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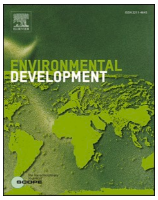

A vulnerability assessment of rice farmers to climate change in Yamoussoukro, central Côte d'Ivoire

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ABSTRACT

Small-scale farmers in Africa are particularly vulnerable to climate change due to their limited adaptive capacity and scarce resources. While numerous studies have explored farmers' perceptions of climate change and its anticipated impacts on food production, few have directly examined their perceived vulnerability, and the adaptation measures they implement in response. This study investigates 123 rice farmers in the Yamoussoukro Department, central Côte d'Ivoire, through semi-structured interviews, the matrix method, and a multi-criteria analysis to evaluate their vulnerability. The assessment combines farmers' perceptions, adaptation strategies, and observed climatic data (temperature and rainfall trends from 1979 to 2020). Results indicate that 93 % of surveyed rice farmers are aware of climate change and its adverse effects on irrigated rice production. Their perceptions align with observed climatic trends, particularly decreasing rainfall, rising temperatures, delayed rainfall onset, and shorter rainy seasons. The adaptive capacity of the farmers is rated as moderate, and their overall vulnerability is also moderate. The most effective adaptation strategies identified include improving cultivation practices, adopting heat- and drought-tolerant rice varieties, implementing alternative irrigation techniques, and adjusting cropping calendars. These findings highlight the urgent need for targeted awareness-raising and support programs to enhance the adaptive capacity of rice farmers in the Yamoussoukro region. Furthermore, the study offers a practical methodological framework for assessing agricultural vulnerability to climate change, which could inform future interventions and policymaking aimed at strengthening farmer resilience and ensuring long-term food security.

1. Introduction

Climate change and its impacts on agriculture represent one of the most pressing challenges facing humanity in the 21st century

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(IPCC, 2007), with Africa being particularly affected. According to estimates from the Food and Agriculture Organization of the United Nations (FAO), the number of people experiencing severe food insecurity in Africa rose from 192 million in 2014 to approximately 250 million in 2019, including nearly 70 million in West Africa alone (FAO, FIDA, OMS, PAM, UNICEF, 2020). The effects of climate change are expected to be more severe on the African continent due to several compounding factors, including high climate variability, heavy dependence on natural resources, low income levels, and insufficient infrastructure to support adaptation to climate-related stressors (Tubiello et al., 2007). Smallholder farmers across Africa are particularly vulnerable to climatic and environmental shocks, as they often lack the resources needed to diversify their livelihoods and income streams (Ochieng et al., 2016). In West Africa specifically, small-scale agriculture is especially susceptible to the impacts of climate change due to farmers limited adaptive capacity (Bojang et al., 2020). To strengthen their resilience to the current and future adverse impacts of climate change, it is essential to assess the adaptive capacity and vulnerability levels of smallholder farmers in Africa.

Climate change significantly affects irrigated rice cultivation by influencing the availability of water in reservoirs, irrigation requirements, crop growth and development, and crop productivity. Climate variability—particularly changes in rainfall—can greatly impact surface runoff (Qiu et al., 2020) and alter hydrological seasonality, thereby affecting reservoir inflows (Robles-Morua et al., 2015). An increase in precipitation may enhance inflows into agricultural reservoirs, potentially improving water storage levels. Conversely, rising temperatures can lead to increased irrigation water demand due to higher evapotranspiration rates (Cho et al., 2016). Moreover, climate change generally exerts a negative influence on rice production by reducing water use efficiency and irrigation efficiency (Wang et al., 2014). It also affects the length of the growing period, which varies depending on the rice variety (early, late, or single season) (Wang et al., 2017). High temperatures—particularly those exceeding 38°C—can cause spikelet sterility, resulting in significantly reduced grain yields (Salack, 2006; Korres et al., 2017).

One of the key pillars of smallholder farmers' response to the impacts of climate change is their adaptive capacity, which primarily depends on their perception of the phenomenon and the resources at their disposal. Moreover, numerous studies on agricultural vulnerability to climate change have emphasized the importance of incorporating farmers' perceptions (Sillitoe, 1998) to ensure sustainable and effective outcomes. Accurate climate perception is therefore essential for properly assessing climate risks and enabling rational risk management (Kosmowski et al., 2015). Furthermore, the extent to which rice production is affected by climate change depends not only on farmers' adaptive capacity (Boonwichai et al., 2019), but also on their perception of climate change, which strongly influences the types of adaptation strategies adopted (Roncoli et al., 2001). The adoption of adaptation strategies is, in part, determined—and sometimes constrained—by how rural populations perceive climate variability (Arnaud et al., 2019). These perceptions significantly shape both the nature and scope of implemented strategies (Roncoli et al., 2001), indicating a direct interdependence between perception and adaptation (Agossou, 2008). According to Kosmowski et al. (2015), farmers tend to perceive the impacts of climate change more readily than the phenomenon itself, which often leads to reactive rather than anticipatory adaptation. Therefore, establishing a convergence between local perceptions of climate change and scientific data appears essential to designing anticipatory adaptation strategies that are more effective and better grounded in local realities (Bambara et al., 2013).

In West Africa, numerous studies have explored agricultural vulnerability to climate change through farmers' perceptions and adaptation strategies (Brou et al., 2005; Allé et al., 2013; Loko et al., 2013; Comoé et al., 2014). However, few have specifically focused on the vulnerability of rice farmers, particularly those engaged in irrigated rice cultivation (Doumbia and Depieu, 2013; Bojang et al., 2020; Anugwa et al., 2022). Most studies indicate that farmers have a good awareness of the phenomenon of climate change. For instance, . Gana et al. (2020) found that most farmers they surveyed in Nigeria perceived changes in rainfall patterns and temperature during the decade 2000–2010. Similar findings were reported by Doumbia and Depieu (2013), among rainfed rice farmers in the Central-Western region of Côte d'Ivoire. Furthermore, the results of Béhanzin et al. (2018) in Benin suggest that farmers who are members of agricultural organizations and possess greater farming experience are more likely to perceive the effects of climate change on their production systems.

In Côte d'Ivoire, a West African country, rice holds a prominent position among staple crops (FAO, 2014; ONDR, 2017), with per capita annual consumption estimated at 115 kg in 2017 (MINADER, 2018). Between 1975 and 2021, the country's urbanization rate increased from 32 % to 54 %, while the average annual population growth rate fluctuated between 2.6 % and 2.9 % from 2014 to 2021 (INS, 2021). Irrigated rice farming is considered one of the key strategies to achieve rice self-sufficiency and ensure national food security (FAO, 2010). The country's rice self-sufficiency rate is estimated at 65 %, while import dependency exceeds 50 % (MINADER, 2018). Despite its importance, irrigated rice farming accounts for only 13 % of the total cultivated rice area and contributes approximately 15 % of national production, with average paddy yields ranging from 3 to 10 t/ha (ADERIZ, 2022). The Yamoussoukro department, located in central Côte d'Ivoire, is one of the major irrigated rice-producing areas (JICA, 2013). It currently hosts around ten hydro-agricultural schemes dedicated to irrigated rice production.

This study aims, on the one hand, to analyze rice farmers' perceptions of climate change in the Yamoussoukro department and assess their consistency with observed regional climate data. On the other hand, it evaluates the vulnerability of these farmers to the impacts of climate change on their production systems. The research is grounded in the critical question of whether smallholder rice farmers in the Yamoussoukro department will be able to sustain rice cultivation in the long term, given the increasing threats posed by rainfall and temperature variability. More broadly, this study contributes to understanding the challenges faced by small-scale irrigated rice farmers in general, and in central Côte d'Ivoire in particular.

