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Analysis of Perceptions of Rainfall Variability and Typology of Agricultural Seasons in the Rural Commune of Bande (Southern Zinder Region)

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Abstract

This study aims to analyze climate variability, farmers' perceptions, and changes in agricultural seasons in the rural commune of Bandé—located in the southern Zinder region—over the past seventy-five years. The methodological approach combines daily rainfall records from the Magaria synoptic station (1950-2024) provided by the AGRHYMET-Niger (Regional Centre for Training and Application in Agrometeorology and Operational Hydrology) with a socio-economic survey of 320 farming households across nine villages, supplemented by 9 focus group discussions and 12 Key informant interviews. Agro-climatic indicators were computed using Instat+ software, while non-parametric Pettitt and Mann-Kendall tests were applied to analyze breakpoints and trends. The results reveal three distinct phases: a wet period (1950-1967; mean 673.12 mm), a severe drought period (1968-1990; mean 490.39 mm; Pettitt K = 412.0, p = 0.001), and a period of relative rainfall recovery (1991-2024; mean 613.61mm; Pettitt k = 298.5, p = 0.012). While the overall 75-year linear trend in annual rainfall is not statistically significant (Z = +1.48, p = 0.138, Sen's slope = +1.12 mm/year), a statistically significant upward trend is observed during the post-1990 recovery phase (1991-2024: Z = +2.34, p = 0.019, Sen's slope = +4.85 mm/year). Onset dates display stability (mean June 20, p = 0.955) with an early-shifting trend post-1990 (−0.57 days/year, p = 0.091), whereas end-of-season dates show a significant extension after 1992 (+0.31 days/year, p = 0.0031). Farmers' perceptions align strongly with climatic observations: 80.31% (257/320) report a lengthening

of agricultural seasons, 72.50% (232/320) perceive later end dates, and 56.88% (182/320) highlight early-season dry spells. The study demonstrates that family farming vulnerability stems primarily from intra-seasonal rainfall distribution, dry spells, and intense flood events rather than total annual rainfall volume.

Keywords

Climate Variability, Farmers, Perceptions, Family Farming, Agro-Climatic Indicators, Bandé, Niger

1. Introduction

Over the past three decades, Niger—like other Sahelian countries—has experienced major climatic changes characterized by high rainfall variability and a succession of extreme events. Following the severe droughts of the 1970s and 1980s, the region has seen a relative recovery in rainfall since the 1990s, though without returning to previous climatic conditions [1] [2]. This trend is accompanied by increased instability in rainfall patterns, marked by temporal irregularity, more intense extreme events, and shifts in the agricultural calendar [3] [4]. In this context, Sahelian agricultural systems—and family farming in particular—appear especially vulnerable [5] [6]. In Niger, rain-fed agriculture is the primary source of livelihood for a large portion of the rural population [6]. Climatic fluctuations directly affect crop yields, food security, and household living conditions [7] [8]. Furthermore, several studies [8]-[10] have shown that intra-seasonal rainfall variability—specifically the start and end dates of the rainy season and the occurrence of dry spells—is a decisive factor in the success of agricultural seasons in the Sahel. In Niger, farmers rely heavily on consistent rainfall for successful sowing, crop emergence, and development. False starts to the rainy season, dry spells following sowing, and early season endings can jeopardize agricultural yields [10]-[14]. These factors directly influence farming decisions, such as the choice of crop varieties, sowing dates, and adaptation strategies adopted by farmers. Consequently, the analysis of climatic data should be complemented by a study of farmers' perceptions, which provide essential insight into environmental changes and local adaptation strategies [15] [16]. Through their daily experience, farmers develop a detailed understanding of climate variability and its impacts. Comparing climatic data with local knowledge thus enables a better understanding of ongoing transformations and their implications for agricultural systems. This study is conducted within this framework, aiming to analyze rainfall variability in the rural commune of Bandé (southern Zinder, Niger) from 1950 to 2024 by linking observed trends with farmers' perceptions and lived experiences. Specifically, the study aims to: i) characterize trends in cumulative rainfall and rainy seasons; ii) analyze intra-seasonal variability regarding season start and end dates as well as dry spells; and iii) assess the impacts of these changes on farming practices and

yields, based on survey data. By combining quantitative and qualitative approaches, this study contributes to a better understanding of the interactions between climate change and family farming in the study area and highlights current adaptation challenges in the context of increased climate variability.

2. Materials and Methods

2.1. Study Area

The study area covers the rural commune of Bandé, located in the Magaria department within the Zinder region of southeastern Niger (Figure 1). This commune is characterized by an essentially agricultural economy that is heavily dependent on climatic conditions. The local climate is Sahelian, marked by alternating dry and rainy seasons, with significant inter-annual variability in precipitation and temperatures. Figure 1 below shows the geographical location of the commune.

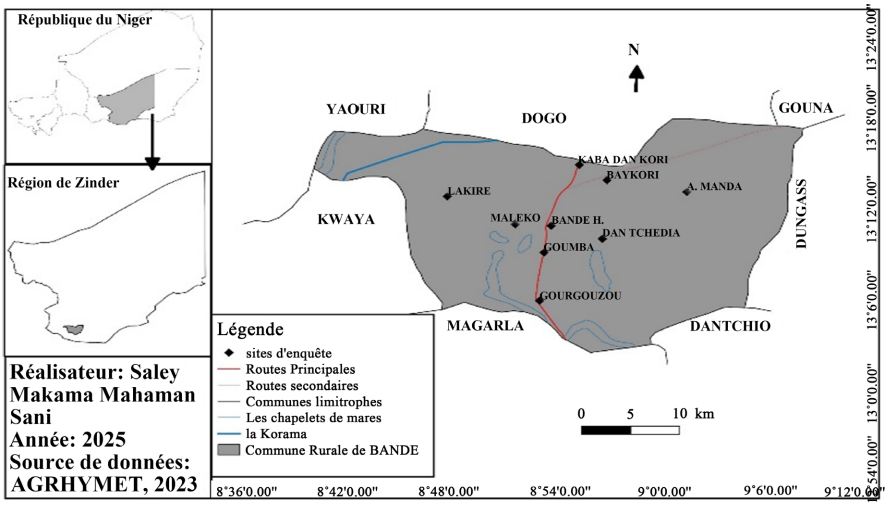

Figure 1. Geographical location of the study area.

