ECONOMIC ANNALS, Volume LXVII, No. 234 / July – September 2022
UDC: 3.33 ISSN: 0013-3264

https://doi.org/10.2298/EKA2234109M

*Geetilaxmi Mohapatra**
*Meera George***
*Suchitra Pandey****

VULNERABILITY AND ADAPTATION TO CLIMATE CHANGE IN RAJASTHAN

ABSTRACT: *Climate change is a globally challenging phenomenon that is particularly distressing for the agricultural sector, as agricultural products and productivity depend on the climate. This study analyses agricultural households' perception of climate change and the adaption strategies undertaken to mitigate it. A purposive random sampling technique is used to collect primary data from a survey conducted in the arid and semi-arid regions of Rajasthan, India. The study employs logistic regression to identify the determinants of the perception of climate change and adaptation strategies, while a livelihood vulnerability index is constructed to indicate households' degree of vulnerability, focusing especially on adaptive capacity. Out of the total sample of 600 households analysed, 534 perceive a long-term change in the climate. Farmers' adaptation strategies include crop diversification, mixed cropping, crop rotation, and farm ponds. The major factors affecting adaptation are the educational status of the household head, farming experience, type of financial support, agricultural training, land size, access to agricultural institutions, distance between the household and farmland, and storage. The livelihood vulnerability index shows that most of the households are moderately vulnerable. The study recommends an efficient weather forecasting system and effective government policies to improve credit availability, financial support, and agricultural mechanization.*

KEY WORDS: *climate change, perception, adaptation, vulnerability, agricultural households, Rajasthan*

JEL CLASSIFICATION: Q54, Q12, Q18

* Associate Professor, Department of Economics and Finance, BITS, Pilani, Pilani Campus, Rajasthan-333031, India. E-mail: geetilaxmi.bits@gmail.com; ORCID: https://orcid.org/0000-0002-0037-4622

** Research Scholar, Department of Humanities and Social Sciences, NIT Trichy, Tamil Nadu -620015, India. E-mail: meerageorgev@gmail.com; ORCHID: https://orcid.org/0000-0001-5564-8283

*** Research Scholar, Department of Economics and Finance, BITS, Pilani, Pilani Campus, Rajasthan-333031, India, E-mail: p20190025@pilani.bits-pilani.ac.in; ORCID: https://orcid.org/0000-0002-9881-5827

1. INTRODUCTION

Climate change is a major developmental challenge (Adzawla et al., 2020), whose adverse impacts are being felt all over the world. It is becoming warmer, rainfall is erratic, the sea level is rising, and extreme weather events are more frequent and intense. Climate variability generating an irregular precipitation pattern and an unfavourable rise in temperatures affects lives in most developing countries. Poor people and poor-income countries are exposed and vulnerable to climate shocks, including natural disasters, drought, crop failure, a spike in food prices, and extreme weather conditions (Hallegate et al., 2016). Though every sector of the economy is affected by climate change the impact is notably higher in agriculture due to its climate-sensitive nature, resulting in low or poor agricultural productivity (Narayanan & Sahu, 2016). The concern is exceptionally high for countries like India that are highly dependent on agriculture. With nearly half of its population and nearly 20% of its GDP depending on agriculture, India is one of the country's most vulnerable to climate change risks.

Vulnerability is a function of exposure, sensitivity, and adaptation capacity regarding a specific risk (IPCC, 2007). A system is less vulnerable if it is less exposed, less sensitive, or has a strong adaptive capacity (Smit and Wandel, 2006). Adaptation is an adjustment in the socio-ecological and economic system in response to actual and expected change in climate (Smit & Pilifosova, 2003), and a planning and decision-making process to mitigate the problems caused by any hazards (Ahmed et al., 2021). For example, to cope with changes in climate, farmers adopt adaptation choices such as planting new crop varieties, changing planting dates, using pest-resistant varieties (Suresh et al., 2021, Webber et al., 2014), water conservation (Boyer et al., 2021; Meckonnen et al., 2021), selling off livestock (Kehler & Birchall, 2021), changing crop composition (Schlingmann et al., 2021), and applying fertilizers (Erbas & Solakoglu, 2017; Wing et al., 2021). Over the years, adaptation to climate change has evolved as the most effective tool in mitigating adverse climatic effects (Chattopadhyay & Hulme, 1997).

