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Climatic Variability, Perception, and Farmers' Adaptation Strategies in the Ramsar Sites of the Middle Niger

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Abstract

Sahelian wetlands play a central role in the livelihoods of local populations, while being highly vulnerable to climate variability and change. This study analyzes recent trends in climatic parameters, farmers' perceptions, and local adaptation strategies in the Ramsar sites of the Middle Niger wetlands (MN I and MN II). The methodological approach combines observed climate data (precipitation, temperature, and wind) for the period 1993-2024 with socio-economic surveys conducted among 434 households across 14 riparian villages. The results indicate pronounced interannual variability in precipitation, characterized by alternating periods of deficit and surplus, with longer and more frequent dry spells observed in MN II. Thermal analysis reveals a general increase in temperatures, with average maximum temperatures reaching 39.66˚C (MN I) and 39.34˚C (MN II), alongside a more rapid rise in minimum temperatures, whose averages reach 20.10˚C and 20.14˚C, respectively, indicating a marked intensification of nocturnal warming. Furthermore, a significant intensification of wind speed is observed, heightening environmental vulnerability, particularly in MN II. These climatic trends are largely consistent with local perceptions: 69.9% to 78.1% of respondents reported an increase in daytime temperatures, and 40.9% to 60.1% observed a rise in nighttime temperatures. The main perceived environmental impacts are declining water levels (48 - 54%), degradation of aquatic vegetation (46 - 58%), and loss of wildlife (13 - 20%). In response to these constraints, local populations have developed adaptation strategies primarily involving the use of organic fertilizer, mulching, and adoption of resilient crop varieties; however, the effectiveness of these measures remains limited for ensuring ecosystem sustainability.

Keywords

Climate Variability, Sahelian Wetlands, Farmers' Perceptions, Climate Change Adaptation, Ramsar Sites, Middle Niger

1. Introduction

Global warming and the changes observed since the 1950s are unprecedented in their impact on biodiversity and humanity as a whole [1]. Africa remains one of the most vulnerable continents to climate variability and change due to multiple stresses and its limited capacity to respond and adapt [2]. The Sahel is characterized by high rainfall variability, marked by severe droughts and rainfall deficits of 25% to 40% between 1970 and 1980 compared to the period from 1930 to 1960 [3]-[6]. These severe droughts have led to environmental degradation, resulting in the loss of millions of trees and animals [7] [8].

Studies have shown that several factors continue to impact water resources in the Sahel [9] [10]. Over the past thirty years, numerous wetlands have disappeared at an alarming rate—three times faster than forests—resulting in serious consequences for local populations. Between 1970 and 2015, approximately 35% of the world's wetlands were lost, with a significant acceleration of this trend in recent years [11].

In sub-Saharan Africa, approximately 65% of wetlands are concentrated within the four main river basins: Lake Chad, the Niger River, the Congo River, and the Nile River [12]. Climatic degradation beginning in the 1970s and intensifying in the 1980s led to reduced precipitation, resulting in an overall decline in runoff and a drastic decrease in wetland areas. At the same time, increasing demographic pressure has accelerated the depletion of resources in these environments, which are often regarded as vital arteries of Sahelian ecosystems. For their preservation, the Ramsar Convention recommends the rational management of wetland resources. Thus, reconciling economic development with ecosystem conservation, especially in the Sahel, is a key scientific concern today, necessitating the development of sustainable management strategies that can only be effective based on a thorough understanding of these fragile environments. This highlights the relevance of the present study, which aims to characterize, on the one hand, the variation in climatic parameters and, on the other hand, local populations' perceptions of climate change. The study also seeks to identify environmental impacts and the various adaptation strategies proposed by local communities.

2. Materials and Methods

2.1. Study Area Description

The study area consists of the Ramsar sites of the Middle Niger wetlands (**Figure 1**), with a total surface area of 153,900 ha, divided as follows: 88,050 ha for the

Ramsar site of the Middle Niger (MN) I, and 65,850 ha for the Ramsar site of Middle Niger (MN) II. The MN I is located in the departments of Gaya and Dosso, on the left bank of the Niger River, and stretches for approximately 100 km from Kouassi to Dolé. It comprises the Niger River and its floodplains, along with the Walwal tributary. This area is distinctive in that it provides a unique habitat in the region, made up exclusively of two dominant native plant species: *Echinochloa stagnina* (a high-quality forage plant), known as "bourgou" in Zerma, and *Anthephora nigritana* (a hardy grass species), which serve as habitat for thousands of waterbirds during the low-water season, and as pasture, after burning, for livestock during the lean season [13]. The MN II is located in the Department of Dosso and extends from Boumba to Kouassi over a 25 km stretch of the Niger River, along the border with Benin in the southwest of the country. It consists of floodplains and associated ponds. The area is of significant ecological importance due to the presence of plant species such as *Echinochloa stagnina* in Zerma and *Anthephora nigritana*, which provide habitat for thousands of waterfowl and serve as pasture. It also shelters threatened animal species, including the white-tailed mongoose (*Ichneumia albicauda*), the Cape fox (*Vulpes pallida*), and the African manatee (*Trichechus senegalensis*) [14].

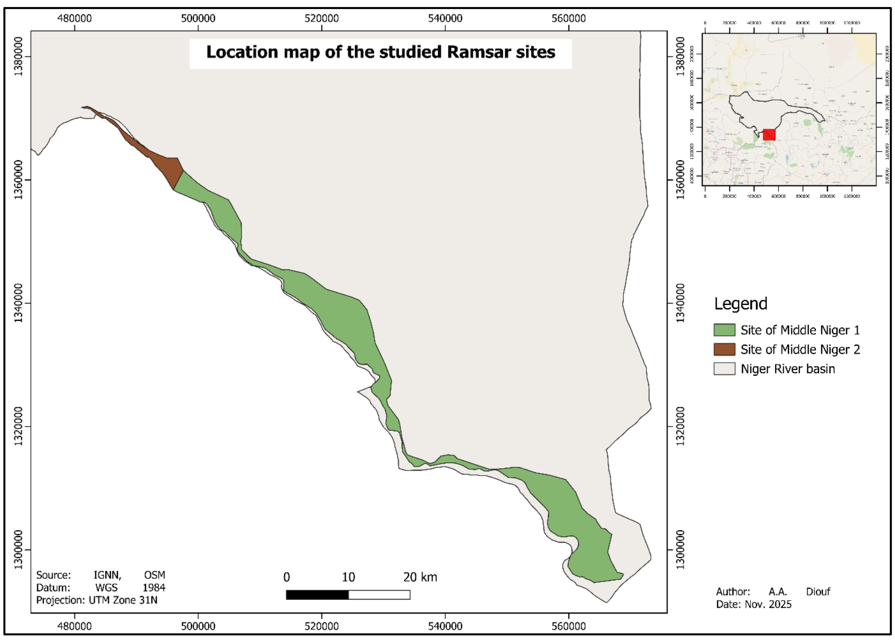


Figure 1. Location map of the study area.

