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Extreme rainfall variability and trends in the district of Ouedeme, municipality of Glazoue (Benin)

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ABSTRACT

This study aims to assess the extreme rainfall variability and trends in Ouedeme district, Glazoue municipality, Benin. Rainfall fluctuations, droughts, and floods pose major risks to food crops, mainly yams and rice, threatening food security and local agricultural systems' resilience. The research is based on daily rainfall data from Savè synoptic station, covering 1961 to 2020. Seven ETCCDI climate indices (including PTOT, JP, SDII, P10, P20, PX1J, and CDD) have been used to quantify the intensity, frequency, and variability of extreme events. Statistical methods (mean, standard deviation, Lamb index) and software tools such as Excel have been used to process data and identify trends. The findings reveal that average annual precipitation amounts to 1,180 mm (±235 mm), with an overall downward trend. Also, while the mean number of rainy days is 82 (±11 days), the daily intensity (SDII) is 11 mm/day (±1 mm), both decreasing. However, a slight increase in heavy rainfall days (P10: 36 days ±7) and a moderate increase in very heavy rainfall days (P20: 18 days ±4) have been observed. Furthermore, consecutive dry days (CDD) are up to 34 days (±4), highlighting a trend towards more frequent dry spells. Overall, 32 of the 60 years analyzed had a deficit, compared to 28 with a surplus, reflecting significant interannual variability. Results highlight increased climate variability, with more frequent dry spells and intense rainfall, affecting crop cycles directly. Farmers' adaptation strategies (early sowing, crop rotation, etc.) remain limited by insufficient resources and infrastructure. Improved water management and technical support are crucial to strengthening agricultural resilience to climate extremes.

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INTRODUCTION

Climate risks are key challenges for rural and farming communities, especially regions prone to climate change. Located in Central Benin, the municipality of Glazoue is highly subject to these risks, including droughts, floods, and unpredictable rainfall patterns. These phenomena have a direct impact on agricultural practices, food security, and natural resource management (Rings *et al.*, 2015, p. 10). Given this, studying climate trends, especially rainfall, is key to understanding how risks are changing and how they affect agriculture.

Climate change adaptation requires an in-depth analysis of hydroclimatic trends over several decades. Previous studies have shown that the intensification of climate extremes negatively affects agricultural systems (Wezel *et al.*, 2009, p. 28). Precipitation variability, coupled with high temperatures and shorter drought periods, has direct consequences on production cycles and water resource management (Barro, 2023, p. 18). In addition, changes in rainfall patterns have been associated with disruptions to traditional agricultural systems and natural ecosystems (Altieri and Nicholls, 2012, p. 5). These extremes have had a particularly strong impact in areas where farming practices are based on systems with low resilience, often characterized by a weak capacity to adapt (Côte, 2002, p. 8).

In addition, research on climate risk adaptation shows that farmers often lack the required infrastructure to cope with these challenges in regions affected by climate variability (Dugué, 2013, p. 30). Training in agroecology and access to resilience techniques (such as agroforestry or sustainable soil management) are key levers for mitigating the adverse effects of climate change (Toutain *et al.*, 1988, p. 11). The main objective of this study is to analyze extreme rainfall trends in the district of Ouedeme, Glazoue municipality. Climate trend analysis is essential for assessing future climate risks and guiding adaptation policies (Benmihoub *et al.*, 2021, p. 3). In short, recommendations are made to enhance climate resilience in the region and improve the sustainability of agricultural systems in the face of increasing climate challenges (Collin and Ayouz, 2006, p. 12). Ouedeme is one of the 10 districts of the municipality of Glazoue. It is bordered to the north by the district of Aklampa, to the south by the district of Kpakpaza, to the east by the district of Magoumi, and to the west by the district of Lahotan (Fig. 1).