2.2. Data Collection and Analysis

2.2.1. Climate Data Provider, Quality Control, and Representativeness

Daily rainfall data spanning 75 years (1950-2024) were provided by AGRHYMET-Niger (Regional Centre for Training and Application in Agrometeorology and Operational Hydrology). The rainfall series originates from the Magaria synoptic station, located at geographical coordinates 12˚59′; N latitude and 8˚56′; E longitude at an altitude of approximately 390 m. Missing daily records over the 1950-2024 period accounted for less than 1.8% of the total dataset and were imputed using linear interpolation and cross-validated against adjacent meteorological stations using Instat+ software (Statistical Services Centre, University of Reading). Data quality and time series homogeneity were verified using the Standard Normal Homogeneity Test (SNHT/Alexandersson test) and the Buishand range test at a significance level of alpha = 0.05. The Magaria station was selected as representative of rainfall conditions across Bandé commune because it is the nearest

synoptic weather station (located approximately 25 km from Bandé center), shares identical agro-ecological and topo-climatic characteristics (southern Sahelian Sudanian transition zone), and offers the most continuous, quality-controlled 75-year historical record in the department. Statistical and agro-climatic analysis of daily rainfall data was performed using Instat+ software [17].

➢ The main climatic indicators calculated include annual total rainfall, number of rainy days, start and end dates of the rainy season, duration of the agricultural season, intra-seasonal dry spells, and return periods for extreme rainfall events. Start and end dates were determined using standard Sahelian agro-climatic thresholds [11]:

- Onset of the rainy season (from May 1st): the first date after May 1st receiving a cumulative rainfall total of at least 20 mm over 1 to 3 consecutive days, not followed by any dry spell exceeding 10 consecutive days during the subsequent 30 days.
- End of the rainy season (from September 1st): the date after September 1st when accumulated plant-available water in the top 60 cm soil profile is fully depleted, assuming a soil water holding capacity of 60 mm and an average daily evapotranspiration (ETP) of 5 mm/day.
- Dry spells: uninterrupted sequences of consecutive dry days (daily rainfall; 1.0 mm) during the active growing months of June, July, and August.

2.2.2. Statistical Trend Tests and Mann-Kendall Decision Rule

Detection of climate breakpoints in time series was performed using Khronostat software based on the non-parametric Pettitt test (Pettitt, 1979) and the Hubert-Mendell method [18]. Long-term trends were evaluated using the non-parametric Mann-Kendall test. The decision rule for the Mann-Kendall test is as follows: The null hypothesis (H0: absence of monotonic trend) is rejected in favor of the alternative hypothesis (Ha: presence of a statistically significant trend) when the calculated p-value is strictly less than the chosen significance level alpha = 0.05 ($p < 0.05$). The magnitude and direction of trends were quantified using Sen's slope estimator (beta, expressed in mm/year or days/year). Prior to trend analysis, serial autocorrelation was assessed using the first-order autocorrelation function (ACF at lag-1). For series exhibiting significant autocorrelation, prewhitening was applied to eliminate serial dependence and avoid inflating type I error rates.

2.2.3. Household Sampling, Survey Execution, and Qualitative Interviews

Field surveys were conducted from September to November 2025 across eight representative rural villages and the administrative center of Bandé commune. The sampling frame was derived from the official agricultural household registry provided by municipal services and INS Niger (2022). The theoretical sample size ($n = 384$) was calculated using Cochran's formula at a 95% confidence level ($t = 1.96$), an estimated proportion $p = 0.50$, and a margin of error $e = 0.05$:

$$n = \frac{t^2 \times p(1-p)}{e^2} = \left(1.96^2 \times 0.5 \times 0.5\right) / 0.05^2 = 384.16$$

From the 384 targeted agricultural households, a final total of N = 320 fully completed and valid household questionnaires were obtained (representing an effective response rate of 83.33%). The difference of 64 uncompleted surveys was due to seasonal male labor migration (exodus) during field visits and the exclusion of incomplete questionnaires. Household selection within villages followed a simple random sampling protocol. To complement household questionnaires, 9 Focus Group Discussions (FGDs)—comprising 8 to 10 participants per group representing elders, women, and young farmers—were held across the villages, along with 12 semi-structured key informant interviews with local municipal authorities, traditional chiefs, and agricultural extension officers. Table 1 summarizes the final distribution of surveyed households and response proportions across the study villages.

Table 1. Number of people surveyed by village.

Villages	Households surveyed	Proportion (%)
Angoual Manda	28	8.75
Bandé	94	29.37
Beykori	34	10.62
Dan Tchédia	30	9.37
Gomba	23	7.18
Gourgouzou	25	7.81
Kaba Dan Koro	31	9.68
Lakiré	28	8.75
Malam Léko	27	8.43
Total	**320**	**100**

2.2.4. Analysis of Farmers' Perceptions

Data from the agricultural household surveys were processed based on their contribution to understanding the climate and characterizing agricultural seasons. The variables related to this information were grouped and analyzed as quantitative data using SPSS software. The selected indicators are those conventionally used in agro-climatic analysis: the onset and end of the rainy season and their trends, the duration and types of seasons, and the occurrence of dry spells and extreme rainfall events. This approach allows for a comparison of observed climatic trends with farmers' perceptions regarding rainfall patterns, drought frequency, and their impacts on agricultural calendars and yields, in line with integrated climate-society approaches [16] [19].

