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Landscapes of uncertainty: Mangrove rice farmers' perceptions of rainfall variability and climate change adaptation in three coastal regions of Guinea-Bissau, West Africa

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A R T I C L E I N F O

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A B S T R A C T

Rainfall variability poses growing challenges to mangrove rice farming in Guinea-Bissau, threatening both local livelihoods and food security. This study investigates how farmers in the coastal regions of Cacheu, Oio, and Tombali perceive changing rainfall patterns and adapt their cropping calendars accordingly. Using a companion modelling approach, we co-designed a serious game with 45 mangrove rice farmers from 13 villages, complemented by group interviews and participant observation. The results reveal that farmers possess detailed, experience-based knowledge of rainfall variability—particularly regarding the delayed onset, mid-season dry spells, and early cessation of rains—which directly influences key agricultural decisions such as nursery establishment, transplanting, and harvesting. Through the serious game, participants collectively identified and validated four main adaptation strategies: (1) flexible adjustments to cropping systems (e.g., shifting to direct seeding in erratic years), (2) strategic use of short- and medium-cycle rice varieties, (3) enhanced water management through reinforced dykes and drainage innovations, and (4) diversification into complementary livelihood activities such as cashew cultivation and fishing. The serious game proved to be an effective tool for facilitating dialogue, sharing local knowledge, and collectively refining context-specific adaptation pathways. These findings underscore the value of integrating farmers' ecological knowledge with participatory methodologies to support resilient agricultural planning under climate uncertainty.

1. Introduction

Mangroves are salt-tolerant evergreen forests in intertidal environments at the land-sea interface (FAO, 2023). These ecosystems are home to great diversity that protects and support countless coastal communities around the world (Leal and Spalding, 2024). This is the case for the local communities of the Southern Rivers (a stretch of West African coastline stretching from Senegal to Sierra Leone, via Gambia, Guinea-Bissau and Guinea Conakry), who largely depend on these ecosystems for their livelihoods (Cormier-Salem, 2015). One of the most distinctive features of the mangroves of the southern rivers is the presence of rice farmers (Cormier-Salem, 1994; 1999; Mendy, 1994). Of the approximately 1.2 million hectares of mangroves in West Africa, 200,000 ha are used for swamp mangrove rice production (Agyen-Sampong, 1994). Guinea-Bissau, an integral part of the Southern Rivers, has the largest area of mangrove rice fields (Ecoutin et al., 1999; Temudo, 2011). In this country, mangrove rice cultivation is mainly practised by the Felup ethnic communities in the north (Cacheu region), Balant in the centre (Oio region) and south (Tombali region), Nallu in the south (Penot, 1994). Rice plays a key role in daily family meals, religious and traditional ceremonies (e.g. rites of passage, weddings, funeral rites, etc.), the organisation of village's land and the calendar of

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activities, among other social aspects (Pélissier, 1966; Sané, 2017; Badiane, 2022; Badiane et al., 2025).

In addition to these functions, rice is still used in some cases as a barter currency (Agyen-Sampong, 1994) and is a real source of income for farmers in the Oio and Tombali regions, who sell surplus production (Conde et al., 2024). The importance attributed to rice has led some researchers to speak of a "African rice civilisation" (Pélissier, 1966). Mangrove rice cultivation is therefore the main agricultural activity in the coastal communities of the Cacheu, Oio and Tombali regions. Rice culture depends essentially on climatic conditions, particularly rainfall, and requires a high level of labour (e.g. young people, men and women) throughout the production chain, especially for building and maintaining dykes, ploughing, transplanting and harvesting (Sousa et al., 2025). The originality of this type of rice-growing lies in the local and traditional ecological knowledge and know-how of rice-growers, who have been able to convert mangrove areas into rice fields, using diking and damming techniques to improve water control (Pélissier, 1966; Penot, 1994; Ecoutin et al., 1999). The process of converting mangrove areas into rice fields requires extensive knowledge and expertise in traditional land management. In the three regions studied, local communities gradually settled in mangrove zones located near waterways in search of arable land (Ecoutin et al., 1999). Once established, they identified areas suitable for rice plots and began constructing perimeter dikes to isolate the selected zone from tidal influence (Garbanzo et al., 2024). The mangroves within these enclosed areas were then cleared, initiating a soil desalination process that can take more than three years, depending on rainfall conditions, before the optimal development of future rice plots can begin. These rice farmers also have specialist knowledge of water management, soil fertility and toxicity control (Montoroi, 1994); variety selection and a good understanding of rainfall conditions, which have enabled them to adapt to past climatic conditions (Cormier-Salem, 2015).

However, over the last few decades, mangrove rice farming has been going through a multifaceted crisis, both climatic and socio-economic, with direct consequences on the decline in rice-growing activity and rice production (Cormier-Salem, 2015). During the 1970s, 1980s and 1990s, this region of Africa went through a long drought, marked by a general decline in rainfall (Lamb, 1982; Descroix et al., 2015). This drop in rainfall had a greater impact on the northern regions of Guinea-Bissau, where rainfall could be as low as 1500 mm/year in some years (Penot, 1994). The drought of the 1970s accelerated the mass exodus of young people from rural areas to the big cities, gradually exacerbating the problem of the availability of agricultural labour in certain regions such as Casamance in Senegal (Badiane, 2022) and northern Guinea-Bissau. Numerous studies show a return to wetter rainfall conditions since the beginning of the millennium (Descroix et al., 2013, 2015, 2020; Bodian, 2014; Sultan et al., 2015; Mendes and Fragoso, 2024). Despite this return, which is expressed in higher annual averages, the disruption of the rainfall regime persists in Guinea-Bissau (Mendes and Fragoso, 2024). At present, the rich farmers' ecological knowledge and skills are increasingly threatened by climate change, in particular the spatiotemporal variability of precipitation and the phenomenon of tides (Temudo et al., 2022; Sousa et al., 2025;). In addition, the lack of regular access to climate forecasts on different scales (national, regional and local) makes it difficult to plan agricultural calendars and anticipate climate risks (Badiane, 2022). Today, national rice production is a long way from meeting the food needs of a growing population, which today relies heavily on rice imported from Asia to make up the shortfall (République de Guinée-Bissau, 2015). As a result, adapting to rainfall variability and climate change, in general, is more important than ever for mangrove rice farmers if they want to keep their rice ecological knowledge heritage alive and face the challenge of food insecurity.

This study investigates how variations in rainfall influence cropping calendars and how mangrove rice farmers in Guinea-Bissau adapt to these changes. It attempts to answer the following questions: How do mangrove rice farmers perceive rainfall variability? What strategies have they developed to adapt to rainfall variability? Although several perception studies have been conducted in West Africa (Adou et al., 2025; Badiane et al., 2025; Konkobo et al., 2021; Mushagalusa Balasha et al., 2021; Ouédraogo et al., 2010; Vodounou and Onibon Doubogan, 2016), a systematic understanding is still lacking regarding the adaptation strategies that mangrove farmers are developing—drawing on their traditional ecological knowledge—in response to rainfall variability and broader climate change. For this reason, our study examines the three mangrove rice-growing regions of Guinea-Bissau to provide a more systematic overview and to capture the potential variations that occur along the climatic gradient. Rather than relying solely on conventional tools such as participant observations, questionnaires and interviews, it introduces a more integrative and interactive methodological framework to deepen the analysis of farmers' adaptive strategies. Specifically, it employs a companion modelling approach (Collectif ComMod, 2013), which allows researchers and farmers to jointly explore decision-making processes, simulate changing environmental conditions, and reveal forms of traditional ecological knowledge that typically remain implicit or unarticulated in standard perception studies. The study extends beyond documenting perceptions of rainfall variability: it provides a more systematic understanding of how mangrove rice farmers interpret rainfall shifts and adjust their cropping calendars and management practices accordingly. This approach makes it possible to identify not only what strategies exist, but also how and why they emerge within the socio-ecological dynamics of Guinea-Bissau's mangrove agriculture.

