Journal of Geoscience and Environment Protection, 2026, 14(1), 85-101
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Flood-Risk Perception among Banana Producers in Tambacounda, Senegal: A Case Study Approach

Ousseynou Badji[1*], Lamine Diop[1,2], Aminata Sarr[3], Ansoumana Bodian[4], Aliou Diop[5]

[1]Faculty of Agronomic Sciences, Aquaculture and Food Technology, Gaston Berger University, Saint-Louis, Senegal
[2]Laboratory of Biological, Agronomic and Food Sciences and Modelling of Complex Systems (LABAAM), Gaston Berger University, Saint-Louis, Senegal
[3]Renewable Energy and Energy Efficiency Laboratory, International Institute for Water and Environmental Engineering (2iE), Rue de la Science, Ouagadougou, Burkina Faso
[4]Leïdi Laboratory, Territorial Dynamics and Development, Gaston Berger University (UGB), Saint-Louis, Senegal
[5]Laboratory for Study and Research in Statistics and Development, Gaston Berger University, Saint-Louis, Senegal
Email: *badji.ousseynou2@ugb.edu.sn

How to cite this paper: Badji, O., Diop, L., Sarr, A., Bodian, A., & Diop, A. (2026). Flood-Risk Perception among Banana Producers in Tambacounda, Senegal: A Case Study Approach. *Journal of Geoscience and Environment Protection, 14,* 85-101.
https://doi.org/10.4236/gep.2026.141006

Received: December 1, 2025
Accepted: January 18, 2026
Published: January 21, 2026

Abstract

In the context of increasing climate-related flood events in eastern Senegal, understanding producers' perceptions has become essential for assessing local vulnerability. Building on this premise, this study examines how banana producers in Tambacounda perceive and interpret flood risk through a descriptive and analytical approach combining surveys with 85 producers, systematic field observations, and supporting environmental data. Results show that from 2003 to 2024 the region experienced flooding during 11 different years, corresponding to an average recurrence interval of approximately once every two years. Findings indicate that 55% of producers attribute flooding primarily to natural drivers such as intense rainfall and river overflow, while 37% identify anthropogenic pressures including deforestation, inadequate land-use planning, and insufficient hydraulic infrastructure. Risk perception remains uneven: around 38% of respondents report strong awareness of flood hazards, whereas 35% declare limited or no knowledge, a disparity closely linked to education level and past exposure. Reported impacts include substantial agricultural production losses, irrigation constraints, and increased logistical and transportation costs. In response, producers implement a variety of individual and collective adaptation measures, from temporarily relocating production sites to installing rudimentary drainage systems, despite generally weak institutional support and limited technical assistance. from key institutions such as agricultural extension services, local disaster-management agencies (notably the Flood Prevention and Management Department), and municipal authorities, whose support in technical guidance, early-warning information, and coordinated flood-management interventions remains insufficient. Overall, these findings highlight the need to incorporate local knowledge and risk perceptions into territorial planning and disaster-prevention policies to strengthen resilience to climate-induced hazards.

Keywords

Tambacounda, Flood Risk Perception, Agriculture, Adaptation Strategies, Resilience

1. Introduction

Senegal has been experiencing a marked increase in extreme hydroclimatic events, particularly floods, which have intensified in both frequency and severity over the past decades (Faye et al., 2021). This escalation results from the combined effects of climate change, land degradation, rapid urban expansion, and strong demographic pressure, all of which contribute to amplifying exposure and vulnerability to hydrological hazards across the country (Faye et al., 2021; GIEC, 2014).

Within this national context, the Tambacounda region in eastern Senegal, traversed by the Gambia River, presents a particularly alarming situation. Recognized as the country's leading banana production zone and contributing nearly 60% of national output (Badji, 2017; Diallo, 2021), this agricultural basin is regularly exposed to recurrent flooding. These events are triggered by the combined influences of river overflow, intense seasonal rainfall, low-lying topography, and soil saturation creating prolonged water stagnation (Faye et al., 2021). Between 2003 and 2024, multiple flood episodes inundated extensive irrigated areas, damaged rural infrastructure, displaced households, and generated substantial economic and social losses.

Understanding the actual recurrence of flood events and their temporal evolution has therefore become a crucial issue for assessing hazard dynamics and for interpreting how farming communities perceive the return intervals of risk within their lived environment. Despite the importance of this issue, existing research on flooding in Senegal has largely concentrated on urban centers such as Dakar, Saint-Louis, and Kaolack, often overlooking rural territories exposed to equally severe impacts (Diongue, 2014; Ndour, 2021; Wade, 2007). In addition, most studies primarily adopt a sectoral approach emphasizing physical determinants including rainfall variability, geomorphology, and hydrological processes, while overlooking social, territorial, and perceptual dimensions of risk. Consequently, there is a notable gap in the literature concerning how rural communities, particularly those situated in irrigated agro-ecosystems of eastern Senegal, perceive flood risk and integrate it into agricultural decision-making and adaptive practices.

Yet perception of hazards plays a fundamental role in shaping behavioral responses, influencing preparedness levels, adaptive capacity, and community resilience in the face of climate-related extremes (Gotham et al., 2018; O'Neill et al., 2016; Zhou et al., 2012). A deeper understanding of local risk perceptions represents an essential prerequisite for improving prevention strategies, strengthening adaptation planning, and fostering resilient territorial development.

Responding to this need, the present study adopts a qualitative research design based on field surveys with banana producers, supplemented by observational and documentary analysis, in order to reconstruct the history of flooding in the region, analyze its perceived recurrence, and examine local perceptions of climate change, associated risks, and the range of adaptation strategies implemented within the irrigated agricultural systems of Tambacounda.