3. Results

3.1. Annual Rainfall Dynamics and Breakpoint Verification

Figure 2 illustrates the long-term trend in annual cumulative rainfall at Magaria station from 1950 to 2024. Application of the Pettitt test confirms two highly significant climate breakpoints: the first break in 1967 (Pettitt K = 412.0, p = 0.001) marking the transition from a wet era to severe drought, and the second break in 1990 (Pettitt k = 298.5, p = 0.012) marking the onset of rainfall recovery. Across the entire 75-year period (1950-2024), the overall Mann-Kendall test indicates a non-significant linear trend (Z = +1.48, p = 0.138, Sen's slope = +1.12 mm/year). However, sub-period trend analysis confirms that during the recovery period (1991-2024), annual precipitation displays a statistically significant upward trend (Z = +2.34, p = 0.019, Sen's slope = +4.85 mm/year).

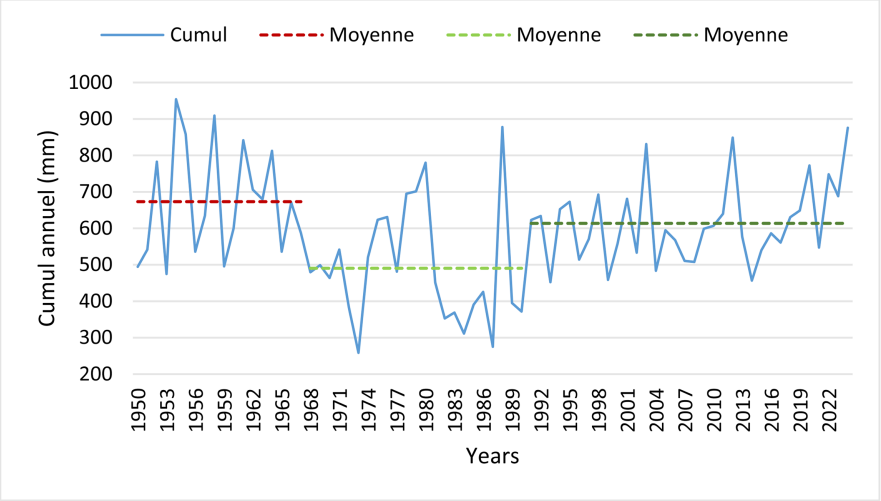

Figure 2. Trend in annual precipitation in the study area from 1950 to 2024.

Descriptive Statistics for the Period

Table 2 presents descriptive statistics for the period from 1950 to 2024. The years 1950 to 1967 constituted a wet period characterized by high and consistent rainfall. The mean precipitation for this period was 673.12 mm, with a minimum of 474.9 mm and a maximum of 954 mm; the standard deviation was 153.67 mm. This period also saw numerous years with rainfall exceeding 700 mm, creating favorable conditions for rain-fed agriculture. However, this pattern was interrupted by a sharp break in the series—identified via the Pettitt test (1979)—occurring between 1968 and 1990. This subsequent period was marked by a drastic drop in precipitation, with an average of 490.39 mm. There is a difference of more than 122.73 mm between the 1950-1967 and 1968-1990 periods, representing a 20.01% decrease. Minimum precipitation was 258.5 mm and maximum precipitation was 779.8 mm, while the standard deviation remained high (162.14 mm). This decline in rainfall has a major impact on water resources and agricultural practices. This period is characterized by years with

precipitation levels below 300 mm. The 1991-2024 period marks a return of rainfall, showing a significant increase of 123.22 mm compared to the 1968-1990 period—an increase of 25.12%. It is characterized by high inter-annual precipitation variability, featuring both dry and wet years. However, the years with rainfall deficits during this third period are significantly wetter than those of the preceding period. The end of the series is marked by abundant rainfall. The period's mean precipitation is 613.61 mm, with a minimum of 452.3 mm, a maximum of 875.7 mm, and a lower standard deviation (108.84 mm). This period sees the return of years with precipitation exceeding 800 mm. While this resurgence would normally be expected to improve agricultural yields, it is hampered by episodes of intense rainfall that cause flooding, thereby hindering agricultural activities.

Table 2. Descriptive statistics for the 1950-2024 series.

Periods	Number of years	Average rainfall (mm)	Standard deviation (mm)	Min (mm)	Max (mm)
1950-1967	18	673.12	153.67	474.9	954
1968-1990	23	490.39	162.14	258.5	779.8
1991-2024	34	613.61	108.84	452.3	875.7

3.2. Intra-Seasonal Agro-Climatic Trends and Farmers' Perceptions

3.2.1. Start of the Rainy Season (1950-2024)

Figure 3 shows that the average onset of the season over the entire study period (1950-2024), occurs on day 172 of the year (June 20), with a standard deviation of 18.88 days (coefficient of variation CV = 10.93%). During 1950-1990, season onset averaged day 175.95 (June 25) with high stability (Sen's slope = −0.02 days/year, Mann-Kendall Z = −0.06, p = 0.955). From 1991 to 2024, season start shifted toward earlier dates (−0.57 days/year, Sen's slope = −0.568, Z = −1.69, p = 0.091). While this trend remains statistically non-significant at the 5% level, inter-annual onset variability has intensified significantly since the late 1990s. Survey results reveal strong consistency with climatic data: 47.50% (152/320) of surveyed farmers perceive that rainy seasons now start earlier, while 37.81% (121/320) emphasize that onset dates have become highly unpredictable from year to year, and 14.69% (47/320) report delayed starts.

