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# Climate risk perception and adaptation strategies of smallholder farmers in The Gambia

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**Abstract**
Climate risk poses significant challenges to agriculture in The Gambia, especially for smallholder farmers reliant on rain-fed farming. Adaptation efforts will be ineffective unless farmers' perspectives of climate change are understood. The objectives are to examine smallholder farmers' perceptions of climate risk, identify their adaptation strategies, and examine the factors that influence the adoption of these adaptation strategies at farm and off-level. Data were collected from 420 smallholder farmers across three regions of rural Gambia using a survey and multistage sampling technique. Binary logistic and multivariate probit models were used to analyse the determinants of farmers' decision to adopt adaptation strategies. The empirical result of the binary logistic model indicates that land tenure, access to government support, access to markets, witness to extreme weather events, and climate change perception influenced farmers' choice to adopt adaptation measures. The findings further indicate that female farmers are less likely to adopt adaptation measures. However, the multivariate probit model revealed that age, education, access to extension services, membership of farm groups, and perceived climate change are the main determinants of on-farm adaptation strategies. Off-farm strategies such as petty business are mainly influenced by being female, middle age, and primary education. The results suggest that gender-disaggregated support and targeted policies are necessary to encourage the adoption of adaptation strategies among female farmers. It is recommended that the government enhance access to credit, provide tailored support for women farmers, and improve extension services to foster effective adaptation in rural Gambia.

**Keywords** Climate risk · Adaptation · Binary logistic · Multivariate probit · Perception · Farm adaptation · Off-farm adaptation · The Gambia

**Abbreviations**

| | |
|---|---|
| LTS | Long-term strategy |
| IPCC | Intergovernmental Panel on Climate Change |
| UNDP | United Nations Development Program |
| NBR | North Bank Region |
| CRR | Central river region |
| URR | Upper river region |
| MVP | Multivariate probit |

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## 1 Introduction

Located in the Sahel region, The Gambia is a country with severe food insecurity and high susceptibility to the adverse effects of climate change such as inundations, droughts, and storms. The country's low-lying topography, with 20% of the area covered by tidally inundated swamps is threatened by permanent flooding from a 1 m sea level rise. Coupled with its heavy dependence on rain-fed subsistence farming, inadequate water management systems, widespread poverty, and limited adaptive capacity, The Gambia is one of the nations highly susceptible to the impact of climate change[1, 2]. According to the report of the [3], The Gambia ranks 41st in terms of vulnerability to climate change out of 180 countries. Global climate change causes substantial challenges in The Gambia, such as the rising occurrence and severity of droughts. Hotter days and nights, as well as lengthier heatwaves, are forecast in the inland Gambia as average temperatures climb by the end of the century. As a result, droughts will escalate in frequency and severity [4]. Water scarcity and droughts are expected to occur every five years on average [5]. According to The Gambia's National Adaptation Report 2007 [6], the country had many droughts between 1951 and 2007. Rainwater irrigates over 99% of its arable land [7], and rising temperatures and diminishing rainfall are projected to hinder agricultural production. Heavy rainfall, flooding, strong winds, dry spells, low temperatures, interseasonal droughts, heatwaves, and extreme rainfall are all weather-related hazards in Gambia [5].

Due to climate change, The Gambia faces considerable development challenges in both the near and distant future. Short-term severe climatic phenomena include strong winds, droughts, and dust storms. In the long run, land loss, sea level rise, and coastal erosion will become significant issues [7]. According to the IPPC [8], climate change has a substantial influence on The Gambia, which is ranked among the top 100 countries impacted by climate change, and the population is the world's most vulnerable to the consequences of increasing sea levels and coastline erosion [9]. The Gambia has recently seen an increase in the frequency and severity of floods, droughts, coastline erosion, storms, severe temperatures, and unpredictable rainfall. Such weather events, particularly droughts, impede efforts toward sustainable development and poverty alleviation [10]. Climate data analysis reveals expected temperature and precipitation patterns for The Gambia in recent years. A second national report [11] reveals a 0.50 °C per decade increase in temperature since the 1940s. Rainfall patterns in The Gambia have changed throughout time, according to historical climate records.

Between 1951 and 2018, the country had five major droughts [4]. As a result, The Gambia exhibits a high sensitivity to climate change and is inadequately prepared, ranking 141st out of 192 nations in the 2018 Notre Dame Global Adaptation Index [5]. Despite this, there is limited research on the impact of climate change on agriculture in the country [12] The methodology employed in most of the existing studies lacks scientific rigour and robustness, for instance [9, 12–18]. As a result, they are insufficient and imperfect in giving a full scientific prognosis of the country's response to climate risk. Most existing studies [19–21] have focused on specific farming sectors, particularly rice farmers, cattle herders, and fishermen, respectively. These studies do not capture the broader agricultural community's perception of climate risk. Furthermore, many studies focused solely on farm-level adaptation without considering the various livelihood strategies rural households employ [22]. Analysed farmers' views and elements which determine their adaptation to climate change but variables that impact the selection of adaptation were lacking. Most research and policies regarding climate change adaptation analyses focus on the factors, limitations, and prospects for farm households' adaptation, with a strong analytical emphasis on the adjustment of farming operations [23–27]. These studies scarcely consider the various livelihood possibilities undertaken by households residing in rural areas. There is strong evidence that rural households rely on a range of livelihood activities that can be categorized as farm and non-farm-level strategies [28–30]. As a result, focusing just on farm-level adaptation only captures a portion of the comprehension narrative of climate change adaptation. It overlooks a key component in the adaptation research because non-farm activities account for up to 50% of the income of rural households in sub-Sahara Africa (SSA) [31]. Similarly, non-farm strategies are critical to rural communities' livelihoods in The Gambia. Diversification of livelihoods is crucial for adapting to climate change [28, 32] underline the need to comprehend the full scope to which environmental variability and climate change are reshaping impoverished people's livelihood possibilities. They emphasize the importance of understanding which livelihood options and approaches result in long-term adaptation to climate change.

To fully understand local-level susceptibility to climate change risk and adaptation measures, field-based research is becoming increasingly important [33]. There are still gaps in our understanding of the many adaptation tactics used by rural households, as well as the elements that influence their selection of adaptation. Considering the literature deficit, this study contends that rural livelihood households should be at the forefront of research and policy agendas regarding climate change adaptation in developing countries such as The Gambia. Thus, initiatives that try to mitigate the effect of climate change on impoverished households in rural areas without taking into consideration their livelihood possibilities undervalue their capacity to respond to harsh climate patterns. Placing livelihood as the central focus of adaptation methods, on the other hand, allows for the design of appropriate policy interventions for rural households that are vulnerable based on their domestic and household circumstances.

The research gap this study aims to address is the lack of studies in The Gambia that econometrically analyse factors that determine farmers' perception of climate-related risks. Existing studies are limited in scope, often failing to rigorously assess how farmers perceive climate risks and socioeconomic factors that influence their adaptation measures. Furthermore, current literature focuses primarily on farm-level adaptation strategies without considering the role of off-farm activities in rural farmer's climate risk adaptation strategies This is substantial as farmers' perception of climate risk directly affects their ability to adapt, and comprehending these perceptions is crucial for formulating effective adaptation policies. Without a comprehensive, data-driven analysis of factors shaping these perceptions, policymakers may neglect critical obstacles that farmers have in adapting to climate change.

If urban farmers' perceptions of climate change are still unclear [34], rural farmers may face even more uncertainty due to potential limitations in access to information, education, and other resources needed to understand and adapt to its impact. There is a lack of understanding of Gambian smallholder farmers' perspectives on climate risk and the factors influencing their adaptation strategies. Specifically, the study highlights the need for more research on the gender-disaggregated factors affecting the adoption of both farm and off-farm adaptation strategies, with a focus on how climate change perceptions, socioeconomic variables, and access to resources influence decision-making. It also seeks to fill the gap in targeted support for Gambian female farmers, whose adaptation efforts are often limited by various social and economic barriers. This is substantial as farmers' perception of climate risk directly affects their ability to adapt, and comprehending these perceptions is crucial for formulating effective adaptation policies. Moreover, the application of binary and multivariate logistic models allows for a more intricate analysis of the different adaptation strategies smallholder farmers employ, considering that households often employ multiple strategies at the same time. By addressing these gaps, the study offers significant insights into how smallholder farmers perceive climate risks and the factors that shape their adaptation decisions. This will contribute to better-informed policy interventions that bolster climate resilience in The Gambia's agriculture sector, ultimately augmenting the capacity of smallholder farmers to cope with the impacts of climate change.