2. Materials and methods

2.1. Study area

With a total surface area of 36,125 km^2, Guinea-Bissau is a small country in the West African coastal strip, located between Senegal and Guinea Conakry (Fig. 1). It is characterised by the presence of numerous estuaries and rivers bordered by mangrove forests, forming a complex aquatic network dotted with islands and islets, where the influence extends up to 100 km from the shore (Mendy, 1994). The total mangrove area is estimated at 461500 ha (République de Guinée-Bissau, 2015), representing approximately 12.77 % of the national land area. The mangrove forests, mainly located in the regions of Tombali, Quinara, Biombo and Cacheu, enable the development of a range of socio-economic activities, including mangrove rice farming (République de Guinée-Bissau, 2015). Of the approximately 106,000 ha of exploitable mangrove rice fields, 39,027 ha are developed (République de Guinée-Bissau, 2015) and produce most of the country's agricultural output (Sá, 1994).

The coastal zone of Guinea-Bissau is characterised by a tropical subguinean climate, with an average annual rainfall of between 1500 mm in the north and 2500 mm per year in the south (Republique Guinée-Bissau, 2018; Mendes and Fragoso, 2024). The rainy season lasts between 5 and 6 months, from the second half of May to early November. Most of the rain falls between July, August and September (Mendes and Fragoso, 2024). Guinea-Bissau is considered to be one of the largest consumers of rice per person in the West African sub-region, consuming 130 kg of rice per person per year (République de Guinée-Bissau, 2015).

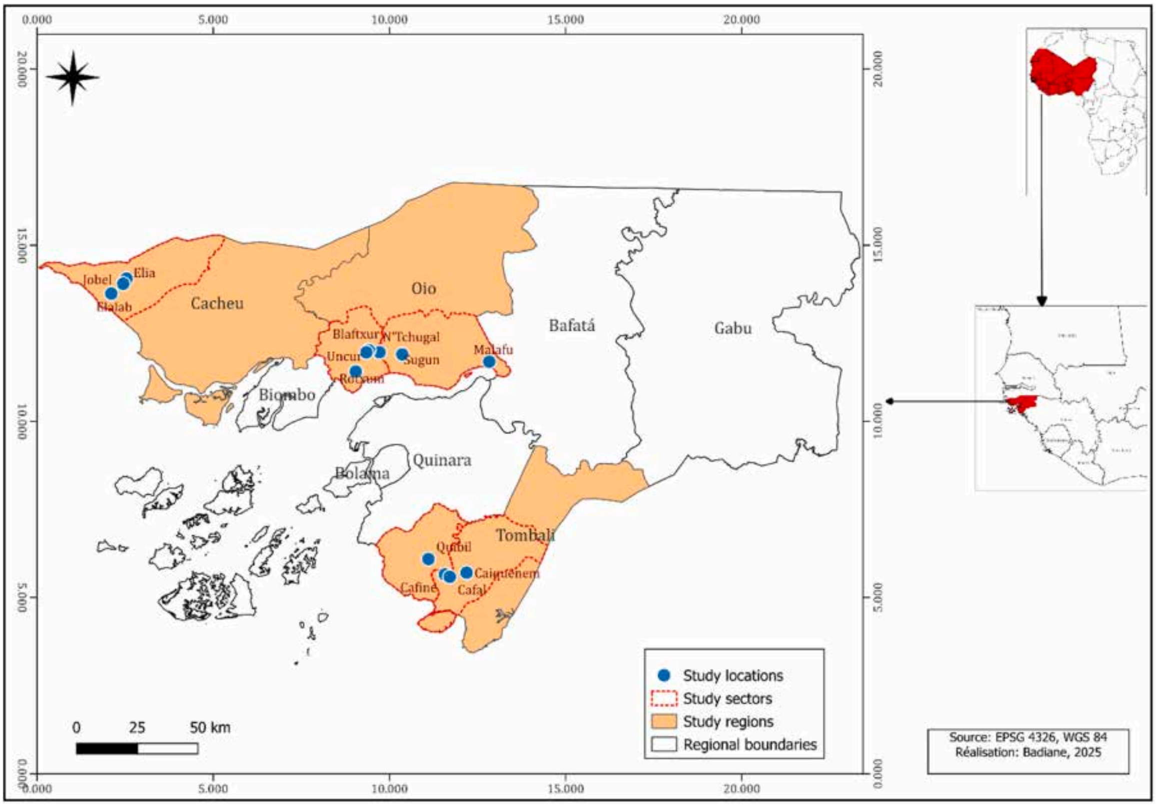


Fig. 1. Location map of intervention regions, sectors and villages.

Today, the major challenge is to increase national rice production to meet the demand of a growing population in the context of climate change. This study focuses on three regions of Guinea-Bissau chosen by the MALMON/DeSIRA project[1] (Cacheu, Oio and Tombali), where mangrove rice cultivation is widely practised by the local communities living there. A total of thirteen intervention villages have been selected by the Malmon project (Fig. 1) based on criteria incorporating the diversity of microclimatic and agro-ecological conditions as well as the heterogeneity of ethnic groups, production systems and management practices. This multi-site approach aims to maximise synergies between stakeholders and encourage the exchange of knowledge and innovation between farmers, based on participatory serious game workshops organised in the field.

2.2. Methodological approaches

Our methodological approach was based on the companion modelling tactic (Collectif ComMod, 2013). This is a participatory method that uses modelling (i.e. the term modelling here covers a broad spectrum, ranging from serious games to multi-agent computational systems) as a tool to support knowledge production on complex systems and collective decision-making processes (Barreteau et al., 2010; Etienne, 2010; Collectif ComMod, 2013). This approach enables participating stakeholders to share their points of view on an issue that concerns them collectively, so that they can engage together in the process of dealing with these uncertainties (Collectif ComMod, 2013). The companion modelling approach has been applied in research on several topics, including agriculture, biodiversity, water management, fisheries and forestry (Daré et al., 2009; Trébuil et al., 2021; Chapuis et al., 2021; Da Hora et al., 2023, 2024). In this study, the companion modelling approach was applied to mangrove rice farming in local communities in Guinea-Bissau. We engaged these farmers in the development of a game aimed to better understand the socio-ecological system of rice cultivation and explore with them the challenges related to rainfall variability and its uncertainties. This was supplemented by additional surveys and participant observation of the various rice-farming development operations. This approach, based on participatory workshops and group interviews with farmers in the different regions and areas of intervention, aimed to provide a better understanding of the perception of rainfall variability and its impact on mangrove rice farming and identified, collectively, the strategies to be put in place to adapt to climate change.

2.2.1. Serious game co-construction process

The process of co-constructing a serious game perceived as an application (with or without computer support) that combines serious aspects (teaching, learning, communication, information) and playful aspects (Alvarez, 2007; Schmoll, 2011) has become an important tool for scientific research and facilitates the emergence of collective solutions to various problems (d'Aquino, 2016; Mendes De Melo et al., 2022; Goria et al., 2024). In line with the ComMod collective (Hassenforder et al., 2020), serious games are mainly used in this work in the form of role-playing games based on a game board constructed with mangrove rice farmers. The MALMON project identified climate change, and in particular, rainfall conditions as one of the primary concerns of rice farmers. We conducted a major literature review between March and June 2023 on the rice farming system in Guinea-Bissau and rainfall conditions. During this period, we formulated the preliminary research questions and game objectives and developed the first basic elements of the game (game board components), which was presented and discussed

[1] MALMON was a 5-year project (2020–2025) funded by the European Community within the "Development Smart Innovation through Research in Agriculture" (DeSIRA) initiative [FOOD/2019/412–700, DeSIRA_GB]" (Desira | Malmon). The project aimed to increase the productivity and stabilising the inter-annual mangrove swamp rice production, as well as better understanding and improving the drivers and complex dynamics of mangroves' ecosystem change in Guinea Bissau, West Africa.

with the rice farmers. This step was followed by nine months of fieldwork in the Cacheu, Oio and Tombali regions, divided into three missions, to co-construct the game board, run the game and validate the results of the serious game.