3.2.2. End of the Rainy Season and Reconciliation of Breakpoints

Figure 4 shows that the mean cessation date of the rainy season occurs on day 261.70 (September 17) over the period 1950-2024. Breakpoint detection on end-of-season dates identifies major shifts in 1971 (Pettitt k = 310.5, p = 0.008) and 1992 (Pettitt k = 285.0, p = 0.014). To reconcile these dates with the annual rainfallbreakpoints (1967 and 1990), we note that annual rainfall volume breaks (1967/1990) reflect large-scale atmospheric monsoon moisture transport, whereas

end-of-season cessation dates (1971/1992) are governed by local agro-climatic soil moisture dynamics (depletion of 60 mm plant-available water in topsoil under ETP = 5 mm/day). The 2- to 4-year lag between volume drops and end-of-season shifts illustrares the buffer capacity of soil moisture storage. Prior to 1971, end-of-season dates average day 266 (September 23) with no significant trend (p = 0.630). During 1972-1991, season end dates moved earlier (−0.57 days/year, mean day 253.5/ September 9, p = 0.091). In contrast, the 1992-2024 period exhibits a statistially significant upward trend in end-of-season dates (+0.310 days/year, Z = +2.96, p = 0.0031, total delay +16.43 days over 32 years), indicating a clear delay in seasonal cessation in recent decades. Household survey responses strongly reflect this agro-climatic signal (Figure 5): 72.18% (231/320) of farmers observe that rainy seasons end noticeably later in recent years, 20.62% (66/320) report heightened inter-annual instability in cessation date, and 6.88% (22/320) perceive earlier season endings.

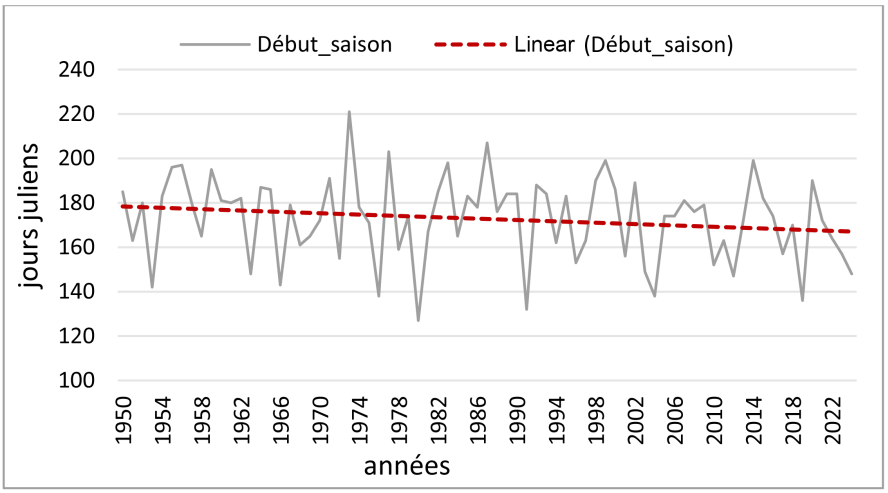

Figure 3. Changes in season start dates, 1950-2024.

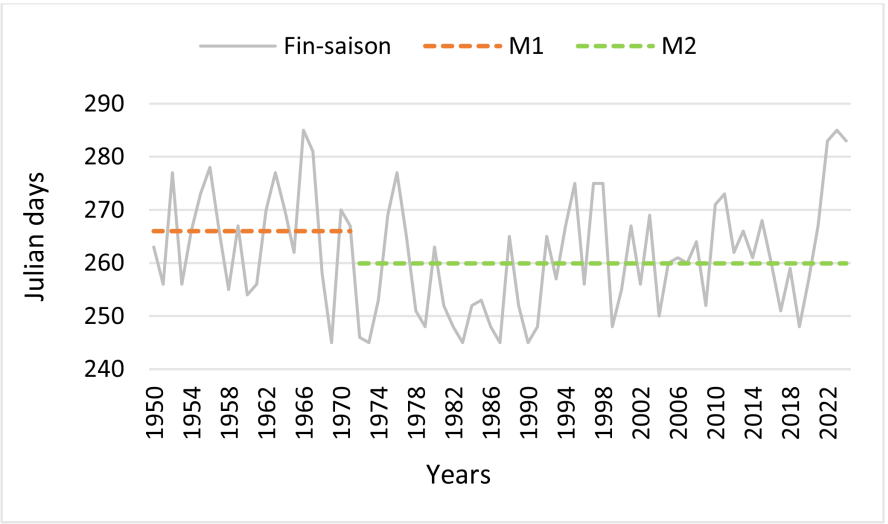

Figure 4. Evolution of season endings (1950-2024).