The climate of the area is Sudanian, characterized by consistently high temperatures and spatiotemporal irregularity of precipitation, which ranges from 600 to 800 mm annually [15]. At the regional scale, atmospheric circulation is largely determined by the opposition of two air masses: the harmattan, a hot and dry northeasterly wind driven by the Azores anticyclone, and the monsoon, a humid southwesterly wind whose air masses are associated with the Saint Helena anticyclone.

Solar radiation remains intense throughout the year, resulting primarily in high evaporation rates. The longest seasonal variations in the average monthly duration of daily sunshine occur in October-November, with values exceeding 9 hours, while the shortest durations are recorded in July-August, with values of 6.8 hours for Gaya [15].

With regard to potential evapotranspiration (PET), the evaporative capacity of the atmosphere is very high, but the actual evaporation potential is limited. Monthly average PET values calculated for the Gaya station between 1977 and 2004 range from 136.8 mm in September to 231.1 mm in March [15]. For actual evapotranspiration, which is the quantity of water actually evaporated, the annual values calculated range from 626 to 795 mm, with an average of 783 mm over the 1977-1998 period. As for the water balance, according to the work of [16], in the Gaya area, a surplus is recorded only in August and September, and, in rare cases, in July.

2.2. Field Data Collection

2.2.1. Sampling of Households to Be Surveyed

Based on the 2012 General Population Census, the surveyed households for data collection were sampled from five (5) municipalities bordering the two Ramsar Sites of the Middle Niger in the Dosso region, namely: Falmey, Sambera, Tanda, Gaya, and Tounouga. Subsequently, fourteen (14) villages were selected across the study area, comprising 2,551 agricultural households. Slovin's formula was used to determine the sample size of households to be surveyed:

$$n = \frac{N}{1 + Ne^2}$$

With N representing the total number of agricultural households

e: the margin of error assumed in this study is 6.5% and

n: the sample size of households to be surveyed.

The Slovin formula was used to estimate the minimum sample size of households to be surveyed at 217 (n = 217). By applying the design effect (n * 2), the resulting sample size required was n = 434. To obtain the 434 households, this sampling approach enabled the selection of a representative number of households from the population, with a quota of 35% women. The ages of respondents ranged from 45 to 85 years. Surveys were conducted in fourteen (14) villages distributed across the five (5) communes (**Table 1**).

Table 1. Number of surveyed households by locality in the Middle Niger Wetlands.

Villages	Number of surveyed households	Percentage of surveyed households
Koulou	13	3%
Ouna	62	14%
Tondika	3	1%

Continued

Boumba	30	7%
Djabou Kiria	25	6%
Kouassi Peulh Haoussa	15	3%
Tara	103	24%
Tondika	17	4%
Albarkaizé	7	2%
Konza	16	4%
Mombeye Tounga	35	8%
Dolé	64	14%
Gattawani Kaina	44	10%
Total	434	100%

2.2.2. Conducting Field Surveys

A questionnaire was developed for random household interviews. Additionally, targeted focus groups were conducted, involving technical services, key informants, and natural resource users from both wetland areas. The questionnaire included questions concerning perceptions of climate change, its impacts on wetlands, and the adaptation strategies developed by the communities. Multiple responses were allowed to better capture existing livelihoods and adaptation strategies. During the surveys, rainy-season onset was defined as the significative rain event after which farmers seeded their fields. Also, a dry-spell was considered to be period of ten days where no rainfall events were registered. These criteria were solely based on the population perception. In order to mitigate the recall bias, historical questions were restricted to older respondents both during individual interview and focus group.

2.3. Data Processing and Analysis

2.3.1. Survey Data

The Sphinx and Excel tools were used, respectively, to develop the questionnaire and process the data concerning population perceptions and adaptation to climate change. The analysis focused on changes in the characteristics of climatic parameters (rainfall, season parameters, temperature, wind, and climatic extremes) and the adaptation strategies implemented by communities. Additionally, several thematic figures were produced based on these climatic parameters.

2.3.2. Climate Data

Excel and SPSS software were used to process the climate data, specifically precipitation and temperature, for the period from 1993 to 2024. The climate database was obtained from the National Meteorology Directorate related to stations located in Gaya (11,8833 N; 3,4500 E) for MN1 and Boumba (12.4044 N, 2.8458 E) for MN2. Precipitation data were used to calculate the annual Standardized Precipitation Index (SPI) for the Middle Niger region. It should be noted that this index, a simple metric, was adopted in 2009 by the World Meteorological Organization (WMO) [17] [18]. The SPI facilitates the comparison of different series, the synthesis of information, and the visualization of trends over long periods [19]. It reflects either a precipitation surplus or deficit for a given year relative to the reference period (1993-2024). The SPI was calculated as a simple standardized anomaly (z-score) using the following formula, as proposed by Balme et *al*., (2006):

$$SPI = (Pi - Pmoy)/\sigma$$

where Pi = annual rainfall, $Pmoy$ = mean annual rainfall of the series; σ = standard deviation of the series.

Annual, monthly, maximum, and minimum average temperatures were analyzed for the entire study area. Similarly, the maximum relative wind speed was included in the analysis.

3. Results

3.1. Main Activities Carried Out by Local Populations

Survey results indicate that agriculture is the predominant activity in the study area, involving 42.5% of the population. Fishing, which ranks as the second main activity, is practiced by 24% of residents in the Ramsar sites of the Middle Niger, primarily Nigeriens, Nigerians, and Malians. Livestock rearing, though less widespread, involves 20% of the area's inhabitants and is mainly carried out by the Peulh and Touareg communities, who engage in small-scale transhumance. Finally, commerce—which is primarily based on agricultural, fishing, and livestock products—constitutes a significant share of livelihoods and is more common in the Middle Niger 1 zone, where it involves 15% of the study area's population.