Over the course of these three field missions, we held twelve regional workshops, culminating in a national workshop to finalize and validate the results. During the first mission, conducted between June and September 2023, we organized six participatory workshops across the three studied regions, with two workshops held in each region. The first three workshops, held in the Cacheu, Oio, and Tombali regions, aimed to engage stakeholders, assess the state of mangrove rice cultivation, identify the constraints hindering its development, and collaboratively formulate the game objectives and design the initial prototype of the serious game. This prototype was then tested during the second participatory workshops organised in each region, in order to consider the additions, corrections and suggestions made by the participants to improve the prototype. The second field mission, carried out between December 2023 and March 2024, enabled three participatory workshops to be organised in the three regions, to define the rainfall scenarios with the participants and test the serious game simulator. The third and final field mission took place between June and August 2024. During this mission, four participatory workshops were organised, including three regional workshops and one national workshop. The regional workshops enabled the serious game to be organised according to the previously defined scenarios. The national workshop, which brought together representatives from each region and area of intervention, provided an opportunity to discuss and validate the results obtained.

2.2.2. Selection of workshops' participants

The serious game was essentially co-constructed with mangrove rice farmers from the three studied regions, previously tested with students and researchers working in the mangrove rice sector in Guinea-Bissau. A total of 45 rice farmers from three regions and thirteen intervention areas took part in the process of co-constructing the serious game and validating the final results. These included thirty farmers who work directly with the MALMON project and 15 others who are not directly involved in the project. Participants were chosen from rice farmers with good knowledge and experience of mangrove rice production. Participants were chosen from each region, ensuring that they were also available throughout the eighteen-month process. Most of the participants chosen were community spokespeople. These participants have good experience working with projects and programs in their area and are actively involved in local decision-making.

The participants were mainly men (67.5 %) and women (32.5 %) from different ethnic groups such as Balant (60 %), Bayote (17.5 %), Diola (10 %), Nallu (10 %) and Sussou (2.5 %). Several age groups are represented throughout the process, ranging from the youngest (between 20 and 30 years old) who represent 22.5 % to the oldest (over 50 years old) who represent 12.5 % of participants. The other age groups, 30–40 and 40–50, are respectively more represented (37.5 % and 27.5 % respectively) in the process. In addition, 90 % of participants are educated, including 15 % who left school at primary level, 7.5 % at secondary level, 22 % at high school and 12.5 % who have completed higher education. Only 10 % of participants had not attended school. A variety of profiles, made up of men and women, young people and elderly people, both those in and out of school, were mobilised to take part in the process of co-constructing the serious game and validating the results. Although this choice was based on non-probabilistic sampling and purposive sampling, we tried to make it representative of reality.

2.3. The djugu di bolanha serious game

2.3.1. The game board

The rice-farming areas had different morphological characteristics that can be grouped into two main categories. The first category consists of land bordered entirely by mangrove swamps and rice fields that gravitate around the dwellings, giving rise to the appearance of an island (e.g. Elia, Elalab, Jobel and Cafine). The second category consists of areas with a plateau where the dwellings and other crops are located, and a floodplain made up of rice paddies and mangrove mudflats. Taking all these characteristics into account, the serious game board is made up of three large zones defined according to the toposequence of the rice-farming areas: plateau zone, intermediate zone and mangrove zone (Fig. 2). Three types of rice fields were identified by mangrove farmers, including high rice fields or *bolanha di riba* [Kr = Guinean Creole], intermediate rice fields or *bolonha di metadi* [Kr] and rice fields close to the mangrove under the influence of the tides, also known as *bolanha di tarafe* [Kr] or *bolanha Salgado* [Kr].

At the beginning of the session, participants may introduce optional landscape elements such as canals in *bolanha* and choose the layout of the plots allocated to rice cultivation (aligned along the topographic gradient or randomly distributed), thereby accounting for the diversity of contexts encountered across the three regions and facilitating players' identification with the system being represented.

2.3.2. Objective and rules

The role playing game is designed to investigate how mangrove rice farmers adjust their practices in response to seasonal rainfall variability and the uncertainty associated with climate change. The game involves up to six players, or groups of players, each representing a mangrove rice-farming household. Each player's objective is to meet the needs of their family by organizing their agricultural and extractive activities throughout the year. The shared implicit objective is to manage rainwater in such a way that all families are able to sustain their livelihoods.

The game proceeds through monthly time steps, or through the grouping of several months depending on the duration of the activity considered, and each round represents an agricultural year (May–April), reflecting Guinea-Bissau's farming calendar. In each round, families are required to complete a record sheet to keep track of their decisions throughout the game.

At the beginning of the game session, players are allocated three plots in the *bolanha* zone.In addition, depending on the local context, each family is allocated one plot in the *bolanha*, surrounded by water and located within the mangrove zone of the board. Each family must choose the rice variety or varieties they wish to cultivate in each plot from three major types, based on the length of the growing cycle: short, intermediate, or long.

Each family may additionally choose two supplementary activities, either extractive—such as fishing, oyster harvesting, or palm oil collection—or agricultural, such as vegetable gardening, cassava or cashew cultivation. These activities were introduced at the farmers' request in order to better reflect the diversity of activities they practice on a daily basis. For each of these activities, the player receives a card describing the different operations to be carried out and the labor required to achieve a good level of production.

2.3.3. Development of the serious game

Each regional serious game workshop was organised in one of the intervention areas, bringing together all the participants from the region concerned (around fifteen per regional workshop) for a duration of five to six hours. All the workshops were recorded using a dictaphone and a video camera upon previous consent. During each workshop, the participants were divided into four working groups, considered as families, and supervised by two researchers. Each family received a kit with the materials they needed to play the game (an answer sheet for the families to record their decisions and the game pieces they will use to demonstrate their decisions on the board) and told which square they occupy on the board. The objective, components and dynamics of the game were then explained. Each round of the game is equivalent to an agricultural year, which begins in May and ends in April, corresponding to the length of the rice harvest in Guinea-Bissau. The participants play the game

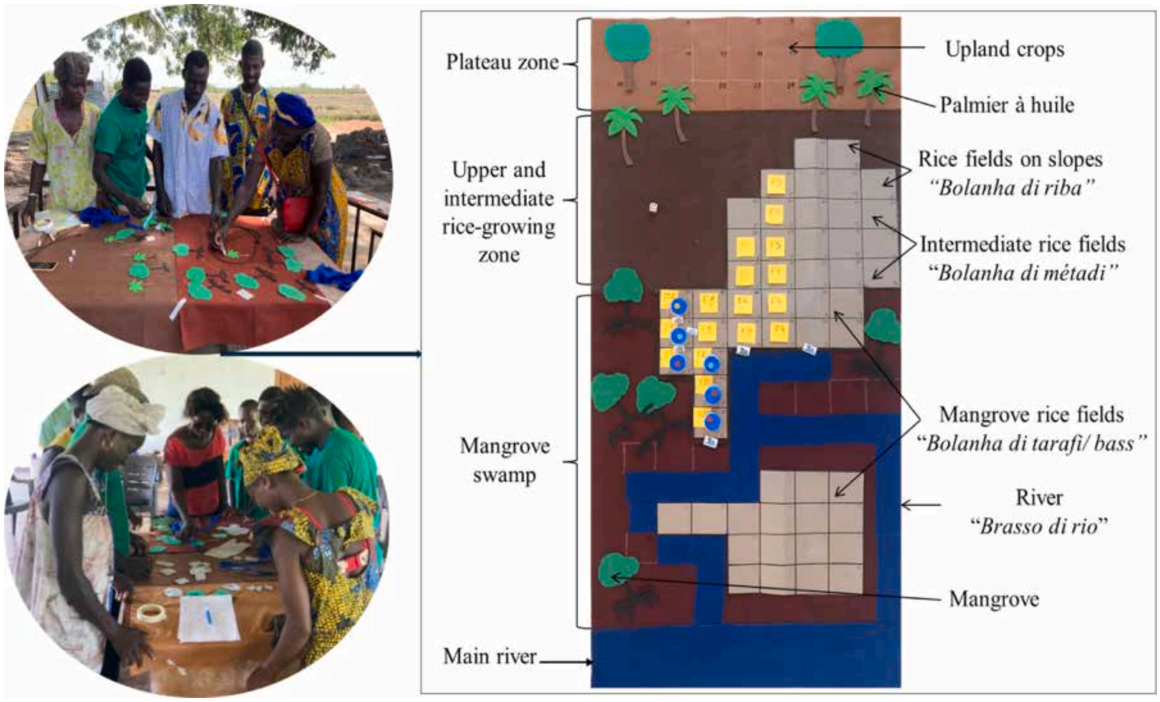


Fig. 2. Serious game board co-constructed with mangrove rice farmers in Guinea-Bissau.