2. Study area and data

2.1. Study area

The department of Yamoussoukro, also known as the Autonomous District of the same name, is the political and administrative capital of Côte d'Ivoire. Yamoussoukro department is in the center of the country, precisely between coordinates 05°00′ and 05°40′ west longitude, and between coordinates 06°30′ and 07°10′ north latitude (Fig. 1). The zone's climate is of attenuated transition equatorial type currently characterized by two (2) seasons: a rainy season from March to October and a dry season from November to February (Kouakou et al., 2017). The rainfall regime in Yamoussoukro department is now of monomodal type (Kouassi and Brou, 2020). Annual rainfall ranges from 800 mm to 1600 mm. Rainfall amounts have a highly variable temporal distribution from one year to the next (N'guessan et al., 2014). The average annual temperature in Yamoussoukro ranges from 26 °C to 30 °C, with an average of 27 °C over the period 1979–2020.

2.2. Data acquisition

Daily meteorological data used in this study were obtained from the synoptic station of the National meteorological service (Société d'Exploitation et de Développement Aéroportuaire, SODEXAM) in Yamoussoukro. These data were sourced from the iAIMS Climatic Data repository of the Texas A&M AgriLIFE Research Center in Beaumont (World Map Page (tamu.edu)) (Wilson et al., 2024). The dataset spans a period of 42 years, from 1979 to 2020, and includes minimum and maximum temperatures as well as precipitation.

A structured questionnaire was administered during semi-structured interviews with 123 rice farmers from five (5) irrigated perimeters located in five (5) villages within the Yamoussoukro department. These perimeters include Zatta (20), Séman (16), Nanan (20), Kpoussoussou (23), and Subiakro (44) (Fig. 1). The selection of respondents was carried out using a convenience sampling method, also known as purposive or opportunistic sampling, as described by Ritchie et al. (2014). This non-probability sampling approach relies on accessibility, availability, relevance, and active involvement of participants, rather than on random selection or sample size requirements typical of probabilistic methods. As such, the sample consisted of voluntary rice farmers without strict randomization. This method is often recommended in participatory research conducted in rural settings (Babbie, 2010; GRET, 2019), as it is easy and quick to implement, cost-effective, and suitable for reaching hard-to-access populations.

The questionnaire consisted of both open-ended and closed-ended questions. The open-ended questions focused on farmers' perceptions of climate variability and change, their adaptation strategies, and the resources available to them. The closed-ended questions addressed farm characteristics and the technical implementation of irrigated rice cultivation in the study area. The

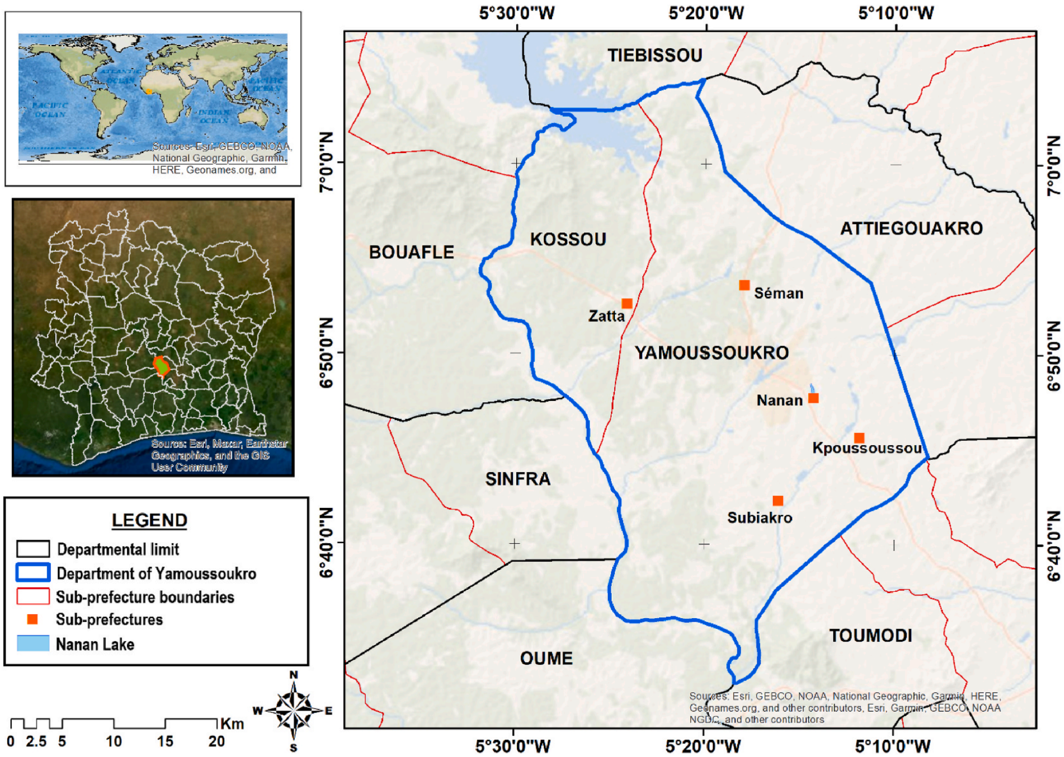


Fig. 1. Location of Yamoussoukro department and surveyed localities: Séman, Zatta, Nanan, Kpoussoussou and Subiakro. (Source: Author).

criteria of "Experience" and "Age" were used to select respondents, to account for their ability to observe climatic variability and change over past decades. Consequently, interviews were exclusively conducted with rice farmers who had been engaged in irrigated rice farming for over ten years and who were over 35 years old.

3. Data analysis

3.1. *Interviews*

Semi-structured interviews were conducted at each of the selected sites. These interviews involved administering a pre-designed questionnaire to the sampled rice farmers. The unit of observation chosen was the head of the household or farm, as the aim was to capture individual perceptions, levels of vulnerability, and the specific adaptation strategies implemented at the farm level.

3.2. *Analysis of climate variability*

The analysis of climate variability was structured around both quantitative and analytical approaches using statistical methods. Climate variability was assessed through the calculation of the Standardized Precipitation Evapotranspiration Index (SPEI) (Vicente-Serrano et al., 2010), which is used to monitor drought conditions. Pettitt's change-point detection test (Pettitt, 1979) and Student's T-test for mean comparison (Student, 1908) were also applied.

Trends in precipitation and temperature were analyzed using the Mann-Kendall trend test and simple linear regression. The Mann-Kendall test was applied at a 95 % confidence level, with the threshold of the standard normal statistic Z set at 1.96 (Chen et al., 2020). A trend (increasing or decreasing) is considered statistically significant when the absolute value of Z is greater than 1.96; otherwise, it is not significant. Simple linear regression was used to fit a regression line ($\mathbf{Y = aX + b}$) and estimate the slope "a" to characterize the direction and rate of change (Dion et al., 2009). In this model, "Y" represents the dependent variable (precipitation or temperature), "a" is the regression coefficient (slope), "X" is the independent variable (time), and "b" is the intercept. A positive slope ($a > 0$) indicates an increasing trend, while a negative slope ($a < 0$) reflects a decreasing trend.

The onset, duration, and end of the rainy season were determined using the agronomic method developed by Sivakumar (Sivakumar et al., 1988; Balme et al., 2005).