## 2 Background

### 2.1 Climate risk in The Gambia

According to the report of the Global Climate Risk Index 2021 [3], The Gambia ranks 41st in terms of vulnerability to climate change out of 180 countries. Global climate change causes substantial challenges in The Gambia, such as the rising occurrence and severity of droughts. Hotter days and nights, as well as lengthier heatwaves, are forecast in the inland Gambia as average temperatures climb by the end of the century. As a result, droughts will escalate in frequency and severity [4]. Water scarcity and droughts are expected to occur every five years on average [5]. According to The Gambia's National Adaptation Report 2007 [6], the country had many droughts between 1951 and 2007. Rainwater irrigates over 99% of its arable land [7], and rising temperatures and diminishing rainfall are projected to hinder agricultural production. Heavy rainfall, flooding, strong winds, dry spells, low temperatures, interseasonal droughts, heatwaves, and extreme rainfall are all weather-related hazards in Gambia [5]. Due to climate change, The Gambia confronts considerable development challenges in both the near and distant future. Strong and high winds, droughts, and dust storms are examples of short-term severe climatic phenomena. Land loss, sea level rise, and coastal erosion will be important issues in the long run [7].

According to the IPCC [8], climate change has a substantial influence on The Gambia, which is ranked among the top 100 countries impacted by climate change, and the population is the world's most vulnerable to the consequences of increasing sea levels and coastline erosion [9]. The Gambia has recently seen an increase in the frequency and severity of floods, droughts, coastline erosion, storms, severe temperatures, and unpredictable rainfall. Such weather events, particularly droughts, impede efforts toward sustainable development and poverty alleviation [10]. Climate data analysis reveals expected temperature and precipitation patterns for The Gambia in recent years. A second national report [11] reveals a 0.50 °C per decade increase in temperature since the 1940s. Rainfall patterns in The Gambia have changed throughout time, according to historical climate records. Between 1951 and 2018, the country had five major droughts

[4]. As a result, The Gambia exhibits a high sensitivity to climate change and is inadequately prepared, ranking 141st out of 192 nations in the 2018 Notre Dame Global Adaptation Index [5].

### 2.2 Climate risk perception

How people, communities, and organizations view the threat of climate change is known as 'climate risk perception. It involves a personal judgment about both the possible effects of climate change and the chance that these would happen. When developing adaptation measures and responses, it is imperative to consider farmers' perceptions of climate-related threats [35]. The risks posed by climate change to human and ecological systems include abnormal weather, rising sea levels, shortages of food and water reserves; and diminishing biodiversity. But people's judgments of such risks may differ based on their personal experience, geographic location, socioeconomic class; cultural and societal norms along with media coverage as well as scientific fact. Take sea level rise and increased storm activity along the coast, for example. People who live near the seaside may be more concerned about these risks than people living further inland whose biggest worries are most likely droughts and heat waves. Having experienced major weather disasters, such as hurricanes or wildfires may make a person more likely to characterize the threats of climate change in terms of potential seriousness and importance.

Risk perception, according to [8] is the subjectively formed judgment by people about the nature and magnitude of a risk [36], found that a large proportion of farmers in the region believed climate change was caused by both man and natural processes. Also, most farmers are worried about increasing risks of pest attacks and disease outbreaks as well as flooding along with rising crop heat stress. Knowing how farmers view the impact of climate change on agriculture and what concerns they have is a necessary first step toward developing adaptation strategies for addressing climate change. Their experiences with climate change will alter farmers 'attitudes [37, 38]. Perception of climate risk is important because it can influence individuals and groups in their efforts to respond by mitigating or adapting to consequences. Those who do not consider climate threats to be serious or fallible may also be less willing either to cut back on greenhouse gas emissions or adapt themselves to the future effects of global warming. However, for people and society, the threats may only prompt action if they are seen as serious. Risk perception is a decision-maker's judgment of the dangers present in any given situation. Often, they are evaluated by eliciting reactions to the idea of how "serious," "concerned," or. For a decision maker, information about danger is risk perception. They play an important role as indicators of decision-making behaviour since it is known, from research studies [39, 40], that they can distort judgments, knowledge, and ability to perform in dangerous situations. Generally speaking, risk perceptions are measured by the extent to which people feel threatened or worried about a specific event.

Climatic risk communication is important It helps inspire people to act and lower their susceptibility, as well as helping them adapt to changing climates. It is necessary to understand the different factors that determine what people regard as risk and to change methods of communication accordingly. For example, this could involve using a few simple words, focusing on the local impact of global warming, and highlighting gains from action. It is also not surprising that there exists a positive correlation between education and the way farmers perceive climate change, as well as how they will respond to it. Generally speaking, more highly educated people are aware of the threats involved in climate change [41]. Cognitive capacities and knowledge of new technology are sure to increase with education so that the farmers will accept these innovations. These results are in keeping with those of [26, 42].

### 2.3 Farm-level vulnerability

It is widely accepted that vulnerability differs across communities, regions, and countries as well as over time. When it comes to climate change, food security, and the field of political ecology there are various ways in which vulnerability can be understood. The research identifies two categories of vulnerability: biophysical vulnerability and social vulnerability. Biophysical vulnerability primarily addresses the likelihood of natural disaster impacts, with an emphasis on the extent, frequency, and extent [43, 44]. Social vulnerability often considers the condition of the human system, which is influenced by elements such as political, social, and economic aspects that might put people at risk while also reducing their adaptive capacity to such risks [44, 45]. Concerning climate change. Vulnerability encompasses both biophysical and social variables [8]. Defines vulnerability as "the propensity or predisposition to be adversely affected." It includes several concepts and components, such as sensitivity to injury and the inability to effectively cope and adapt. Until the fourth IPCC Assessment Report [46], a vulnerability was thought to consist of three components: exposure, sensitivity, and adaptive capability. However, according to the 2014 IPCC [47], vulnerability solely refers to sensitivity and capacity, while exposure is more adequately included in the concept of risk. According to the [8] study, vulnerability is a component of risk; these risks arise from the combination of hazards, vulnerability, and exposure.

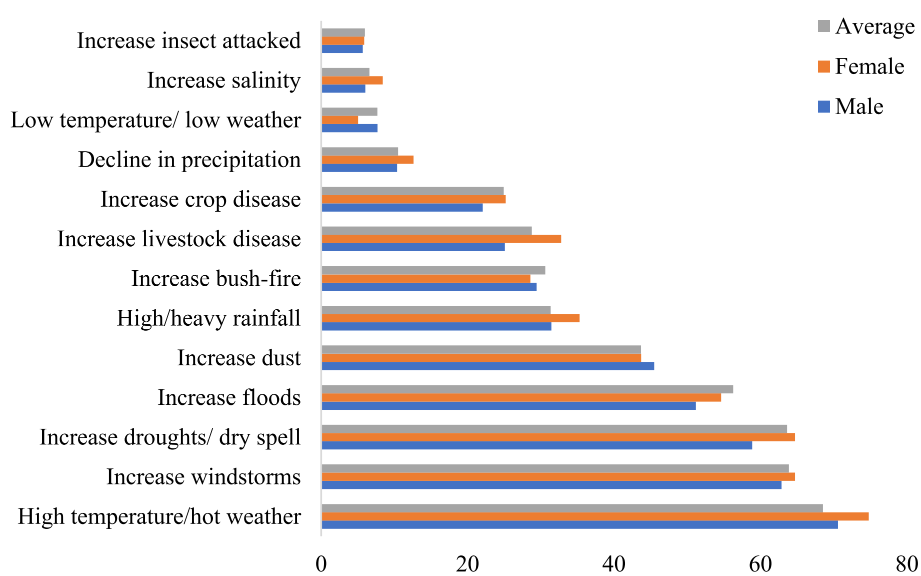
If a system is highly exposed to climate-related risks, with low resilience and adaptive capacity it may be referred to as fragile. In contrast, a system is more robust if it shows low sensitivity or has high resilience [48]. The system's level of sensitivity depends on its ability to be inversely influenced or even act against the external stimulus and resist adverse consequences [49]. Adaptive ability is often described as a critical characteristic of risk reduction for the system [50]. People's business and agricultural activities are impacted by various climate-related risks, such as floods, droughts, and extreme temperatures that lead to low crop yields or water shortages. However, farmers can reduce their exposure to these risks by learning how to adapt appropriately. As [51] note farmers are ultimately the owners and primary decision-makers in this area. How they understand climate uncertainties and risks can influence not only short-term farm management techniques but adaption choices as well. Farmers who understand these risks accurately make reasonable choices about crops, seasons, and inputs. Other facets that could affect a farmer's ability to adjust include the availability of technological, financial, and information resources or the social structure and local exchanges [52, 53].