2. Materials and Methods

2.1. Presentation of the Study Area

The study area is situated in southeastern Senegal within the administrative boundaries of the Tambacounda region, covering approximately 9546.9 km^2. It lies along the Gambia River, between 13.517˚ North latitude and −12.995˚ West longitude, and includes the municipalities of Missirah, Nétéboulou, Dialacoto, and Tambacounda, with extensions toward the Vélingara department in the Kolda region (Badji, 2017). Its geographical location is illustrated in **Figure 1**.

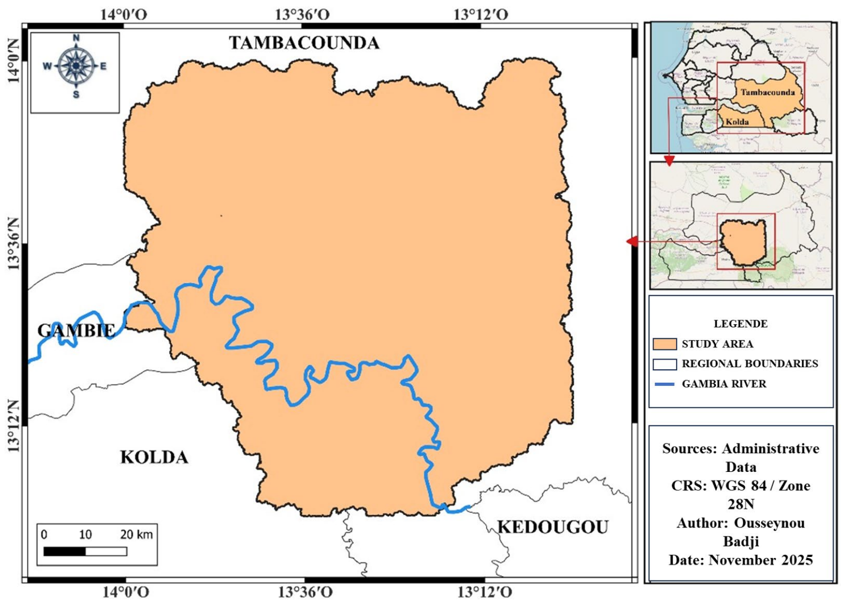

Figure 1. Location of the study area (Source: Administrative boundaries from the National Agency of Statistics and Demography (ANSD, Senegal). Map produced by the author using GIS data. Coordinate Reference System: WGS 84/UTM Zone 28N).

The region is characterized by a North Sudanian climate, with annual rainfall ranging from 568.8 to 1218 mm and a mean annual temperature of around 28.4˚C, providing highly favorable bioclimatic conditions for banana cultivation when supplemented by irrigation systems (Diallo, 2021; Faye et al., 2019; Sène, 2021).

The physical landscape consists of low-lying alluvial plains at altitudes between 10 and 20 m along the river margins, as well as slightly elevated plateaus ranging from 30 to 60 m, which significantly influence surface runoff patterns and flood dynamics (Diallo, 2021). The soils are predominantly hydromorphic, clay-rich, and high in organic matter, offering strong water retention capacity but presenting a high risk of saturation during intense rainfall episodes (Gomis, 2000). The Gambia River constitutes the primary water source for irrigation, which is generally carried out using motor pumps and PVC piping, although the system remains unevenly developed and technologically limited (Diallo, 2021).

More than 1000 hectares are currently devoted to banana cultivation, representing nearly 80% of national production and organized into Economic Interest Groups coordinated by the Association des Producteurs de la Vallée de la Gambie (APROVAG) (Badji, 2017; Diallo, 2021). The original vegetation cover, formerly dominated by natural savanna ecosystems, has been substantially transformed by the expansion of Musa spp. plantations, while regional biodiversity remains partially preserved but increasingly threatened, particularly given interactions with the adjacent Niokolo-Koba National Park. Banana cultivation was initially introduced in the 1970s by the NGO OFADEC with support from international partners including USAID and Secours Catholique, before being progressively taken over and reorganized by local producer structures (Badji, 2017).

2.2. Methodology

The methodological approach adopted in this study combines qualitative and spatial analytical tools in order to assess both the historical dynamics of flooding and the perceptions of risk among agricultural communities. It is structured around three complementary components: the reconstruction of past flood events and the calculation of their recurrence, the collection and processing of empirical data through field surveys and documentary analysis, and the use of statistical and geospatial tools to analyze hydrological variability and map the spatial distribution of vulnerable zones. This integrated approach provides a solid framework for understanding the interactions between environmental processes, agricultural practices, and local perceptions of risk.

2.2.1. History and Calculation of Flood Frequency

1) Collection of local historical data

The reconstruction of the flood history in the Gambia River basin was carried out using a qualitative approach combining the collection of local and institutional data. Semi-structured interviews were conducted with key stakeholders in the area, including the presidents of Economic Interest Groups, private agricultural producers, the Secretary General of CORPROBAT, and officials from the hydraulic brigade in Tambacounda. These interviews made it possible to identify and precisely date major flood events, particularly those affecting agricultural production zones such as banana plantations. At the same time, a review of local archives was undertaken with the technical services and the municipal administration of Tambacounda, including technical reports, meeting minutes, and documentation related to disaster management. For the purpose of calculating flood recurrence, a "significant flood event" was defined according to three criteria: 1) inundation of at least 10 hectares of irrigated agricultural land, 2) reported crop losses exceeding 30% of the affected plots, or 3) disruption of transportation or irrigation infrastructure for more than 48 hours. Only events meeting at least one of these criteria were included in the final frequency calculation to ensure methodological consistency.