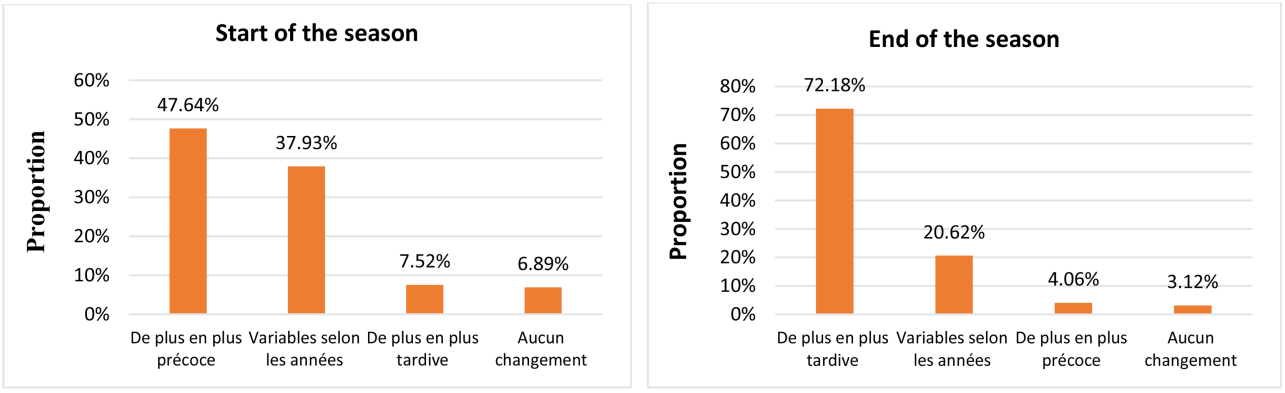

Figure 5. Farmers' perceptions of changes in the start and end of the seasons.

3.3. Intra-Seasonal Dry Spells and Extreme Rainfall Events

Analysis of intra-seasonal dry spells indicates that June experiences the longest dry spells (frequent dry sequences exceeding 20 days, e.g., in 1971, 1982, 1986, 2014), causing severe sowing failures and requiring repeated re-sowing (**Figure 6**). Overall, 56.88% (182/320) of survey respondents identified early-season dry spells as the primary operational constraint on crop emergence. Dry spells in July and August are shorter (rarely exceeding 10 - 12 days). Concurrently, extreme daily rainfall events (90th percentile = 113.19 mm/day; 10-year return period) have increased significantly since 2010, causing destructive field flooding, soil erosion, and crop losses.

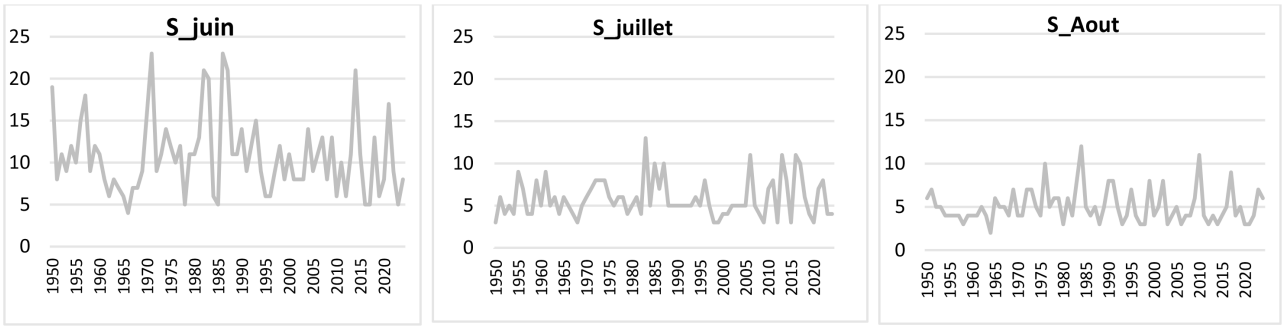

Figure 6. Trends in dry spells during June, July, and August from 1950 to 2024.

During the 1980-1985 period, an increase in dry spells was observed across all three months simultaneously, characterized by episodes of severe drought.

The situation in June is of particular concern for the agricultural sector. Dry spells lasting more than 20 days at the start of the season hinder the beginning of the growing season, potentially causing delays that can lead to a poor agricultural year.

Despite these dry spells, there has been a rise in high-intensity rainfall events since 2010. These intense rains cause flooding in both urban and rural areas, leading to land destruction, a reduction in available land, and a need for agricultural imports. Based on this dataset, the extreme rainfall level (corresponding to the 90th percentile) is 113.19 mm—a rainfall event with a ten-year return period.

3.4. Typology of Agricultural Seasons and Cumulative Rainfall

Surveys show that 80.31% (257/320) of farming households perceive a general lengthening of agricultural seasons in recent years, compared to 19.06% (61/320) observing variable durations and 0.63% (2/320) nothing shorter seasons. Table 3 presents the typology and occurrence frequencies of agricultural season types across the 75-year record based on agro-climatic cluster analysis [16].

Table 3. Frequency and year of occurrence of season types.

Type	Number	Year of occurrence	
Normal	39	1950; 1951; 1954; 1956; 1957; 1965; 1968; 1970; 1971; 1974; 1988; 1989; 1992; 1993; 1994; 2008; 2009; 2013; 2015; 2016	1958; 1959; 1960; 1962; 1964; 1975; 1978; 1981; 1984; 1985; 2000; 2002; 2005; 2006; 2007; 2017; 2018; 2020; 2021
Early	8	1953; 1969; 1972; 1979; 1991	1996; 2004; 2019
Long	13	1963; 1966; 1976; 1980; 1997; 2022; 2023; 2024	2001; 2003; 2010; 2011; 2012
Short	7	1973; 1982; 1983; 1986; 1987	1990; 1999
Late	8	1952; 1955; 1956; 1967; 1977	1995; 1998; 2014