Adaptation depends on adaptive capacity, which depends on the socio-economic attributes of households vulnerable to climate change. Poor households in rural areas that depend on agriculture face many social and institutional constraints, such as poor education, lack of information, lack of agricultural extension services, social incompatibility, no access to credit, and inadequate capital, which act as barriers to adaptation and limit the capacity to adapt, leaving them highly vulnerable to climate change. Adaptation also depends on another significant factor: perception. Bryant et al. (2000) find that how the perception of climate change is translated into agricultural decision-making constitutes adaptation in agriculture, so it is crucial to include farmers' perception of climate change in adaptation studies (Maddison, 2007; Banerjee, 2015; Waibel et al., 2018). The perception of climate change helps to negotiate the need for adaptation and explain the most efficient and effective strategy to minimize risks and future losses. The major factors influencing perception are socio-political events, economic factors, and individual factors, including views and ideas (Whitmarsh & Capstick, 2018).

Formulating effective policies to address the climate vulnerability of agricultural households requires an understanding of adaptation strategies, barriers to adaptation, and households' perception of climate change. Besides presenting an overview of agricultural households' perception of and vulnerability to climate change and the adaptation strategies employed, this study attempts to unravel the socio-economic factors that influence these perceptions and adaptations. The objectives of the study are:

1) To study agricultural households' perception of climate change and the factors influencing it.
2) To analyse the factors influencing agricultural households' adaptation strategies.
3) To calculate a livelihood vulnerability index of households in the arid and semi-arid regions of Rajasthan.

Several studies have addressed these issues globally but studies relating to the desert state of Rajasthan are lacking. Rajasthan is the largest state in India, with 10.4 % of the total geographical area. The climate is very harsh: it receives scanty rainfall with high air and soil temperatures, intense solar radiation, and high wind velocity. In India nearly 317,090 sq. kms. are arid, of which 2,46,790 sq. kms. are hot arid areas, and roughly 80% of the hot arid areas is in Rajasthan. The arid and semi-arid areas are more vulnerable to climate change due to their dependence on sensitive sectors such as agriculture, fisheries, forestry, and water (Prasad et al., 2014). This paper deals exclusively with agricultural households in these semi-arid and arid regions of Rajasthan.

The remaining sections of the paper are organized as follows. Section 2 reviews the related literature. Section 3 provides the methodology and Section 4 discusses the results. Section 5 presents a summary and conclusions.

2. LITERATURE REVIEW

Several studies have examined farmers' perception of climate risks and the adopted adaptation strategies and have identified factors constraining adaptation to climate change. Using a bottom-up approach, Gbetibouo (2009) examines farmers' perception of climate change and variability in South Africa and finds that although they accept secondary data on climate variability, only half of them make adjustments in response to climate change. The main adaptation strategies are changing crop varieties and planting dates, switching crops, and increasing irrigation. Farm size, household size, farming experience, wealth, extension services, and access to credit are found to be significant determinants of adaptation strategies.

Bose (2014) assesses farmers' perception of climate variability in the semi-arid region of north-eastern Nigeria using secondary climate data. Employing a questionnaire survey and non-parametric Mann-Kendall test, the author finds that farmers perceive long-term changes in temperature and precipitation that match the recorded data on annual temperatures and adopt different strategies to reduce the effects of climate change, such as changing planting dates and improving crop seedlings, irrigation, and soil conservation.

Limantol et al. (2016) examine farmers' perception of and adaptation to climate change in the Vea catchment of northern Ghana between 1972 and 2012. They find that the farmers adopted different strategies to cope with the perceived climate change. The farmers fell into two groups, one relying exclusively on rain-fed agriculture and the other adopting a mix of rain-fed and irrigation strategies. The farmers using a mixed strategy kept using fertilizers while the rain-fed group were inclined to vary crop type as their adaptation strategy.

Nhemachena & Hassan (2018) investigate farmers' perception of long-term changes in temperature and precipitation, farm-level adaptation strategies, and barriers to adaptation in Southern Africa. A multivariate discrete choice model is used to identify the determinants of adaptation. The results show that most farmers perceive a long-term increase in temperatures and that the region is getting drier, with pronounced changes in rainfall patterns and drought frequency. Access to credit and extension services and awareness of climate change are found to be the most important determinants of adaptation choices.

In the Indian context, Das (2010) analyses farmers' perception of climate change in villages in Andhra Pradesh and Maharashtra and finds that most farmers have observed the increase in temperature, decline in the level of precipitation, and more erratic rainfall. The farmers have adopted strategies such as migration, taking credit, selling off assets, diversifying livelihoods, using savings, and shifting from cereal to non-cereal crops.

Dhaka et al. (2010) uses a questionnaire to collect data from 500 farmers on perception of and adaptation to climate change in the Bundi district of Rajasthan. Most farmers perceive that temperatures have increased, the climate is getting drier, and the timing of rains and frequency of droughts is changing. They have adapted by integrating farming systems, changing planting dates, and changing crop sequences and rotation.