2) Collection of local historical data

Based on the documented history covering the period from 2003 to 2024, each year in which a significant flood occurred was counted as a distinct event. The total number of flood years was then divided by the total duration of the study period, corresponding to 22 years, in order to calculate the mean annual flood frequency using Equation (1):

$$f = \frac{N}{P} \tag{1}$$

where N denotes the number of years affected by flooding and P represents the duration of the study period in years. This frequency provides a preliminary quantitative estimation of flood risk in the region derived from the synthesis of qualitative and documentary evidence.

3) Data processing and analysis tools

Statistical analyses related to hydrological series and parameter estimation using extreme value theory were carried out with the R software environment, which enabled trend testing, flood modeling, and the production of graphical outputs for interpretation. Spatial analyses, including watershed delineation, slope extraction, and hydrographic network mapping, were conducted within a GIS environment using QGIS for geospatial processing and cartographic representation of monitoring stations and flood-prone areas.

2.2.2. Perceptions of Agricultural Producers

The analysis of producers' perceptions was based on field surveys conducted within the study area. A participatory and integrated methodological approach was adopted, combining quantitative and qualitative techniques. This approach aims to examine how producers perceive the causes and risks associated with flooding and to assess the impacts of these events on local agricultural systems.

1) Sampling strategy

The survey was conducted in the Gouloumbou valley, an area highly exposed to flooding from the Gambia River and characterized by the vulnerability of irrigated banana plantations and the organizational presence of CORPROBAT. The target population consisted of 3836 producers, including 2881 men and 955 women, representing both members of Economic Interest Groups and private producers. The sampling frame was developed using the CORPROBAT database, which provided essential information such as producer identity, gender, cultivated area, geographic location, and contact details.

To ensure balanced representation across villages and organizational categories, a stratified sampling approach was applied. The population was distributed across 23 strata, including 12 Economic Interest Groups and 11 private farms. The initial sample aimed to cover 75 percent of the total entities, equivalent to 17 Economic Interest Groups and 18 private producers, in order to maximize representativeness and minimize sampling error. However, due to field constraints related to accessibility, producer availability, and logistical limitations, the number of surveyed private farms was adjusted to 11. Within each Economic Interest Group, five producers were randomly selected to ensure diversity of perspectives while maintaining operational feasibility. This selection process incorporated spatial variability by considering production plots located near the river, intermediate zones, and more distant areas, thereby capturing heterogeneous levels of exposure to flooding.

To preserve proportionality between groups and reduce sampling bias, a stratified sampling method with proportional allocation was used. The sample size for each stratum was calculated according to the following Equation (2):

$$n_i = \frac{N_i}{N} \times n \quad (2)$$

where n_i represents the sample size for stratum i, N_i is the population size of stratum i, and N corresponds to the total target population. This approach, widely used in statistical surveys, ensures that the sample composition reflects the structure of the broader population while improving the reliability of the estimates (Cochran, 1977).

The sampling strategy implemented in this study aimed to ensure balanced representation of producers across the different villages and organizational structures within the Gouloumbou valley. Table 1 shows the distribution of interviewed producers across villages and Economic Interest Groups, illustrating the spatial organization and diversity of production settings. Table 2 complements this by presenting the sample of private producers and their level of participation in the data collection.

Table 1. Sampling for economic interest groups.

Village Name	Number of EIGs per Village	Surveyed EIGs	Surveyed Producers
Adiaf	1	1	5
Bantantinty	2	1	5
Bira	1	1	5
Faraba	1	1	5
Gouloumbou	1	1	5
Koar	4	3	15
Koulary	1	1	5
Nguene	4	3	15
Saal	4	3	15
Sankagne	3	2	10
Wassadou	1	1	5
Grand Total	23	18	85

Table 2. Sampling for PRIVATE individuals.

Village Name	Number of Villages	Surveyed Private Producers	Surveyed Producers
Adiaf	3	2	10
Afia	1	1	5
Courbambé	1	1	5
Gouloumbou	6	4	20
Koar	2	1	5
Kourianthe	1	1	5
Laboya	1	1	5
Grand Total	15	11	55

2) Data collection and analysis tools

Several digital tools were employed for data collection, processing, and analysis. The mWater platform was used to design questionnaires and interview guides. Survey data were analyzed using the R software, while summary tables, graphs, and pivot tables were generated with Microsoft Excel. Spatial data were processed using QGIS, which was employed for mapping and GIS analyses.

3. Results and Discussion

3.1. Flood History in the Gambia River Basin

The chronological analysis of floods in Tambacounda highlights a progressive intensification of flood events since 2003, a year marked by significant agricultural and material losses. The floods of 2005, 2007, and 2009 illustrate the lack of effective drainage systems and the resulting extensive damage to agricultural production, compounded by health risks associated with stagnant water. Although some years of relative calm occurred, flood recurrence resumed in 2013, with further intensification observed in 2015, 2017, and 2020, reflecting increased climatic variability and the growing isolation of rural areas. The floods of 2022 and 2023 further reveal the negative consequences of unplanned urbanization, which exacerbated impacts on infrastructure and rural populations. Table 3 presents the chronological record of flood events reported in the Tambacounda region over the study period. The rows highlighted in red correspond to the years in which flooding events were effectively observed by producers and confirmed through local data sources. This visual distinction facilitates a quick understanding of the frequency, recurrence, and irregularity of floods over time, enabling a clearer interpretation of critical periods and their potential impacts on banana production systems.

This context underscores the urgent need for integrated risk management, combining the mapping of vulnerable zones, the adaptation of agricultural practices, and the strengthening of flood control infrastructure.

Table 3. Chronology of floods in the tambacounda region.