according to the instructions given beforehand, taking into account the realities on the ground. A debriefing session was then organised after each playing session, with the group leader speaking first, followed by the other members of the group. The other groups also had the opportunity to make criticisms, suggestions or ask questions. The workshops then closed with open debates between the various participants, where a great deal of additional information was gathered.

2.4. Complementary survey and participant observation

The construction of the serious game also required the mobilisation of complementary tools and approaches, such as one interview schedule and the participatory observation approach (Lapassade, 2002) and the processing of rainfall data. These tools were used in particular during the various field missions carried out in the regions and villages of Guinea-Bissau. Several group interviews were organised in the thirteen intervention areas with men, women, young people and the elderly. During the various missions, we stayed with the mangrove rice farmers and attended the various rice-growing operations (from preparing the plots to harvesting the rice) alongside them. These various moments of exchange and sharing with the rice farmers, in their homes or in their rice fields, enabled us to enrich our knowledge of rice-growing systems, to better understand the knowledge and practices of mangrove rice farmers, and the strategies put in place to adapt to the current climatic context. Much of the information collected was used to improve the game board constructed and to analyse the results presented in this paper.

2.5. Data processing

The data collected in this study were processed specifically according to their nature. The recordings from the serious game and the group interviews were manually transcribed using Express Scribe software. Rainfall data was processed using R software, and maps were produced using ArcGis 10.8.2. Ethnographic data was analysed according to a thematic analysis content approach (Paillé and Mucchielli, 2012). Qualitative data were analyzed using triangulation across sources, methods, and themes. Themes derived from the game transcripts were compared with those from interviews and field observations in order to identify points of convergence and divergence, as well as to highlight complementarities among the different data sources.

3. Results and discussion

3.1. Rainfall variability in Guinea-Bissau

It is difficult to characterise rainfall variability at the village level in Guinea-Bissau due to the lack of a long series of observational data. The only data available are those from the MALMON project, for which observations began in 2021. Although these data do not cover a long period, they give an idea of recent rainfall variability at the scale of the Elalab, Ntchugal and Cafine villages (Fig. 3). These villages are located respectively in the north, centre and south of Guinea-Bissau. Analysis of Fig. 3 shows spatio-temporal variability in rainfall in the Cafine, Ntchugal and Elalab villages over the last four years. The general trends show strong inter-annual variability in rainfall for each month of the rainy season at the three stations studied: With a cumulative annual rainfall of 2503 mm in 2021, 2125 mm in 2022, 1825 mm in 2023 and 2848 mm in 2024, the Cafine village receives more rainfall than the Ntchugal and Elalab villages (tabl 1, Supplementary material). These observations confirm national trends, which show an increasing trend in rainfall from north to south, as demonstrated in the work of Mendes and Fragasso (2024). In addition, the 2024 rainy season was very regular at the three stations, with a relatively high number of rainy days, 109 at Cafine, 86 at Ntchugal and 77 at Elalab, which was more than sufficient for mangrove rice cultivation (tabl 2, Supplementary materiel). While some years were characterised by good rainfall regularity, others were very irregular, especially at the start of the rainy season. This was the case in 2021 and 2023 at the Elalab and Ntchugal stations, where there was very little rainfall in May and June, making it impossible to start rice-growing.

Like other regions of West Africa, Guinea-Bissau has experienced three main periods of rainfall change: a pre-drought period (1960–1967) when rainfall was relatively abundant, a drought period (1968–1990) marked by a drop in rainfall and a post-drought period (1991-Present) characterised by a return of rain (Mendes and Fragoso, 2024). Today,

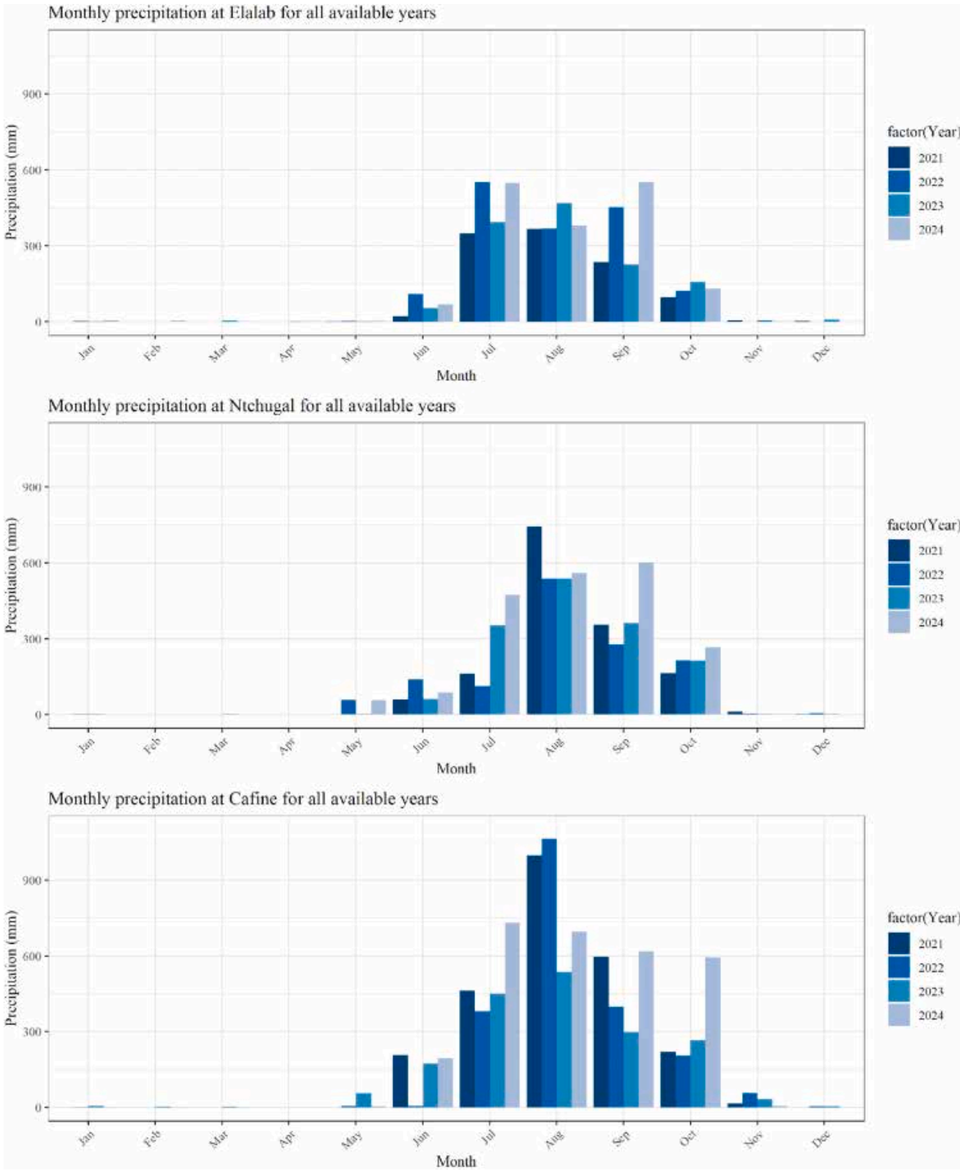


Fig. 3. Interannual and intermonthly variability at Elalab (1), Ntchugal (2) and Cafine (3) stations corresponding to the coastal zones of Cacheu, Oio and Tombali in Guinea-Bissau respectively.

the question of the return of rainfall is no longer in doubt at the West African level, since numerous studies carried out in this region show a return to wetter conditions since the end of the 1990s (Descroix et al., 2013, 2015, 2020; Bodian, 2014; Sultan et al., 2015; Nouaceur, 2020; Mendes and Fragoso, 2024). The issue of greatest concern to mangrove rice farmers in Guinea-Bissau is the high spatiotemporal variability of rainfall observed in their village. This rainfall variability in Guinea-Bissau is demonstrated by the work of Mendes and Fragoso (2024), but on a regional scale. Rainfall variability is now a reality that is well understood by mangrove rice farmers in Guinea-Bissau.