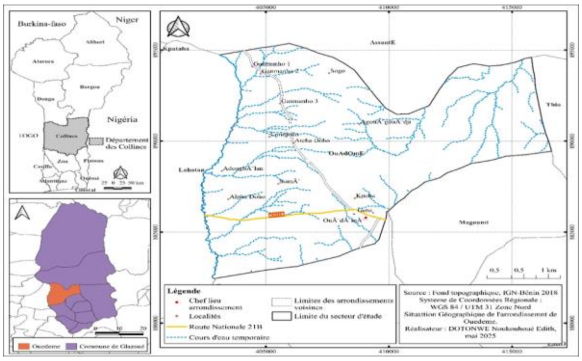

Fig. 1. Geographical location and administrative division of the district of Ouedeme

Source : IGN topographic map, 2018

MATERIALS AND METHODS

A thorough methodology is employed in this research. It combines weather data with advanced statistical methods and software tools to process and process the data. Several types of climate data have been collected for this analysis. Rainfall data covers the 1961-2020 period and mainly concerns daily rainfall measurements in Glazoue, including the nearest synoptic station, Savè. These include daily rainfall totals, enabling a detailed analysis of precipitation trends over the decades.

Data processing methods

Extreme rainfall data processing begins with statistical analysis of rainfall series. The data have been analyzed on the basis of the climate indices suggested by the Expert Team on Climate Change Detection and Extreme Climate Indices (ETCCDI), through ClimPACT 2 (N'guessan *et al.*, 2018, cited by Batchi-Mava *et al.*, 2020). This method makes it possible to quantify extreme events and monitor climate variations over a given period.

ETCCDI experts have defined a set of climate indices, 27 of which are used to characterize climate risks. Thus, seven indices have been selected for analyzing rainfall extremes, namely:

PTOT : Overall annual precipitation
JP : Number of damp days (precipitation ≥ 1 mm)
SDII : Average rainfall per day (Simple Day Intensity Index)
P10 and P20 : Days with precipitation ≥ 10 mm and ≥ 20 mm
PX1J : Daily maximum rainfall recorded
PX5J : Five-day maximum rainfall recorded

These indices are used to determine not only the total amount of rainfall but also the spread of extreme rainfall events, by analyzing interannual variations and the frequency of extreme events. In addition, the average monthly and annual rainfall amounts is calculated by means of the following statistical formula to determine the interannual average:

$$\overline{X} = \frac{1}{N}\sum_{i=1}^{n} x_i$$

With N as total population; $\overline{X}$ as series average; and x_i as studied characteristic modality.

Lamb's index (1882) has been used to assess wet and dry years, measuring the deviation between observed values and the normal mean, normalized by the standard deviation. The index is calculated using the following formula:

$$X = \frac{x_i - \bar{x}}{\sigma}$$

Where X represents the average annual accumulation recorded by station or location for year i; ($\bar{x}$) and σ represent the mean and standard deviation of the series in question, respectively. A year is considered normal if its index is between -1 and 1.

1. A standard year is when the index is between -1 and 1.
2. It is damp if the index is greater than 1.
3. It is dry if the index is below -1. (Adjovi *et al.*, 2019).

Data processing equipment and tools

Microsoft Excel software is mainly used for processing and analyzing climate data. This software is used to perform statistical calculations, analyze climate indices, and generate the graphs needed to visualize climate and hydroclimatic trends. Data processing also includes the use of specialized tools for calculating climate indices and generating climate maps for specific periods using statistical processing and climate mapping software.

RESULTS

Changes in annual precipitation

Precipitations are a key parameter for analyzing annual rainfall trends in intertropical regions such as Benin. Fig. 2 shows the variation in annual precipitation over 1961-2020 period.

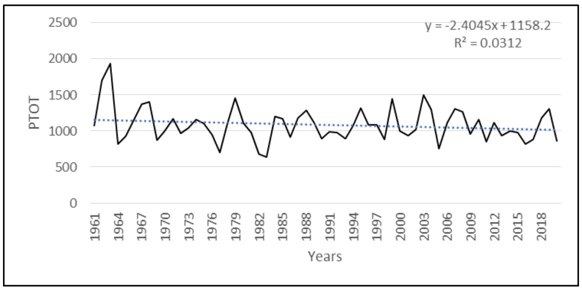

Fig. 2. Interannual changes in total precipitation (1961-2020)

Source : Meteo-Benin, 2025

Fig. 2 shows that annual precipitation fluctuates over the period 1961-2020. Overall, the total annual precipitation curve shows a downward trend over this period. The interannual average precipitation is 1,180 mm, with a standard deviation of ± 235 mm, reflecting the extent of variation in the data. 1963 and 2020 recorded the highest total precipitation values, with 1,497 mm. In contrast, 2018 registers the lowest total precipitation value with 235 mm.