CHRONOLOGY OF FLOODS IN THE TAMBACOUNDA REGION	
Year	DESCRIPTION
2003	The 2003 flood was the most severe ever recorded in Tambacounda. It was caused by particularly heavy rainfall combined with the effects of the Gambia River. The damage was so extensive that the government at the time spent nearly 532 million CFA francs, homes were displaced, production sites were relocated, and a recommendation was made to avoid farming in the riverbeds.
2004	
2005	Heavy rains led to flooding that caused significant damage to crops and displaced several families. Roads were impassable, complicating access to relief efforts.
2006	
2007	A series of floods hit the region, exacerbated by an inadequate drainage system. Houses collapsed and dozens of families had to be temporarily relocated. Several plots of land were abandoned.
2008	
2009	118 hectares, including 109.75 hectares of banana trees, were flooded and destroyed. This year saw major flooding that affected several neighborhoods in Tambacounda. Schools and health centers were temporarily closed due to standing water, leading to a minor health crisis.
2010	
2011	
2012	
2013	In 2013 2014, water began to enter the banana plantations on September 13, 2013, and completely receded on September 26. This was mainly due to excess water moving along the river towards the mouth, which caused flooding along the way.
2014	
2015	Torrential rains caused flooding that not only destroyed homes but also damaged public infrastructure. The government was forced to intervene to provide emergency relief.
2016	
2017	Tambacounda suffered particularly destructive flooding this year, with water levels reaching record highs. Several plots of land were submerged.
2018	
2019	
2020	The 2020 floods were triggered by incessant rains, particularly affecting the Mamacounda valley. The damage included destroyed homes and flooded fields, causing the loss of crops vital to the local population.
2021	
2022	This time, the floods affected several new areas, exacerbated by unplanned urbanization. Hundreds of families were displaced and essential infrastructure, such as roads and bridges, was severely damaged.
2023	The most recent floods continued to cause disruption, with increased efforts to improve infrastructure and drainage systems to minimize future damage. However, the floods continued to displace populations and damage property.
2024	In 2024, the Tambacounda region was hit hard by violent floods that caused significant damage. The departments of Tambacounda, Goudiry, and Bakel were particularly affected: livestock losses in Kothiary and Koar, flooding of vegetable crops in Sénédébou, destruction of infrastructure such as the Diyabougou bridge, isolating entire villages. More than 1,000 hectares of crops were submerged in the region. The government was called upon to take urgent action, and humanitarian aid was deployed.

The following table presents the chronology of floods in the Tambacounda region, highlighting for each event the main characteristics and associated impacts. The highlighted columns provide detailed descriptions of each recorded flood.

Regarding flood frequency, Tambacounda experienced 11 years with significant flooding between 2003 and 2024, corresponding to a mean annual frequency of approximately one year in every two. The intervals between successive floods ranged from 1 to 4 years, with an average interval of 2.1 years and a standard deviation of 0.83, indicating a relatively regular recurrence of flooding over this period.

Table 3 provides a detailed chronology of flood events in the Tambacounda region, highlighting the timing, main characteristics, and associated impacts of each episode. This overview allows for a comprehensive understanding of the temporal patterns of flooding, the severity of their effects on agricultural production and rural infrastructure, and the evolving vulnerability of local communities over the period under study.

3.2. Producers' Perceptions

The study focused on a group of producers that was predominantly male (75% men versus 25% women), a distribution reflecting national trends in irrigated agriculture (ANSD, 2024) and providing an important context for analyzing their risk perceptions and adaptive practices in response to flooding. Although exposure levels are similar for both men and women, some women reported constraints related to access to land, financial resources, and mobility, which may limit their ability to implement certain adaptation strategies. These dimensions deserve further investigation in future research.

3.2.1. Perceived Causes of Flood Risk

The analysis of perceived causes of flooding in Tambacounda, as illustrated in Figure 2, highlights a predominance of natural factors in local representations, with 30% of respondents citing river overflow and flooding, and 25% referring to heavy rainfall, together accounting for 55% of the responses. This perception aligns with observations in the Kou basin in Burkina Faso, where the majority of rural respondents identified intense precipitation as the primary cause of floods (Guelbeogo & Ouedraogo, 2022), confirming that climate-related hazards, exacerbated by climate change, are widely regarded as the main triggers of flooding in agricultural areas. This interpretation is often based on direct experience of past events, a factor recognized as central to heightened risk perception (Terpstra et al., 2006).

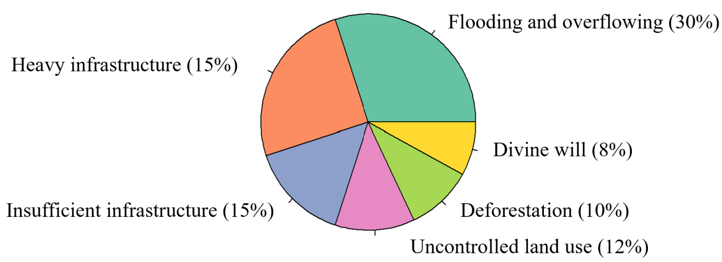

Figure 2. Perceived causes of flooding in Tambacounda.

At the same time, anthropogenic causes including insufficient infrastructure (15%), unplanned land use (12%), and deforestation (10%) account for 37% of responses, reflecting a growing acknowledgment of the role of human activities in flood vulnerability. These results corroborate findings from Léogâne, Haiti, where demographic pressure, weak planning policies, and environmental degradation were identified as aggravating factors (Hyppolite, 2022).