Prasad et al. (2014) examine farmers' perception of climate change and adaptation options in the Panna district of Madhya Pradesh. The results show that farmers are well aware of the changing climatic conditions and realize their impact on agriculture. The farmers have adapted by planting trees, changing planting dates, and adopting agroforestry.

Varadan & Kumar (2014) study the perception of climate change and adaptation strategies of dryland farmers. The farmers realize that there is an urgent need to devise appropriate adaptation strategies to cope with the negative effects of climate change and have adapted strategies such as manipulating sowing dates, changing cropping patterns, reducing fertilizer use, and diversifying crops. Their adaptation strategies are supported by the farming experience of elderly people, access to irrigation, and availability of livestock.

Dhanya & Ramachandran (2016) explore farmers' perceptions of climate change in South India's semi-arid region using both quantitative and qualitative data. They find that most farmers are aware of climate variability and use adaptation strategies such as cultivating short-duration pulses and fruits, and flowers and vegetables.

Banerjee et al. (2013) examine barriers to adaptation, based on a qualitative survey. They find that although farmers perceive the changes in climate, they face many constraints that limit their capacity to adapt, including lack of access to information, finance, technological inputs, and infrastructure. Small farmers and women are most affected by the lack of resources and improper implementation of government schemes.

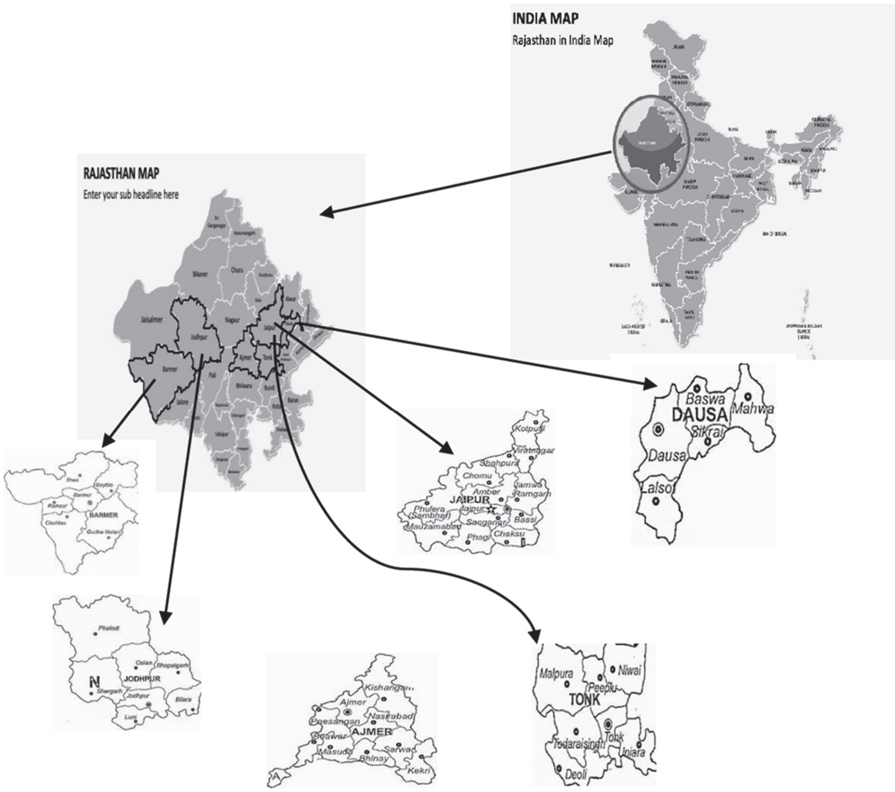
Based on primary and secondary data in Maharashtra, Udmale et al. (2014) find that farmers recognise the impact of drought on their livelihoods and use various drought preparedness and adaptation measures to mitigate its effect. Lack of education, low income, and small landholding size act as major constraints on adaptation.

3. METHODOLOGY

3.1 Area of study

Rajasthan has 10 agro-climatic zones. The arid region covers 4.74 million hectares and the semi-arid region 2.96 million hectares. These regions have low, erratic rainfall and high mean maximum temperatures (Manga et al., 2015), resulting in unexpected losses and poor income. This study was conducted among agricultural households in two arid regions of Rajasthan, Barmer and Jodhpur, and four semi-arid regions, Ajmer, Jaipur, Tonk, and Dausa.

Figure 1: Map of study area



3.2 Sampling technique and data collection

Purposive random sampling was used to collect data from agricultural households. The sample size was set at 600: two administrative blocks from each district were selected for data collection and five villages were selected from each tehsil. The study used a structured household questionnaire, focus group discussions, and personal interviews. Focus group discussions were conducted to review farmers' perception and understanding of climate change and their general opinion regarding interventions to mitigate climate change. Each group consisted of 8 to 10 members from similar localities. Officials and heads of Farmer Producer Organisations (FPOs) and other agricultural extension services were interviewed to attain a general understanding of the area and the standard of living.