3.2. Analysis of Climatic Factors

3.2.1. Evolution of the Standardized Precipitation Index in the Middle Niger from 1993 to 2024

Figure 2(a) and **Figure 2(b)** illustrate the evolution of the SPI in the Middle Niger I and II regions from 1993 to 2024. A strong variability in precipitation was observed, characterized by alternating wet (surplus) and dry (deficit) periods. According to these figures, there has been pronounced interannual precipitation variability across the entire study area from 1993 to 2024. Specifically, the Middle Niger 1 region (**Figure 2(a)**) experienced four (4) wet periods with an SPI of 2.36: two (2) wet periods lasting three (3) years each (2005-2007 and 2022-2024); one (1) long wet period lasting four (4) years (2017-2020); and one (1) two-year wet period (2009-2010). Extended dry periods of four (4) years were also observed (1999-2002; 2013-2016), along with alternating wet and dry years from 1993 to 1998 (**Figure 2(a)**).

In contrast, the Middle Niger II region (**Figure 2(b)**), with an ISP of 2.38, experienced the highest number of deficit (dry) periods. Notably, there was an extended dry spell from 2000 to 2006. Additionally, a three-year dry period occurred from 2016 to 2018, along with two two-year periods (2008-2009 and 2013-2014), and alternating sequences of one dry year followed by one wet year. Regarding wet periods, two major wet spells were identified: a prolonged six-year wet period from 2019 to 2024, a two-year wet period from 1998 to 1999, and single-year alternations between wet and dry periods (Figure 2(b)).

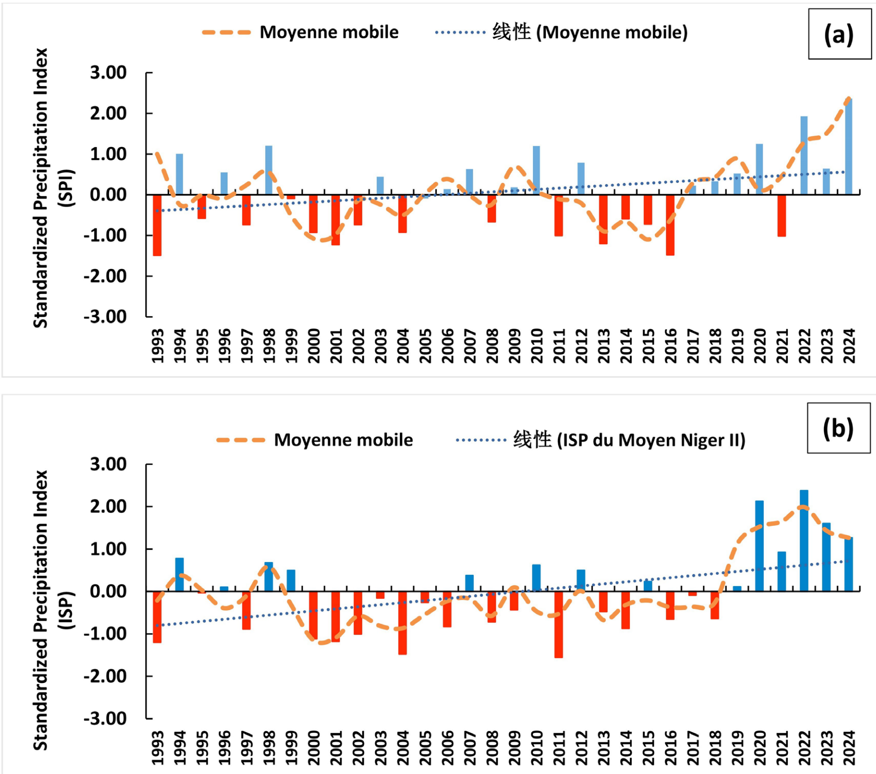


Figure 2. Temporal variations of ISP in Middle Niger I (a) and Middle Niger II (b) from 1993 to 2024.

3.2.2. Evolution of the Annual Mean Temperatures at the Ramsar Sites of Middle Niger I and II from 1993 to 2024

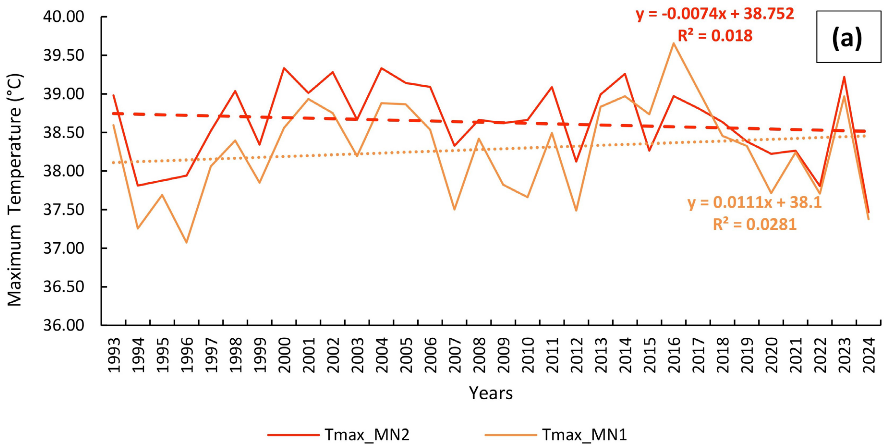
1) Analysis of Average Maximum Temperatures

Analysis of the annual mean maximum temperatures over the 1993-2024 period revealed interannual variability (Figure 3(a)). The mean maximum temperature during this period was 38.28˚C (standard deviation = 0.51˚C) at MN1 and 38.63˚C (standard deviation = 0.62˚C) at MN2. The highest maximum temperatures were observed in 2016 (39.66˚C) at MN1 and in 2000 (39.34˚C) at MN2. The lowest values were recorded in 1996 (37.8˚C) at MN1 and in 2024 (37.38˚C) at MN2. The trend is increasing at MN1, while at MN2 it has been decreasing since 2008.

2) Analysis of Average Minimum Temperatures

Analysis of the annual means of minimum temperatures over the period 1993-2024 also revealed interannual variability and an upward trend in minimum temperatures (Figure 3). The average minimum temperature during this period was 19.09˚C (standard deviation = 0.44˚C) at MN1 and 19.38˚C (standard deviation = 0.40) at MN2. The highest temperatures were recorded in 2016 (20.10˚C) at

MN1 and in 2023 (20.14˚C) at MN2. The lowest values were observed in 1996 (18.22˚C) at MN1 and in 2001 (18.52˚C) at MN2.



