 2000s did not continue in the 2010s. In fact, unlike in Saint-Louis and Dakar, in Banjul the upward trend since the 1990s stopped in 2012 with a peak of 1075.4 mm.

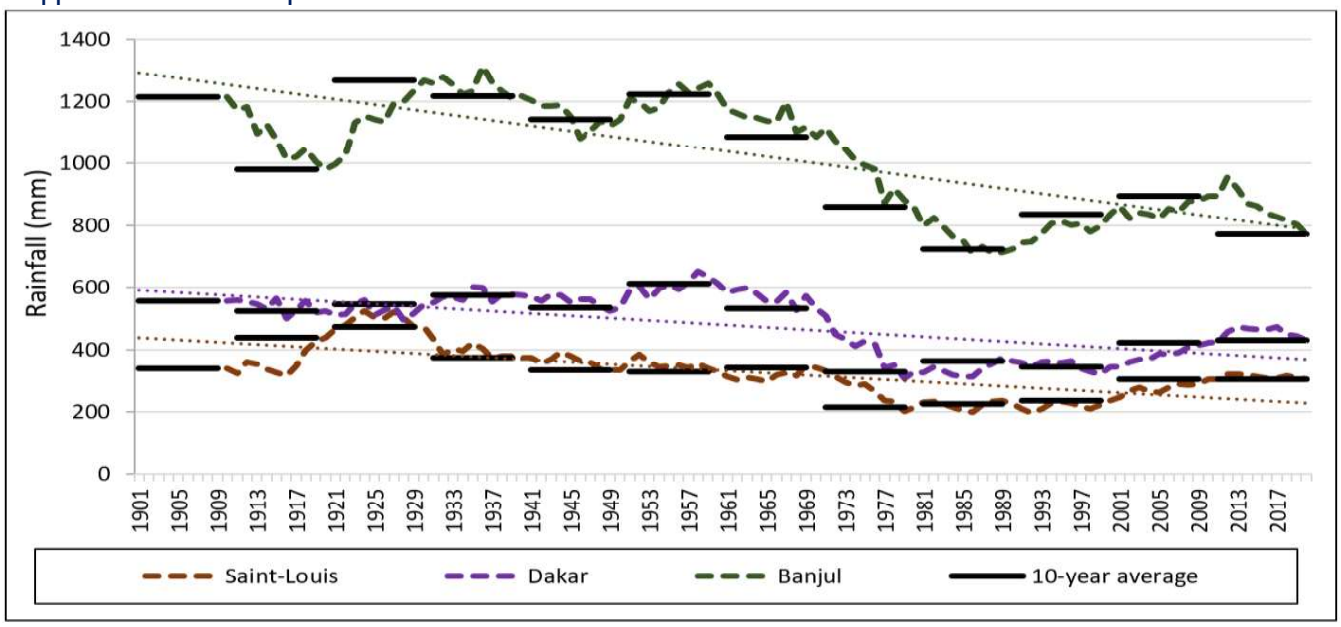

Fig. 3 – Ten-year moving average and ten-year average in Saint-Louis, Dakar and Banjul from 1901 to 2020.

In spite of the differences in the evolution of the decadal average of rainfall, the 1920s and 1950s appear in all three stations as wet decades. The 1920s showed the highest average in Saint-Louis and Banjul, while the 1950s is the wettest for Dakar. As it is showed by the 10-year moving average, from the 1950s the drop in rainfall led to the lowest amounts recorded in the 1980s in all stations.

3.2 *Evolution of the Percent of Normal Precipitation (PNP) from 1901 to 2020*

The evolution of rainfall in Saint-Louis, Dakar and Banjul from 1901 to 2020 shows two change points in Saint-Louis (1969 and 2009) and Dakar (1969 and 2004) (Fig. 4). In Banjul, the break year occurred in 1967.

The rainfall series in Saint-Louis, which has an average of 321.3 mm, can be divided into three periods. The first period (1901-1969) is wet with an average annual precipitation total representing 131.8% of the series average. The rainiest year of this period was 1922 with a proportion of 171.5% compared to the average of the series and the lowest rainfall was recorded in 1931 with 57.9%. The second period (1970-2009), which is dry, has an average annual proportion of 84.3%. The lowest rainfall fell in 1992 with 20.8%. The third period (2010-2020), which is described as wet with an average of 113.7%, is characterized by percentages higher than 150%. In fact, in the first and third periods annual rainfall amounts can be higher than 150%. In the last period, the rainfall amounts varied between 43.7% (in 2014) and 171.8% (in 2010).