3.2. Mangrove rice farmers' perception of rainfall variability

Mangrove rice farmers in Guinea-Bissau have a good knowledge of rainfall variability, based on a reading of the rainfall situation in their area over the years and on the observation of biotemporal markers (appearance of certain birds or flowering of certain trees that herald the start or end of the rainy season). They are generally based on a set of rainfall variables, such as the start, intensity and end of the rainy season, as well as rainfall regularity over the season, to define a good or bad rainy year. These variables are the most important in agronomy (Balme et al., 2006) and prior knowledge of them enables better planning of cropping calendars and the choice of varieties adapted to the rainfall context (Badiane, 2022). However, rice farmers often do not have access to local weather forecasting information. The few available climate forecasts are generally produced at the scale of West Africa as a whole and do not take into account the local realities of Guinea-Bissau. Moreover, farmers often face difficulties in accessing these forecasts.

They focus on current rainfall conditions and past experience when planning rice-growing operations. This sometimes makes it difficult to anticipate climatic risks. The perception of rainfall variability is analysed here on the basis of the experience and local knowledge accumulated by mangrove rice farmers on past and current rainfall behaviour within their village. These rice farmers have defined two main rainfall scenarios that they have been facing for more than a decade, taking into account the variables mentioned above: a normal rainy year and a year with contrasting rainfall.

Fig. 4 shows the perception of rainfall variability by mangrove rice farmers, who defined two types of rainfall scenarios and criteria for characterising them. According to one rice farmer in the Cafine south

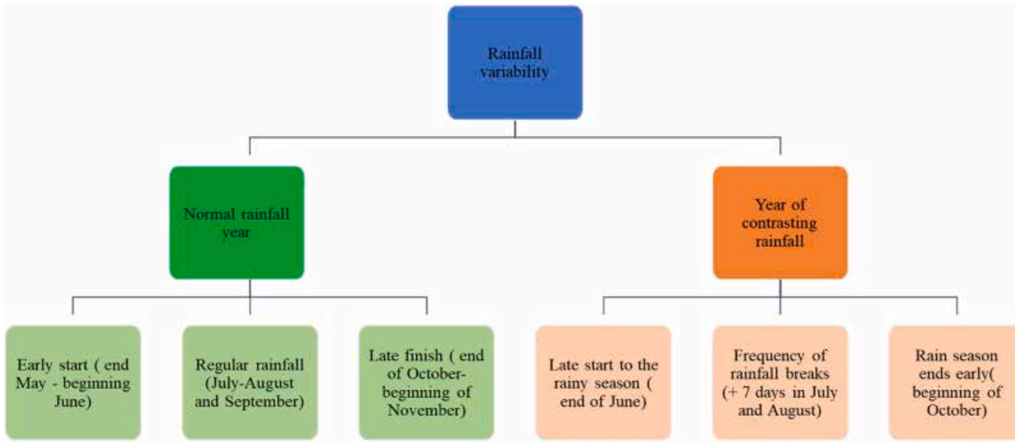


Fig. 4. Perception of rainfall variability among rice farmers in Guinea-Bissau.

region:

"We usually have the rainfall of a normal year around the second half of May until the beginning of November at the latest, with periods of regularity and intensity between July, August and September, without a long break. We consider this to be good rainfall for farmers".

This statement is shared by other farmers in the North and Centre coastal regions, for whom, in a normal year: "*there is no break in rainfall of more than seven days between the end of July, August and September*". These three months corresponded to the period of rice-growing operations (e.g. ploughing, sowing and transplanting, etc.) during which rice farmers have the greatest need for regular rainfall. As this is a "contrasted" rainy year, rice farmers highlight three situations that they can observe from one season to the next: the late start of the rainy season (end of june, beginning of july), the frequency of rainy breaks lasting more than seven days and the early end of the rainy season, which can occur at the end of September or beginning of october (Fig. 4).

This perception of rainfall variability thus confirms the rainfall data previously analysed and highlights the knowledge of mangrove rice farmers in Guinea-Bissau about climate, and more specifically about the variability of rainfall conditions. These results corroborate those obtained by (Badiane, 2022) in Basse-Casamance; (Abou et al., 2024) in Cameroon; (Sidi et al., 2022) in Mali; (Sohou and N'Da Kouadio, 2022) in Côte d'Ivoire; (Kpekpassi et al., 2021) in Benin. The latter have shown that farmers are well aware of climate variability at the local level, through irregular rainfall conditions and rising temperatures. These unfavourable rainfall conditions often have major repercussions on rice-growing activities, and even on yields.

3.3. Impact of rainfall variability on the rice-growing calendar

The rainfall variability observed in Guinea-Bissau has an impact on rice-growing activities, particularly on the operating calendar, with possible repercussions on yields. Mangrove rice farmers plan operations taking into account rainfall conditions, the variability of which can lead to changes in cropping calendars. The late onset of the rainy season, the frequency of long breaks in rainfall during the season and the early end of rains are seen as the main constraints that prompt farmers to rearrange their rice-growing calendars. Table 1 shows the rice-growing schedules defined with mangrove farmers in the Cafine (Tombali region), Ntchugal (Oio region) and Elalab (Cacheu region) areas based on the two major rainfall scenarios identified earlier. The analysis in Table 1 shows the changes made by rice farmers to their rice-growing calendars according to the rainfall scenarios. The main changes are observed in nursery establishment, water management and harvesting operations in the Cafine, Ntchugal and Elalab villages. Generally speaking, rice farmers rely on the amount and regularity of rainfall to start rice-growing operations. When setting up rice nurseries, rice farmers wait for the soil to be sufficiently wet and practicable, with around 3–4 days of intense rain at the start of the season without a long break, before starting ploughing and sowing. For example, in a normal rainy year, rice farmers start setting up rice nurseries between the end of June and mid-July in N'tchugal, and from the beginning of July to mid-July in Elalab (tabl 1). However, in a year of contrasting rainfall, marked by a late start to the rainy season, the dates on which the nurseries are set up can be shifted, as is the case in Cafine, Ntchugal and Elalab (tabl 1).

The calendar of operations defined by mangrove rice farmers is flexible and depends largely on rainfall conditions, disruption of which can have repercussions on the various operations. This result is in line with the work of Badiane, (2022); Badiane et al., (2025); Mballo et al., (2021); Layou et al., (2023); Sognon et al., (2020) and Djohy et al., (2015), who showed a modification of sowing dates in the context of a late onset of rainfall conditions.