Trend in rainy days

known as the overall number of days when rainfall is greater than or equal to 1 mm, rainy days are a key indicator for assessing trends in wet days over the course of a year. This is particularly useful for evaluating the distribution and frequency of rainfall over a given period, allowing changes in rainfall patterns over time to be identified. Figure 3 depicts the wet day trend over the period 1961-2020, highlighting interannual variations in rainy day frequency.

Fig. 3 shows a sawtooth pattern in wet days (precipitation ≥ 1 mm) over the period 1961–2020. Overall, the curve shows a downward trend in the frequency of rainy days, indicating a decrease in wet days over the decades. Wet days average 82 days per year, with a standard deviation of ± 11 days, reflecting the level of variation in the data series. A high standard deviation reflects considerable fluctuations in the data, leading to years with marked variations in rainy days. Indeed, 1963 records the highest number of wet days, with a total of 115 rainy days, while 2020 has the lowest number of wet days, with only 64 days. These results show significant interannual fluctuations, reflecting significant variability in precipitation patterns over recent decades.

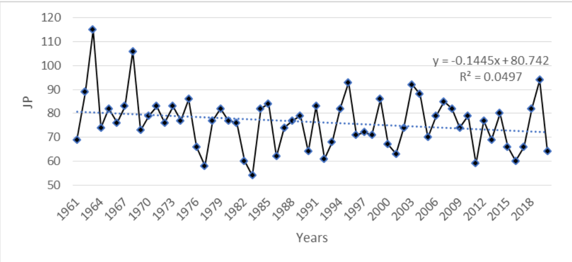

Fig. 3. Wet day trend over the period (1961-2020)

Source : Meteo-Benin, 2025

Days of intensity with single index (SDII)

The SDII (Simple Daily Intensity Index) represents the average amount of rainfall per rainy day over the course of a year. This index is particularly useful for analyzing the intensity of daily precipitation, providing a measure of the average amount of water that falls on days when precipitation is recorded. The SDII can be used to assess not only the total amount of rainfall, but also the distribution and intensity of rainfall events throughout the year. Figure 4 shows variations in average rainfall per rainy day over the period 1961-2020, illustrating changes in daily rainfall intensity over the decades.

Fig. 4 shows a sawtooth pattern in the average daily rainfall over the period 1961-2020. The overall trend shows a decrease in daily precipitation intensity over time. The interannual average rainfall is 11 mm, with a standard deviation of ± 1 mm, showing relatively little variation around the mean. The standard deviation provides an insight into the level of variability in daily precipitation within the study period. Extreme years show that the highest SDII index values occurred in 1963 and 1979, with values of 14 mm. In contrast, 1964 had the lowest value, with 7 mm, highlighting the high variation in precipitation over this period.

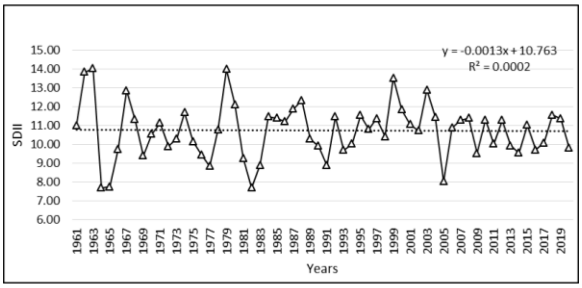

Fig. 4. Trend in average daily rainfall over the period (1961-2020)

Changes in rainfall patterns ≥ 10 mm (P10)

Rainfall frequencies ≥ 10 mm (P10) are the number of days with precipitation reaching or exceeding 10 mm. It is particularly useful for analyzing heavy rainfall trends and their annual distribution. In fact, it tracks changes in the number of days with heavy precipitation each year.