"Normal" seasons constitute the dominant category, accounting for 52.7% of cases—a proportion higher than those reported by [16] (33.9%) in 2020 and by [20] (40%) in 2009. Their occurrence is relatively evenly distributed over time, with 11 cases during the wet period (1950-1967), 11 cases during the drought period (1968-1990), and 17 cases since 1990; this indicates a certain stability for this type of season, despite the climatic fluctuations observed in the region. "Early" seasons remain infrequent and appear with relative balance between the wet and dry periods, though their occurrence has risen slightly since 1990. In contrast, "long" seasons are markedly more frequent in the recent period (9 occurrences between 1990 and 2024) compared to the 1950-1967 and 1968-1990 periods, when they were observed only twice each. This trend may reflect a recent tendency toward a lengthening of the rainy season—a phenomenon already noted in several studies on Sahelian rainfall variability. Conversely, "short" seasons are concentrated primarily in the drought period (1968-1990), with six occurrences, compared to just one after 1990 and none during the wet period. This result confirms the significant impact of the major Sahelian drought on the reduction of the rainy season's duration. Finally, "late" seasons are observed more frequently during the wet period (four occurrences) and become less common during the drought period (one occurrence), before reappearing to a moderate extent since the 1990s (three occurrences). Overall, these results demonstrate strong interannual variability in the duration and timing of the rainy season, a characteristic feature of the Sahelian climate. The prevalence of normal seasons, combined with the increase in long seasons since the 1990s, suggests a relative recovery in rainfall conditions following the severe drought of the 1970s and 1980s, albeit within a context marked by heightened variability and an alternation of contrasting years (Figure 7).

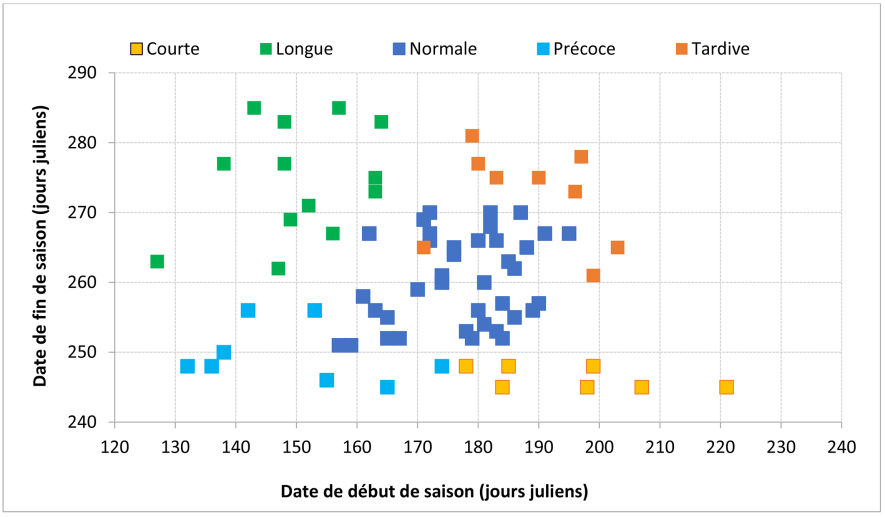

Figure 7. Representation of the seasonal types observed in the study area.

3.5. Relationship between Seasonal Type and Rainfall

To analyze the relationship between agricultural seasonal types and rainfall variability, the annual cumulative rainfall for each seasonal type was compared to the interannual mean rainfall (**Figure 8**). In this plot, each point represents a year characterized by a specific agricultural seasonal type (normal, early, late, short, or long). The horizontal line indicates the interannual mean rainfall. Points above this line represent years with above-average rainfall, while those below indicate years with rainfall deficits. The analysis reveals a clear relationship between the seasonal type and the level of cumulative rainfall. Long seasons are characterized by generally high rainfall totals: 12 out of 13 long seasons show rainfall exceeding the interannual mean. This prevalence of above-average rainfall indicates that a longer agricultural season is strongly associated with favorable rainfall conditions. Furthermore, these long seasons are predominantly observed after the 1990s (9 out of 13 cases), suggesting that certain recent years experienced relatively abundant rainfall despite the general context of climate variability. Conversely, short seasons are consistently associated with rainfall deficits. Indeed, all seven identified short seasons show cumulative rainfall totals below the interannual average. This result highlights a strong link between a shortened agricultural season and insufficient rainfall, which can have significant implications for agricultural activities. Regarding normal seasons, the majority are characterized by rainfall totals below the interannual average, reflecting an overall trend toward a deficit. However, 11 of the 39 normal seasons occurred during the wet period of 1950-1967; this indicates that, during this more favorable climatic phase, even seasons classified as "normal" could be associated with relatively higher rainfall. This observation underscores the influence of the underlying climatic context on the characteristics of different agricultural season types. Finally, early and late seasons show a wider distribution relative to the interannual average, reflecting less consistent rainfall patterns. This variability suggests that such seasons can occur in contexts

of either slight surplus or deficit, without a systematic relationship to overall rainfall levels.

Overall, these results reveal a structured relationship between the duration of agricultural seasons and rainfall conditions: long seasons are generally associated with wet years, whereas short seasons correspond primarily to years with rainfall deficits.