3.3. *Analysis of rice farmers' vulnerability to climate change*

The approach adopted to analyze the vulnerability of rice farmers in the Yamoussoukro department to climate change is the matrix method recommended by the World Bank (Chédé, 2012a; Pereira, 2012a; Amuzu et al., 2018), combined with a multi-criteria analysis of adaptation strategies (Rotich and Mulungu, 2017). This participatory approach integrates both quantitative and qualitative data and involves identifying climate-related risks and their likelihood of occurrence, as well as the variables likely to be affected by these risks. Subsequently, impact, adaptation, vulnerability, and decision matrices are developed, and the most effective adaptation strategies are prioritized. The adopted approach follows the steps below.

a **Identification of climate risks and their impacts**

The main climate risks likely to affect irrigated rice farming were identified based on respondents' answers, climate variability analysis, and relevant literature. The probability of occurrence of each identified climate risk was assessed using the terminology proposed by the IPCC (2007). A background color was assigned to each level of probability in a summary table. Accordingly, a risk is considered: (i) "extremely likely" if its probability of occurrence exceeds 95 %; (ii) "very likely" if the probability exceeds 90 %; (iii) "likely" if it exceeds 66 %; and (iv) "unlikely" if it is greater than 50 %. The occurrence of a given risk generates impacts on various components of the farming system (water availability, soil, crops, etc.). Depending on the severity, the impact may be classified as "minor," "moderate," "major," or "severe."

b **Development of the climate risk impact matrix**

The climate risk impact matrix is used to highlight the degree of impact—or level of severity—of each identified risk on the various potentially affected variables within the irrigated rice production system. The degree of impact of a risk on a given variable is determined by combining the frequency of occurrence of the risk with the magnitude of its potential consequences. The resulting impact level may be classified as "low," "moderate," "high," or "extreme." The impact matrix is therefore constructed by aggregating the color assigned to the impact level of the risk with the specific impact it generates (Amuzu et al., 2018).

c **Determination of adaptive capacity**

Some authors argue that farmers' adaptive capacity to climate change depends on the resources (financial, logistical, etc.) available to them (Chédé, 2012; Eyasmin et al., 2017). Livelihood resources include capacities, possessions (both material and social), and activities necessary for survival. Thus, the Livelihood Assessment method (Schultz et al., 2004) was used to determine the adaptive capacity of rice farmers in the Yamoussoukro department. This method primarily focuses on analyzing livelihood indicators such as physical, social, natural, financial, and human capital. It has notably been applied by Bokoto de Semboli (2008); Chédé (2012a).

Each indicator may be composed of one or several sub-indicators or resources. The determination of adaptive capacity begins by identifying the sub-indicators that make up the basic indicators. Then, each sub-indicator is assigned a score ranging from 0 to 3, based on its availability and accessibility. For a given basic indicator, the score of each sub-indicator is calculated as the average of all scores for that sub-indicator among the surveyed rice farmers, by irrigation perimeter and for the entire study area. The average scores of the sub-indicators are then used to determine the score of the basic indicator. The overall average score of all basic indicators is then used to assign a final score reflecting the adaptive capacity of rice farmers across the study area. Adaptive capacity is finally classified on the adaptive capacity diagram according to the following scale: (i) "low" if the adaptive capacity score is less than or equal to 1; (ii) "medium" if it is greater than 1 and less than or equal to 2; (iii) "high" if the adaptive capacity score is greater than 2.

d Development of the vulnerability matrix

The vulnerability matrix aims to illustrate the susceptibility of rice farmers to the impacts of climatic variations. It highlights the climate risks that can affect, on the one hand, the practice of irrigated rice cultivation and, on the other hand, the farmers themselves through their livelihoods. Before constructing the vulnerability matrix, the degree of vulnerability of the rice farmers is determined. This determination involves confronting the degree of impact of climate risk with the adaptive capacity to that risk. A color is then assigned to each degree of vulnerability. Depending on its magnitude, the degree of vulnerability can be classified as "low", "moderate", or "high". The vulnerability matrix is then populated by aggregating the color assigned to the degree of vulnerability with the adaptive capacity to a given climate risk (Amuzu et al., 2018).

e Multi-criteria analysis and prioritization of adaptation strategies

The strategies developed by farmers in response to the effects of climatic variations depend on their understanding of past, present, and future climate changes. In this step, adaptation strategies are ranked according to their priority based on the degree of vulnerability to threats. The higher the degree of vulnerability, the higher the priority of the adaptation strategy. Since the degree of vulnerability has already been determined, the color assigned to it is now combined with the adaptation strategies to address the impact of each risk, thus forming the adaptation matrix.

The identified adaptation strategies are ranked based on prioritization criteria, which include cost, effectiveness, speed, capacity, acceptability, and ease of implementation. These criteria are considered important because they influence the implementation of adaptation strategies (Rotich and Mulungu, 2017) and are used to develop the decision matrix. An adaptation strategy is considered "low," "medium," or "high" depending on how much the criterion favors its implementation. According to the relevance of the adaptation strategy, a score is assigned to each prioritization criterion: 1 = low; 2 = medium; 3 = high. For a given adaptation strategy, the sum of the scores for each prioritization criterion allows its initial ranking relative to other strategies. Thus, adaptation strategies with a total criterion score below 12 are discarded in favor of those scoring 12 or above. In a second step, adaptation strategies are prioritized in descending order of their criterion scores. The most prioritized adaptation strategy over others is the one with the highest criterion score, and so on.

4. Results

4.1. Farmers' perception of climate change

Table 1 presents the results of farmers' perceptions regarding the effects of climate change in the Yamoussoukro department.

Table 1
Rice farmers' perceptions in the Yamoussoukro department on agro-climatic variables.

Rice farmers' perception of:		Frequency	Rate (%)
Climate change	Yes	115	93.5
	Not	8	6.5
Rainfall	More rain	14	11.4
	Less rain	109	88.6
The start of the rainy season	Early beginnings	24	19.51
	Late start	99	80.49
The end of the rainy season	Early Endings	75	61.0
	Late endings	48	39.0
The duration of the rainy season	Longer	12	9.8
	Shorter	96	78.0
	I have no idea	15	12.2
Temperatures	Higher	100	81.30
	Weaker	7	5.69
	I have no idea	16	13.01
Total		**123**	**100**

Climate variability and change are unanimously recognized across all surveyed irrigation schemes. Moreover, more than 115 farmers, representing 93 % of the samples surveyed, report perceiving changes in the climate behavior within the study area. The proportion of respondents who believe that rainfall is decreasing is 88.6 %, while 11.4 % of producers think otherwise.

For nearly all farmers (86 %), the rainy season typically starts in March and ends in July, then resumes at the end of August and finishes in late November. However, they perceive that the rain now starts later (80 %) than in the past and end much earlier (61 %). A large proportion of the respondents (78 %) affirm that the rainy season is shorter than before. Additionally, 12.2 % (i.e., 15 farmers) have no idea about the current duration of the rainy season.

According to 81.3 % (100 farmers), temperatures in Yamoussoukro have increased over the past 20 years (1980–2000), while 5.69 % (7 farmers) say otherwise. The remaining 13 % stated they have no knowledge regarding this aspect.

4.2. Characterization of climate variability and rainy seasons

4.2.1. Evolution of precipitation

Fig. 2-a illustrates the interannual variations of the Standardized Precipitation Evapotranspiration Index (SPEI) over the period 1979–2020. A succession of dry and wet sequences is observed. These variations are characterized by a gradual decrease in the intensity of wet periods alongside a progressive increase in the intensity of dry periods. The SPEI indicates a dominance of wet sequences from 1979 to 2009. However, the last decade (2010–2020) is marked by a strong dominance of dry sequences. The trend of precipitation evolution is shown in Fig. 2-b. The analysis reveals a strong downward trend in precipitation with a negative regression slope ($a = -2.50$). However, the Mann-Kendall test statistics ($Z = -1.53 < 0$ and $|Z| < 1.96$) indicate a non-significant downward trend that might not be solely attributed to time.

4.2.2. Evolution of minimum temperatures

The Pettitt test revealed a breakpoint in minimum temperatures in 2004 (Fig. 3-a). The means of the sub-series before the breakpoint (M1 = 20.98 °C) and after the breakpoint (M2 = 22.41 °C) are highly significantly different according to the Student's t-test, with a difference of 1.43 °C. Results from linear regression and the Mann-Kendall test show a non-significant upward trend in minimum temperatures (Fig. 3-b), with a positive slope a (0.0237) and Z statistic ($0.52 < 1.96$).

4.2.3. Evolution of maximum temperatures

Linear regression and the Mann-Kendall test reveal a strong upward trend in maximum temperatures, with a regression slope of 0.0386 and a Z value of $5.35 > 1.96$ (Fig. 4-a). A breakpoint occurred in 1996 (Fig. 4-b), with the means of the sub-series before the breakpoint (M1 = 31.91 °C) and after the breakpoint (M2 = 32.86 °C) being highly significantly different according to the Student's t-test (difference M2 – M1 = 0.95 °C).