3.3 Conceptual Framework

3.3.1 Perception and adaptation

The major factors governing agricultural households' perception of climate change were determined using binary logistic regression. The logistic regression model helps to analyse events given the probability of occurrence. The mathematical model for the logistic regression is represented below:

$$p/1-p = e\hat{}y \tag{1}$$

where y is the independent variable.

Here, $p/1\text{-}p$ is the odds ratio which calculates the ratio of the probability of success to the probability of failure. The logistic regression model uses the natural logarithm of the odds ratio, given as:

$$log\ (p/1-p) = y \tag{2}$$

This study employed a binary logistic regression model to analyse the determinants of farmers' perception. . Each category was regressed separately using the logistic regression and the marginal effects were calculated to interpret the data. The major changes perceived by the farmers include increased temperature, decreased rainfall events, decreased rainfall intensity, and decrease in rainfall duration. Binary logistic regression was run for each response category to find the determinants and eliminate the possibility of error due to multiple responses. This is expressed mathematically as:

$$\Pr\left(Y = \frac{a}{X}\right) = \frac{e^{\text{XiBA}}}{\left(1+ e^{XiB2}+ e^{XiB3}+ e^{XiB4}+\cdots..e^{XiBA}\right)} \tag{3}$$

Here the dependent variable a can take the value of either 1 or 0, where a=0 when the farmers have not perceived the change and a=1 when the farmers have perceived the change. XB_1, XB_2……XB_G show the independent variable or the characteristics of household i. The household characteristics considered in the model are gender of the household head, social responsibility of the household head, literacy status and educational status of the household head, number of years involved in farming, household size, access to institutions, and visit of extension services.

The study employed a binary response model to analyse the factors determining agricultural households' adaptation to climate change. Since the farmers employed more than one strategy to mitigate the effects, binary logistic regression was used to analyse the factors determining the adoption of each strategy. The major strategies were using a variety of crops, mixed cropping, selling livestock, planting trees, crop rotation, and construction of farm ponds. The variables used were educational status of the household head, number of years involved in farming, external support, agricultural training, land size, agricultural income, agricultural institutions, farmland distance, and storage.

$$\Pr\left(Y = \frac{m}{X}\right) = \frac{e^{\mathrm{XiBJ}}}{\left(1 + e^{XiB2} + e^{XiB3} + e^{XiB4} + \cdots .. e^{XiBJ}\right)} \qquad (4)$$

Here m takes two values, 0 and 1. If m=0 it indicates that the farmer has not adopted any specific strategy and if m=1 it indicates that the farmer has adopted the strategy. XB_1, XB_2……XB_J show the independent variable or the characteristics of household i .

3.3.2 Vulnerability index calculation

A livelihood vulnerability index was constructed to analyse the households' vulnerability to climate change. The vulnerability index has 8 sub-indices: economic wellbeing and stability (EW), gender discrimination (GD), dependency burden (DB), interconnectivity (IC), susceptibility to environmental change (SE), housing quality (HQ), awareness level (AL), and institutional and infrastructural environment (IE). Each sub-index contains several indicators and each was assigned a weight. Once the weights were assigned, each indicator was standardized as an index using the formula:

$$IndexR_d = R_d - R_{dmin}/(R_{dmax} - R_{dmin})$$

Here R_d is an indicator of the major component M_d, and $R_{d\,max}$ and $R_{d\,min}$ are the maximum and minimum values of the indicator. Once the indicators were standardized, they were averaged together to find the value of their respective major components using the following equation:

$$M_d = \sum_{i=1}^{n} R_{di} / n$$

Here M_d is the major component. Index R_{di} is the standardized indicator of the major component M_d, where *i* take the values 1, 2, or 3 according to the number of indicators the major component has. *n* is the total number of indicators in the major component M_d. The other major components are also calculated using the above equation. Once the values of the major components are calculated, the livelihood vulnerability index is calculated using the following equation:

$$LVI = \frac{[n1(EW) + n2\ (GD) += n3\ (DB) + n4(IC) + n5(SE) + n6\ (HQ) + n7(AL) + n8(IE)]}{n1 + n2 + n3 + n4 + n5 + n6 + n7 + n8}$$