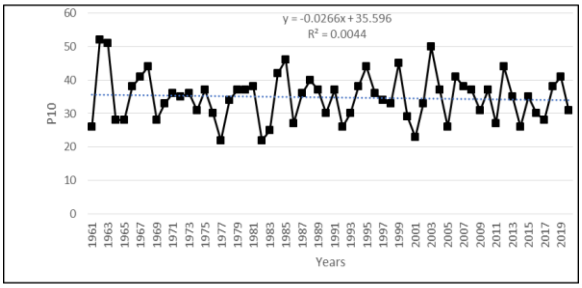

Fig. 5. Variations in rainfall frequencies ≥10 mm (P10) over the period (1961-2020)

Source : Meteo-Benin, 2025

Fig. 5 shows variations in the frequency of rainy days with precipitation greater than or equal to 10 mm over 1961-2020 period, highlighting variations in these extreme events over time.

Fig. 5 shows a sawtooth pattern in rainfall frequencies ≥ 10 mm (P10) over the period 1961-2020. The curve generally shows an upward trend in the frequency of rainy days with precipitation greater than or equal to 10 mm, pointing to a gradual increase in these events over the decades. The interannual average frequency of rainfall ≥ 10 mm is 36 days, with a standard deviation of ± 7 days, reflecting moderate variability in the data series. The standard deviation quantifies the disparity between years, highlighting the fluctuation in heavy rainfall days across years. Highest rainfall frequencies have been recorded in extreme years, with 1962 and 2003 having 52 days, while 1983 had the lowest frequency with only 22 days of rainfall ≥ 10 mm.

Changes in rainfall patterns ≥ 20 mm (P20)

Rainfall frequencies ≥ 20 mm (P20) reflect the number of days on which precipitation reaches or exceeds 20 mm. It is particularly useful for analyzing trends in heavy rainfall days over the course of a year, highlighting the frequency of intense rainfall events. Analyzing trends in rainfall ≥ 20 mm provides a better understanding of changes in extreme rainfall and its potential impact on agriculture and natural resources. Fig. 6 shows the trend in the number of days with 20 mm or more of precipitation over the 1961-2020 period, providing a clear picture of variations in the occurrence of heavy rainfall over the decades.

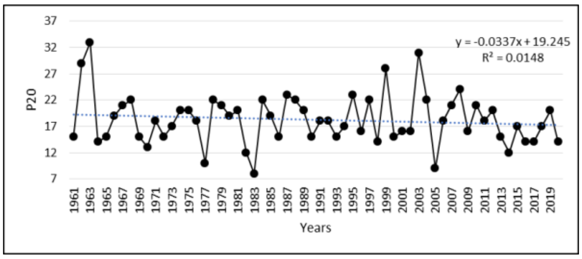

Fig. 6. Rainfall frequency changes ≥20mm (P20) over the period (1961-2020)

Source : Meteo-Benin, 2025

Fig. 6 shows a sawtooth pattern in the frequency of rainfall events ≥ 20 mm (P20) over the period 1961–2020. Overall, the curve shows a general upward trend, pointing to an increase in heavy rainfall days over the years. The interannual average frequency of rainfall ≥ 20 mm is 18 days, with a standard deviation of ± 4 days, reflecting moderate variability in intense rainfall events. The standard deviation helps to assess the year-to-year disparity in heavy rainfall days. Extreme years show that the highest values have been recorded in 1963 and 2003 (33 days), while 1983 has the lowest frequency of days with rainfall ≥ 20 mm (8 days).

Dry day streak variation

Consecutive dry days (CDD) are the number of days in a row when there's less than 1 mm of rain. This is an important way to see how dry it is during the year, showing how long droughts or dry spells last. Analyzing this trend in consecutive dry days makes it possible to assess the frequency and duration of dry events, which is crucial for understanding the impacts of droughts on agriculture and water resources. Fig. 7 shows the evolution of consecutive dry days (CDD) over the period 1961-2020, illustrating dry period fluctuations over the decades.