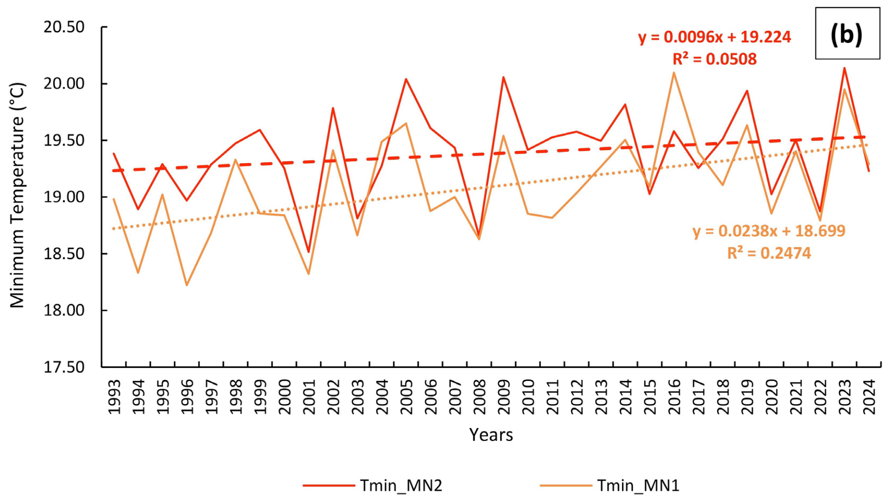


Figure 3. Evolution of the annual maximum (a) and minimum (b) average temperatures of MN1 and MN2 from 1993 to 2024.

3.2.3. Evolution of the Maximum Relative Wind Speed in the Middle Niger I and II Zones from 1993 to 2024

Analysis of **Figure 4** showed that all areas within Middle Niger I and II are experiencing an increase in wind speed. Specifically, the Middle Niger I area recorded its highest annual maximum wind speed in 2001 at 40.02 m/s (the highest annual value observed), while Middle Niger II reached 40.08 m/s during the same period. According to this figure, it is therefore observed that the Middle Niger II area is more exposed to the risk of strong winds, which have greater significant impacts on the environment compared to the Middle Niger I area.

3.3. Analysis of Climatic Factors Based on Population Perceptions

3.3.1. Evolution of the Duration of the Rainy Season

Analysis of the collected data revealed that thirty (30) years ago, the rainy season began in May and ended in late September. This was confirmed by 79% of respondents, while 21% indicated that, in the past thirty years, the rainy season started in June and ended in late October. Twenty years later, as confirmed by 89%, the rainy season had shifted to begin in June. During this period, the end of the rainy season remained stable, still coinciding with the end of September. However, this trend has since evolved, resulting in a shift in the seasonal calendar. Today, 91% of respondents reported that rainfall occurs mainly during the last ten days of June, compared to just 9%, and now extends into October. This change in the seasonal cycle reflects ongoing climatic changes and variations in the study area.

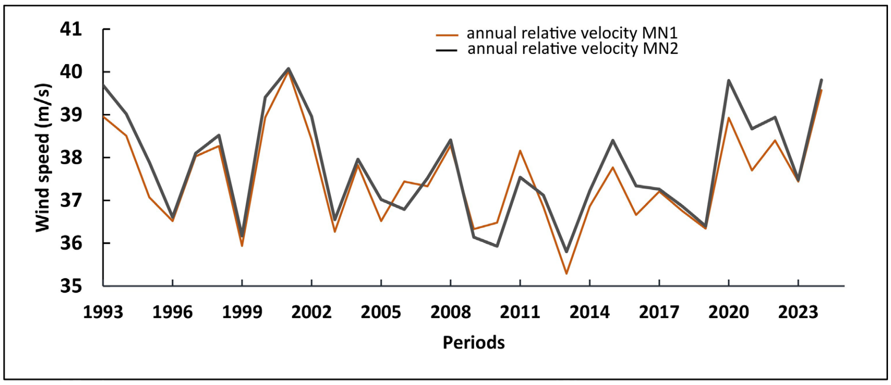


Figure 4. Evolution of the relative velocity of MN I and MN II from 1993 to 2024.

3.3.2. Dry Spells during the Rainy Season in the Study Area

Analysis of the collected data revealed that the duration of dry spells during the rainy season has changed significantly over the decades. Thirty years ago (in 1994), 30.87% of respondents reported no change, while 28.10% indicated that dry spells during the rainy season were less frequent and shorter, as confirmed by 23.73% of respondents in Middle Niger I. During the same period in Middle Niger II, these dry spells were less frequent according to 26.10% of respondents, with 25.87% reporting no change, and 23.73% stating that dry spells were shorter. However, today, there is clear evidence of a substantial change in the frequency of dry spells during the rainy season across the entire study area in both Middle Niger sites. These dry spells have become longer and more frequent, as confirmed by 38.47% and 30.72% of respondents in Middle Niger I, and 41.47% and 31.72% in Middle Niger II, respectively (Figure 5(a) and Figure 5(b)).

3.3.3. Evolution of Daytime and Nighttime Temperatures

Surveys revealed that a majority perceived an increase in daytime temperatures in recent years. This trend is more pronounced in the Middle Niger II zone, where 78.11% of household heads report it, compared to 69.88% in Middle Niger I (Figure 6). Conversely, a minority believe that temperatures have remained stable (20.89% in Middle Niger I; 15.21% in Middle Niger II) or have decreased (9.23% and 6.68%, respectively).