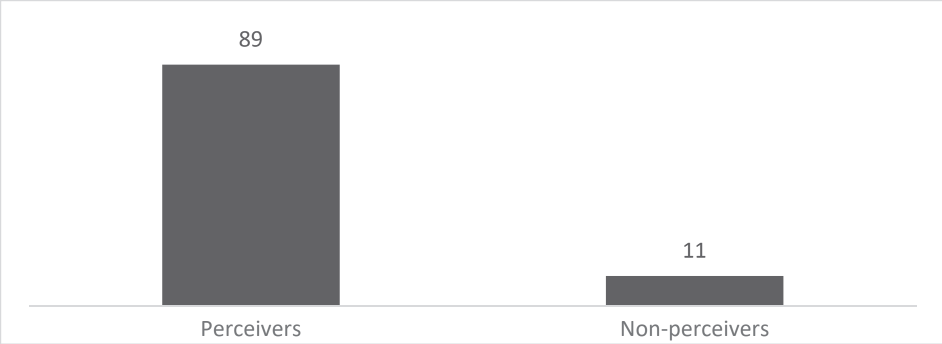
Here $n_1, n_2, n_3 \ldots\ldots n_8$ indicate the total number of indicators of their corresponding major component.

4. RESULTS AND DISCUSSION

4.1 Perception of climate change

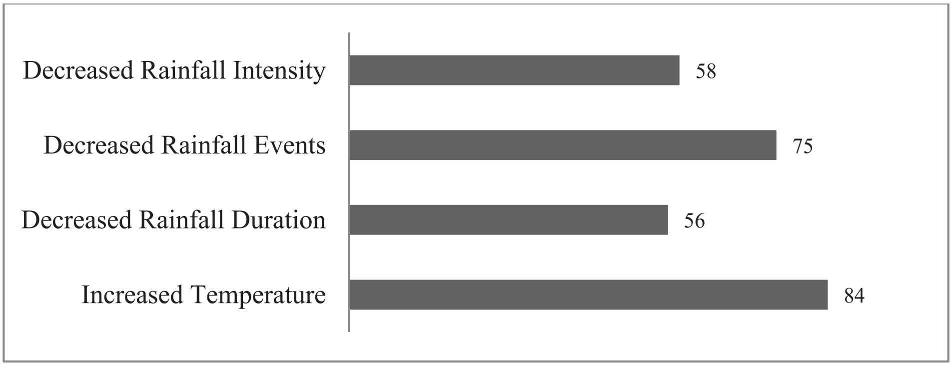
The agricultural households in the arid and semi-arid regions were asked about the long-term changes that have occurred in their environment over the past 10 years. The farmers who reported changes in the climate were considered 'perceivers' and the households who did not notice any changes were considered 'non-perceivers'. Figure 2 shows that 89% of the households were perceivers and 11% were non-perceivers. Analogous to the meteorological data, the major changes recognised by the households were increased temperature, decreased rainfall duration, decreased rainfall events, and decreased rainfall intensity (see Figure 3); these findings are consistent with those of Das (2010) and Dhaka et al (2010). However, a minute percentage of the households also reported an increase in rainfall events and decreased temperature.

Figure 2: Percentage of perceivers and non-perceivers



Source: Primary data

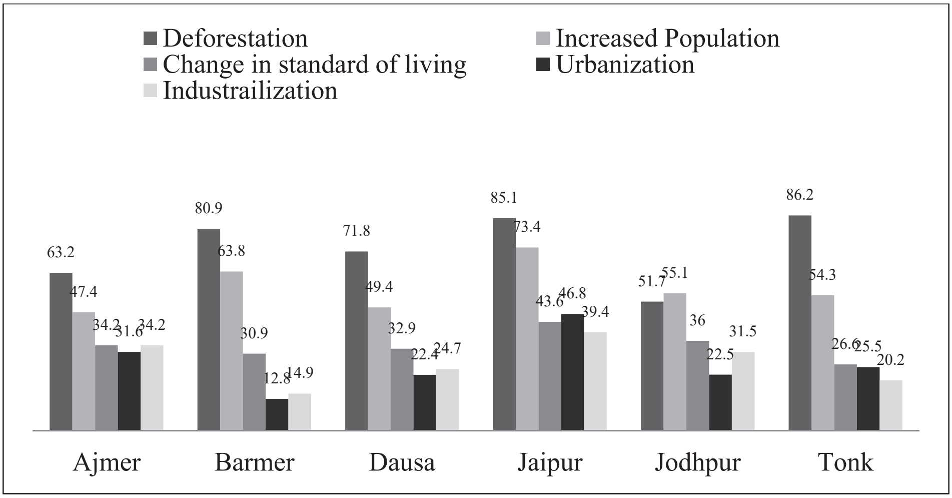
Figure 3: Major perceived changes (in Percentage (%))