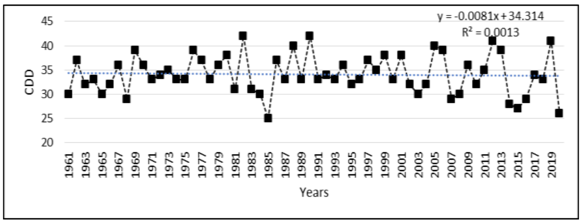

Fig. 7. Evolution of consecutive dry days (1961-2020)

Source : Meteo-Benin, 2025

Fig. 7 shows a seesaw pattern in consecutive dry days over the period 1961–2020. Overall, the curve shows a general upward trend, reflecting longer dry periods over time. Consecutive dry days average 34 days, with a standard deviation of ±4 days, reflecting the variability of dry periods from year to year. The standard deviation provides a measure of the fluctuation of these events over the years. Extreme years show that 1982 and 1990 had the highest values for consecutive dry days, with 42 days. Conversely, 1985 registered the lowest value, with only 25 consecutive dry days.

Trend in consecutive wet days (CWD)

Consecutive wet days (CWD) refer to the number of consecutive days with precipitation greater or equal to 1 mm. This is a really useful indicator for analyzing trends in continuous rainy periods throughout the year. Studying consecutive wet days makes it possible to track changes in periods of sustained rainfall and assess an extended rainy event's impact on water resources and ecosystems. Fig. 8 shows the evolution of consecutive wet days (CWD) over the period 1961-2020, showing variations in the duration of rainy episodes over the decades.

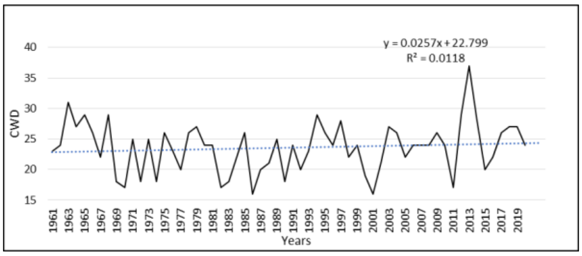

Fig. 8. Consecutive wet days (CWD) trends over the period (1961-2020)

Source : Meteo-Benin, 2025

Fig. 8 shows a sawtooth pattern in consecutive wet days (CWD) over the period 1961–2020. Overall, the curve shows a general upward trend, showing increased periods of continuous rain over time. The interannual average for consecutive wet days is 24 days, with a standard deviation of ±4 days, reflecting this series' variability in extended rainy events. The standard deviation measures the data's spread around the mean, showing years with significant fluctuations in consecutive wet days. 2013 has the highest number of consecutive wet days with 37 days, while 2020 has the lowest value with 0 consecutive rainy days.

Daily maximum precipitation trends (PX1J)

The maximum daily rainfall (PX1J) represents the maximum precipitation recorded on a given day. This is essential for analyzing variations in the intensity of extreme rainfall events throughout the year, enabling periods of heavy rainfall and their evolution to be assessed. Analyzing maximum daily rainfall also helps identify major trends in the intensity of extreme weather events, such as floods or other severe weather phenomena. Fig. 9 shows maximum daily rainfall over the period 1961-2020, highlighting extreme event trends over the decades.

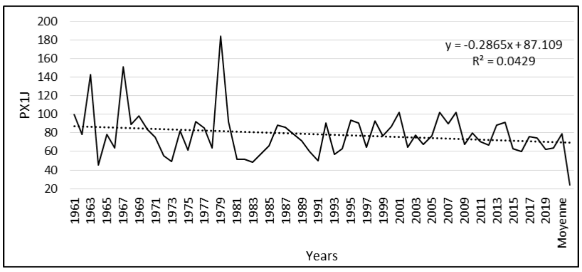

Fig. 9. Maximum daily rainfall (PX1J) trends over the period (1961-2020)

Source: Meteo-Benin, 2025

Fig. 9 shows a sawtooth pattern in the daily maximum precipitation series over the period 1961–2020. Overall, the curve shows a downward trend in daily maximum precipitation, indicating a reduction in the intensity of extreme rainfall events over time. The interannual average maximum precipitation is 79 mm, with a ± 24 mm standard deviation, indicating significant variability in maximum precipitation from year to year. This standard deviation measures the dispersion of values around the mean and highlights years when maximum precipitation deviated significantly. Extreme years show that 1979 has the highest maximum precipitation (184 mm), while 1964 recorded the lowest value (45 mm), highlighting a marked fluctuation in heavy rainfall events over this period.