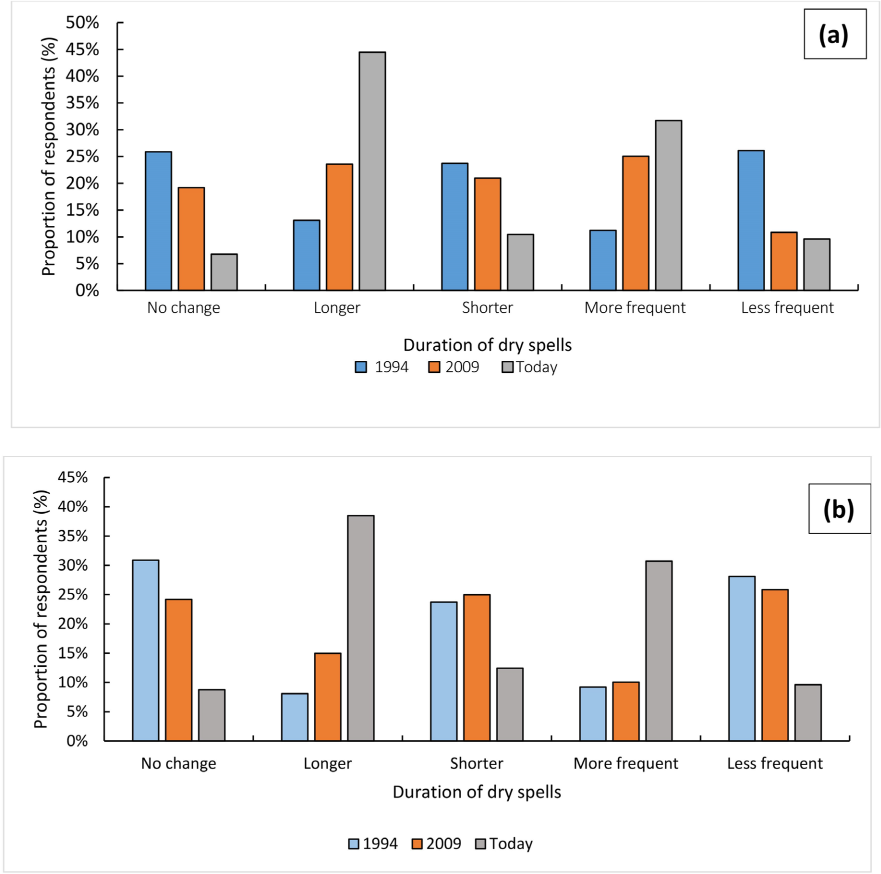


Figure 5. Proportion of responses concerning dry spells during the dry season, as perceived by respondents from (a) the Middle Niger I zone and (b) the Middle Niger II zone.

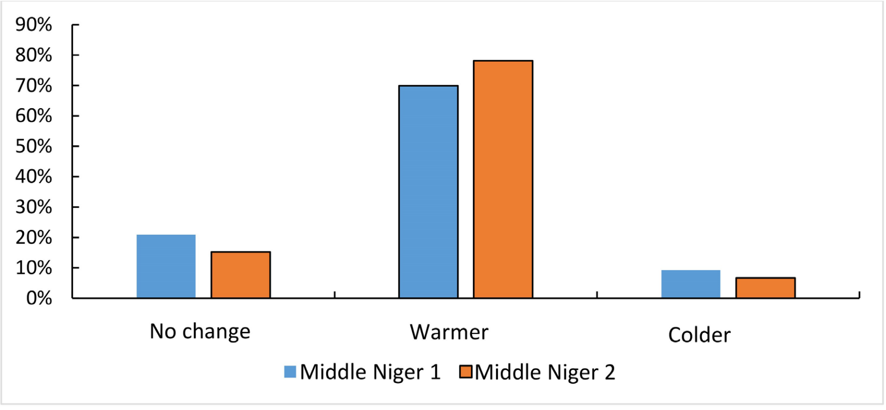


Figure 6. Peasant perception of changes in daytime temperatures in the areas of Middle Niger I and II.

Regarding nighttime warming, it is perceived as significant and shows an increasing gradient from Middle Niger I to Middle Niger II. Specifically, 60.11% of respondents in Middle Niger II report this increase, compared to 40.90% in Middle Niger I, indicating an intensification of the phenomenon in the western part of the study area (Figure 7).

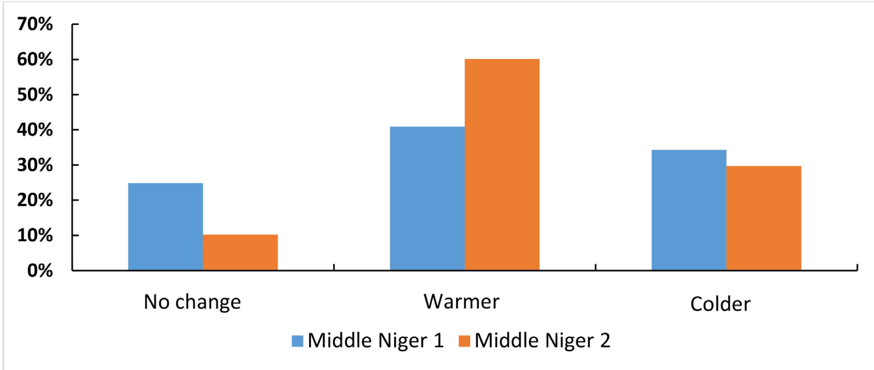


Figure 7. Farmers' perceptions of changes in nighttime temperatures in the Middle Niger I and II zones.

This overall increase in both daytime and nighttime temperatures is linked by local populations to several major negative impacts on the local ecosystem, listed here in order of citation frequency (**Figure 8**):

- **An accelerated decline in water levels**: This is the most frequently reported consequence, confirmed by 54% of respondents in Middle Niger II and 48% in Middle Niger I;
- **A decline in aquatic plant species**: Reported by 58% of respondents in Middle Niger I and 46% of those in Middle Niger II.
- **A loss of wildlife**: Reported by 20% of respondents in Middle Niger I and 13% in Middle Niger II.

These perceptions, illustrated in **Figure 8**, highlight the extent of environmental disturbances associated with climate change in the area.

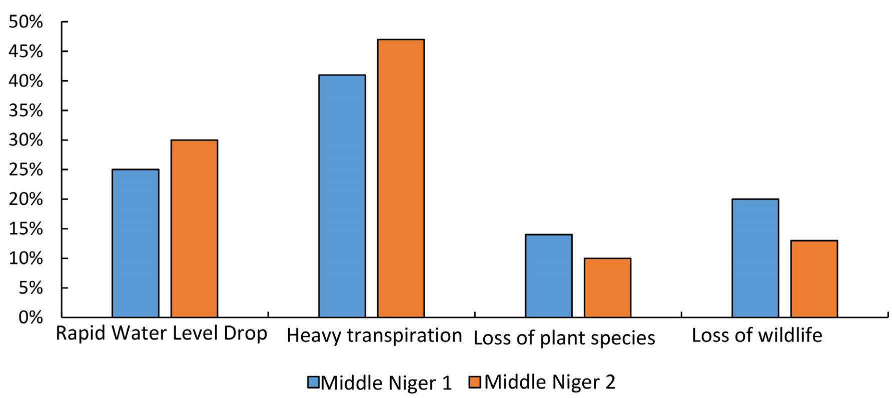


Figure 8. Proportion of responses regarding the types of impacts of high temperatures in the Middle Niger I and II zones.