Source: Primary data

The main reasons given for these changes were deforestation, increased population, changing living standards, industrialisation, and urbanisation (see Figure 4). Deforestation was found to be a major cause of the climatic changes by 86.2% of the households in Tonk, 85.1% in Jaipur, 80.9% in Barmer, and 71.8% in Dausa. Cutting down trees to clear land and construct buildings has considerably damaged the ecological balance. Increasing population was accounted a major reason in all districts and the main cause of climate change in Jodhpur, resulting in over-utilisation of resources and fuelling long-term changes in the state. In Jaipur 46.8% of the households said that increased urbanisation has also caused climate change. Construction of social infrastructure and other industries has deteriorated land quality and gradually turned agricultural fields into barren land. The households also pointed out that changing living standards can play a major role in environmental change. The expanding needs of the population have led to further exploitation of resources and climate change.

Figure 4: Reasons for the long-term changes (in Percentage (%))



Source: Primary data

Table 1 analyses the major factors influencing farmers' perception of climate change. Previous studies have found farm size (Ojo & Baiyegunhi, 2021; Mairura et al., 2021), education level (Guodaar et al., 2021), access to rain-fed agriculture (Tesfahunegn et al., 2016), and access to extension services (Fahad et al., 2020) to be factors influencing households' perception of climate change. Table 1 shows that the gender of the household head significantly influences the perception of rainfall duration. In the study area most of the women work in household chores, making them less observant of the changing rainfall duration than the men. The social responsibility of the household head is negatively related to all the changes because when the primary concern is community issues rather than resolving household problems the result is less observance of climatic changes and more concern with overall agricultural production failures. The household's literacy status positively influences the perception of increased temperatures and decreased rainfall intensity, while the household head's education is negatively related to the perception of increased temperatures and positively related to the perception of decreased rainfall duration.

The years involved in farming positively influence the perception of decreased rainfall duration. Households that have a long experience of farming are highly observant of the changes around them and notice any change in temperature, rainfall, and especially rainfall duration. This is consistent with studies that show experience to be a major determinant of perceptions regarding climate change (Linden, 2015; Horne et al., 2021). Surprisingly, large households did not perceive increased temperatures, because most members have either migrated to cities or are too young to perceive changes. Households that have access to institutions immediately recognize any increase in temperature or decrease in rainfall duration because of their access to resources and effective social interaction. The visit of an extension officer can improve the capacity of households to perceive increased temperatures or decreased rainfall intensity because the officers have access to climate records and can make households aware and inform them about climate change.

Table 1: Factors influencing households' perception (marginal effect)

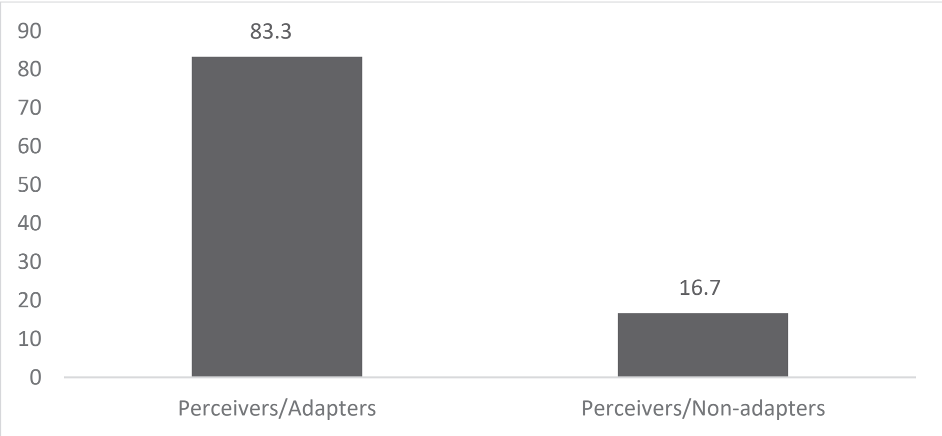
Variable	Increased Temperature	Decreased rainfall duration	Decreased rainfall events	Decreased rainfall intensity
Gender of the HH head	-0.043	0.154*	0.018	0.131
Social responsibility of HH head	-0.092**	-0.129*	-0.141**	-0.301***
Literacy status of the HH head	0.062***	-0.025	0.026	0.035*
Education of the HH head	-0.041***	0.056**	0.007	0.015
Years involved in farming	-0.013	0.053**	0.0193	0.009
Household Size	-0.07***	0.040	0.035	-0.049
Access to Institutions	0.112***	0.18 **	-0.042	0.004
Visit of Extension officer	0.035***	0.011	0.004	0.054***

Note: * indicates significance at 0.1%, ** indicates significance at .05%, *** indicates significance at .01%
Source: Primary data analysis

4.2 Adaptation

The farmers have employed various techniques to adapt to climate change. Figure 5 shows that most of the households have adapted to the changes by employing more than one strategy. 83.3% of the perceivers have adopted strategies to fight climate change and 16.7% have not, even though they are aware of climate stress and losses.