Maximum daily rainfall trends (PX1Jp)

Maximum daily rainfall share (PX1Jp) represents the proportion of maximum daily precipitation within overall annual rainfall. This is crucial for analyzing variations in the relative intensity of extreme rainfall events within overall annual precipitation, enabling assessment of their contribution to climate systems and potential impact on ecosystems and agriculture. Studying trends in the daily maximum rainfall share provides insight into the evolution of extreme weather events over time. Fig. 10 shows the evolution of this proportion over the 1961-2020 period, highlighting variations in the intensity of extreme rainfall based on annual fluctuations in total precipitation.

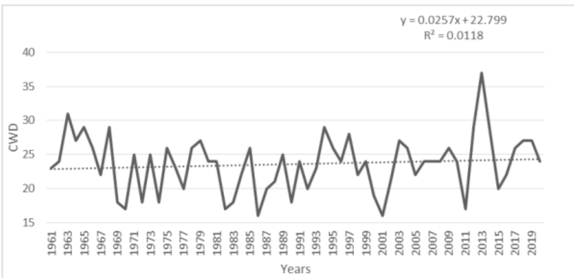

Fig. 10. Maximum daily rainfall (PX1Jp) trends over the period (1961–2020)

Source : Meteo-Benin, 2025

Fig. 10 shows a discontinuous increase in the daily maximum rainfall share (PX1Jp) series over the 1961-2020 periods. In fact, the curve shows an upward trend, indicating that maximum daily rainfall as a proportion of total annual rainfall has increased over time. The interannual average of this proportion is 24%, with a ±4% standard deviation, implying moderate variability in the data. The standard deviation, measuring the magnitude of fluctuations around the mean, shows a year-to-year dispersion of values. Extreme years reveal that the highest value of 37% has been recorded in 2013, while 1964 registered the lowest value, with only 16% of maximum daily rainfall in the annual total.

Interannual variation in the rainfall index

The research environment experiences significant climatic fluctuations throughout the research period, as illustrated by the studied statistical series. These fluctuations are reflected in climatic anomalies, as shown in Fig. 11. This figure depicts marked variations in climatic parameters over the years, highlighting substantial deviations from normal averages and underscoring extreme weather events.

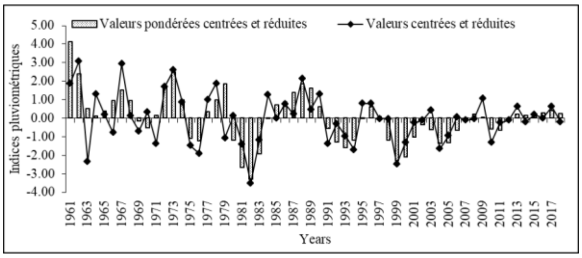

Fig. 11. 1961-2020 rainfall indices

Source : Meteo-Benin, 2025

Fig. 11 shows a marked alternation between dry and wet years over the 1961-2020 period. The shortfall years are 1963, 1966, 1969, 1971, 1975, 1976, 1979, 1981, 1982, 1983, 1985, 1991, 1992, 1993, 1994, 1997, 1998, 1999, 2000, 2001, 2002, 2004, 2005, 2007, 2008, 2010, 2011, 2012, and 2014. Over the 60 years covered by the time series, 32 years are characterized by rainfall deficits, while 28 years have wet conditions. This rainfall variability, with dry periods alternating with periods of excess rainfall, has a significant impact on agricultural activities, especially food crops. Managing these variations is essential, and providing information on deficit and surplus years could prove crucial to improving agricultural strategies and ensuring greater food security in the region.