### 2.4 Farmers' perception of climate risk

When developing adaptation measures and responses, it is imperative to consider farmers' perceptions of climate-related threats [35]. Figure 1 shows the perceived impacts of climate change and variability. The responses indicate that high temperature/hot weather, an increase in windstorms, an increase in droughts/dry spells, and an increase in floods are the most commonly recognized impacts [36]. Found that a large proportion of farmers in the region believed climate change was caused by both human activity and natural processes. Also, most farmers are worried about increasing risks of pest attacks and disease outbreaks as well as flooding along with rising crop heat stress. Approximately 69% of the participants in the sample recognized high temperature as one of the most often reported climate threats in the investigated regions. Likewise, almost 64% of the entire group of participants experienced a rise in both drought and windstorms. 56% and 44% indicated a rise in occurrences of floods and dust respectively. 31% of respondents reported a rise in cattle disease, while 25% reported an increase in crop disease.

Other climate risks encompass substantial precipitation (31%), reduced precipitation (11%), increased insect attack (8%), elevated salinity (7%), and cold temperatures (6%). For most climate-related issues, the percentage of female responses is slightly higher than that of male responses. This suggests women are highly aware of the various ways in which climate change can affect communities, agriculture, and the environment. It is crucial to acknowledge farmers' perceptions of climate-related risk when formulating efficient adaptation strategies and responses. Approximately 88% of farmers have observed a discernible shift in the climate within the last 10–20 years, the finding of [54] supports this.

**Fig. 1** Climate risk perception



## 3 Material and methods

### 3.1 Study area

The Gambia's water coverage extends across an area of around 1300 square kilometres (500 square miles), which accounts for 11.5% of the total land area. This study was carried out in the North Bank Regions (NBR), Central River Regions (CRR), and Upper River Region (URR) of The Gambia. These three regions were purposely selected owing to their vulnerability, flooding damage, and agricultural importance. It is a rain-fed contextual setting in rural Gambia. Based on the integrated household survey2015/16, the rural population stood at 865, 483 people, and the selected regions comprised 596, 640 people. The target population for the investigation consisted of smallholder farmers from three regions of rural Gambia (Fig. 2). The major crops cultivated in these regions are groundnut (Arachis hypogaea), maize (Zea mays) sorghum (Sorghum bicolour), rice (Oryza sativa), millets (Panicum miliaceum). The region is characterized by a semi-arid climate with a low and erratic monomodal type of rainfall with 98% of precipitation falling between June and October. Agricultural productivity is heavily reliant on rainfall. The rainfall amount and distribution have been erratic, seriously affecting agricultural production. Almost all agricultural land in The Gambia receives about 98% of its rainfall, so reduced rainfall and rising temperatures are expected to limit crop yields.

### 3.2 Sampling strategy and data collection

The study population comprised 38,614 households. The sample size was determined using the Raosoft online sample size calculator, with a 5% margin of error and 95% confidence level. The sample was further adjusted to accommodate missing data. The study utilized a multistage sampling technique. During the initial phase, a deliberate selection was made of three primary agricultural regions out of the six regions in The Gambia. The chosen regions are NBR, URR, and CRS regions. The regions are primarily characterized by the prevalence of cereal crop farming as the major production system. The selection criteria for the target population of farm households in the communities is that the primary source

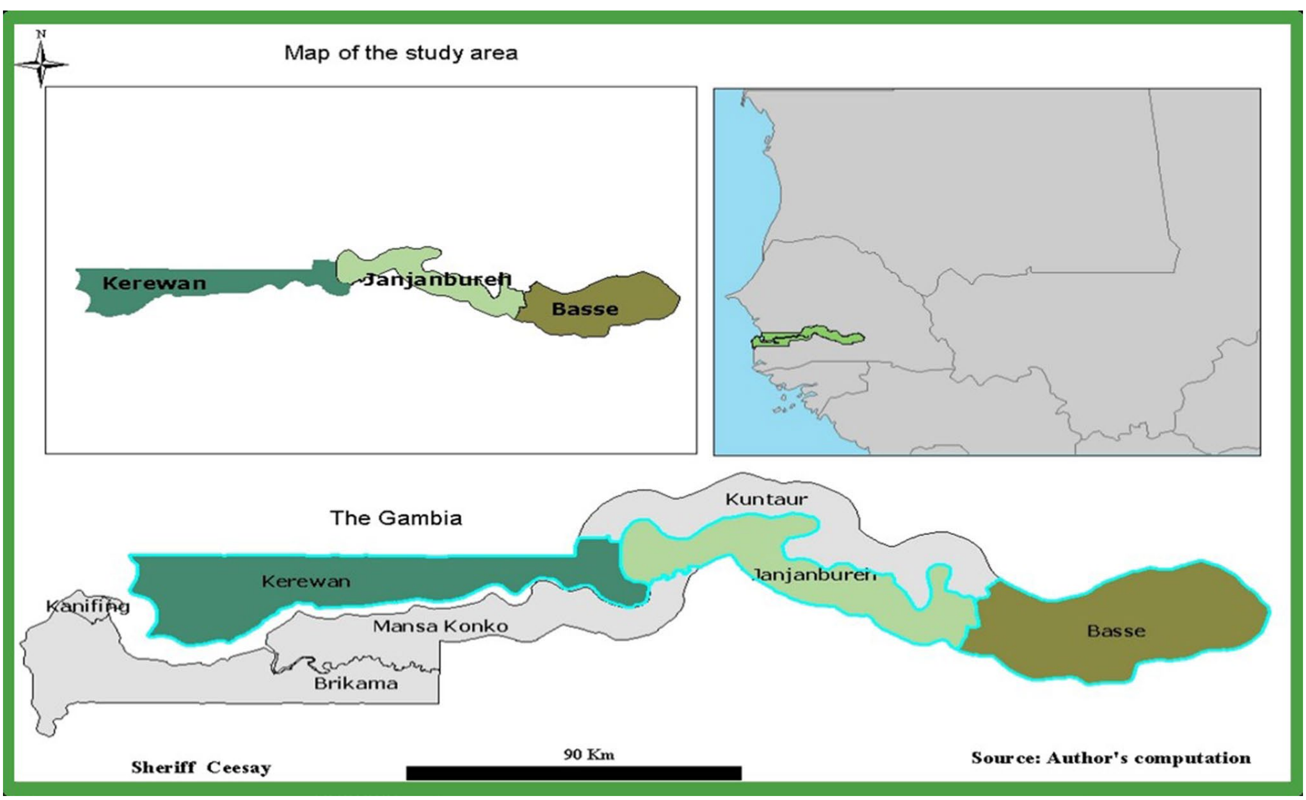



Fig. 2 Map of the study area. Author's computation, 2023

of income for a household should be farming. This criterion is used to gain a deeper understanding of the influence of climate risk on agriculture. In the second stage five districts from the NBR regions, four districts from the URR, and three districts from the CRRS were selected randomly. This was informed by the difference in population size of the regions. In the third stage, five communities were randomly chosen from each district, and seven farmers were randomly picked from each community to participate in the study. Therefore, a total of 420 agricultural households were incorporated into the investigation, and the survey was conducted in the year 2023. A structured survey was conducted among smallholder farmers' household heads to address the research objectives. The questionnaires were administered by enumerators whose selection was based on their proficiency in administering questionnaires and fluency in English and local dialects. The enumerators underwent a one-week training program to acquaint themselves with the topics of climate change, farm-level adaptation to climate change, the importance of research on climate change adaptation, as well as the fundamental principles of sampling, interviewing, and data processing.