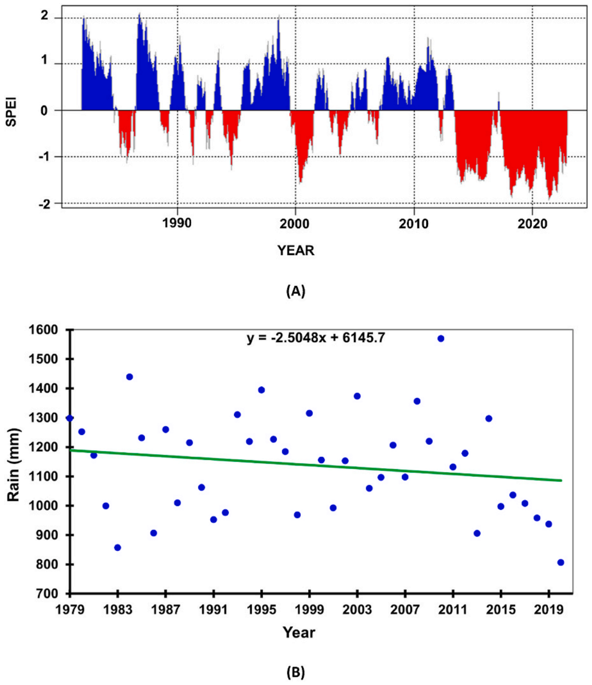


Fig. 2. Annual change in standardized precipitation and evapotranspiration index (A) and rainfall trend (B) in Yamoussoukro from 1979 to 2020.

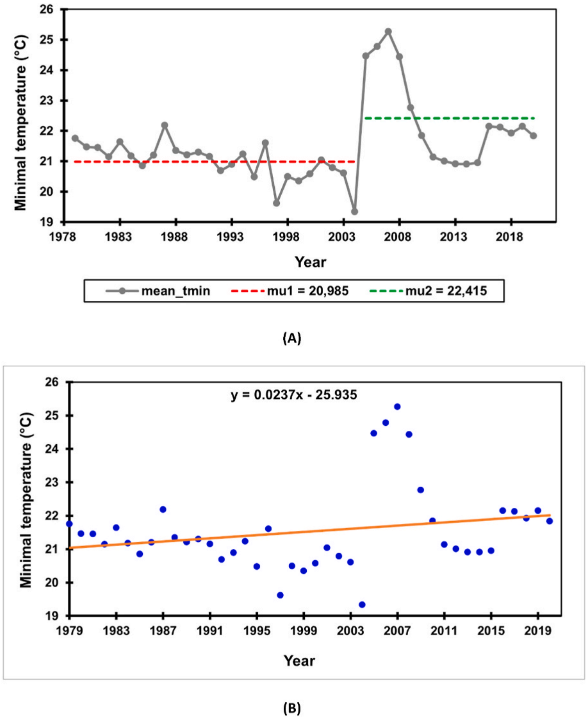


Fig. 3. Annual change (A) and trend (B) in minimum temperatures in Yamoussoukro from 1979 to 2020; mu1: average before rupture, mu2: average after rupture.

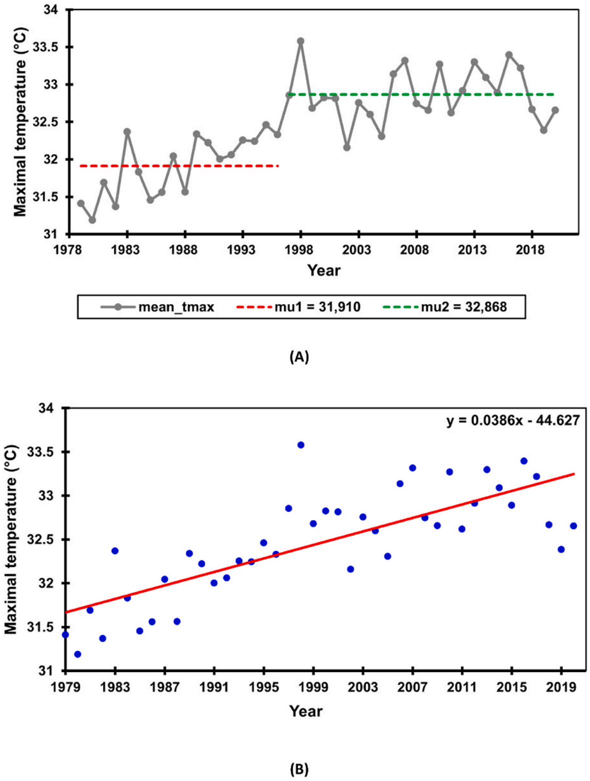
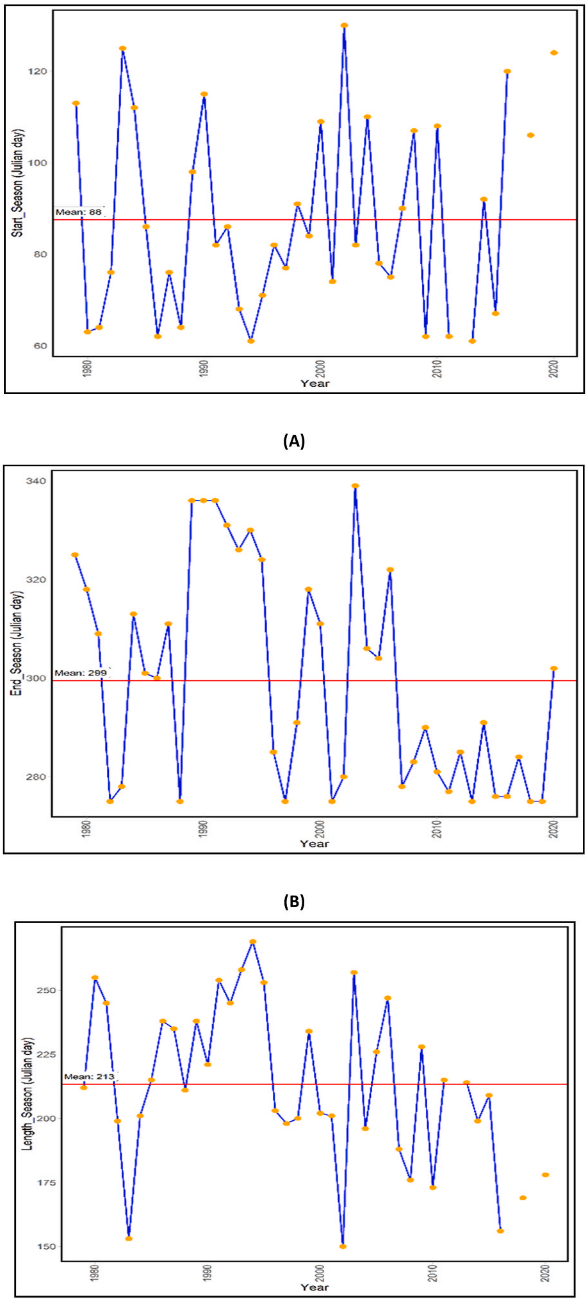


Fig. 4. Annual change (A) and trend (B) in maximum temperatures in Yamoussoukro from 1979 to 2020; mu1: average before rupture, mu2: average after rupture.

4.2.4. Characterization of the rainy seasons

The onset, end, and duration of the rainy season in Yamoussoukro over the period 1979–2020 are illustrated in Fig. 5-a, 5-b, and 5-c, respectively. The results show increased interannual variability in the start dates of the season, ranging between March 1st and May 9th, with an average date of March 28th (the 88th Julian day). Early onset of the rainy season occurs between March 1st (day 61) and March 8th (day 68). Furthermore, late onset occurs between April 17th (day 108) and May 9th (day 130). More late starts than early starts are observed (Fig. 5-a). The start of the rainy season is delayed on average by 2 days per decade.

The end dates of the rainy season range between October 1st and December 4th, with October 25th (the 299th Julian day) as the average. High annual variability is also observed in the end dates of the rainy seasons. Early end dates fall between October 1st (day 275) and October 4th (day 278), while late end dates occur between November 14th (day 319) and December 4th (day 339) (Fig. 5-b).