The mention of "divine will" as a perceived cause (8%) reflects a form of cultural resignation, often interpreted within the framework of protection motivation theory: when a threat is perceived as high but the capacity to respond is considered low, individuals tend to adopt passive or fatalistic attitudes (Grothmann & Reusswig, 2006). This reference to "divine will" must be understood within the broader cultural and religious context of eastern Senegal, where Islamic beliefs and traditional worldviews coexist and strongly shape perceptions of environmental phenomena. In many rural communities, extreme events are interpreted as manifestations of divine testing or fate, which can reduce the perceived ability to anticipate or prevent hazards. Such fatalistic interpretations have been documented in several Sahelian contexts and help explain why some producers adopt passive attitudes toward flood preparedness (Lechowska, 2018; Schmuck, 2000).

It is important to note that risk perception is uneven among producers. According to survey data, around 38% of respondents report strong awareness of flood hazards, whereas 35% declare limited or no knowledge. This disparity is consistent with structural education gaps in the region. The Situation Économique et Sociale de la Région de Tambacounda (2020-2021) reports that 77.9% of unemployed individuals have no formal education, and literacy remains low among women aged 15 - 49, with 75.1% unable to read a complete sentence (ANSD, 2024). Such indicators suggest that both limited education and access to information may affect how populations including agricultural producers perceive, understand, and interpret flood risks.

These heterogeneous perceptions reveal a risk interpretation that is both grounded in local experience and shaped by cultural beliefs and structural factors, highlighting the importance of an integrated approach that combines awareness-raising, territorial planning, and community empowerment to enhance resilience to flooding.

3.2.2. Perception of Flood Risk

The analysis of flood risk perception in the banana plantations of Tambacounda, as shown in **Figure 3**, reveals a shared but uneven awareness among producers. Approximately 38% of respondents consider themselves fully aware of the danger, 27% report moderate awareness, while 35% either underestimate or are unaware of the risk. This distribution reflects a common situation in areas exposed to climatic hazards. Individuals who have previously experienced flooding often develop a heightened perception of risk, as demonstrated in studies conducted in Burkina Faso and Haiti, where farmers affected by losses are more sensitive to the threat (Hyppolite, 2022).

However, the fact that one-third of respondents remain poorly or not at all aware of the risk indicates that prevention messages do not always reach the target population. This lack of awareness may be attributed to the isolation of certain areas, limited access to information, or low levels of education.

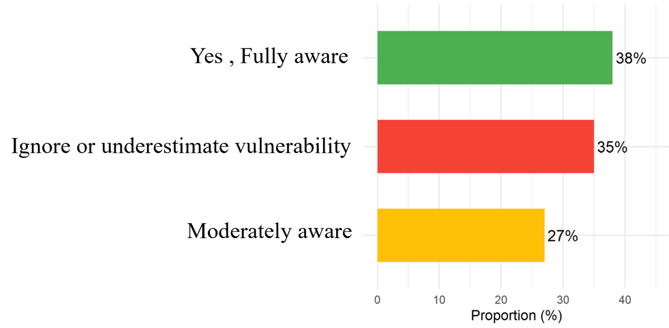

Figure 3. Flood risk perception in the banana plantations of Tambacounda.

Finally, those who are "moderately aware" often hesitate between acknowledging the risk and taking action. This may result from a lack of infrastructure, technical support, or safe alternatives. In this context, it is essential to strengthen awareness-raising efforts in the banana plantations of Tambacounda. Messages should be simple, concrete, and adapted to local conditions, while also providing visible local solutions. Only under these conditions will communities fully recognize the risk and be able to adapt more effectively to flooding.

3.2.3. Distribution of Months Favorable to Flooding According to Producers

As illustrated in **Figure 4**, banana producers in Tambacounda primarily identify September and October as the months most prone to flooding, corresponding to regional rainfall peaks (Sène, 2021). During this period, soil saturation promotes overflows, as observed during the 2009 flood that inundated more than 113 hectares in Gouloumbou (DRDR, 2013). Rainfall variability, with intense episodes concentrated over short periods, increases crop vulnerability, particularly when water infrastructure is insufficient (Bodian, 2014; Verlynde, 2018).

However, some producers are unable to precisely identify the high-risk period, reflecting the uncertainty associated with the spatial and temporal variability of rainfall in this semi-arid climate (Sène, 2021). This unpredictability reinforces a sense of vulnerability, as shown by Grothmann & Reusswig (2006) and O'Neill et al. (2016). Exceptional floods in 2009 and 2013 also heightened farmers' caution and anticipation of flood risks.

To better manage this uncertainty, it is essential to develop anticipatory tools such as risk zone mapping, flood modeling, and farmer training. Effective risk management relies on the dissemination of accurate and contextually relevant information, supported by awareness-raising initiatives (Lindell & Perry, 2003). Experiences in Léogâne demonstrate that participatory mapping and local awareness campaigns enhance prevention efforts (Hyppolite, 2022). Therefore, integrating local perceptions with scientific data is a key lever for guiding risk reduction policies in the banana plantations of Tambacounda.

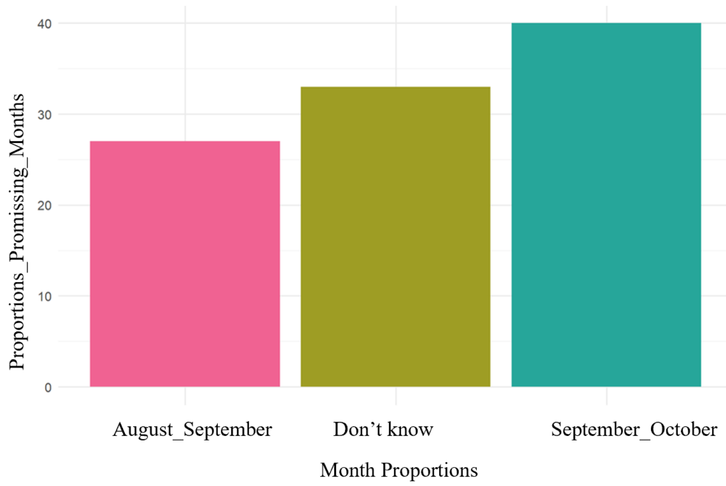

Figure 4. Months most prone to flooding according to producers.