### 3.3 Dependent and independent variables

Adaptation options were divided into two types, farm and off-farm categories. Farm-level approaches are activities or changes done on a household's land or land obtained through cash or shared tenancy, with the goal of enhancing agricultural production and productivity [23–25, 52, 55]. Farmers' actions outside of farming are referred to as off-farm strategy [56]. For this study, six adaptation techniques were chosen based on these categories: four farm-level and two off-farm strategies. The decision was made based on the survey data on the adaptation strategies farmers mostly employed. The explanatory variables were chosen based on a survey of existing literature on adoption research and climate change adaptation. Household characteristics (age, education, family size, household wealth, etc.) and institutional factors (access to markets, credits, extension services, and perception of climate change, etc.) are independent variables. Independent variables are chosen based on an assessment of relevant literature and data availability [57–65].

### 3.4 Conceptual framework

The conceptual framework Fig. 3 serves as a valuable instrument for comprehending the factors that shape individuals' perceptions of climate risk and how these factors can influence their perceptions and reactions to climate risk. The conceptual framework illustrates the determinants of climate risk perception, categorized as internal and external elements. Internal drivers refer to the factors originating from within an individual or society, which have the potential to shape their perception and response towards climate change concerns. External drivers of climate risk perception are factors originating from sources external to an individual or community, which have the potential to shape individuals' and communities' perceptions and responses to climate risk.

Identifying climate risk adaptation strategies used by farmers is critical to understanding the implementation of practical farm-level coping strategies [66, 67]. Several studies have shown that household characteristics significantly influence the adoption of adaptive strategies [25, 66, 68]. Research by [69–71], highlights how socio-demographic

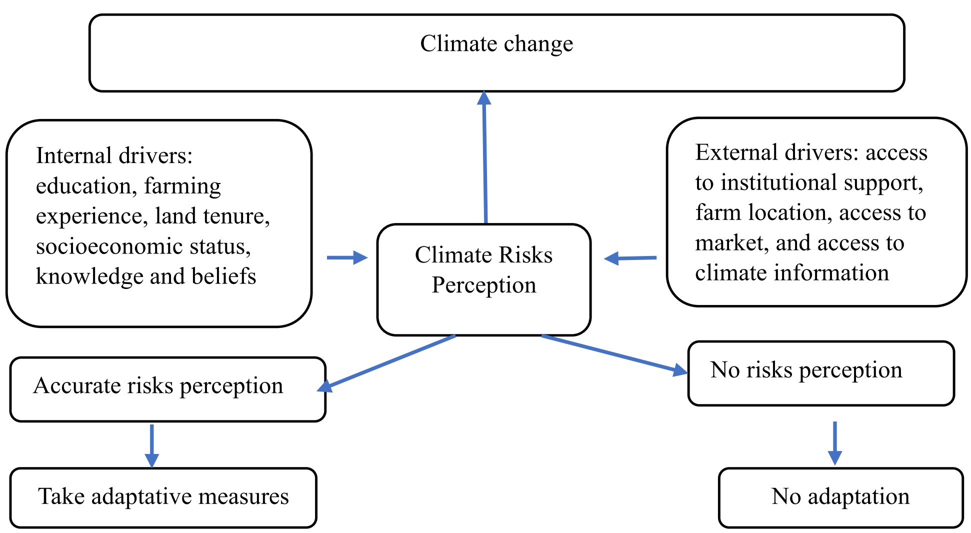



Fig. 3 Conceptual framework. Author's illustration, 2023

variables influence farmers' perceptions. Education plays a key role in shaping farmer's perceptions of climate risk and their willingness to adopt adaptation strategies. Studies by [72–75] show that better education creates awareness of potential benefits and a willingness to adapt to new climate risk management strategies. This could mean that as household heads become more educated, they are also more likely to be aware of climate change. Farmers' ability to receive and process information, as well as their propensity to act, improves with increased education and training [41, 76], ultimately leading to increased cognitive performance. Proximity to markets is an important factor in adapting to climate risks, and markets probably serve as an opportunity to exchange information with other farmers.

Studies have shown that market access plays a significant role in managing drought risk [77–79]. Long distance from markets however reduced the likelihood of technology adoption in agriculture [80]. Access to information and credit enhanced awareness among farmers [64, 75, 81, 82]. Access to support services and credits gives farmers the information they need to make decisions and take adaptation measures. For example, funds enable farmers to purchase new crop varieties, irrigation techniques, and other essential inputs. The availability of credit lines increased farmers' financial resources and their ability to cover the operating costs associated with multiple adaptation options.

### 3.5 Empirical model

This study employed binary logistic and multivariate probit (MVP) models to analyse the determinants of farmers' decision to adopt a climate risk adaptation strategy and factors that influence the adoption of on-farm and off-farm adaptation strategies. The multivariate probit model can reduce these associations [83–85]. The data collected indicates that farmers in the study area have a wide range of adaptation techniques to climate risk. The MVP was developed using the specifications of [86], with six dummy dependent variables that represent the adaptation strategies (on-farm and off-farm) employed by in the research area to mitigate the impacts of climate change. The MVP model was also chosen due to its ability to permit the simultaneous analysis of the impact of several regressors on each adaptation strategy [86–88] while allowing free correlation between the error term. The MVP regression in particular, outspread error terms with a zero mean normal distribution with a variance–covariance matrix in which the variance and covariance allow for such a relationship [89]. Another merit of employing an MVP model is that it does not force each farmer to use only one adaptation method. Farmers can utilize multiple adaptations at the same time with a multivariate model. Furthermore, it is not necessary to satisfy the independent of irrelevant alternatives (IIA) criterion which is often unachievable [90]. Farmers may employ a variety of adaptation options. As a result, this model assists in obtaining as much insight as possible from the numerous adaption processes in which a farmer is involved. According to [91], adoption decision modelling using the MVP framework increases estimation efficiency in the situation of simultaneous adoption, compensates for contemporaneous correlation, and decreases bias.

Farm households will adopt strategies to mitigate the impact of climate change only if they anticipate a decrease in agricultural production risk or a rise in predicted net farm profits. Adoption decisions require farmers to be aware of local over-time climate variability, like patterns of precipitation and temperature [52]. The binary logit model analyses the multitude of factors influencing farmers' decisions in implementing adaptation strategies to extreme weather occurrences in agricultural productivity. The decision made by farmers in applying adaptation strategies follows a discrete choice model, where the options are limited to "yes" or "no").

Taking into account the following model:

$$Y_{ij}^* = \alpha + \sum \beta_k X_k + \varepsilon_{ij} \tag{1}$$

where $Y_{ij}^*$ is a latent variable corresponding to the expected benefit of adopting a particular adaptive strategy. The equation $Y_{ij}^*$ is an unobserved parameter for the farmer $i$ who is using adaptation strategies $j$ climate change. The degree of climate risk adaptation options in the choice set is represented by the base category $j$. $X_k$ represents a set of exogenous predictor variables that impact a farmer's decision to choose a specific adaptation strategy. And $k$ in the subscript indicates the particular explanatory variables. The vector of regression coefficients is denoted by $\beta_k$ and the error term is denoted by $\varepsilon_{ij}$ which is uniformly distributed, characterized by a zero mean and a constant variance [92].

The model is defined by a collection of n binary predicted variables [86].