(A)

(B)

(C)

Fig. 5. Annual change in the start (A), end (B) and duration (C) of rainy season in Yamoussoukro from 1979 to 2020.

The end of the rainy season has advanced on average by 7 days between the last two decades (2000–2010 and 2010–2020).

The duration of the rainy season is as highly variable year-to-year as its start and end dates. The rainy season lasts on average 213 days. The minimum duration is 150 days, while the maximum duration is 269 days. A shortening of the rainy season by an average of 18 days is observed during the last two decades. However, a period of long rainy seasons (1979–1999) and a period of short rainy seasons (2000–2020) are noted (Fig. 5-c).

4.3. Vulnerability of rice farmers to climate change

4.3.1. Impact matrix of climate risks

The analysis of climate variability, interviews with rice farmers, and the literature have identified the following as plausible climate risks that may impact irrigated rice production: decreased rainfall, delayed onset of the rainy season, shortening of rainy seasons, and rising temperatures. Accordingly, the variables of the irrigated rice production system considered likely to be affected are irrigation water availability, soils, and crops.

The impact matrix (Table 2) shows that decreased rainfall and rising temperatures have a "high" degree of impact on water availability. Meanwhile, delayed onset and shortening of the rainy season have a "medium" degree of impact on water availability. These latter risks have a "low" and "medium" degree of impact on soils and crops, respectively. Rising temperatures have a "high" degree of impact on both soils and crops. In contrast, decreased rainfall has a "low" and "medium" degree of impact on soils and crops, respectively.

4.3.2. Adaptive capacity of rice farmers to climate change

Fig. 6 presents the results of the estimation of the adaptive capacity of rice farmers to climate change in the Yamoussoukro department. It can be observed that the average adaptive capacity level of rice farmers in the department is 1.93. This value, which lies between 1 and 2, indicates a moderate adaptive capacity of rice producers in Yamoussoukro.

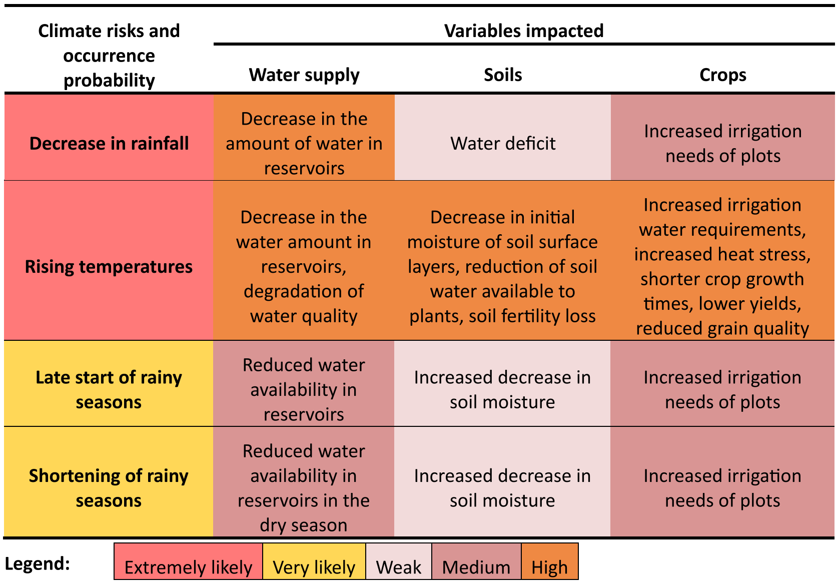
4.3.3. Vulnerability matrix of rice farmers to climate change

The overall impact level across all identified climate risks is moderate. Given that the adaptive capacity of the rice farmers is also moderate, the resulting vulnerability levels are categorized as low, moderate, and high. It is therefore concluded that the rice farmers in the Yamoussoukro department have a moderate level of vulnerability (Table 3).

4.3.4. Adaptation matrix and prioritization of adaptation strategies

Fig. 7 presents the various adaptation strategies adopted by the surveyed rice farmers to cope with the impacts of climate change. Among them, 84 % reported changing rice varieties over the past 20 years, 89 % increased their seeding density, 93 % adopted medium-cycle rice varieties, 33 % changed their farming techniques, 76 % expanded their cultivated area, 35 % introduced other crops (such as vegetables) within the scheme, 39 % engaged in alternative activities besides rice farming, 53 % practiced late sowing, and 16 % adopted alternate wetting and drying irrigation. The vulnerability level (represented by color) is overlaid onto each adaptation

Table 2
Matrix of climate risk impacts on irrigated rice variables.



Climate risks and occurrence probability	Variables impacted		
	Water supply	Soils	Crops
Decrease in rainfall	Decrease in the amount of water in reservoirs	Water deficit	Increased irrigation needs of plots
Rising temperatures	Decrease in the water amount in reservoirs, degradation of water quality	Decrease in initial moisture of soil surface layers, reduction of soil water available to plants, soil fertility loss	Increased irrigation water requirements, increased heat stress, shorter crop growth times, lower yields, reduced grain quality
Late start of rainy seasons	Reduced water availability in reservoirs	Increased decrease in soil moisture	Increased irrigation needs of plots
Shortening of rainy seasons	Reduced water availability in reservoirs in the dry season	Increased decrease in soil moisture	Increased irrigation needs of plots

Legend: Extremely likely | Very likely | Weak | Medium | High

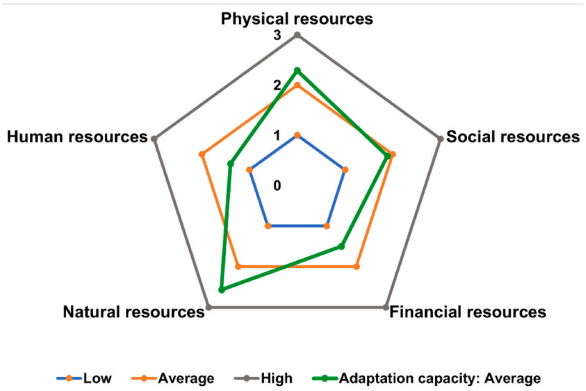
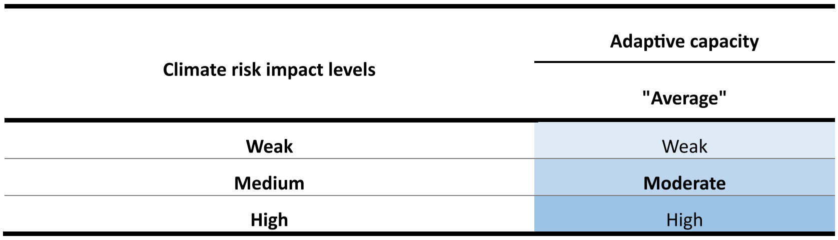


Fig. 6. Rice farmers' adaptive capacity in Yamoussoukro department: the value of physical resources is 2.29, social resources is 1.89, financial resources is 1.5, natural resources is 2.57 and human resources is 1.4; giving an adaptive capacity of 1.93 (average).

Table 3
Rice farmer's vulnerability matrix in the department of Yamoussoukro.