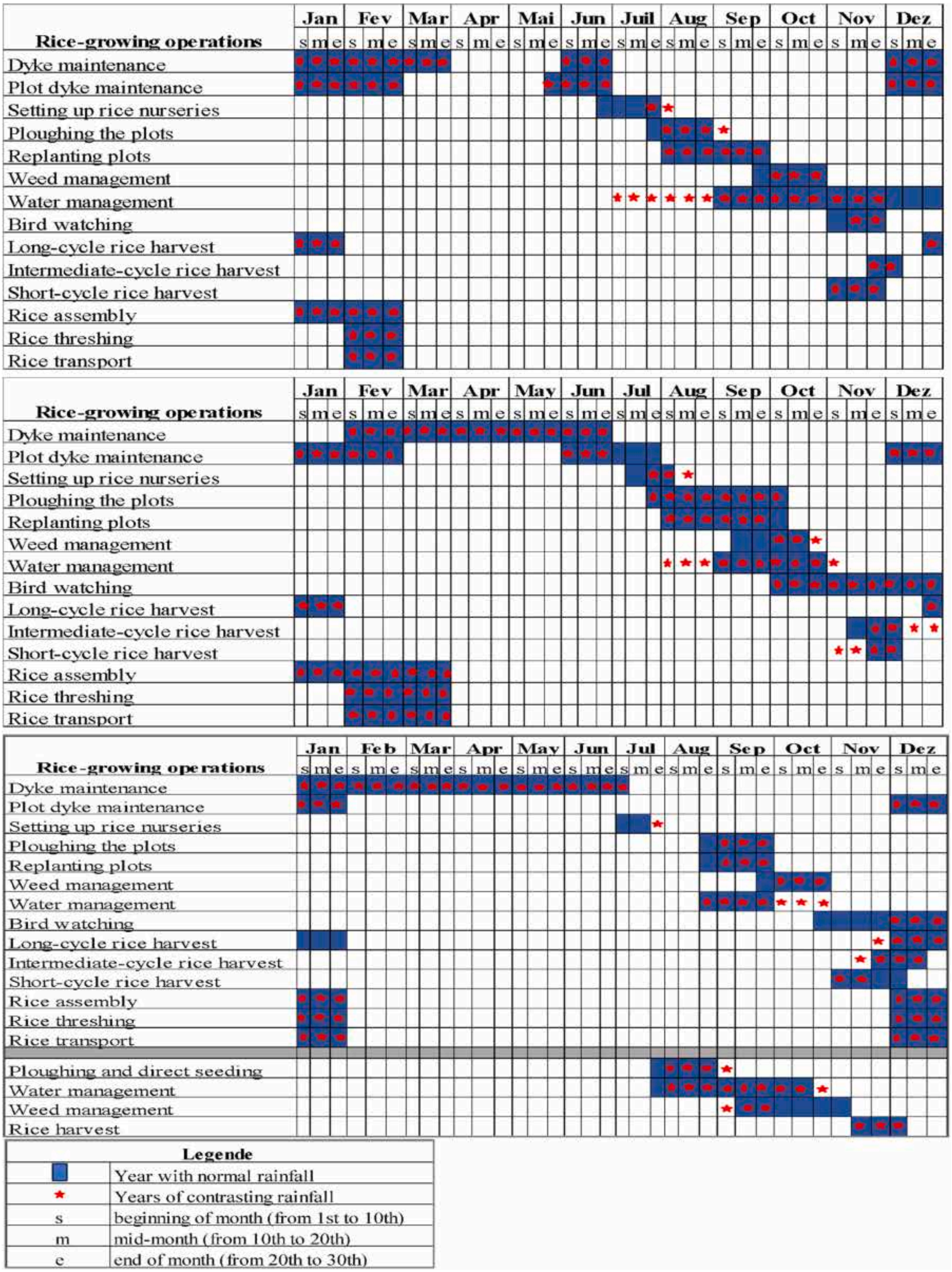
3.4. Adaptation strategies of mangrove rice farmers in Guinea-Bissau

In the face of climate change, which seems unavoidable, and its increasingly obvious impacts on the agricultural sector, adaptation is becoming an imperative to reduce the risks and vulnerability of populations around the world (IPCC., 2023; PNUD., 2023). Today, small-scale family farmers need to adapt to climate change to avoid worsening food insecurity in the years to come (PNUD., 2023). In developing countries, people have not waited for expert decisions and adaptation policies to begin adjusting their livelihood strategies to the changes they can perceive and anticipate (Janicot et al., 2015). This is the case in Guinea-Bissau, where in the face of climate variability, particularly rainfall variability, mangrove rice farmers have developed strategies to adapt and keep their rice-growing heritage alive. Generally speaking, these rice farmers rely on their knowledge and know-how to adapt to past and current climatic conditions, sometimes even with the support of certain research and development projects and programs. These strategies are structured around four main categories identified with mangrove rice farmers: adaptation of cropping systems, varietal adaptation, water management and diversification of agricultural and non-agricultural activities (Fig. 5).

3.4.1. Adapting cropping systems

Generally speaking, mangrove rice cultivation in Guinea-Bissau requires a large input of rainwater (an average of 1500 mm per year) to wash out the salt present in the plots and meet the water requirements of the rice varieties grown. The rice-growing system is characterised by the predominance of ridge cropping (Fig. 6), with the use of rudimentary "*arado*" [Kr] tools and the transplanting system. This traditional system allows good water management in the furrows throughout the growing

Table 1
Evolution of rice-growing calendars in Cafine (1), Ntchugal (2) and Elalab (3) according to identifie rainfall scenarios.



cycle of the cultivated variety. However, local rainfall variability often upsets this balance, especially in years when the rainy season starts late. To adapt to this situation, rice farmers are increasingly anticipating ploughing and sowing at the start of the rainy season to limit the risks. This strategy of anticipating ploughing is seen as one of the best adapted to this context of variability and uncertainty in rainfall conditions. Other rice farmers, particularly those in the Cacheu region (Elia, Elalab and Jobel), prefer to practise direct seeding in the high rice fields or the rice fields located inside the mangrove swamps known as Niataba. In 2023, a year marked by a late start to the rainy season and frequent breaks in