In Dakar, the rainfall series shows an average of 482.1 mm and displays three periods. A first wet period (1901-1969) has on yearly average 139.9%. The rainiest year of this period was 1906 with a proportion of 238.8% compared to the average for the series, and the lowest percentage was observed in 1968 with 64.6%. The second period (1970-2004) of this series is dry and has an average of 84.5% in yearly percentage of rainfall. The largest quantities of that period were recorded in 1975 with a proportion of 140.7% and the lowest were recorded in 1972 with 29.1%. The third period (2005-2020) of the series is wet with an average proportion of 114%. The percentages of annual precipitation totals ranged between 165.5% (in 2005) and 40.2% (in 2014).

In Banjul, with an average of 1018.7 mm, the annual rainfall reveals two periods. The first one ended in 1967 with an average yearly proportion of 140.4% of the average of the series. The highest value of the period was recorded in 1936 with 203.4% and the lowest was in 1913 with a proportion of 72%. The second period was dry. It begins in 1968 and ends in 2020 with a yearly average of 98.6%. With an average proportion of 98.6%, the yearly percentage of rainfall varied between 42.4% (in 1983) and 153.5% (in 2010).

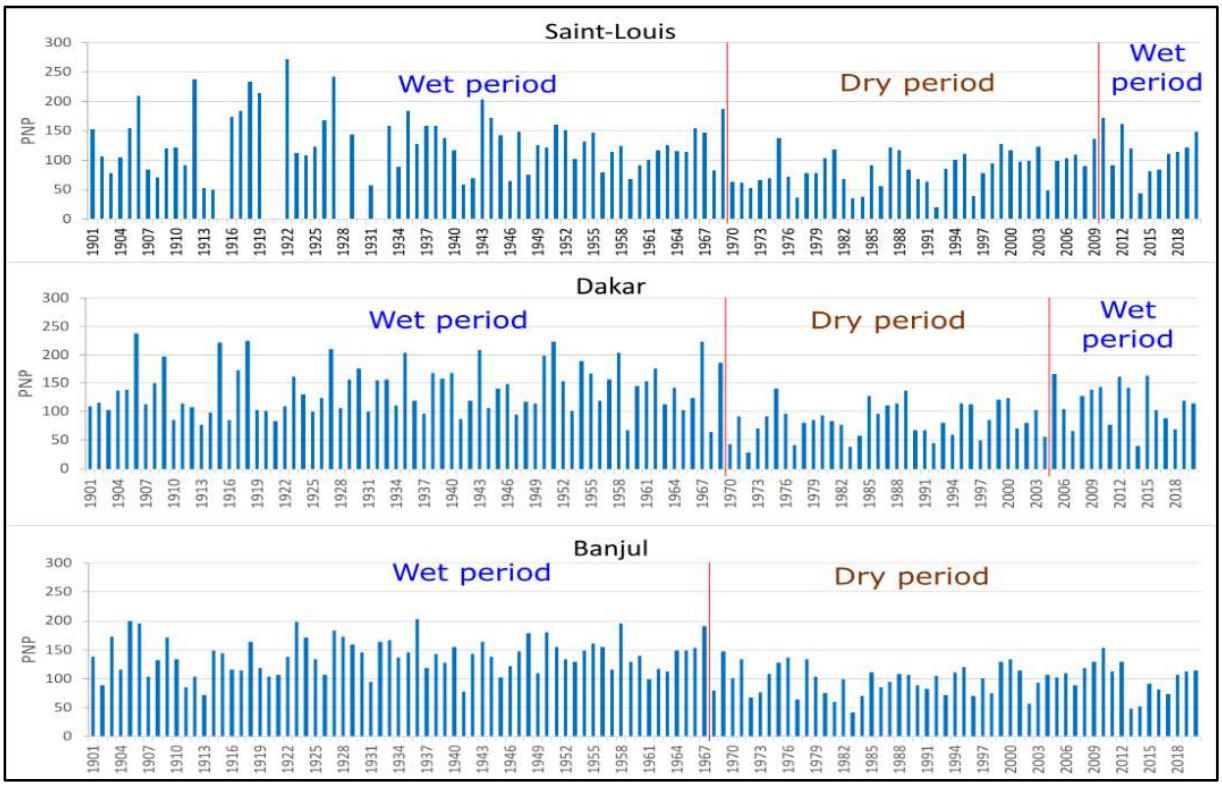

Fig. 4 – Percent of Normal Precipitation (PNP) in Saint-Louis, Dakar and Banjul from 1901 to 2020.