Because the latent variable $Y_{ij}^*$ is not readily apparent, we utilize $Y_{ij}$, which accepts 0 or 1 as values in accordance with the following rules:

$$Y_{ij} = \begin{cases} 1\ if\ Y^*_{ij} < 0 \\ 0\ if\ Y^*_{ij} \le 0 \end{cases} \quad (2)$$

where $Y_{ij}$ is an observed variable that indicates that farmer $i$ will adapt to perceived climate risk using specific tactics $j$, $Y_{ij} = 1$) if the expected gains exceed zero ($Y^*_{ij} > 0$).

And otherwise, farmer $i$ would not take for the adaptation strategy $j$ if the expectation for gains is equal or less than zero ($Y^*_{ij} \le 0$).

Hence Eq. (4) can be interpreted in terms of the observed binary variable $Y_{ij}$ as.

$$Pr(Y_{ij} = 1 = Y_{ij} = G(X_k\beta_k) \quad (3)$$

where, $G(.)$ represents specific binomial distribution [93]. $Pr(Y_{ij} = 1)$ is the probability of selecting the adaptation alternatives $j$. $\beta_k$ is a vector of the estimated parameter of the binary logistic model which describes the effect of the direction of the relationship between the explanatory and the binary observed variables, plus the statistical significance of increasing the independent variable using the OLS (ordinary least squares) coefficient [94].

Thus, $Y_{ij}$ has a binary output ($Y_{ij} = 1$) if the farmer $i$ adopts the adaptation strategy $j$, and $Y_{ij} = 0 otherwise$). We attempt employing one or more explanatory factors to explain the variances $X_k$.

The coefficient of the multivariate probit method is insufficient to deduce the connection between the response and the independent variables. The only directly interpretable factor is the sign as well as the importance of the regression coefficients [95]. Positive $\beta_k$ indicates that the independent variable $X_k$ will improve the likelihood of implementing a specific adaptation method.

However, the coefficient $\beta_k$ cannot show how likely farmer $i$ is to choose a given adaptation strategy. ($Y_{ij} = 1$) will change when we alter $X_k$ i.e., the coefficient $\beta_k$ does not convey the extent result of a change in independent variable $X_k$ on $\Pr(Y_{ij} = 1)$. For the results to be interpreted and quantified, we must compute the logistic model's marginal effects utilizing the coefficients by computing the likelihood derivative with respect to the element, $k$ of $X$ (derivative of Eq. 7). The marginal effect is usually computed at the sample mean data and changes depending on the values of $X$. They explain how changing the units of the predictor variables affects the probabilities of the response variable ($\Pr(Y_{ij} = 1$).

A marginal effect derivation ($y_{ij}\prime$) gives:

$$y'_{ij} = \Pr(Y_{ij} = 1).\left(1 - \Pr\left(Y_{ij} = 1\right)\right)\beta_k \quad (4)$$

Dummy variable marginal effects are underreported, and coefficients are interpreted as odds ratio marginal effects rather than probability [95].

The use of partial elasticities is another method for analysing the outcomes of logistic regression. It calculates the percentage change in the likelihood of the response variables (implementation of specific adaption mechanisms in reaction to changes and variability in climate) consequently an increase of 1% in explanatory variables $X_k$.

The logit model's partial elasticity calculated at mean can be expressed as:

$$\eta\gamma\left(X_k = \beta_k X_k \Pr\left(Y_{ij} = 1\right)\right)\beta_k \quad (5)$$

In this analysis, a null hypothesis is created by setting regression coefficients in the logistic model equal to zero against the alternative that one of the regression coefficients ($\beta_k$) is nonzero [94].

$$H_0 : \beta_k = 0 and H_1 : atleastone \beta_k \ne 0$$

# 4 Results

## 4.1 Descriptive statistics

The adoption rate of adopting at least one adaptation strategy among farmers was 87% as shown in Table 1. The average values for all the adaptation techniques, except petty business (PB), are more than 0.3, suggesting that most farmers have used at least one strategy. The most prevalent approach, with a mean of 0.490, is crop rotation (CR), followed by

**Table 1** Descriptive statistics of variables

| Variable | Description | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| Dependent variables | | | | | |
| Adopted adaptation strategy | Dummy: 1 if the farmer adopted an adaptation strategy, 0 otherwise | 0.867 | 0.340 | 0 | 1 |
| Crop rotation (CR) | Dummy: 1 if the farmer adapted crop rotation as an adaptation strategy, 0 otherwise | 0.490 | 0.501 | 0 | 1 |
| Change planting date (CPD) | Dummy: 1 if the farmer adapted change planting date as an adaptation strategy, 0 otherwise | 0.386 | 0.487 | 0 | 1 |
| Use of inorganic fertilizers (UIF) | Dummy: 1 if the farmer adopted use of inorganic fertilizer as an adaptation strategy, 0 otherwise | 0.345 | 0.476 | 0 | 1 |
| Change crop variety (CCV) | Dummy: 1 if the farmer adapted use change crop type as an adaptation strategy, 0 otherwise | 0.452 | 0.498 | 0 | 1 |
| Petty business (PB) | Dummy: 1 if the farmer adapted petty business as an adaptation strategy, 0 otherwise | 0.057 | 0.232 | 0 | 1 |
| Migration (Mg) | Dummy: 1 if a family member adapted migration as an adaptation strategy, 0 otherwise | 0.031 | 0.173 | 0 | 1 |
| Explanatory variables | | | | | |
| Age | Continuous: In years | 48.783 | 13.689 | 18 | 85 |
| Education | Categorical | 0.331 | 0.736 | 0 | 3 |
| Household size | Continuous: In numbers | 19.686 | 14.344 | 2 | 103 |
| Farming experience | Continuous: In years | 29.031 | 13.821 | 2 | 80 |
| Farm size | Continuous: Number of hectares | 5.064 | 3.665 | 1 | 27 |
| Land tenure | Dummy: 1 if plot owned, 0 otherwise | 0.888 | 0.316 | 0 | 1 |
| Log annual income | Continuous: Amount in '000 GMD | 10.089 | 1.012 | 6.908 | 13.122 |
| Distance to the main market | Continuous: In km | 8.405 | 7.703 | 1 | 35 |
| Access gov't support | Dummy: 1 if the farmer has access to gov't support, 0 otherwise | 0.181 | 0.385 | 0 | 1 |
| Access to marketing information | Dummy: 1 if the farmer has access to marketing information, 0 otherwise | 0.890 | 0.313 | 0 | 1 |
| Access to extension services | Dummy: 1 if the farmer has access to extension services, 0 otherwise | 0.652 | 0.477 | 0 | 1 |
| Access to credit | Dummy: 1 if the farmer has access to credit, 0 otherwise | 0.088 | 0.284 | 0 | 1 |
| Training | Dummy: 1 if the farmer has received training, 0 otherwise | 0.205 | 0.404 | 0 | 1 |
| Member of social/farm group | Dummy: 1 if the farmer is a member of a group, 0 otherwise | 0.905 | 0.310 | 0 | 2 |
| Witness unexpected weather events | Dummy: 1 if the farmer had witnessed unexpected weather events, 0 otherwise | 0.867 | 0.340 | 0 | 1 |
| Climate change perception | Dummy: 1 if the farmer perceived change in climate, 0 otherwise | 0.883 | 0.321 | 0 | 1 |

changing the planting date (CPD) with a mean of 0.386, and the use of inorganic fertilizers (UIF) with a mean of 0.345. The mean age of the farmers is 48.8 years. The education variable is a categorical variable, with a mean value of 0.331.

This indicates that the average educational attainment is situated in the second quartile out of four possible categories. The mean household size is about 20 individuals, with a standard deviation of 14.3 individuals. The mean experience of farmers is 29 years. The mean farm size is 5.1 hectares, and approximately 88.8% of farmers possess land ownership. The mean logarithmic arrival income is 8.4, which is equivalent to an average income of around GMD 2417 per annum. The mean distance to the primary market is 7.7 kms. Government funding is accessible to 18.1% of farmers. Marketing information is accessible to 89.0% of farmers. The percentage of farmers with access to extension services is 65.2%. Only 8.8% of farmers can obtain financing. Approximately 20.5% of farmers are affiliated with a social or farmer group. 86.7% of farmers have observed unforeseen meteorological occurrences. 86.7% of farmers are aware of climate change. The table offers a valuable synopsis of the data concerning climate change adaptation in The Gambia.