3.3.4. Intensification of Strong Winds

Survey analysis indicated a marked intensification of strong winds in the study area over the past three decades. In 1994, strong winds were considered less intense and carried less dust, as reported by 30% and 22.25% of respondents, respectively. Additionally, 20.41% of respondents felt that wind intensity had remained unchanged, while 14.24% and 13.10% observed an increase in dust content and wind violence, respectively.

In contrast, the current situation is marked by a notable worsening of the phenomenon. Specifically, 40% of respondents report an intensification of strong winds, while 31% indicate an increase in dust content. This deterioration is largely attributed to a significant reduction in vegetation cover, which serves as a protective barrier against wind erosion. Conversely, only 13% of participants observed a decrease in dust carried by the wind, 10.75% noted a reduction in wind intensity, and 5% believe that there has been no change (**Figure 9**).

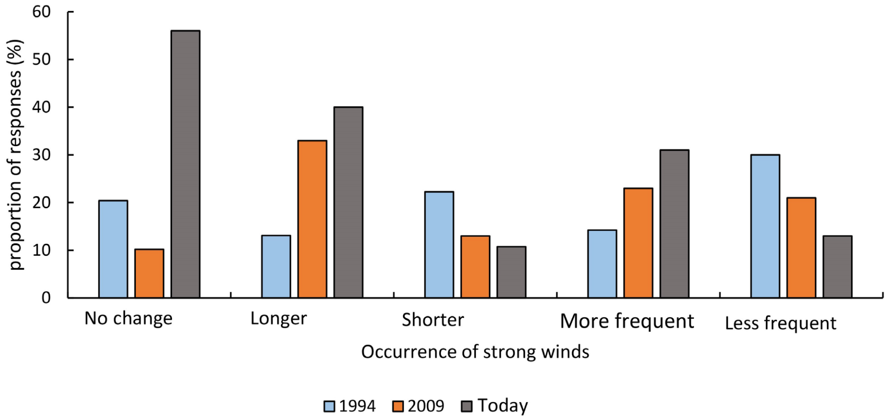


Figure 9. Proportion of responses regarding the intensification of strong winds in the Middle Niger I and II zones

These strong winds have harmful effects on the environment. According to survey results, their main impacts are crop destruction (46%), loss of seedlings (20%), degradation of plant species (18%), sand deposition in water points (10%), and soil crusting (6%).

3.3.5. Causes and Impacts of the Most Extreme Climate Risks

Analysis of the collected data revealed an intensification of extreme climatic events. Currently, the primary climate risks reported in the Middle Niger I area are floods (25% of respondents), violent winds (21%), extreme heat (18%), extreme cold (14%), an early end to the rainy season (11%), and a delayed onset of the rainy season (10.5% of respondents). In the Middle Niger II area, the most frequent and dangerous climate risks are violent winds (23%), floods (21%), and extreme heat (20%). Respondents also identified several other climate risks, notably the delayed onset of the rainy season (13%), the early end of the rainy season (13%), and extreme cold (10%) (**Figure 10**).

Survey data analysis revealed that the main drivers of climate risks observed in the study area are diverse. They include natural causes (28%), degradation of natural resources (18%), deforestation (34%), desertification (15%), and, to a lesser extent, air pollution (5%). These climate risks exert significant negative impacts on the environment and local economic activities, notably disrupting ecosystems and agricultural productivity in the area (**Table 2**).

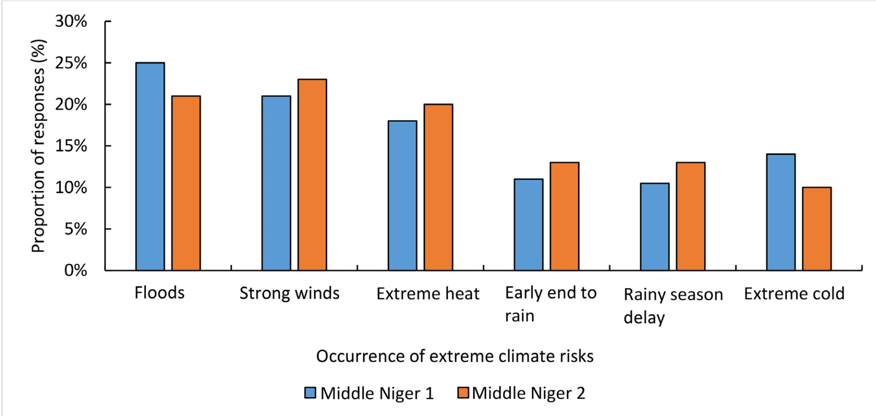


Figure 10. Proportions of responses concerning the most extreme climate risks in the Middle Niger I and II zones.

Table 2. Characteristics of different climate risks and their impacts.

Risks in order of importance	Causes	Frequency	Impact 1	Impact 2	Impact 3
Flood	Deforestation	2 - 3 years	Crop (field) losses	Deterioration of housing	Animal losses
Delay of the first useful rains	Rainfall variability	Annual	Losses of seedlings	Animal losses	Food insecurity
Strong winds	Desertification, excessive logging	Annual	Deterioration of dwellings	Tree loss	Crop pests
Heat waves	Desertification, Unsustainable logging	Annual	Human diseases	Animal losses	Water scarcity
Drought	Desertification, excessive logging	5 years	Famine	Animal losses	Reduction of fish stocks
Early stopping	Rainfall variability	Annual	Crop losses	Famine	Locust invasions

3.4. Adaptation Strategies in Response to Climate Risks

3.4.1. Strategies to Mitigate the Effects of Runoff and Wind

To mitigate the impact of runoff and wind on crops and seedlings, several measures have been implemented by local communities. These include windbreaks (45%), household waste spreading (32%), water channelling (14%), and compartmentalization (9%) in the Middle Niger I area. In contrast, in the Middle Niger II area, the main community actions are household waste spreading (46%), establishment of windbreaks (34%), followed by compartmentalization (12%) and water channelling (8%) (**Figure 11**).