The drop in rainfall in the 2010s in Banjul manifests in the series with the existence of two periods. In the first one, the percentage can go beyond 150%, whereas in the second one it reached that value only one time

(in 2010). Most of the years, the amount of rainfall is below average. In contrast to Saint-Louis and Dakar, Banjul did not show any sustained improvement in the evolution of the rainfall.

3.3 *Temporal distribution of the lowest and highest annual precipitation totals from 1901 to 2020*

Except for the year 2010 in Saint-Louis, the ten highest annual precipitation totals were recorded before 1969 (Tab. 2). This testifies that the first periods in the three stations are wetter than the rest of the series. In the last period, even though there is an increase in rainfall, the precipitation totals are not as high as in the first period.

Table 2 - Highest annual precipitation totals from 1901 to 2020.

Saint-Louis	Year	2010	1916	1935	1917	1969	1943	1906	1919	1918	1912	1927	1922
	Rainfall	487	493	521.6	524	531	577.9	595.5	605.6	663.5	674.9	685.8	769.5
Dakar	Year	1954	1909	1950	1935	1958	1943	1927	1915	1967	1951	1918	1906
	Rainfall	760.6	793.4	802.2	817.4	818.4	840.1	847.3	892.9	895.4	901	901.8	957.5
Banjul	Year	1909	1928	1903	1948	1950	1927	1967	1958	1906	1923	1905	1936
	Rainfall	1437.4	1447.5	1451.1	1498.6	1512.2	1538.5	1601.7	1628.8	1634	1664.3	1678.1	1699.1

In Saint-Louis, the twelve wettest years are scattered throughout the period 1901 and 1969, especially between 1906 and 1927. As it has been shown in the decadal analysis, the 1920s are the wettest years in Saint-Louis. In Dakar, the 1950s are well represented among the wettest years on record. Actually, the ninetieth decile appears in the wettest period, that is before 1969. Banjul recorded its twelve highest rainfall amounts mostly in the 1920s. Some of them were recorded in the 1900s and in the 1950s.
The first decile corresponds to the lowest amounts of rainfall. They are mainly recorded in the 1970s and the 1980s (Tab. 3). Therefore, they are peculiar to dry periods, but they appeared in the last twenty years characterized as wet in Saint-Louis and Dakar.

Table 3 - Lowest annual precipitation totals from 1901 to 2020.

Saint-Louis	Year	1992	1983	1977	1984	1996	2014	2004	1914	1913	1972	1986	1931
	Rainfall	59.1	99.7	102.3	109.1	110.8	124	139.7	143.7	150.1	152.1	160.2	164.3
Dakar	Year	1972	1983	2014	1977	1970	1992	1997	2004	1984	1994	1968	2007
	Rainfall	116.7	154.9	161.3	171.2	177	181.3	202	228.2	234.4	241.3	258.9	266.1
Banjul	Year	1983	2013	2014	2002	1981	1977	1972	1984	1996	1913	1993	**2017**
	Rainfall	353.8	401.9	437	474.8	496.9	542.7	561.8	585.8	593	601.4	602	619.9

In Saint-Louis, the year 2014 recorded only 124 mm, one of the lowest amounts ever recorded. Similarly, in Dakar 2004 and 2007 are among the twelve lowest rainfall amounts ever recorded. In Banjul, the lowest annual rainfall appeared four times in the last decades (in 2002, 2013, 2014 and 2017). In fact, the recent upward trend is not observed in Banjul. Unlike the highest rainfall annual precipitation totals (the last decile), the lowest ones (the first decile) appeared in the recent years described as wet in Saint-Louis and Dakar. This means that the recent period shows some similarities with the previous dry period in terms of low annual amounts, but when one considers the wettest years, they find that they do not appear during the recent wet period. This finding is proof that the resumption of precipitation totals comparable to those of the1920s, 1950s or 1960s is not supported by the data.