DISCUSSION

It results from this study that there are significant trends in hydroclimatic risks and their evolution in the municipality of Glazoue. An analysis of precipitation data, rainy days, daily precipitation intensity, and extreme events highlights significant variability in climate patterns over the 1961-2020 periods. These results are consistent with other studies in the region which highlight the increasing variability of climate risks and their impact on agricultural systems.

The rainfall variability analysis highlights a downward trend in annual precipitation over the past six decades, with marked peaks and troughs, showing significant fluctuations in annual rainfall amounts. These interannual variations in total precipitation are consistent with the work of Vodonou *et al.* (2016) and Tabou Talahatou (2020), who highlight changes in rainfall levels and increasingly severe periods of drought in several regions of Benin. According to these authors, these rainfall variations reflect global climate change, which has direct consequences on agricultural production, especially maize, yam and rice crops.

Rainy days, defined as days with precipitation greater than or equal to 1 mm, also show a general downward trend during the study period. This implies a reduction in the frequency of wet days, which may have significant implications for natural soil irrigation and water management on farms. This trend is consistent with the findings of Kpadonou *et al.* (2012), who conclude that the reduction in rainy days in certain areas of Benin negatively affects agricultural yields, particularly rice and yam crops, which are highly dependent on rainfall patterns.

The Single Day Intensity Index (SDII) analysis shows a downward trend in daily rainfall intensity. This reduction in rainfall intensity points to a possible shift towards lighter but more frequent rainfall, which may impact natural irrigation and increase the risk of water stress for crops that are sensitive to prolonged periods of drought. This phenomenon is also reported by Hountondji *et al.* (2011), who observe changes in rainfall patterns affecting yam crop growth due to decreased soil moisture.

This study also shows an increase in the frequency of heavy rainfall (≥10 mm) and very heavy rainfall (≥20 mm) over the 1961-2020 period, although this trend is relatively modest. Extreme rainfall is particularly worrying because it can cause flooding, especially in rice and yam growing areas, which are highly sensitive to excess water. Boko Michel (2002) has already identified an increase in flood risk in some parts of Benin due to the intensification of extreme weather events, a phenomenon also confirmed by the data from this study. Improved management of drainage and water retention systems is therefore essential to limit losses associated with these extreme events. Consecutive dry days (CDD), which indicate the duration of dry periods, have shown an upward trend, suggesting an increase in droughts and periods of water stress for agricultural crops. This finding is reinforced by the work of Tovignan Serge and Boko Michel (2010), who find that crop cycles are being disrupted by increased droughts and unpredictable rainy seasons. This phenomenon may affect the productivity of rice and yam crops that are essential for farmers in Ouedeme.

Farmers' adaptation strategies are crucial to maintaining food security and resilience in rural communities in view of these increasing climate risks. These strategies include early sowing, crop rotation, adjusting agricultural calendars, and using seeds that are resistant to climate hazards. These approaches are in line with the recommendations of Gnanglè Pascal (2013), who finds that adapting agricultural practices and diversifying crops can improve the resilience of farms to climate change. However, as Akponikpè Gédéon and Johnston Pierre (2011) point out, the effectiveness of these strategies is hampered by a lack of infrastructure, technical support, and access to financial resources.

In a nutshell, this study shows that hydroclimatic risks in the municipality of Glazoue have a major impact on agriculture, but also on the resilience of local agricultural systems. Although adaptation strategies are set up, they are still limited by a lack of infrastructure, limited access to resources, and economic constraints. So, it is imperative to strengthen climate governance, promote appropriate agricultural policies, and support farmers to improve their ability to cope with climate shocks.

CONCLUSION

This study shows that extreme rainfall variations in the municipality of Glazoue have a direct and growing impact on agricultural activities. Fluctuations in extreme rainfall intensity and frequency, both heavy and abundant, alter production cycles, disrupt agricultural calendars and increase the risk of extended droughts and floods. These extreme weather events lead to reduced yields, crop losses and disruptions in water management, hitting sensitive crops such as yams and rice. It is therefore crucial to strengthen adaptation strategies and invest in water infrastructure to support farmers in the face of these growing challenges.

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