In the face of this uncertainty, anticipatory measures such as risk zone mapping, flood modeling, and farmer training are indispensable for improving flood risk management. As emphasized by Lindell and Perry (2003), effective risk management depends on the provision of accurate, comprehensible, and locally contextualized information, accompanied by training programs adapted to the profiles of exposed populations. In this regard, the work of Hyppolite (2022) in Léogâne shows that participatory mapping and local awareness initiatives foster better appropriation of early warning tools and preventive behaviors. Thus, a better understanding of perceived critical periods, combined with scientific data, constitutes an essential lever for guiding local risk reduction policies in the banana plantations of Tambacounda.

3.2.4. Impacts of Floods and Low Water Levels on Banana Production

Banana plantations located in the Gambia River valley, particularly in Gouloumbou, are strongly affected by fluctuations in river levels, amplified by the return of heavy rains since the 2000s. Floods regularly inundate plantations near the riverbanks, rendering the land temporarily unproductive. In 2003, an exceptional flood with a flow rate of 1844 m^3/s affected 737.5 ha over 57 km, particularly impacting plots situated below 13 m in elevation (Diallo, 2021). Such floods, like the one in 2015 in Gouloumbou, caused major production losses.

The isolation of plantation areas and river level fluctuations also complicate irrigation. During the dry season, the distance to water sources makes irrigation difficult and costly. Producers are forced to relocate pumps or invest in more efficient systems, which limits the expansion of cultivated areas. Floods also affect producers' mobility and the transport of harvests. Inundated roads, impassable access routes, and longer journeys to the fields result in additional logistical costs and deterioration in banana quality, impacting their marketability. These seasonal constraints require constant adaptation. The implementation of sustainable solutions, such as developing plots outside flood-prone areas, using high-pressure pumps, or constructing windbreaks, is essential to enhance the resilience of banana plantations to the hydrological hazards of the river.

3.2.5. Flood Management in Banana-Producing Areas

Floods, whether caused by river overflow or heavy rainfall, pose complex challenges for banana producers. They affect the sustainability of plantation areas, imposing constraints on plot layout and agricultural practices. To cope with these challenges, various adaptation strategies are implemented, ranging from collective village-level interventions to initiatives specific to Economic Interest Groups (GIEs).

- **Individual strategies for flood management**

Analysis of individual strategies in response to flooding in Tambacounda, as illustrated in **Figure 5**, reveals a wide variety of behaviors. The most common strategy is abandoning flooded plots (30%), followed by replanting after stabilization and continuing cultivation despite the risk (25% each), and relocating to non-flooded areas (20%).

Land abandonment is often a default choice, made when farmers lack the technical means or support necessary to continue production. This type of response has also been observed in Léogâne, Haiti, where many producers refrain from cultivating their land in the face of flood risks (Hyppolite, 2022).

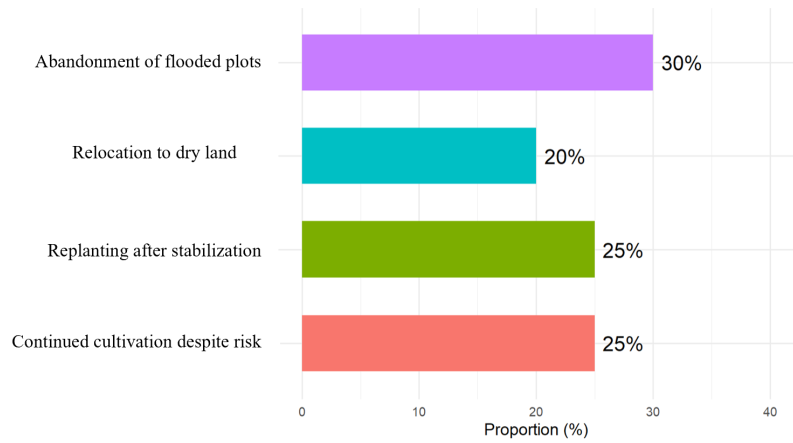

Figure 5. Individual flood management strategies.

In contrast, those who replant or continue cultivation despite the risk demonstrate an active adaptation strategy, often based on experience and economic necessity. These producers have learned to live with the risk, as described by Terpstra et al. (2006). Sometimes they have no other choice, particularly due to limited land availability or their dependence on production for survival. This also aligns with Burton's (1978) coping theory, which explains that risk responses are often dictated by what is feasible rather than what is ideal. Relocation, although less common (20%), indicates that some producers attempt to adapt by moving to other areas. However, this option is rarely easy to implement due to land scarcity, relocation costs, or food insecurity. Similar situations have been observed in the Kou basin in Burkina Faso, where populations sometimes temporarily move their activities when state interventions are ineffective (Guelbeogo & Ouedraogo, 2022).

Overall, these behaviors reflect an individual and uncoordinated response to a collective risk, with each person acting according to their means, perception of danger, and available resources. In a context where floods are becoming more frequent and severe due to climate change, these individual strategies are no longer sufficient. There is an urgent need to establish structured institutional support to shift from reactive management to organized prevention, adapted to the realities of local producers.