DISCUSSION

By erasing abrupt interannual variations of the rainfall, moving averages allow a better visualization of the 120-year-long series analyzed in this paper. This simplification of the erratic evolution of precipitation in the Sahel is often used to grasp the trends over the decades. Pnevmatikos and Katsoulis [21] used a 5-year moving average to find that a decline in annual precipitation totals in Greece started in the 1980s. With this method and the calculation of departures, they were able to detect a new normal in the rainfall amounts. The interdecadal variations are also visualized by the ten-year averages. They have been efficient in showing the decadal changes in Banjul where the rainfall is higher than in Saint-Louis and Dakar. Indeed, unlike in northern stations (Saint-Louis and Dakar), in Banjul there are significant changes from one decade to another. For

instance, the 10-year average decreased by 13.9 percent in Banjul between the 2000s and the 2010s, whereas it varied only by 1,8 percent in Dakar and by 0,4 in Saint-Louis. The moving averages have been used in the southern part of West Africa to analyze the evolution of annual precipitation totals. We can find an application of this approach in the study of Baidu et al. [22]. They used the 5-year moving average and the decadal anomaly with the series 1901-2010 to analyze the rainfall trend in Ghana. That approach allowed them to confirm the decreasing trend in rainfall over the agroecological zones in Ghana.

With the wet period that ended in the late 1960s in West Africa, rainfall amounts had been decreasing until the 1990s [23]. A growing body of studies showed the increase in rainfall in the 1990s and 2000s after a dry period that started in the 1970s. Nkrumah et al. [24] analyzed a rise in rainfall in Southern West Africa. Through a review paper, Nicholson [25] showed the changes in rainfall in the Sahel. The publications she referred to highlighted the two wet periods separated by the dry period of the 1970s and 1980s. The recent increase in rainfall is associated with higher frequency of heavy rain. In fact, observational as well as gridded data showed a higher frequency of heavy rain in West Africa from 1951 to 2100 [26]. The well-above average years in West Africa (e.g. 2012) are associated with exceptionally high daily rainfall [15]. So, the upward trend of the rainfall since the 1980s is a manifestation of high daily rainfall amounts recorded in some years like in 2005 or 2012 in Dakar [27, 28].

The Percent of Normal Precipitation showed the different phases in the evolution of precipitation totals. The highly variable character of the rainfall in West Africa is documented and updated. Biasutti [29] explained that variability by the warming of the Sahara desert and the ocean changes. The droughts of the 1970s and 1980s are associated with sea surface temperature anomalies. In fact, interannual and interdecadal variability can be caused by regional changes on land and at sea. The prevalence of below average annual totals is in accordance with the paradoxical variation in extreme events. In spite of extreme precipitation intensity, dry spells are recorded in recent years in West Africa from 1970 to 2100 [30].

The spatial variability in the changes in recent decades (1990-2020) is not peculiar to Senegal and the Gambia. Some works found similar trends in other African countries. In Côte d'Ivoire, Konaté et al. illustrated different characteristics of the increase in rainfall in the south, the west and the center of the country [31]. In fact, the starting year of the recent increase in precipitation is not the same in all climatic areas. The same differences have been highlighted by Dacosta and Konaté when they analyzed the change points in Senegal in a series of a hundred years [13]. Independently from the climate type, changes in the variations of rainfall can also differ from one station to another.

CONCLUSION

The long time series made it possible to analyze the significance of the recent trend in the evolution of annual precipitation totals in the western part of Senegal and the Gambia. The centennial observing stations (Saint-Louis, Dakar and Banjul) showed a declining trend of rainfall even though the annual amounts have been increasing since 2010 in Saint-Louis and 2005 in Dakar. The 1970s and 1980s drought years appear as of historical significance regarding the exceptional low rainfall amounts that are not offset by the recent rise in rainfall. Furthermore, the 1920s in Saint-Louis and in Banjul, and the 1950s in Dakar remain unparallelled. The twelve highest annual precipitation totals have been mainly observed before 1969. They appeared only once (in 2010 in Saint-Louis) in the last two decades (2000-2020). Conversely, the lowest annual precipitation totals are well represented among the recent years characterized as wet. Indeed, the data showed that in all three stations some of the lowest rainfall amounts have been recorded – in 2004 and 2014 in Saint-Louis; in 2007 and 2014 in Dakar; in 2013, 2014 and 2017 in Banjul. In spite of the improvement in the annual rainfall, there are signs of drought-like years.