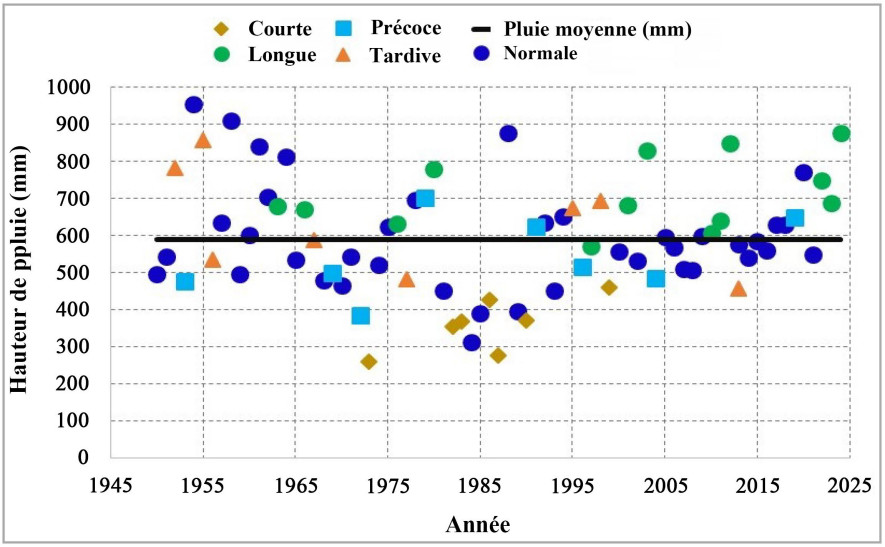

Figure 8. Relationship between seasonal types and rainfall.

4. Discussion

The results reveal a rainfall regime characterized by a succession of wet years (1950-1967), drought years (1968-1990), and a relative recovery in rainfall since 1990. This dynamic aligns with the work of [16] and [3], who confirm high rainfall variability and recurring droughts since the 1970s. These findings also concur with those of [21], who highlight the alternation between prolonged droughts and a partial return of rainfall, accompanied by an increase in extreme events. However, the recent increase in cumulative rainfall has not led to a significant improvement in agricultural yields. Survey results indicate a perceived decline in agricultural production. This paradox is explained by rainfall irregularity and the increased frequency of floods, heavy rainfall, and dry spells. These results are consistent with the work of [22], demonstrating that the intensification of extreme events significantly impacts food security and rain-fed agricultural systems in Niger and across the Sahel. The study also reveals a strong correlation between climate data and farmers' perceptions. Farmers accurately identify changes in the agricultural calendar, the irregular onset of the rainy season, and the increase in dry spells. This alignment is confirmed by the work of [19], which shows that local farming knowledge is a vital resource for identifying and managing agro-climatic risks within Sahelian agricultural systems.

The study also highlights the pivotal role of intra-seasonal variability. Dry

spells, particularly early in the season, pose a major challenge for the start of the agricultural season. In Niger, these breaks in rainfall are recognized as one of the most limiting factors for agricultural production due to their direct impact on crop germination and growth. Several agro-climatic studies—notably [23]—confirm that high spatio-temporal rainfall variability makes agricultural yields highly uncertain in the Sahel region.

Furthermore, the relative lengthening of the rainy season observed since the 1990s does not guarantee successful agricultural production. Research by [21] demonstrates that the duration of the season, in isolation, is insufficient to ensure favorable agricultural conditions when rainfall remains irregular and poorly distributed.

Finally, the study underscores the high vulnerability of rain-fed agriculture—the dominant form in Niger—to climate variability. This reliance on rainfall explains the recurring difficulties regarding production and food self-sufficiency. Conversely, irrigated systems appear relatively more resilient, highlighting the importance of water access in adaptation strategies. Overall, the study confirms that the primary challenge for Nigerien family farming lies less in the total volume of rainfall than in rainfall irregularity, the intensification of extreme events, and intra-seasonal variability.

5. Conclusions

The study provides an integrated quantitative and qualitative analysis of rainfall variability and agricultural seasons in the rural commune of Bandé (1950-2024). By combining 75 years of daily meteorological data from Magaria station with household surveys (N = 320) and focus group discussions, the research establishes three primary conclusions:

Annual rainfall has experienced a statistically significant recovery since 1991 (+4.85mm/year, $p = 0.091$; Pettitt breakpoint in 1990, $k = 298.5$, $p = 0.012$), following the severe 1968-1990 drought era.

Agro-climatic seasons are extending significantly due to delayed end dates (+0.31 days/year since 1992, $p = 0.0031$), with 80.31% of local farmers confirming longer growing seasons. However, intra-seasonal dry spells in June (reported by 56.88% of respondents) and extreme flood events constrain agricultural production.

Local farmers' perceptions display a remarkable alignment with observed agro-climatic trends, underscoring the necessity of incorporating indigenous knowledge into rural climate adaptation policies. To build agricultural resilience in Bandé commune, local policy must prioritize soil and water conservation techniques, expansion of small-scale irrigation, crop diversification, and accessible agro-meteorological forecasting.

Author Contributions

Conceptualization, M.S.S.M. and M.B.A.B.; methodology, M.S.S.M.; software,

M.S.S.M.; validation, M.S.S.M., S.A., I.M., and M.B.A.B.; formal analysis, M.S.S.M.; investigation, M.S.S.M.; resources, S.A. and I.M.; data curation, M.S.S.M.; writing—original draft preparation, M.S.S.M. and M.B.A.B.; writing—review and editing, M.S.S.M., S.A., I.M., and M.B.A.B.; visualization, M.S.S.M.; supervision, S.A. and I.M.; project administration, S.A. and I.M.; funding acquisition, S.A. and I.M. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Ozer, P., Hountondji, Y.C., Manzo, N.A., Djaby, B. and de Longueville, F. (2022) Évolution de la pluviométrie au Niger (1950-2020): Une reprise factice? *Climatologie*, **19**, 12-27.