### 4.2 Mean annual precipitation and temperature

The scientific data collected also corroborated household views of climate risk perception. An increased trend in the mean annual temperature from 1901 to 2021 was discovered in the research area, as shown in Fig. 4. The mean rainfall data exhibited a marginal decline throughout the same time frame, aligning with the observations made by households. The preceding discussion suggests that farmers in the research region are aware of local climatic changes and variations, which in turn prompt them to implement adaptive strategies to mitigate the negative impacts of climate change.

### 4.3 Main climate risk faced by farmers

Figure 5 illustrates the primary climate risk experienced by farmers, within the study area. Flood is the predominant climate hazard encountered by farmers in all regions, with an average of 70% of farmers reporting its occurrence. The districts of NBR and URR have the highest prevalence of farmers who reported experiencing floods, with 102 and 55 farmers respectively. Drought ranks as the second most prevalent risk, with an average of 35% of farmers reporting its occurrence. Insufficient precipitation is the third most prevalent risk, exhibiting a notable disparity between NBR and the remaining regions. Windstorms and elevated temperatures pose the lowest frequency of dangers, with an average of 12% and 4& of farmers respectively reporting them.

### 4.4 Binary logistic estimate and marginal effect on farmers' decision to implement an adaptation strategy

The predicted result of the binary logit model can help illuminate what factors lead farmers to adopt climate risk strategies in agriculture. The coefficients represent the degree and direction of association between each variable with the adoption of climate risk strategies. Marginal effects showed how likely a farmer's adaption can change in connection to a single-unit shift in any one of the explanatory variables. The estimated coefficients of the empirical binary logit model

**Fig. 4** Mean annual precipitation and rainfall

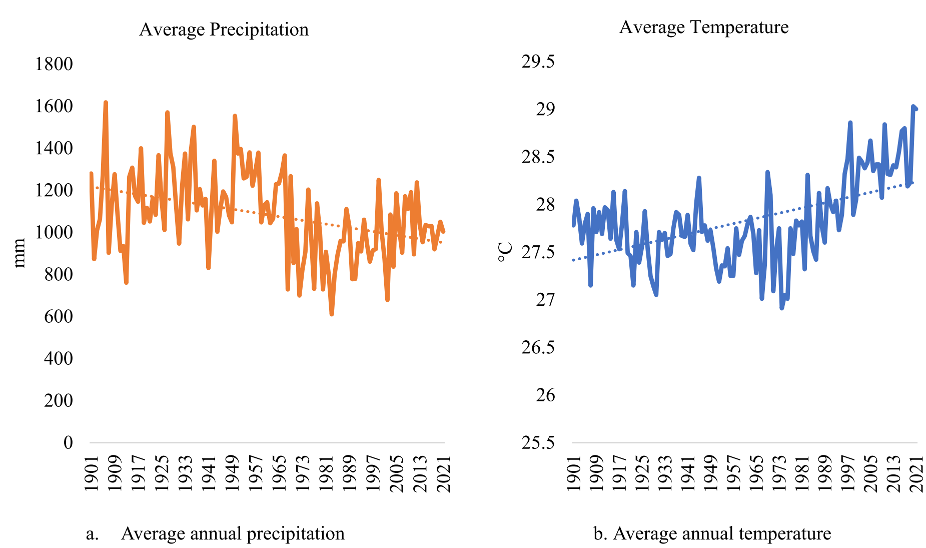
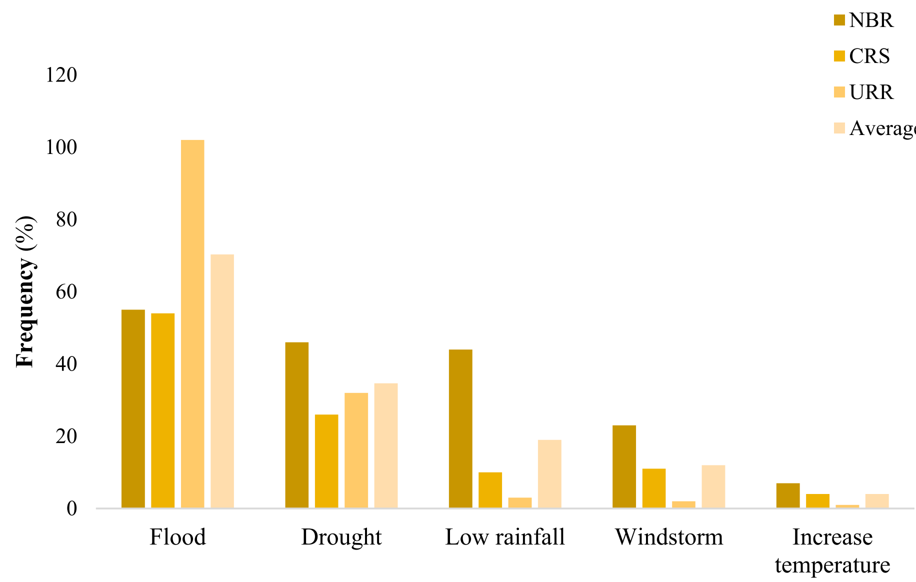


Fig. 5 Main climate risks faced by farmers




are presented in Table 2. The value of Pseudo $R^2$, which is 0.501, suggests that the explanatory factors accounted for 50.1% of the probability farmers would take climate change adaptation measures. The intensity of adaptation by farmers is driven mainly by access to information, external support, and experience with climate events. The results of the model indicate that farmers who are informed, supported, and aware of climate risk are mostly to take adaptive measures. This highlights the importance of providing targeted support, especially to women smallholder farmers.

The results have shown that six major elements increase the probability of farmers adjusting their adaptation strategies in response to climate change. Among these were land tenure, average annual farming income, gov't support, marketing information access, and witnessing unexpected events and climate change perception. Access to marketing information was the most noteworthy and statistically significant variable affecting farmers 'probability of adopting measures to deal with global warming. The probability of adoption by farmers who had access to marketing information was 11.7% higher than those who did not have that privilege. The results also showed that farmers with governmental support, experienced unexpected events and a perceived change in the climate tended to be more inclined towards an adjustment strategy for adaptation than other farmers. Adaptation probability was 10.3% higher for farmers who receive support from the gov't and 9.5% for farmers who believe that climate has changed in recent years compared to those with no such perception of change. The coefficient of gender (female) and the marginal effect are both negative. This suggests there is a negative relationship with adoption for female farmers, the probability of adoption by male farmers was 6.6% higher than females. Farm size was statistically significant but had a negative effect on the adoption of adaptation strategies. This finding contradicts the one made by [61].

## 4.5 Multivariate probit estimates of the determinant of farmers' adaptation strategies

The parameter estimate obtained from the (MVP) analysis of the factors that impact the adoption of climate risk adaptation techniques by smallholder farmers in The Gambia for both on-farm and off-farm strategies is displayed in Table 3.

The positive correlation between the coefficient of petty business and gender (female) and middle-aged farmers indicates that female and middle-aged farmers are more inclined to implement off-farm adaptation techniques in comparison to male, young, and elderly farmers. The coefficient for age and primary education positively influenced the decision to adopt crop rotation as an adaptation strategy, but it did not have a meaningful effect on the other adaptation techniques. The findings of [66] contradict the current result since they found a negative correlation. Farmers in the middle-aged and older age groups exhibit a higher propensity to implement crop rotation tactics in comparison to their younger counterparts. The education coefficients exhibit variation among different degrees of schooling. Primary education appears to enhance the probability of adopting both on-farm and off-farm techniques, however, tertiary education shows negative coefficients, indicating a potential drop in the likelihood of adoption. Primary education has a statistically significant influence on the adoption of a petty business adaptation strategy when pursuing an off-farm approach.