The highly variable nature of the rainfall in the Sahel and in in Banjul is key information for flood prevention and drought mitigation. The last twenty years show that the general climatic context should not shadow the peculiarity of some years marked by extremely high or extremely low rainfall. The downward trend of the annual precipitation totals from 1901 to 2020 is related to the short period (2000-2020) during which low annual rainfall was recorded in some years in spite of the overall increasing trend. Further investigation is needed to shed light on the changes observed in the last couple of decades on the coast of Senegal and the Gambia.

References

[1] C. Ciemer, N. Boers, M. Hirota, J. Kurths, F. Müller-Hansen, R. S. Oliveira R. Winkelmann, Higher resilience to climatic disturbances in tropical vegetation exposed to more variable rainfall, Nature Geoscience, 3 (2019), 174-179.
[2] F.S. Rodrigo, M.J. Esteban-Parra, D. Pozo-Va´ Zquez, Y. Castro-Di´Ez, Rainfall variability in southern Spain on decadal to centennial time scales, International Journal of Climatology, 7 (2000), 721-732.
[3] C. M. Philandras, P. T. Nastos, J. Kapsomenakis, K. C. Douvis, G. Tselioudis, C. S. Zerefos, Long term precipitation trends and variability within the Mediterranean region, Natural Hazards and Earth System Sciences, 12 (2011), 3235-3250.
[4] A. Limsakul, P. Singhruck, Long-term trends and variability of total and extreme precipitation in Thailand, Atmospheric Research, 169 (2016), 301-317.
[5] C. Funk, S. E. Nicholson, M. Landsfeld, D. Klotter, P. Peterson, L. Harrison, The centennial trends Greater Horn of Africa precipitation dataset, Sci Data. 1 (2015), 150050.
[6] R. I Saurral, I. A. Camilloni, V. R. Barros, Low-frequency variability and trends in centennial precipitation stations in southern South America, Intl Journal of Climatology, 4 (2017), 1774–1793.
[7] Z. Nouaceur, O. Murarescu, Rainfall Variability and Trend Analysis of Rainfall in West Africa (Senegal, Mauritania, Burkina Faso), Water, 6 (2020), 1754.
[8] L. Descroix, A. Luxereau, L. A. Lambert, O. Ruë, A. Diedhiou, A. Diongue-Niang, A. H. Dia, F. Gangneron, S. P. Manga, A. B. Diedhiou, J. Andrieu, P. Chevalier and B. Faty, An Interdisciplinary Approach to Understand the Resilience of Agrosystems in the Sahel and West Africa, Sustainability, 13 (2024), 5555.
[9] J. He, P. Feng, B. Wang, W. Zhuang, Y. Zhang, D. L. Liu, J. Cleverly, A. Huete, and Q. Yu, Centennial annual rainfall pattern changes show an increasing trend with higher variation over Northern Australia, Journal of Hydrometeorology, 8 (2022), 1333-1349.
[10] B. Toulier, Saint-Louis du Sénégal, un enjeu pour le patrimoine mondial, In Situ [En ligne], 3 | 2003, mis en ligne le 23 avril 2012, URL : http:// journals.openedition.org/insitu/1623
[11] J. Le Borgne, La pluviométrie au Sénégal et en Gambie, Dakar : ORSTOM, Ministère Français de la Coopération, 1988, 95 p.
[12] ANSD (Agence Nationale de la Statistique et de la Démographie, Situation économique et sociale régionale (Dakar), ANSD, Dakar, 2013, 129 p.
[13] H. Dacosta, Y.K. Konaté, La variabilité spatio-temporelle des précipitations au Sénégal depuis un siècle, FRIEND 2002—Regional Hydrology: Bridging Ihe Gap between Research and Practice: Proceedings of the Fourth International FRIEND Conference, Cape Town, South Africa, March (2002), IAHS Publ., 274 (2002), 499-506.