[2] Descroix, L., Mahé, G., Malam Abdou, M., Vandervaere, J.P., Gautier, E., Faty, B. and Soumaré, S. (2018) Le retour des pluies au Sahel: Une fausse bonne nouvelle pour les ressources en sol et en eau? *Revue Éléments d'Agroclimatologie*, **14**, 45-62. https://hal.science/hal-02154823

[3] Sultan, B. and Janicot, S. (2003) The West African Monsoon Dynamics. Part II: The "Preonset" and "Onset" of the Summer Monsoon. *Journal of Climate*, **16**, 3407-3427. https://doi.org/10.1175/1520-0442(2003)016<3407:twamdp>2.0.co;2

[4] Nicholson, S.E. (2013) The West African Sahel: A Review of Recent Studies on the Rainfall Regime and Its Interannual Variability. *ISRN Meteorology*, **2013**, Article ID: 453521. https://doi.org/10.1155/2013/453521

[5] Mortimore, M. (2010) Adapting to Drought in the Sahel: Lessons for Climate Change. *WIREs Climate Change*, **1**, 134-143. https://doi.org/10.1002/wcc.25

[6] Institut National de la Statistique du Niger [INS] (2022) Rapport d'analyse: Agriculture et conditions de vie des ménages au Niger. INS Niger. https://stat-niger.org

[7] AGRHYMET (2021) Suivi de la campagne agropastorale et sécurité alimentaire au Sahel et en Afrique de l'Ouest: Focus sur la vulnérabilité du secteur agricole au Niger. CILSS/AGRHYMET. https://agrhymet.cilss.int

[8] Sani, A., Yamba, B. and Ousmane, M. (2020). Variabilité intra-saisonnière des pluies et vulnérabilité de la riziculture et de la culture du mil au Niger central. *Revue Ivoirienne de Géographie*, **18**, 64-79. https://revive-edu.org

[9] Alhassane, A., Salack, S., Ly, M., Traoré, S.B., Sarr, B. and Agele, S.O. (2013) Evolution des caractéristiques agroclimatiques de la saison des pluies dans le Sahel central. *Sécheresse*, **24**, 191-202.

[10] Marteau, R., Sultan, B., Moron, V., Alhassane, A., Baron, C. and Traoré, S.B. (2011) The Onset of the Rainy Season and Farmers' Sowing Strategy for Pearl Millet Cultivation in Southwest Niger. *Agricultural and Forest Meteorology*, **151**, 1356-1369. https://doi.org/10.1016/j.agrformet.2011.05.018

[11] Sivakumar, M.V.K. (1988) Predicting Rainy Season Potential from the Onset of Rains in Southern Sahelian and Sudanian Climatic Zones of West Africa. *Agricultural and Forest Meteorology*, **42**, 295-305. https://doi.org/10.1016/0168-1923(88)90039-1

[12] Stern, R.D., Dennett, M.D. and Garbutt, D.J. (1981) The Start of the Rains in West Africa. *Journal of Climatology*, **1**, 59-68. https://doi.org/10.1002/joc.3370010107

[13] Balme, M., Galle, S. and Lebel, T. (2005) Démarrage de la saison des pluies au Sahel: Variabilité à des échelles hydrologique et agronomique, analysée à partir des données EPSAT-Niger. *Climatologie*, **2**, 105-118.

[14] Barron, J., Enfors, E., Cambridge, H. and Moustapha, A.M. (2010) Coping with Rainfall Variability: Dry Spell Mitigation and Implication on Landscape Water Balances in Small-Scale Farming Systems in Semi-Arid Niger. *International Journal of Water Resources Development*, **26**, 543-559. https://doi.org/10.1080/07900627.2010.519519

[15] Tarbiya, M., Ibrahim, B. and Adamou, M. (2022) Perception paysanne de la variabilité climatique et stratégies d'adaptation dans les systèmes de culture au Sud-Ouest du Niger. *Revue Ivoirienne des Sciences et Technologie*, **39**, 142-158. http://www.revist.ci

[16] Malam Abdou, M., Descroix, L., Abba, B., Amadou Boukary, M.B. and Mamadou, I. (2020) Caractérisation des saisons agricoles au Sahel: Analyse des données agro-climatiques versus vécu paysan, cas de la région de Zinder, Niger. *Afrique SCIENCE*, **17**, 83-101. http://www.afriquescience.net

[17] Stern, R.D., Rijks, D., Dale, I. and Knock, J. (2006) INSTAT Climatic Guide. Statistical Services Centre, University of Reading. https://www.reading.ac.uk/ssc/

[18] Pettitt, A.N. (1979) A Non-Parametric Approach to the Change-Point Problem. *Applied Statistics*, **28**, 126-135. https://doi.org/10.2307/2346729

[19] Roncoli, C., Ingram, K. and Kirshen, P. (2002) Reading the Rains: Local Knowledge and Rainfall Forecasting in Burkina Faso. *Society & Natural Resources*, **15**, 409-427.

[20] Sarr, B. and Lona, I. (2009) Les fortes pluies enregistrées au Sahel au cours de l'hivernage 2007: Variabilité et/ou changement climatique. *Proceedings of the 14th International SIFÉE Conference*, Niamey, 26-29 May 2009, 9 p.

[21] Lebel, T. and Ali, A. (2009) Recent Trends in the Central and Western Sahel Rainfall Regime (1990-2007). *Journal of Hydrology*, **375**, 52-64. https://doi.org/10.1016/j.jhydrol.2008.11.030

[22] Ozer, P., Hountondji, Y.C. and Laminou, O.M. (2010) Désertification, variabilité climatique et risques environnementaux au Sahel. *Geo-Eco-Trop*, **34**, 45-68. http://www.geoecotrop.be

[23] Sivakumar, M.V.K. (1992) Empirical Analysis of Dry Spells for Agricultural Applications in West Africa. *Journal of Climate*, **5**, 532-539. https://doi.org/10.1175/1520-0442(1992)005<0532:eaodsf>2.0.co;2