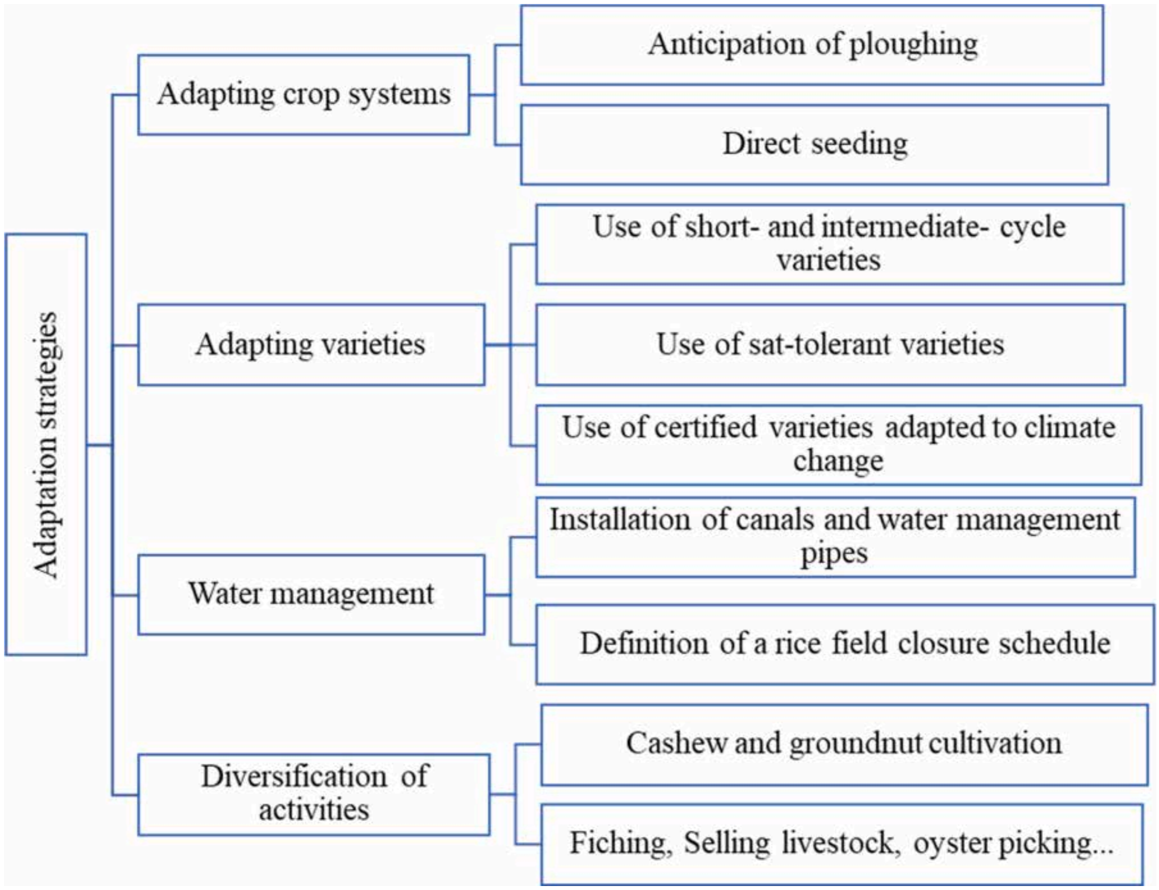


Fig. 5. Main strategies developed by mangrove rice farmers to adapt to rainfall variability.

Fig. 6. Direct-sown rice on a plot in Cafine in a context of late rainfall in 2023.

rainfall, some rice farmers in the Cafine area preferred to use direct seeding to avoid delays in work (Fig. 6).

3.4.2. Varietal adaptation strategies of mangrove rice farmers

Mangrove rice farmers in Guinea-Bissau have inherited very old rice seeds belonging to the species *Oryza glaberrima*, and seeds of Asian origin, *Oryza sativa*, introduced later (Cormier-Salem, 1999). These rice farmers know how to select and manage varieties adapted to each type of rice field and climatic conditions. Generally speaking, rice farmers use long-cycle varieties in deep rice fields, intermediate-cycle varieties in intermediate rice fields and short-cycle varieties in upland rice fields. This distribution takes account of normal rainfall conditions and the length of time that water, necessary for plant growth, is present in the different types of rice field. The current context of rainfall variability is leading mangrove rice farmers to adopt strategies for changing the use of varieties according to rainfall conditions. These farmers prefer short and intermediate cycle varieties when the rainy season starts late or when there is a frequent break in rainfall at the beginning of the season. Others, like the rice farmers in the Cacheu region, use salt-tolerant varieties in the rice fields closer to the mangroves. In this way, mangrove rice farmers use the different varieties they have in a very flexible way, depending on the rainfall context and the types of rice fields developed. This knowledge of variety selection shows the great varietal adaptability of mangrove rice farmers in Guinea-Bissau. These rice farmers also have a good capacity to adapt to certain innovations coming from other communities or research projects. For example, the Malmon project supports mangrove rice farmers in selecting the best local rice varieties adapted to the context of climate change, through exchanges of experience and varieties between rice farmers in the Cacheu, Oio and Tombali regions. In addition, the introduction of certified seeds by projects and programmes (e.g. IANDA Guinea) is creating market value in the Tombali and Oio regions.

However, their adoption by mangrove rice farmers is not unanimous. The latter place more trust in local varieties passed down by their parents, which they preserve themselves and share when necessary. As a rice farmer from the village of Elalab explains:

"*When we receive certified varieties supplied by the projects, we eat them without growing them on our plots. We trust our own varieties more, which we inherited from our ancestors and which are suited to our land.*" (Interview in Elalab, 2024).

Thus, despite the investments made by projects and programs in seeds and inputs, certified varieties are not widely adopted by mangrove rice farmers in the three regions studied. These observations are in line with work carried out in West Africa, particularly in Mali (Sissoko et al., 2008) in Burkina Faso (Olivier, 2021) in Senegal (Badiane, 2022), which also show the reluctance of some farmers to adopt certified varieties. The failure of plant improvement programmes to take account of the specific qualities of local varieties explains the rejection of new cultivars by farmers (Sissoko et al., 2008).

3.4.3. Water management strategies

Water management is considered fundamental to mangrove rice cultivation in Guinea-Bissau. Rice farmers have a good knowledge of water management strategies based on the construction of anti-salt dikes and bunds, and the use of tree trunks (rowan or palm) for water drainage (Fig. 7.B). Work carried out in Guinea-Bissau (Penot, 1994; Ecoutin et al., 1999; Sandoval et al., 2024) and in Basse-Casamance (Pélissier, 1966; Sané, 2017; Badiane, 2022) shows that mangrove rice farmers have considerable knowledge and know-how in building dikes and bunds. These dikes protect rice fields against saltwater intrusion from rivers and facilitate rainwater management through the dikes separating the different plots (Kasanoski et al., *in* prep.). The dikes also facilitate the evacuation of excess rainwater into rivers when plots are sufficiently flooded. Water management on rice-growing plots depends above all on the rainfall context and toposequence, which influence farmers' decisions to evacuate surpluses or conserve available quantities when rainfall conditions are irregular.

However, the vulnerability of anti-salt dykes to tides and extreme rainfall (Dièye et al., 2023; Sandoval et al., 2024) is prompting rice farmers, especially those in the north and south, to install wider, higher dykes. These rice farmers regularly monitor the dikes, especially during the highest tides or after heavy rains, and intervene to repair any dike breaches. This work requires a good command of dyke repair techniques, and a large workforce made up of men, young people and sometimes even women (Fig. 7.A). Mangrove rice farmers' knowledge of hydro-agricultural development is also confirmed by the work of Sandoval et al. (2024), Kasanoski et al., (in prep). Sandoval et al. (2024) show that mangrove rice farmers in Guinea-Bissau have a good knowledge of tides and winds, enabling them to anticipate the risks associated with dike subsidence or failure.

In many localities, rice farmers, through local consultations and with the support of the Nongovernmental organization DEDURAM, have succeeded in implementing innovations in hydro-agricultural development (Fig. 7. C). These include the construction of drainage channels around plots and the installation of water management pipes at the main dykes and plots.

The example of the village of Ntchugal, located in the Oio region, is particularly revealing. In addition to these innovations, local communities have set up a valley management committee and a regulation system defining the opening and closing periods of the rice valley during the rainy season, a system with which all farmers must comply. A farmer from the village says:

"*Since the installation of drainage channels and water management pipes, as well as the definition of the opening and closing periods for the rice fields, we have noticed that all farmers finish their work on time. As a result, yields have increased significantly in recent years.* " (Ntchugal interview, 2024).

This type of development, based on the agricultural use of rainwater, is seen by (Nguimalet et al., 2016) as an adaptation measure that can help communities reduce the effects of low rainfall or prolonged dry spells.

During group discussions, farmers emphasized the importance of having secondary channels and water management systems, both at the level of the main dikes, to control the flow of water in the valley, and at the level of individual plots, to facilitate drainage to the channels or

Fig. 7. Reinforcement of a collapsed main dike at Cafine (A); Palm trunk installed on a dike for water drainage at Elia (B); Water management tube installed on the main dike at Jobel (C).

from one plot to another. According to these rice farmers, these developments enable effective water management in a context of rainfall variability. However, access to these innovations without the intervention of partners is a real problem, due to the high cost of equipment, which is inaccessible to local populations. It would therefore be appropriate for national adaptation policies in the agricultural sector to incorporate these measures aimed at supporting family farmers in their adaptation to climate change.

3.4.4. Diversification strategies

The diversification of agricultural and non-agricultural activities is at the heart of rice-growing systems in Guinea-Bissau, and plays an important role in the food security of the population. Mangrove rice cultivation occupies a central place in the system and maintains a complementary relationship with other income-generating activities such as fishing, livestock breeding, arboriculture and off-season market gardening, among others (Fig. 8.A and 8.D). Part of the income from these complementary activities is reused to finance rice cultivation. These results concur with those of (Cormier-Salem, 2015) and (Badiane et al., 2025), who show the strategies for diversifying activities developed by rice farmers in the Rivières du Sud in response to climate change.