[14] Y. L'hôte, G. Mahé, B. Somé, J.P. Triboulet, Analysis of a Sahelian annual rainfall index from 1896 to 2000: the drought continues, Hydrological Sciences, 47 (2002) 563-572.
[15] L. Descroix, A. Diongue-Niang, H. Dacosta, G. Panthou, G. Quantin, A. Diedhiou, Evolution des pluies de cumul élevé et recrudescence des crues depuis 1951 dans le bassin du Niger-Moyen (Sahel), Climatologie, 10 (2013), 37-49.
[16] P. Sagna, J.M. Dipama, E.W. Vissin, B.I. Diomandé, C. Diop, P.A.B. Chabi, P.C. Sambou, T. Sané, B.L.C.N. Karambiri, O. Koudamiloro, Y.M. Diédhiou, M. Yade, Climate Change and Water Resources in West Africa: A Case Study of Ivory Coast, Benin, Burkina Faso, and Senegal, in Diop, S., Scheren, P., Niang, A., eds., Climate Change and Water Resources in Africa, Springer Nature, 2021, pp. 55-86.
[17] A. Badji, E. Mohino, M. Diakhaté, J. Mignot, A.T. Gaye, Decadal Variability of Rainfall in Senegal: Beyond the Total Seasonal Amount, 16 (2022), 5339-5358.
[18] T. Merabtene, M. Siddique, A. Shanableh, Assessment of Seasonal and Annual Rainfall Trends and Variability in Sharjah City, UAE, Advances in Meteorology, (2016), 6206238.
[19] B.S. Barrett, M. I. Esquivel Longoria, Variability of precipitation and temperature in Guanajuato, Mexico, Atmósfera, 4 (2013), 521-536.
[20] C. Schär, Ni. Ban, E.M. Fischer, J. Rajczak, J. Schmidli, C. Frei, F. Giorgi, T.R. Karl, E.J. Kendon, A.M.G.K Tank, P.A. O'Gorman, J. Sillmann, X. Zhang, F.W. Zwiers, Percentile indices for assessing changes in heavy precipitation events, Climate Change, 1-2 (2016), 201-216.
[21] J.D. Pnevmatikos, B.D. Katsoulis, The changing rainfall regime in Greece and its impact on climatological means, Meteorological Applications, 4 (2006), 331-345.
[22] M. Baidu, L.K. Amekudzi, J.N.A. Aryee, T. Annor, Assessment of Long-Term Spatio-Temporal Rainfall Variability over Ghana using Wavelet Analysis, Climate, 2 (2017), 30.
[23] L. Le Barbé, T. Lebel, D. Tapsoba, Rainfall Variability in West Africa during the Years 1950–90, Journal of Climate, 2 (2002), 187-202.
[24] F. Nkrumah, T. Vischel, G. Panthou, N.A.B. Klutse, D.C. Adukpo, A. Diédhiou, Recent Trends in the Daily Rainfall Regime in Southern West Africa, Atmosphere, 12 (2019), 741.
[25] S.E. Nicholson, The West African Sahel: A Review of Recent Studies on the Rainfall Regime and Its Interannual Variability, ISRN Meteorology (2013), 453521.
[26] I. A. Saley, S. Salack, Present and Future of Heavy Rain Events in the Sahel and West Africa, Atmosphere, 6 (2023), 965.
[27] P. Sagna, O. Ndiaye, C. Diop, A. Diongue-Niang, P.C. Sambou, Les variations récentes du climat constatées au Sénégal sont-elles en phase avec les descriptions données par les scénarios du GIEC ? Pollution atmosphérique, 227 (2015), 1-17
[28] A. Mendy, Variabilité des pluies au XXe siècle à Dakar, Sénégal, Norois, 268-269 (2023), 109-127.
[29] M. Biasutti, Rainfall trends in the African Sahel: Characteristics, processes, and causes, WIREs Climate Change, 4 (2019), e591.
[30] M.B. Sylla, P.M. Nikiema, P. Gibba, I. Kebe, N.A.B. Klutse, Climate Change over West Africa: Recent Trends and Future Projections, in Yaro, J.A., Hesselberg, J., eds., Adaptation to Climate Change and Variability in Rural West Africa, Springer Nature, 2023, pp. 25-40.
[31] D. Konaté, S.R. Didi, K. B. Dje, A. Diédhiou, K. L. Kouassi, B. Kamagate, J.-E. Paturel, H.S.J.P. Coulibaly, C.A.K. Kouadio, T.J.H. Coulibaly, Observed Changes in Rainfall and Characteristics of Extreme Events in Côte d'Ivoire (West Africa), Hydrology, 5 (2023), 104