Climate risk impact levels	Adaptive capacity
	"Average"
Weak	Weak
Medium	**Moderate**
High	High

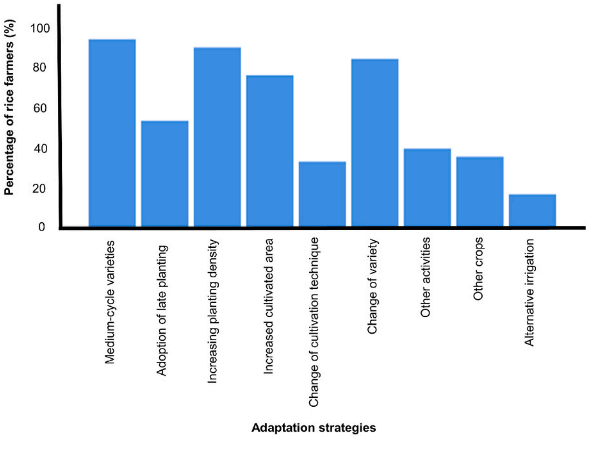
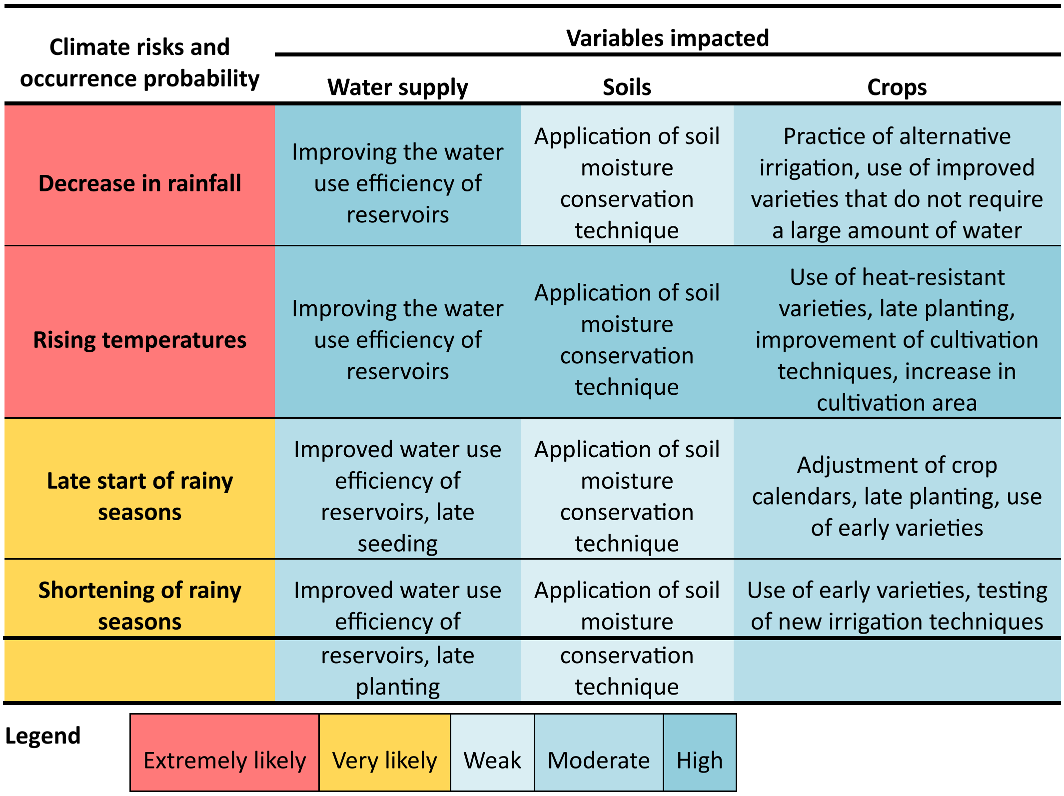


Fig. 7. Rice farmers' adaptation strategies in Yamoussoukro department.

strategy to generate the adaptation matrix (Table 4).

The results of the prioritization of various adaptation strategies for irrigated rice farming in response to climate change impacts in the Yamoussoukro department are presented in Table 5. Except for practicing other crops and/or activities, all strategies were retained. The most prioritized adaptation strategies are improvement of farming techniques, adoption of early-maturing and heat-tolerant rice varieties, alternate wetting and drying irrigation, and adjustment of cropping calendars. The least prioritized strategies include the expansion of cultivated areas and the modification of nursery dates.

Table 4
Climate change adaptation Matrix.



Climate risks and occurrence probability	Variables impacted		
	Water supply	Soils	Crops
Decrease in rainfall	Improving the water use efficiency of reservoirs	Application of soil moisture conservation technique	Practice of alternative irrigation, use of improved varieties that do not require a large amount of water
Rising temperatures	Improving the water use efficiency of reservoirs	Application of soil moisture conservation technique	Use of heat-resistant varieties, late planting, improvement of cultivation techniques, increase in cultivation area
Late start of rainy seasons	Improved water use efficiency of reservoirs, late seeding	Application of soil moisture conservation technique	Adjustment of crop calendars, late planting, use of early varieties
Shortening of rainy seasons	Improved water use efficiency of reservoirs, late planting	Application of soil moisture conservation technique	Use of early varieties, testing of new irrigation techniques

Legend	Extremely likely	Very likely	Weak	Moderate	High

Table 5
Prioritization of identified adaptation strategies.

Adaptation strategies	Cost	Efficiency	Speed	Capacity	Acceptability	Ease	Total	Rank
Increased planting density	1	3	2	3	1	3	**13**	**7**
Use of early and heat-resistant varieties	2	3	2	3	3	3	**16**	**1**
Improvement of cultivation technique	2	3	3	2	3	3	**16**	**1**
Increase in the cultivated area	2	2	2	2	2	2	**12**	**10**
Practice of other cultures and/or activities	2	2	2	1	2	2	**11**	
Adoption of late planting	1	3	3	2	2	3	**14**	**3**
Practice of alternative irrigation	1	3	2	2	3	3	**14**	**3**
Increased use of fertilizers	3	2	2	2	2	2	**13**	**7**
Application of soil moisture conservation technique	3	2	2	2	2	2	**13**	**7**
Adjustment of crop calendars	3	2	2	2	2	3	**14**	**3**
Improving water use efficiency	3	2	3	2	2	2	**14**	**3**

5. Discussion

5.1. Climate variability and rice farmers' perception

The analysis of the rainfall time series reveals an interannual decrease in rainfall amounts in Yamoussoukro over the period 1979–2020. Indeed, both linear regression and the Mann-Kendall test indicate a decreasing trend in annual rainfall during the study period. However, this trend contrasts with the findings of Kouassi and Brou (2020) and Sawadogo (2020), who reported an increasing trend in rainfall from 1980 to 2017 and from 1975 to 2015, respectively. This discrepancy may be explained, on the one hand, by differences in the periods analyzed. On the other hand, the observed decline may also result from the decrease in annual rainfall between 2017 and 2020, from 1007 mm–807 mm, representing a 200 mm difference.

The analysis of the Standardized Precipitation Evapotranspiration Index (SPEI) indicates an interannual variability in rainfall in Yamoussoukro, characterized by alternating dry and wet periods. This pattern was also reported by Sawadogo (2020) in

Yamoussoukro between 1975 and 2015, based on the Standardized Precipitation Index (SPI). Additionally, Sawadogo (2020) identified a dry period between 1975 and 1992 and another between 2011 and 2015, separated by a wet phase from 1993 to 2010. Furthermore, N'guessan et al. (2014) observed a climate pattern indicating a normalization of rainfall starting in the early 1990s (1992–1993). The results of the present study are consistent with the wet period from 1993 to 2010, as well as the dry phase from 2011 to 2015. The calculated SPEI values also showed that the last decade (2010–2020) has been marked by a strong predominance of dry periods. This observation was confirmed by most surveyed rice farmers (around 90 %), who stated that rainfall has significantly declined over the past decade.

Rainfall variability in Yamoussoukro has resulted in changes to the key characteristics of the rainy season: onset, cessation, and duration. About 80 % of farmers surveyed reported that the rains are starting increasingly later compared to the past. Additionally, 61 % of rice farmers observed that the rainy seasons are ending earlier than they used to. This perception regarding the onset and end of the rainy season is confirmed by the analysis of rainfall observations from 1979 to 2020. These findings are consistent with those reported by Kouassi and Brou (2020) for the same study area. Furthermore, Goula et al. (2006) argue that in Côte d'Ivoire, the onset of the rainy season is experiencing increasing delays, with the length of the delay varying greatly from one region to another. Late onsets and early terminations have also been documented in Côte d'Ivoire in the Sassandra River basin by Kouakou et al. (2017). Van de Giesen et al. (2010) predicted that the onset of the rainy season would shift to later dates in West Africa, while the cessation would remain relatively stable. Kouassi and Brou (2020) also reported strong variability in the onset and cessation dates, a finding that aligns with the results of this study. Interruptions in the detection of the start dates of the rainy season—and consequently in the estimation of its duration—were observed in 2012, 2017, and 2019. This may be attributed to the variability in the onset dates of the rainy season, as well as the criteria applied in the Sivakumar method used in this study. Therefore, the precise determination of the beginning and end of rainy seasons remains challenging. Indeed, according to Kouakou et al. (2017), the high variability in the onset of rainy seasons makes it difficult to accurately identify the starting dates. Moreover, as Adefolalu (1986) pointed out, it is difficult to determine whether rainy seasons are truly starting later or ending earlier.