Fishing is an important complementary activity for mangrove rice farmers in Guinea-Bissau. In the regions studied, it is practiced by both men and women. In the Cacheu region, particularly in the Elia and Djobel areas, women mainly fish for shrimp before the rice harvest begins, and more occasionally for fish. These products are intended partly for family consumption and partly for sale in local markets. In the Balanta villages of the Oio and Tombali regions, women are particularly active during the rainy season, before the start of transplanting, in fishing for small fish called "sélébousogne." These are then dried, with some reserved for domestic consumption and others for sale. These activities help to provide income for women, enabling them to cover certain family and personal needs.

Today, the activity that provides most income for rice farmers in Guinea-Bissau remains cashew tree arboriculture. The work of (Badiane et al., 2019), carried out in Basse-Casamance (Commune d′Adéane), shows a gradual abandonment of the rice-growing activity in favor of cashew tree arboriculture. In contrast to this work, our results reveal that mangrove rice farmers in the Cacheu, Oio and Tombali regions consider cashew tree cultivation as a complementary activity to rice cultivation.

Moreover, the results of interviews conducted with farmers who own cashew orchards show that a significant share of the income generated from cashew tree cultivation is used to finance rice farming activities, highlighting the complementary nature of the two practices. However, the growing expansion of cashew cultivation across the national territory of Guinea-Bissau tends to occupy large portions of plateau farmland, thereby limiting the diversification of agricultural activities that were previously practiced in these areas.

3.5. Using serious games to identify adaptation strategies

The study on the perception of rainfall variability, its impacts on mangrove rice production and adaptation strategies, based on the companion modelling approach, reveals conclusive results. The approach, combining participatory workshops, group interviews and participant observation, enabled us to co-construct a serious game board with mangrove rice farmers in Guinea-Bissau. This board takes into account the biophysical characteristics of the environment (topography and type of rice field, hydrographic network and vegetation, etc.) and the various socio-economic activities practiced in the villages and was used to run the serious game in the three intervention regions. This approach is in line with that of Da Hora et al. (2024) and Bonnet et al., (2024) on fishing in the Amazon, and Boulay (2023) and Kekli (2023) on water management in Tunisia. The result of this work is that serious games are an important tool for promoting dialogue between various stakeholders and facilitating the decision-making process on the management of a territory's common resources.

The results of the serious game co-constructed in Guinea-Bissau show that mangrove rice farmers have a good knowledge of rainfall variability within their village, enabling them to develop strategies to anticipate or limit climatic risks. This knowledge of mangrove rice farmers is the fruit of long experience in observing past and present rainfall conditions in their village. Group work, followed by feedback and debates organized during participatory serious game workshops, gave rise to important exchanges, leading to a sharing of experience and knowledge between participants from different villages and regions. Much of the experience shared concerned anti-salt dyke construction and water management techniques, the use of varieties according to rainfall conditions and rice field types, as well as certain innovations introduced in the mangrove rice sector. These innovations were discussed during the debates in order to gather the participants' opinions. While some innovations, such as the installation of water management tubes on dikes, are seen as a necessity by rice farmers, others, such as the distribution of certified seeds, are not unanimously supported. Mangrove rice farmers are very attached to their seed, which they are able to keep and exchange among themselves. Work carried out in Basse-Casamance Badiane et al., (2025), Mali Sissoko et al., (2008) and Burkina Olivier (2021) also shows the reluctance of some farmers to adopt certified seed.

As a simulation tool, the game enabled participants to face situations and make decisions based on their own farming practices. The participants agreed on the need for better planning of rice-growing activities according to rainfall conditions (anticipating and accelerating work

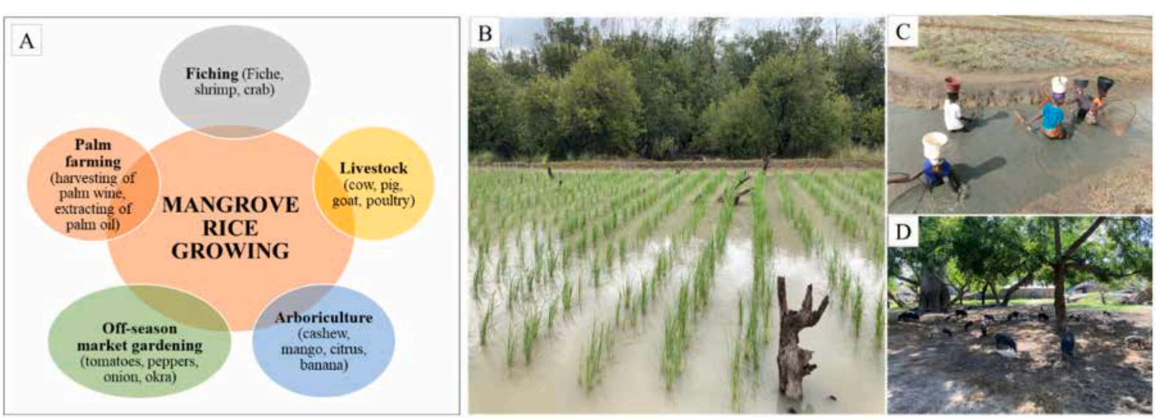


Fig. 8. Diversity of activities practiced by mangrove rice farmers in Guinea-Bissau (A); evolution of transplanted rice in the rice fields of Malafu (B), fishing for small fish by young girls in Quibil (C), pig breeding in Elalab (D).

when rainfall conditions allow). This means that access to weather forecasting information becomes a necessity to enable rice farmers, in addition to their knowledge of the climate, to make the best decisions on whether or not to anticipate rice-growing operations.

4. Conclusion

Mangrove rice production, the main activity of coastal communities in Guinea-Bissau, is strongly influenced by climate variability, particularly rainfall. This variability, confirmed by rainfall data analysis, is clearly perceived by mangrove rice farmers. Drawing on their traditional ecological knowledge, they identify several rainfall scenarios that disrupt rice production, including late onset of the rainy season, frequent interruptions, and premature end. The strategies implemented, focusing on cropping systems, seed and water management, and diversification of activities, demonstrate the importance of local knowledge. However, while these strategies have helped to preserve rice production in the face of past climatic constraints, they remain insufficient to support the development of the sector and sustainably strengthen the adaptation of mangrove rice farmers to ongoing climate change.

In this context, taking local knowledge into account in national adaptation policies is essential to strengthening the resilience of mangrove rice farming systems. This must be accompanied by coordinated technical support for rice farmers, particularly for effective water management in the face of climatic constraints, as well as timely access to reliable and up-to-date climate information, in order to facilitate the anticipation of risks related to climate variability.

Finally, the serious game used in this study proved to be a relevant tool for promoting dialogue, the exchange of experiences, and knowledge sharing among rice farmers, thus facilitating the collective identification of adaptation strategies in the rice sector. As a simulation tool, it enabled participants to face various situations and make decisions based on their own agricultural practices.

CRediT authorship contribution statement

Daniesse Sannara Kasanoski: Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Alexandre Badiane:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Sá Rui M:** Validation, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization. **Marie-Paule Bonnet:** Validation, Supervision, Methodology, Funding acquisition, Conceptualization. **Orlando Mendes:** Validation, Formal analysis, Data curation.

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Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Alexandre Badiane reports financial support was provided by University of Lisbon Higher Institute of Agronomy Department of Forestry. Alexandre Badiane reports financial support was provided by French National Research Institute for Sustainable Development Occitanie Regional Delegation. I, Alexandre Badiane, hereby declare that the following co-authors, Daniesse Sannara Kasanoski, Orlando Mendes, and myself, have all worked on the Malmon-DeSIRA project under the supervision of project manager Marina Temudo and the management team composed of the other co-authors, Marie-Paule Bonnet and Rui M. Sá. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.agwat.2026.110120.

Data availability

Data will be made available on request.

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