3.4.2. Strategies for Mitigating the Effects of Runoff and Wind

To cope with rising high temperatures, local populations in the Middle Niger I area employ techniques such as mulching (38%), tree planting (34%), the creation of shaded areas (19%), and irrigation (9%). In the Middle Niger II area, mulching is the most widely adopted practice (55%), followed by tree planting (22%), the creation of shaded areas (18%), and irrigation (5%) (**Figure 12**).

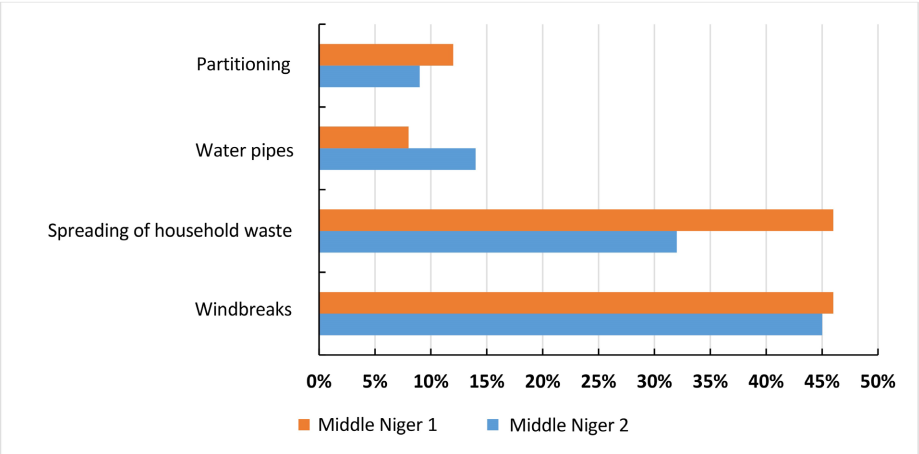


Figure 11. Strategies for reducing the effects of runoff and winds were developed by communities in the Middle Niger I and II areas.

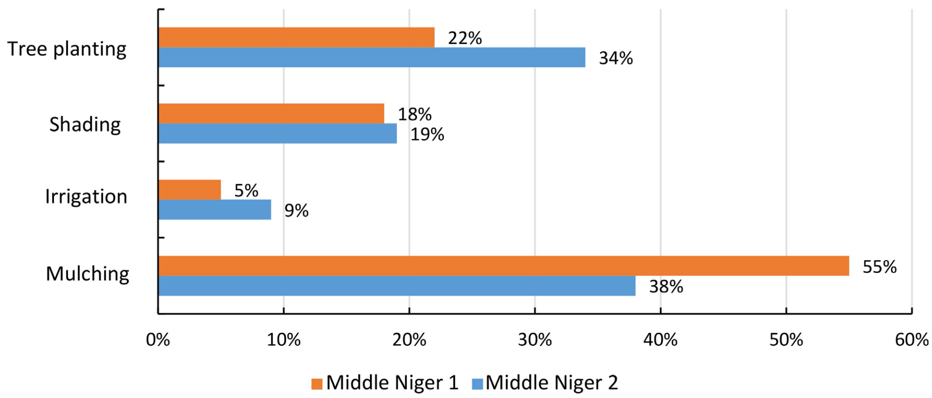


Figure 12. Percentages of responses regarding strategies developed by communities in the Middle Niger I and II areas to mitigate the effects of high temperatures.

3.4.3. Actions to Mitigate the Impact of Dry Spells on Crops and Plantations

To mitigate periods of drought affecting crops and bodies of water, various initiatives have been implemented by local communities. Survey results indicate that 42% of respondents identified the selection of resistant crop varieties as the primary strategy adopted by populations in the Middle Niger I region, compared to 37% in Middle Niger II. Other measures include reseeding (21% in Middle Niger I and 26% in Middle Niger II), supplementary irrigation (20% in Middle Niger I and 27% in Middle Niger II), and, finally, transplantation, which has been adopted by 17% of the population in Middle Niger I and 10% in Middle Niger II. Data analysis reveals that nearly all of these strategies are more prevalent in the Middle Niger II area (**Figure 13**).

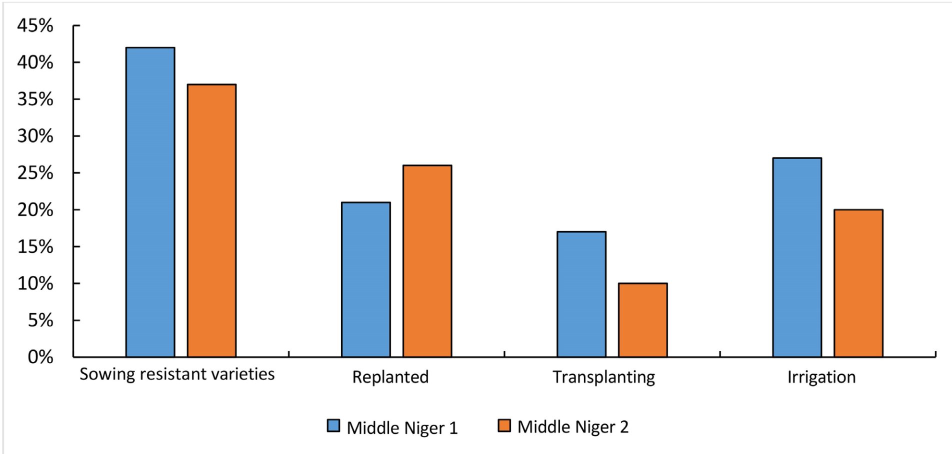


Figure 13. Strategies for reducing dry spells on crops and water bodies in the Middle Niger I and II zones.