Many rice farmers observed that the rainy season has shortened compared to previous years. This observation is confirmed by the analysis of the duration of the rainy seasons from 1979 to 2020, which revealed minimum, average, and maximum durations of 150, 213, and 269 days, respectively. Kouakou et al. (2017) reported that the current lengths of the rainy season in Côte d'Ivoire range between 61 and 200 days. The findings of Kouassi and Brou (2020) fall within a similar range, with minimum, average, and maximum durations of 138, 205, and 249 days, respectively, over the period 1980–2017. Kouassi et al. (2018) obtained slightly lower but comparable results (an average of 191 days) for the period 1951–2000. These differences may be attributed to variations in the periods of analysis, as well as to the criteria used in the Sivakumar method, given the high rainfall variability observed in the study area. A shortening of the rainy season's duration by an average of 18 days was also observed between the last two decades. Djè (2014) reported a reduction in the rainy season length ranging from 10 to 28 days in central Côte d'Ivoire.

Farmers reported that the rainy season generally begins in March, ends in July, resumes in August, and concludes in late October. This observation was also made by Kouassi et al. (2018), who identified two rainy seasons in the Yamoussoukro Department. However, according to Kouassi and Brou (2020), the rainfall regime in Yamoussoukro is shifting from a bimodal to a unimodal pattern, extending from March to October. Furthermore, Diomandé et al. (2017) indicated that the bimodal rainfall regime in the central region of Côte d'Ivoire (V Baoulé) is gradually transitioning toward a unimodal regime. The findings of this study confirm this trend. Additionally, a short period of decreased rainfall occurring between mid-July and mid-August was observed. This period can be described as a brief dry season, though it remains relatively wet, as also noted by Sawadogo (2020).

Maximum temperatures in the Yamoussoukro Department are, on average, lower (33 °C) than the threshold considered harmful to rice cultivation (35–38 °C). Moreover, minimum temperatures average around 22 °C. At or below this threshold, rice can suffer from adverse effects such as uneven ripening, incomplete heading, delayed panicle initiation and flowering, as well as reduced tillering (FAO, 2003). Farmers' perceptions of temperature trends in Yamoussoukro generally align with the results of statistical analyses of this agroclimatic variable. Most respondents reported experiencing higher temperatures today compared to the past. This perception is supported by Mann-Kendall and linear regression tests on both maximum and minimum temperatures, which reveal an upward trend, although less pronounced for minimum temperatures. Similarly, Kouassi & Brou (2020) found an increasing trend in maximum temperatures, but a decreasing trend in minimum temperatures over the 1980–2017 period in Yamoussoukro. The divergence in trends for minimum temperatures may be attributed to differences in the study periods (1979–2020 in the present study). According to Yao et al. (2013), temperatures in the pre-forest zone of central Côte d'Ivoire increased by an average of 1.6 °C between 1960 and 2010. This confirms the upward temperature trend observed in the present study. The findings of Djè (2014) further support this trend. According to this author, the overall warming in Côte d'Ivoire has averaged 0.5 °C since the 1980s and is projected to reach 3 °C by 2100. At the regional scale, temperatures in West Africa have increased by 0.2 °C–0.8 °C per decade since the late 1970s (CEDEAO-CSAO/OCDE, 2008).

Change points were identified in the maximum and minimum temperature series using the Pettitt test, occurring in 1996 and 2004, respectively. The mean values before the change points were 20.98 °C and 31.91 °C, and the means after the change points were 22.41 °C and 32.86 °C, respectively, for minimum and maximum temperatures. These shifts indicate an abrupt increase in temperatures in Yamoussoukro, with a slightly greater increase observed in minimum temperatures, as reflected in the difference between the means. Rice farmers' perceptions of climate variability and change in the Yamoussoukro Department appear to be consistent with the historical agroclimatic trends derived from meteorological data. Farmers in Yamoussoukro are therefore aware of climate change and its impact on their production systems. Doumbia and Depieu (2013) made similar observations among rained rice producers in central-western Côte d'Ivoire. Likewise, Comoé et al. (2014) reported similar findings among farmers in the northern part of the country. Bojang et al. (2020) also obtained comparable results among rice farmers in The Gambia, West Africa. Farmers are aware of climate variability and change (Gbetibouo, 2009; Vissoh et al., 2012; Loko et al., 2013; Bojang et al., 2020; Gana et al., 2020) and perceive these phenomena as detrimental to agricultural production (Maka et al., 2019) and to socio-economic factors (Mustapha et al., 2012). Overall, rice farmers in Yamoussoukro perceive an increase in temperatures and a decrease in rainfall. Moreover, in Côte d'Ivoire, rural populations perceive climate change as a decrease in rainfall, a modification and shortening of the rainy season, and an extension of the dry season. Some rice farmers believe that the effects of climate change are not uniform across all rice varieties. According to their perception, the longer the crop cycle, the less it is affected by climatic disturbances (MINEDD-RCI, 2013). Similar findings regarding farmers' perceptions of climate change have been reported by Eyasmin et al. (2017) among rice farmers in Bangladesh and by Devkota et al. (2018) among rice farmers in Nepal. Indeed, farmers' perceptions of climate trends generally align with the results of meteorological data analysis (Chédé, 2012b; Mubiru et al., 2018). However, some discrepancies exist between observations and farmers' perceptions, particularly regarding the rainiest and driest months, the onset, and the duration of the rainy season. Farmers' perceptions may differ from observational data in terms of precision, but they are generally consistent in terms of trends. According to Agossou (2008), farmers develop empirical perceptions of climate change. In some cases, farmers' perceptions may contradict observed climatic trends. This was observed by Allé et al. (2013) among farmers in southern Benin.

5.2. Adaptive capacity and vulnerability of rice farmers

The decline in rainfall, rising temperatures, and changes in the onset and duration of the rainy seasons represent the main climatic risks for irrigated rice cultivation in the Yamoussoukro Department. These risks were also identified by Mubiru et al. (2018) in Uganda, East Africa. Furthermore, reduced rainfall and increasing temperatures are the climatic risks with the greatest impact on key variables of the production system. Khanal et al. (2018) reported similar findings in Nepal. The observed temperature rise in the study area is likely to significantly affect all identified variables, namely water availability, soils, and crops. Soil appears to be less affected by other climatic risks aside from rising temperatures. Decreased rainfall and changes in the rainy season have limited impact on soil quality. However, higher temperatures could significantly reduce soil moisture and degrade soil structure.

Rainfall, the onset, and the duration of the rainy season represent moderate risks for irrigated rice production. However, this does not imply that they should be overlooked in the planning of adaptation strategies. Rainfall, for instance, is a key component of both the hydrological balance of reservoirs and the water balance of rice fields. Rain contributes through direct precipitation on reservoirs and effective rainfall on cultivated plots, and it constitutes the main inflow to water bodies, thereby determining water availability, especially during dry seasons. As shown by the climate risk impact matrix, declining rainfall poses a significant threat to both the supply and demand of water in irrigated rice systems in the Yamoussoukro Department. Some interviewed rice farmers reported that, during certain dry seasons, the reservoirs intended for irrigation of rice schemes were unable to fulfill their intended function.