**Table 2** The estimated result of the binary logit model and marginal effects on farmers' decisions to adapt climate risk strategies in agriculture

| Explanatory variables | Coefficients | Marginal effects |
|---|---|---|
| Gender (base: male) | | |
| Female | **− 1.062**** | **− 0.066*** |
| Agecat [base: less than 35 (young farmers)] | | |
| 35–55 years (middle age) | 0.088 | 0.005 |
| Above 55 years (old age farmers) | − 0.584 | − 0.035 |
| Education level (base: no formal education) | | |
| Primary | 0.309 | 0.017 |
| Secondary | − 0.037 | − 0.002 |
| Tertiary | 0.000 | 0.000 |
| Region (base: NBR) | | |
| CRS | − 0.365 | − 0.014 |
| URR | **− 2.772***** | **− 0.205***** |
| Household size | 0.008 | 0.000 |
| Farm size | **− 0.164**** | **− 0.009**** |
| Farming experience square | − 0.005 | 0.000 |
| Land tenure | **1.659***** | **0.096***** |
| Average annual farming income | **0.000**** | **0.000***** |
| Access gov't support | **1.777**** | **0.103***** |
| Off-farm income | 0.115 | 0.007 |
| Member of a social/farm group | 0.36 | 0.021 |
| Access to marketing information | **2.019***** | **0.117***** |
| Witness unexpected weather event | **1.289**** | **0.075**** |
| Climate change perception | **1.633**** | **0.095***** |
| Constant | − 1.493 | |
| N | 420 | |
| Log-likelihood | − 81.648 | |
| LR chi2(18) | 163.650 | |
| Prob > chi2 | 0.000 | |
| Pseudo R2 | 0.501 | |

Significance levels are indicated by ***p < 1%. **p < 5%, *p < 10%

## 4.6 Perceived impact of climate change

Figure 6 summarizes the perceived impact of climate and related risks on agricultural production. Overall, 84% of respondents reported low crop yields, and 64% reported a reduction in crop production as an adverse impact due to climate-related risks, consistent with the findings of [54, 96]. While 30% and 26% of respondents reported that altering the climatic condition would increase risk to agriculture, such as water shortage and soil degradation. 16% and 12%reported water logging and change in cropping calendar conditions.

The study further indicated that 8% of the farmers reported climate risk had no impact on their farming. The concerns regarding the effect of climate change and its variability on agricultural productivity are emphasised in the studies conducted by [97].

## 4.7 Adaptation constraints

Figure 7 outlines the main adaptation constraint faced by farmers in adopting to the impact of climate risk. Although farmers identified multiple obstacles to adaptation, the finding showed that lack of credit (77%), inadequate government support (64%), poverty (59%), and a dearth of knowledge and information (52%) are the main barriers faced by farmers.

**Table 3** MVP coefficient estimates for the determinants of farmer's adaptation strategies to climate change

| | On-farm adaptation strategies | | | | Off-farm adaptation strategies | |
|---|---|---|---|---|---|---|
| Dependent variables | CR | CPD | UIF | CCV | PB | Mg |
| Explanatory variables | Coef. | Coef. | Coef. | Coef. | Coef. | Coef. |
| Female | 0.143 | − 0.117 | − 0.182 | − 0.009 | **0.424*** | 0.259 |
| Middle age farmers | **0.320*** | − 0.212 | 0.112 | 0.154 | **1.008**** | 0.252 |
| Old farmer | **0.385*** | 0.000 | 0.075 | 0.150 | 0.431 | 0.166 |
| Primary education | **0.413*** | − 0.043 | 0.175 | **− 0.624***** | **1.000***** | − 5.321 |
| Secondary education | − 0.014 | 0.136 | 0.094 | 0.131 | − 0.225 | − 0.429 |
| Tertiary education | **− 0.122*** | − 0.004 | **− 1.099**** | − 0.244 | − 3.362 | − 4.309 |
| Household size | − 0.010 | − 0.009 | **0.013**** | − 0.007 | 0.009 | 0.004 |
| Average annual farming income | **0.000***** | **0.000*** | **0.000**** | 0.000 | **0.000***** | 0.000 |
| Access to credit | − 0.077 | − 0.302 | − 0.086 | − 0.27 | − 0.126 | − 3.864 |
| Access to extension services | **− 0.318**** | **0.322**** | − 0.215 | **0.655***** | 0.229 | 3.174 |
| Member of a social farm group | **0.668***** | **0.389*** | **0.487**** | − 0.169 | 0.700 | 1.414 |
| Climate change perception | **1.791***** | **1.078***** | **0.786***** | **1.406***** | 0.218 | 2.927 |
| Training | − 0.049 | 0.096 | − 0.054 | 0.184 | **− 1.054*** | **1.294***** |
| Cons | **− 2.377***** | **− 1.430***** | **− 1.792***** | **− 1.588***** | **− 3.897***** | − 9.848 |
| Likelihood ratio test of rho21 = rho31 = rho41 = rho61 = rho32 = rho42 = rho52 = rho62 = rho43 = rho53 = rho63 = rho54 = rho64 = rho65 = 0 | | | | | | |
| Chi2(15) = 75.346 | | | | | | |
| Wald chi2(78) = 221.75 | | | | | | |
| Prob > chi2 = 0.000*** | | | | | | |
| Log likelihood = − 1073.5023 | | | | | | |

Significance levels are indicated by ***p < 1%, **p < 5%, *p < 10%

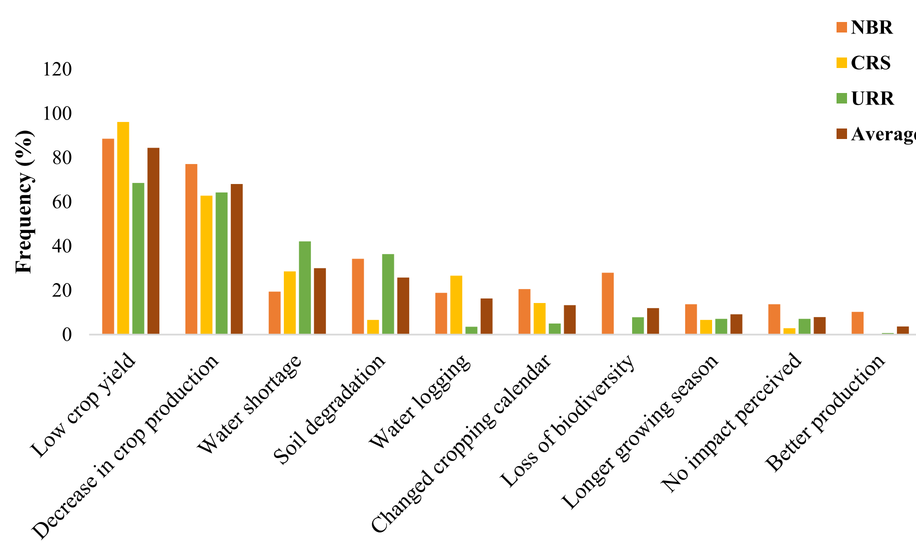



**Fig. 6** Perceived impact of climate risk by farmers

## 5 Discussion

The household size coefficient has shown a statistically significant positive impact on the use of chemical fertilizer as a means of adapting to climate change. The finding aligns with prior studies [26], which also found a direct correlation between the size of a household and the use of chemical fertilizer to adapt to climate change. Additionally, within the framework of our study, migration emerges as a viable climate risk adaptation strategy for smallholder farmers in rural Gambia. Similar, to previous research on climate change in Bangladesh, where farmers who adapt