Figure 5: Percentage of adapters and non-adapters

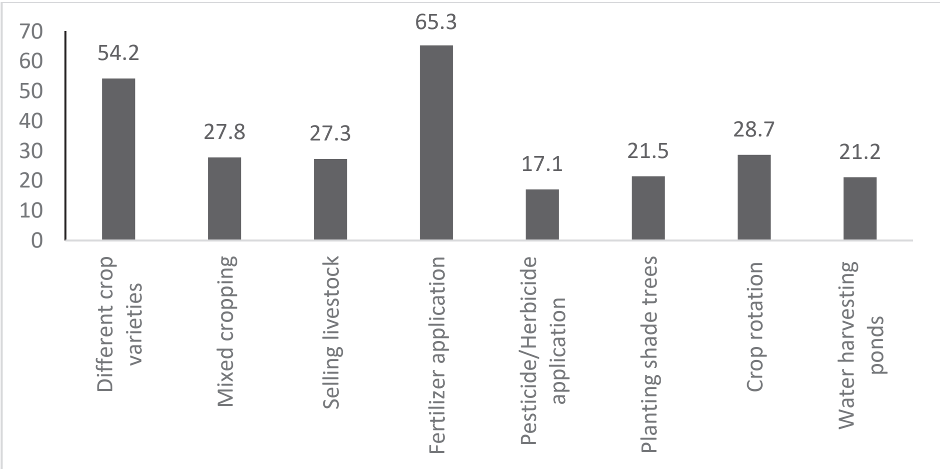


Source: Primary Data

A major adaptation strategy chosen by agricultural households is the application of fertilizers (see Figure 6). Increased economic activity has resulted in land deterioration and reduced crop productivity. 65.3% of the farmers have used fertilizers like urea to improve crop yields and many farmers have started applying bio-fertilizers and vermin composts. 54.2% of households have introduced different crop varieties: crop diversification improves production, especially among farmers with poor access to chemical and technological resources (Lin, 2011). The new varieties are highly water-efficient and require less care, which helps the farmers invest in other assets. 28.7% of the households have adopted crop rotation and 27.8% have opted for mixed cropping, which aids water efficiency, pest control, mutualism and crop co-existence, and use of space and time (Gliessman, 2021).

27.3% of households have sold livestock for temporary financial relief and to meet other requisites or because they no longer have the resources to look after livestock. 21.5% of the households have planted trees to act as windbreaks to protect the soil and crops. Trees also maintain moisture content in the soil and help crops survive drought. Another major strategy is the construction of ponds for irrigation and other water purposes. 21.2% of farmers have constructed water harvesting systems, bore wells, and ponds for irrigation purposes. 17.1% of households have applied pesticides and herbicides to prevent pest infection, which is also a major problem.

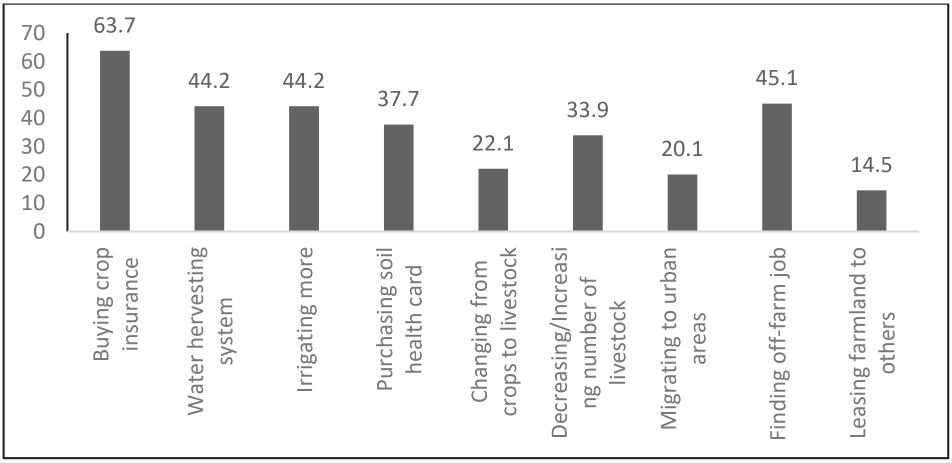
Figure 6: Adaptation strategies (in Percentage (%))



Source: Primary data

Apart from these strategies, Figure 7 shows that the farmers also insure their crops, find off-farm jobs, introduce drip irrigation and sprinkler systems, purchase soil heath cards (A soil health card offers details on the soil's nutritional status and suggestions for the amount of nutrients to be used to increase soil's fertility and health), and lease land to small-scale farmers. Farmers have also migrated to other regions and are willing to move in search of employment if the situation in their area worsens.