The findings of this study suggest that the surveyed rice farmers exhibit a moderate level of adaptation to the impacts of climate change, a result also reported by Mabe et al. (2012) in Ghana and Eyasmin et al. (2017) in Bangladesh. The adaptive capacity of rice producers in the Yamoussoukro Department may be explained by their livelihood assets, particularly their physical, social, and natural capital, as they are located on the urban periphery where they have relatively easy access to various resources. In fact, these rice farmers benefit from access to improved seed varieties, agricultural equipment, and irrigation infrastructure (physical capital). They are members of farmer-based organizations and regularly receive support from the government and non-governmental organizations (social capital). Moreover, they have access to fertile land and water resources (natural capital), which enables them to sustain rice production. However, this adaptive capacity may be limited by factors such as lack of capital, insufficient empowerment through extension services, limited access to climate change information and credit, lack of training and education, and the high cost of agricultural inputs (Mabe et al., 2012; Eyasmin et al., 2017; Chete, 2019). For instance, one or more adopted strategies implemented without access to prior information could counteract or nullify the benefits of another, ultimately diminishing adaptation outcomes. Indeed, adaptive capacity refers not only to access to climate hazard information but also to the effective use of this information in making appropriate decisions (Jones et al., 2018).

The moderate adaptive capacity observed has led to a correspondingly moderate level of vulnerability among rice farmers to the adverse effects of climate change. These findings contrast with those of Chédé (2012a) in Benin, who reported a high level of vulnerability due to the low adaptive capacity of the farmers studied. This discrepancy may, of course, be attributed to differences in adaptive capacity, i.e., livelihood assets, between the two groups of farmers. Similarly, Pereira (2012b) and Ho et al. (2021) found that farmers were highly vulnerable to climate change in Cape Verde and Vietnam, respectively. Overall, rice farmers in Yamoussoukro appear to be moderately susceptible to the negative impacts of climate change and are therefore moderately capable of coping with them. Their vulnerability and adaptive capacity could be significantly enhanced through the strengthening of existing adaptation practices and the adoption of new, more effective and sustainable strategies. Farmers often adjust their own agricultural practices in response to climate change impacts (Barrett et al., 2025). Indeed, rice farmers in Yamoussoukro already employ a range of adaptation strategies, including changing rice varieties and cultivation techniques, increasing sowing density and cultivated area, adopting medium-cycle varieties and other crops (e.g., vegetables), practicing late sowing and alternate irrigation, and engaging in non-rice-based livelihood activities.

These adaptation strategies have also been adopted by rice farmers in Nepal (Devkota et al., 2018). Moreover, these adaptation options are often implemented by farmers without consideration of their effectiveness, feasibility, or sustainability and tend to vary across locations. This observation is consistent with that of Bele et al. (2010) in the Congo and Central African Republic, who noted that farmers are aware that their endogenous adaptation practices are essentially experimental. The selection of these strategies by rice farmers may be influenced by the factors affecting adaptive capacity mentioned earlier. Information and Communication Technologies (ICTs) could play a crucial role in supporting the adoption of adaptation strategies by farmers. As demonstrated in the study by Devkota and Phuyal (2018), access to climate change information through ICTs enabled Nepali rice farmers to implement their adaptation strategies and thereby strengthen their adaptive capacity. Furthermore, rather than prescriptive recommendations, farmers need access to information on available options to enhance their resilience and adaptability to both current and anticipated future climate conditions (Kihara et al., 2012).

The adaptation matrix revealed that adaptation strategies should focus primarily on decreased rainfall and rising temperatures to mitigate their impact on water availability, soil quality, and crop productivity. Regarding water availability, improving water use efficiency and shifting the sowing date are essential. For soil, techniques that conserve soil moisture should be implemented. At the crop level, the most feasible adaptation practices include the use of heat-tolerant varieties, adjustments to planting densities, improved agronomic techniques, and an expansion of cultivated areas. Overall, this study identifies ten (10) adaptation options likely to strengthen the resilience of rice farmers in the Yamoussoukro department. These are prioritized as follows: use of early-maturing and heat-tolerant varieties, improvement of agronomic practices, adoption of late sowing, application of alternate wetting and drying (AWD) irrigation, enhancement of water use efficiency, adjustment of cropping calendars, increase in planting density, greater use of fertilizers, application of soil moisture conservation techniques, and expansion of cultivated land. These adaptation options are consistent with the projected strategies previously identified in this study, notably changes in sowing dates and irrigation scheduling. The findings are also like those of Chédé (2012a), who recommended the use of early and heat-tolerant varieties and the improvement of cropping practices as top adaptation priorities. Furthermore, according to Ali and Erenstein (2017), the main adaptation practices used by farmers in Pakistan were shifting sowing dates, adopting heat-tolerant crop varieties, and switching to alternative crops. Postponing the sowing date significantly reduces irrigation demand (Acharjee et al., 2019) and may lead to increased yields. This is confirmed by the results of this study, which showed that yields on the Nanan irrigation scheme increased when the sowing date was delayed by 30 days.

6. Conclusion

This study addressed a critical research issue: the analysis of smallholder farmers' vulnerability to the impacts of climate change in Africa. It specifically focused on the vulnerability of rice farmers in the Yamoussoukro department, located in central Côte d'Ivoire, West Africa. The main objective was to gain a deeper understanding of their perception of climate change, their adaptive capacity, and their level of vulnerability to the effects of this phenomenon on their production systems.

The results reveal that the surveyed rice farmers are generally aware of climate change and its consequences for agriculture. Their adaptive capacity is considered moderate, and their vulnerability, likewise, is assessed as moderate. Several adaptation strategies are already being implemented. The most prioritized strategies identified in this study are the improvement of agronomic practices and the adoption of early-maturing, heat-tolerant rice varieties. Conversely, strategies such as the expansion of cultivated areas and the modification of nursery dates are among the least favored. While these practices can contribute to strengthening their resilience, rice farmers still face numerous constraints that hinder their ability to adapt. These include limited financial capital, high input costs, restricted access to climate information, difficulties in accessing credit, and insufficient technical support.

Like any research based on interviews, this study has certain limitations. The data collected, being self-reported, may reflect subjective perceptions that do not always align with objective realities. For instance, some rice farmers may claim to adopt specific adaptation strategies without implementing them, which can lead to overestimation or misinterpretation of the reported practices. Moreover, the use of voluntary sampling may limit the generalizability of the findings to the entire study area. The Yamoussoukro department has specific climatic, socio-economic, and agricultural characteristics, which constrain the extrapolation of the results to other rice-growing regions in Côte d'Ivoire. It would therefore be relevant to extend this study to other rice-producing areas in the country to develop regional typologies of rice farming vulnerability to climate change. Furthermore, self-reported data could be complemented by direct field observations conducted over multiple cropping seasons and by a multidisciplinary approach incorporating tools such as Geographic Information Systems (GIS) to analyze land use changes and farming practices within irrigated rice schemes.

Ultimately, this research makes a significant contribution to understanding local climate vulnerability dynamics in the rice sector in Côte d'Ivoire. It highlights the urgent need to strengthen technical, institutional, and financial support to transform existing adaptive capacities into effective levers for resilience. The methodological approach adopted can serve as a foundation for other studies examining agricultural vulnerability to climate change, with the aim of identifying the most effective adaptation strategies. Based on the findings, public policymakers, development partners, and agricultural stakeholders now have a solid empirical basis for designing more proactive, targeted, and equitable policies in response to the growing challenges posed by climate change.

CRediT authorship contribution statement

Konan Jean-Yves N'Guessan: Conceptualization, Data curation, Formal analysis, Methodology, Software, Writing – original draft, Writing – review & editing, Investigation. **Botou Moise Adahi:** Conceptualization, Funding acquisition. **Arthur Brice Konan-Waidhet:** Funding acquisition, Supervision, Validation. **Barbara Sidoine Abonoua Kouassi:** Conceptualization, Data curation, Investigation, Methodology, Writing – original draft. **Jonathan Aser Engelvin Seri:** Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Léandre Junias Kra:** Formal analysis, Investigation. **Satoh Masayoshi:** Supervision. **Nogbou Emmanuel Assidjo:** Funding acquisition, Supervision, Validation.

Ethical statement

The research was done according to ethical standards

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Declaration of competing interest

The authors 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. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envdev.2025.101311.

Data availability

Data will be made available on request.

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