- **Collective Flood Management Strategies**

As shown in **Figure 6**, the analysis of collective strategies for flood management in the banana plantations of Tambacounda reveals a strong preference for simple, locally implemented technical solutions. The majority of actors use gabions and embankments (90%), drainage channels (60%), or continuous water pumping (50%). These responses demonstrate a willingness to directly address the physical effects of flooding, attempting to limit damage on-site. This local mobilization is largely explained by the lived experience of risk. The more communities have suffered from floods, the more they organize to respond. This is consistent with the psychometric theory of risk, which posits that experience, proximity to danger, and repeated flooding events strengthen collective response (Slovic, 1987; Terpstra et al., 2006).

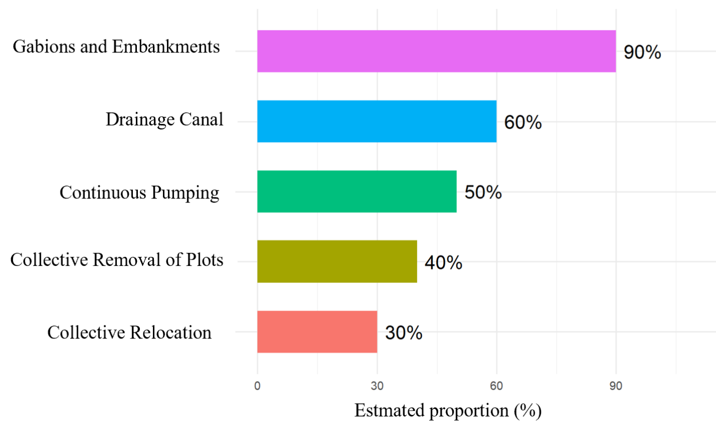

Figure 6. Collective flood management strategies.

In contrast, more substantial measures are much less common. Only 40% mention the collective removal of plots, and 30% refer to relocation to other areas. This indicates that economic, land, and social constraints limit long-term adaptation options.

Thus, a two-speed dynamic is observed in Tambacounda: on one hand, effective but limited local actions; on the other, structural adaptations that are difficult to implement. This highlights the need to strengthen local governance, provide technical and institutional support, and promote coordination among stakeholders.

The results obtained in the banana plantations of Tambacounda reveal a mixed perception of flood risk, marked by a predominance of natural causes, but also an increasing recognition of anthropogenic factors. While a significant portion of the population is fully aware of their vulnerability, a notable proportion continues to underestimate the risk, thus hindering the widespread adoption of preventive behaviors. Individual responses range from abandonment and pragmatic adaptation to resigned exposure, while collective strategies prioritize immediate technical measures such as embankments, drainage channels, or pumping rather than long-term solutions like relocation.

These dynamics illustrate the limitations of a fragmented response, largely dependent on perceived capacity to act, land constraints, and lack of institutional support. Consistent with previous studies (notably Terpstra, Grothmann, Hyppolite, and Guelbeogo), these findings emphasize the urgent need to strengthen awareness, collective organization, and the integration of local knowledge into adaptation policies to address flood risks in a context of climate change.

3.3. Observations and Field Limitations

In practice, several constraints made it difficult to apply the initial methodology. First, the database was outdated: many recorded producers had ceased their activities, either due to death, abandonment of banana cultivation, or a shift to other economic sectors. Second, the number of active producers had significantly decreased, reducing the accessible population and challenging the representativeness of the samples. Additionally, factors such as migration caused by flooding or economic difficulties within zonal unions had not been anticipated, further increasing discrepancies with initial projections. Finally, logistical issues, including inaccessibility of certain areas and absences during surveys, limited geographic coverage and the number of responses obtained.

To overcome these difficulties, several adjustments were made. The number of surveyed producers was reduced, particularly among private producers, where the number of villages was adjusted from 12 to 7, and the number of private respondents decreased from 18 to 11. Moreover, for hard-to-reach areas, online questionnaires were used to complement the field surveys in these villages.

4. Conclusion

This study highlights the diversity of flood risk perceptions among banana producers in Tambacounda, as well as the variety of factors perceived as responsible for these events. It also reveals a high and relatively regular frequency of flooding between 2003 and 2024, with 11 years of flooding out of 21, corresponding to an average of one flood every 2.1 years, confirming the constant pressure on agricultural activities.

In response to this recurring threat, producers develop adaptation strategies, often limited by the lack of structured institutional support. These findings underscore the urgent need to better integrate local knowledge and practices into prevention and resilience policies, taking into account not only physical data but also lived experiences and social representations of risk. Such an approach would strengthen the anticipatory capacity of local communities in the context of pronounced climate change. In practical terms, this integration can be operationalized through the creation of producer advisory committees involved in local and regional water management, participatory mapping exercises to identify flood-prone areas, and the incorporation of farmers' experiential knowledge into early warning systems and land-use planning policies.

Conflicts of Interest

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

References

Agence Nationale de la Statistique et de la Démographie (ANSD) (2024). *Situation économique et sociale de la région de Tambacounda, Édition 2020-2021.* ANSD. https://www.ansd.sn/sites/default/files/2024-01/SES-Tambacounda_2020-2021.pdf

Badji, S. (2017). *Le sud du Sénégal à l'heure de la culture irriguée de la banane: Innovations agricoles et dynamiques territoriales.* PhD Thesis, Université Panthéon-Sorbonne Paris I & Université Gaston Berger. https://theses.hal.science/tel-01737065/

Bodian, A. (2014). Caractérisation de la variabilité temporelle récente des précipitations annuelles au Sénégal (Afrique de l'Ouest). *Physio-Géo, 8,* 297-312.