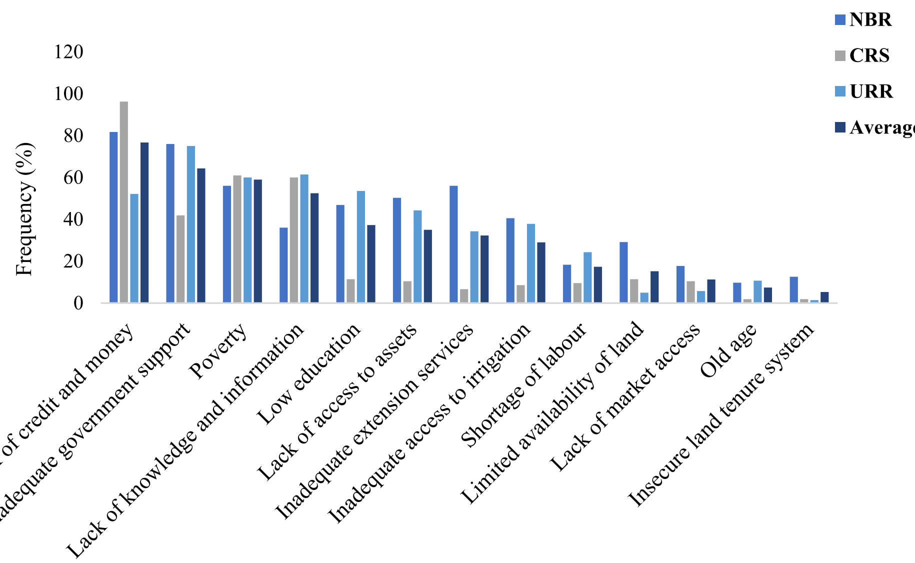



**Fig. 7** Adaptation constraints by farmers

sowing times or adopt stress-tolerant crop varieties experience varying impacts on production efficiency, migration offers an alternative strategy to mitigate climate risks [98]. However, unlike the finding in Bangladesh, where migration opportunities can inversely correlate with other adaptation strategies and pose potential threats to food security, our study found no statistically significant correlation between household and migration. This is contrary to expectation, as it was assumed that larger families, with more adults, would be more likely to use migration as a key adaptation method [99].

Regarding the relationship between farmers' accessibility to extension services and their choice of strategy for change in planting dates or crop variety was positive and significant. Thus, it implies that if farmers have understandable information and extension materials, they can be even more encouraged to adopt climate risk strategies. These findings are consistent with other studies [80, 100] which demonstrate the importance of institutional support and extension services in promoting climate change adaption. Moreover, research shows farmers benefit from being attached to an institution and having facilities for extension services [101]. Research has shown that farmers who lack experience with extension services often struggle to understand the full impacts of climate change [52]. Our findings also reinforce that farmers who have contact with extension workers experience substantial improvement in production and income [102, 103]. Thus, improving access to extension services remains a critical way to support farmers in adapting to climate risks.

Furthermore, membership in social or farm groups has a positive significant influence on farmers' adoption of on-farm strategies. As highlighted by [104], farmer group gatherings offer opportunities to exchange experience and disseminate information regarding adaptation strategies. Cognitive processes have a spill-over effect, as demonstrated by [105], and the act of farmers joining associations results in membership. Farmers' perception of climate plays a critical role in determining their adaptation behaviour. The findings indicate that farmers' perceptions of changes in the climate significantly influence their inclination to adopt farm adaptation techniques. Our findings further indicate that farmers' perceptions of climate change significantly influence their likelihood of adopting on-farm adaptation techniques. Similar to other studies [26], farmers who perceive climate change as a substantial risk are more likely to employ additional on-farm tactics. Therefore, a broad range of adaptation measures is essential to help farmers mitigate climate risk.

Our study also found a deep connection between access to credit and the adoption of climate risk adaptation strategies, consistent with previous research [81, 106, 107]. However, while our results show that the coefficient on credit access was insignificant, potentially due to tight credit conditions among farmers, these findings align with studies that highlight similar financial constraints in rural settings [107, 108]. Likewise, the coefficient for farmers who received climate change training was insignificant and negatively correlated with the adoption of on-farm adaptation measures, an outcome that was unexpected but aligns with other studies [107, 108].

Finally, our results highlight several constraints to adaptation, including low education (37%), lack of access to assets (35%), inadequate extension services (32%), and inadequate access to irrigation (29%) are constraints to adaptation, as confirmed by previous research [96, 109, 110]. Recent research in Bangladesh has also underscored the significant risks posed by environmental degradation driven by industrial development which threatens rice production due to its detrimental effects on soil, water, and air quality, necessitating improved farmer awareness and targeted government interventions to mitigate these impacts [111]. These findings emphasise the need for improved farmer awareness and targeted government intervention to mitigate these impacts.

## 6 Conclusion

The study has used primary farm-level data from rural Gambia to assess farmers' perceptions of climate risk and on-farm and off-farm strategies taken to cope with the changing climate. The study indicates that most farmers had a perception of changing climate (about 88%) during the past 10 -20 years. Farmers adopt different kinds of adaptation strategies to reduce the negative consequences of climate change to maintain and/or improve their livelihood. The results of the binary logit model revealed that land tenure, average annual farming income, gov't support, marketing information access, and witnessing unexpected events and climate change perception are the main factors that influence farmers to adopt climate risk adaptation strategy. Farmers in the study area have been well aware that climate conditions are changing and that strategies should be implemented to cope with the adverse effects of these changes. Furthermore, this study pointed out that 49%, 48%, 41%, and 32% of the farmers were using change crop variety, crop rotation, change planting date, and use of inorganic fertilizer, respectively. And 6% and 3% used petty business and migration as an off-farm adaptation strategy.

The Multivariate probit model was employed to determine the factors determining farmers' choice of adaptation strategies related to climate risk. MVP result confirms that being female and middle-aged farmers has a significant impact on petty business as an adaptation strategy. Crop rotation as an adaptation strategy was influenced by age and primary education members of a social farm group, and climate change perception. Access to extension services, members of a social farm group, and climate change perception positively influenced the decision to adopt change planting dates as an adaptation strategy. The use of inorganic fertilizer was influenced by household size, average annual farming income, members of a social or farm group, and climate change perception. Change in crop variety was significantly influenced by access to extension services and climate change perception. The primary challenges faced by smallholder farmers in implementing measures to mitigate climate risk are insufficient access to credit, inadequate government support, poverty, and limited knowledge and information. The findings provide an initial reference point and a more solid foundation for future research possibly on a larger representative scale. Furthermore, the list of factors that may influence adaptation decisions is not exhaustive. Hence, it is imperative to broaden the study to encompass additional effects of climate change and variability on the vulnerability of farmers.

Given its major role in the agriculture sector, the government should address the credit constraint by ensuring the availability of credit opportunities, increase support for poverty alleviation, and promote the dissemination of climate information. Additional efforts should be made to maximize farmers' participation in the decision-making processes. Developing policies that target the enhancement of adaptation constraints for smallholder farmers poses significant potential to enhance farmer adaptability to climate risk. Directing efforts toward women groups in smallholder rural areas can provide significant benefits in terms of enhancing the adoption of methods by smallholder farmers. Government policies should prioritise the promotion of research, development and dissemination of suitable technologies to assist farmers in adaption to climate change. The study suggests that to explore the subject of women's vulnerability to climate change due to the fact that women have additional challenges in addressing climate change. Furthermore, there is a need for more research to examine the effects of climate-resilient initiatives and government in climate change adaptation techniques on farmers' ability to adapt to climate change.

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**Data availability** The data cannot be shared at this time as they form part of an ongoing study.

**Availability of supporting data** The data used in the study will be available by open request. The data used in the study have been deposited in Mendeley Data. Lehnhardt née Lambarraa, Dr. habil. Fatima; Ceesay, Sheriff; NDIAYE, Mohamed Ben Omar; Niane, Diatou Thiaw; Sawaneh, Mamma (2024), "Data for publication", Mendeley Data, V1, doi: https://doi.org/10.17632/38c273kg8v.1

**Code availability** STATA software version 16 was used and code will be available by open request.

## Declarations

**Ethics approval and consent to participate** The study was approved by the Research Ethic Committee of Gambia College with approval number GC/REC/2023/005. This study was performed in line with the tenets of the declaration of Helsinki.

**Consent for publication** All the research participants provided informed consent for participation and publication of the research findings.

**Competing interests** The authors declare no competing interests.



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