4. Discussions

4.1. Wintering and Heavy Rainfall

According to survey results, a change in the length of the rainy season has been observed. This change was noted by 78% of respondents, who reported a duration of seven (7) months for the rainy season, while 22% did not perceive any change. The study area has already experienced heavy rainfall events, as confirmed by 45.77% of respondents, indicating that in Middle Niger I, such intense rainfall events are more frequent; 30.80% reported that they are less frequent, while only 23.43% did not observe any change. In Middle Niger II, heavy rainfall events are considered more frequent by 56.45% of respondents, less frequent by 29%, and only 14% did not report any change. These findings are comparable to those of [20], who studied local perceptions of wetland dynamics at Ramsar site 1017 in Benin. The study revealed that 93.77% of respondents perceived changes in the wetlands' ecosystems over time and space (including expansion and enlargement of the central zone), while only 6.23% observed no significant modification [20]. In Burkina Faso, a study showed that 76.7% of producers perceived a decrease in rainfall [21]. According to a study by Tidjani in 2016 on the oasis system of Gouré in Niger, farmers perceived the effects of climate variability as increased aridity, rising temperatures, and the unpredictable nature of rainfall. Livestock breeders perceived these changes indirectly, through reduced forage and water availability [22]. Another study in Nakanbé-Dem, Burkina Faso, found that farmers clearly perceived the degradation of lowlands. Farmers use meteorological, floristic, and physical indicators to characterize the state of lowland degradation. The disappearance of several species and the appearance of ubiquitous species allow them to assess the degradation of lowland soils. These endogenous indicators vary according to gender and education level. The study highlighted the importance of endogenous knowledge in analyzing the phenomenon of lowland degradation [23].

4.2. Temperature Variation

With regard to temperatures, the convergence between community perceptions and the analysis of observed data clearly reveals an increase in both minimum and maximum temperatures. This trend aligns with a broader regional dynamic: in West Africa, and particularly in the Sahelian zone, temperature increases have been faster than the global average. Previous studies indicate rises ranging from 0.2˚C to 0.8˚C per decade since the late 1970s in the Sahelo-Saharan, Sahelian, and Sudanian zones [24].

Analysis of the observed data shows that the increase has accelerated sharply, becoming nearly continuous. A notable finding is the difference in the rate of change between minimum and maximum temperatures: the rise in minimum temperatures is both faster and more consistent than that of maximum temperatures. This observation aligns with the conclusions of [24], which indicate that temperature increases in Niger have been continuous for minimum temperatures since the 1980s and for maximum temperatures since the 1990s. Between 1991 and 2010, the increase in minimum temperatures is estimated at +1.2˚C, compared to +0.48˚C for maximum temperatures, indicating a marked intensification of nighttime warming. This differentiated evolution is likely to have important implications for agricultural systems and local bioclimatic conditions.

4.3. Winds

During this period (1994), strong winds were reported to be less dusty and less intense by 30% and 22.25% of respondents, respectively. Additionally, 20.41% of respondents confirmed that the strong winds remained unchanged, while 14.24% and 13.10% indicated that the winds were dustier and more intense, respectively. In contrast, the area now faces a much more severe situation with intensified strong winds. This is supported by 40% and 31% of respondents who report that the winds are now respectively stronger and dustier. These results are consistent with [21], who note that the emergence of strong winds is a new phenomenon for local populations. According to 98.7% of surveyed individuals, winds have become more violent and frequent, manifesting as tornadoes during the rainy season and causing significant damage to homes and crops [21].

Note that because respondents were comparing conditions 20 - 30 years back, the provided answers and interpretations may include some bias that we tried to mitigate by restricting historical question to older respondents.

4.4. Climate Risks

The main factors underlying the observed climatic risks in the study area are diverse. According to respondents, these include natural causes, the degradation of natural resources, deforestation, desertification, and, to a lesser extent, air pollution. These climatic risks have significant negative impacts on the environment and local economic activities, notably disrupting ecosystems and agricultural productivity in the region. In Benin, land degradation is primarily manifested through exposed soils, a reduction in woody vegetation, and low agricultural yields. The principal factors driving wetland ecosystem degradation include land clearing and tenure, uncontrolled grazing, the infilling of water bodies and the widening of riverbeds, as well as climatic variability. The most frequently reported causes of the modification of wetland ecosystems at Ramsar Site 1017 are agriculture, the introduction of new species (primarily flora), flooding, population growth, logging, and climate change observed in the site in recent years [20].

4.5. Adaptation Strategies

Survey data analysis reveals that, similar to Middle Niger I (43.58%) and II (55.12%), the main strategy adopted by farmers and herders is the application of organic fertilizer in cultivated fields. This is followed by the use of chemical fertilizers (41% in Middle Niger I compared to 32% in Middle Niger II), the practice of RNA (34.54% in Middle Niger I compared to 24.51% in Middle Niger II), tree planting (24.12% in Middle Niger I compared to 18.41% in Middle Niger II), and tillage, implemented by 20% in Middle Niger I and 24.51% in Middle Niger II. These results are similar to Palma's 2019 study, where the main adaptation strategies include the adoption of water and soil conservation techniques (CES), ownership of compost pits, irrigation, and varietal adaptation. The determining factors for these adaptation measures include ownership of hoes and shovels, membership in a farmers' organization, training in agricultural technologies, and access to credit. A producer's choice to adopt a specific adaptation strategy depends on their perception of climate change and its causes, its negative environmental impacts, and the available means to provide solutions [21]. In the oasis systems of Gouré, Niger, the effects of climate change have led populations to adopt adaptation strategies such as searching for new short-cycle varieties capable of withstanding drought pockets, adopting dune fixation techniques for grass cover restoration, using organic fertilizer, modifying sowing dates, storing fodder, reducing livestock during the lean season, and organizing collective prayers for rain [22]. In the Yélimané district of Mali, communities have adopted risk behaviors in response to climate variability, developing both individual and collective strategies. The main measures involve the use of early and semi-early varieties, increased cultivation of recession crops, market gardening, storage of crop residues for livestock feed, rural exodus, and migration. Material, financial, and institutional constraints limit community adaptive capacities [25]. Therefore, to adapt to climate change, producers have adopted several agricultural practices. Producers have abandoned some cash crops, such as cotton and tobacco, in favor of cereals like sorghum and millet. Likewise, long-cycle varieties of sorghum and millet have been replaced by short-cycle varieties [21].

5. Conclusion

Riparian populations in the Ramsar site of the Middle Niger, particularly those in floodplain areas, have more complex needs for climate information than users in dry, especially Sahelian and Saharan, zones. These needs pertain to the pluvial-fluvial production system and include local rainfall onset dates, flood arrival dates, the timing of peak flood discharge, and maximum flood height. This study enabled mapping of riparian communities' perceptions regarding the effects of climate change. The impacts of climate change on fishery resources are widely recognized among surveyed populations. Declining precipitation and rising temperatures in recent decades, along with sedimentation, have contributed to reduced river levels and fish catches, both in quantity and quality. Riparian communities have developed a variety of adaptation strategies in response, some of which, unfortunately, are harmful to fishery resources; these include the construction of fishing dams and the use of prohibited fishing gear.

Conflicts of Interest

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

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