Burton, I. (1978). *The Environment as Hazard.* Oxford University Press. http://archive.org/details/environmentashaz0000burt

Cochran, W. G. (1977). *Sampling Techniques.* http://archive.org/details/cochran-1977-sampling-techniques

Diallo, A. (2021). *Aménagements hydro-agricoles et gestion de l'eau dans les bananeraies de la zone de Gouloumbou (Tambacounda).* https://rivieresdusud.uasz.sn/handle/123456789/1434

Diongue, M. (2014). Périphérie urbaine et risques d'inondation à Dakar (Sénégal): Le cas de Yeumbeul Nord. *Eso Travaux et documents, Résumés des Travaux, 37,* 45-54.

DRDR (2013). *Rapport annuel des activités agricoles de la région de Tambacounda*. Regional Directorate of Rural Development (DRDR).

Faye, C., Dièye, S., Fall, A., & Solly, B. (2021). *Cartographie des risques d'inondation à l'échelle du bassin fluvial à l'aide de l'indice de potentiel d'inondation: Cas du sous-bassin du Niéri-Ko (Bassin de la Gambie).* http://rivieresdusud.uasz.sn/xmlui/handle/123456789/1473

Faye, M., Fall, A., Tine, D., Faye, C. S., Faye, B., & Ndiaye, A. (2019). Evolution pluviothermique de 1950 a 2013 au senegal oriental: Cas de la region de Tambacounda. *International Journal of Advanced Research, 7,* 270-287. https://doi.org/10.21474/ijar01/10152

GIEC (2014). *Changements climatiques 2014: Rapport de synthèse. Contribution des Groupes de travail I, II et III au cinquième Rapport d'évaluation du Groupe d'experts intergouvernemental sur l'évolution du climat.* GIEC.

Gomis, D. E. R. (2000). *Synthèse hydrologique du fleuve Gambie en amont de Gouloumbou.* Organisation pour la Mise en Valeur du fleuve Gambie (OMVG).

https://horizon.documentation.ird.fr/exl-doc/pleins_textes/divers17-01/010024679.pdf

Gotham, K. F., Campanella, R., Lauve-Moon, K., & Powers, B. (2018). Hazard Experience, Geophysical Vulnerability, and Flood Risk Perceptions in a Post-Disaster City: The Case of New Orleans. *Risk Analysis, 38,* 345-356. https://doi.org/10.1111/risa.12830

Grothmann, T., & Reusswig, F. (2006). People at Risk of Flooding: Why Some Residents Take Precautionary Action While Others Do Not. *Natural Hazards, 38,* 101-120. https://doi.org/10.1007/s11069-005-8604-6

Guelbeogo, S., & Ouedraogo, L. (2022). Cartographie des risques d'inondation dans le bassin versant du Kou au Burkina Faso. *African Science, 21,* 60-75.

Hyppolite, K. (2022). *Perception locale des agriculteurs de la commune de Léogâne (Haïti) face aux risques d'inondations et stratégies d'adaptation.* https://matheo.uliege.be/handle/2268.2/16084

Lechowska, E. (2018). What Determines Flood Risk Perception? A Review of Factors of Flood Risk Perception and Relations between Its Basic Elements. *Natural Hazards, 94,* 1341-1366. https://doi.org/10.1007/s11069-018-3480-z

Lindell, M., & Perry, R. (2003). *Communicating Environmental Risk in Multiethnic Communities.* SAGE Publications, Inc. https://doi.org/10.4135/9781452229188

Ndour, S. (2021). *Problématique de la gestion des inondations dans la ville de Kaolack: Cas du quartier de Sam en 2020.* https://rivieresdusud.uasz.sn/handle/123456789/1281

O'Neill, E., Brereton, F., Shahumyan, H., & Clinch, J. P. (2016). The Impact of Perceived Flood Exposure on Flood-Risk Perception: The Role of Distance. *Risk Analysis, 36,* 2158-2186. https://doi.org/10.1111/risa.12597

Schmuck, H. (2000). "An Act of Allah": Religious Explanations for Floods in Bangladesh as Survival Strategy. *International Journal of Mass Emergencies & Disasters, 18,* 85-95. https://doi.org/10.1177/028072700001800105

Sène, S. M. K. (2021). *Dynamique des ressources en eau et impacts sur les activités socio-économiques: Cas du bassin versant de Niaoulé (Tambacounda).* https://rivieresdusud.uasz.sn/handle/123456789/1277

Slovic, P. (1987). Perception of Risk. *Science, 236,* 280-285. https://doi.org/10.1126/science.3563507

Terpstra, T., Gutteling, J. M., Geldof, G. D., & Kappe, L. J. (2006). The Perception of Flood Risk and Water Nuisance. *Water Science and Technology, 54,* 431-439. "https://doi.org/10.2166/wst.2006.573

Verlynde, N. (2018). *De la perception du risque d'inondation aux propositions d'adaptation en territoire de côtes basses densément peuplées: Le cas de la communauté urbaine de Dunkerque.* Thèse de Doctorat, Université du Littoral Côte d'Opale. https://theses.hal.science/tel-02085107/

Wade, S. (2007). Télédétection, SIG et géorisques: Applications à l'étude des inondations urbaines de Saint-Louis et du ravinement lié à l'érosion hydrique à Nioro-du-Rip (Sénégal). PhD Thesis, Université Cheikh Anta Diop de Dakar.

Zhou, Q., Mikkelsen, P. S., Halsnæs, K., & Arnbjerg-Nielsen, K. (2012). Framework for Economic Pluvial Flood Risk Assessment Considering Climate Change Effects and Adaptation Benefits. *Journal of Hydrology, 414,* 539-549. https://doi.org/10.1016/j.jhydrol.2011.11.031