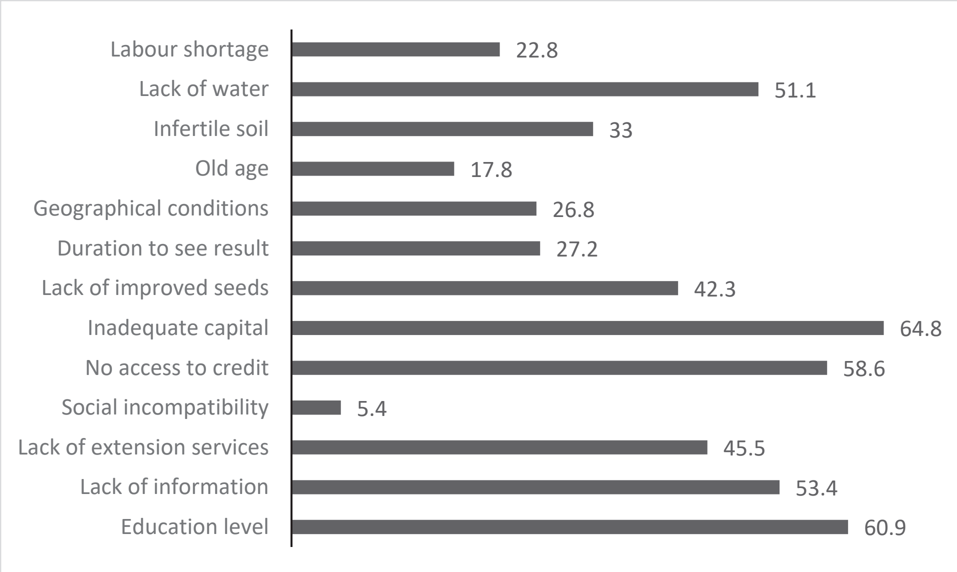
Figure 7: Additional measures (in Percentage (%))



Source: Primary data

The barriers to adopting adaptation strategies include education level, lack of information, lack of extension services, social incompatibility, no access to credit, inadequate capital, lack of improved seeds, duration to see results, geographical conditions, old age, infertile soil, lack of water, and labour shortages (see Figure 8). 64.8% of the households found lack of capital for agricultural investment to be a major barrier. 60.9% believe that their poor education level has made them unaware of new technologies and other practical knowledge required for improving their farming. 58.6% have found lack of credit to be another reason for poor adaptation to climate change. Lack of information (53.4%) followed by inadequate water for drinking and irrigation (51.1%) are other barriers to adaptation. The farmers have no system or technology to forecast the weather and are not informed about climate change. Many households do not have enough water for irrigation, and although some households have constructed farm ponds, many others do not have the finances to do so.

Figure 8: Barriers to adaptation (in Percentage (%))



Source: Primary data

The factors influencing agricultural households' adaptation to climate change can be categorised as personal attributes, psychological factors, and socio-economic factors (Guo et al 2021). Studies have found the main determinants of adaptation to climate change to be gender (Qazlbash, 2021), farm size (Moroda et al., 2021), household size (Getahun et al., 2021), livestock holding (Khan et al., 2021; Alauddin & Sarker, 2021), and income (Sertse 2021). Table 2 shows that education is a major determinant of using different crop varieties, mixed cropping, fertilizers, and tree planting. Farming experience is a major determinant of using fertilizers, mixed cropping, and tree planting: it positively influences the use of fertilizers, as the longer the farmer is involved in farming the more, he improves his land by adding fertilizers, but it negatively influences mixed cropping and tree plantation as experienced farmers limit themselves to the old methods while inexperienced farmers abandon conservative farming methods for new techniques.

External support is a major determinant and influences decisions regarding the use of different crop varieties, mixed cropping, pesticides, tree planting, and the construction of farm ponds. External support in terms of financial backing and provision of agricultural machinery helps farmers adapt to the changes. Agricultural training provides them with crop varieties that are not easily available and encourages them to plant more trees. The size of the farmers' land is another determinant that influences farmers' decisions regarding adaptation strategies. Large farmers are able to construct farm ponds and use mixed cropping methods while small farmers have to depend on local wells and taps for irrigation. When the household income is adequate, farmers adopt new techniques like mixed cropping and reduce the cost of the conventional techniques of applying pesticides and fertilizers.

Access to agricultural institutions is a major factor that determines adaptation strategies (Deressa et al., 2009; Shahid et al., 2021). Households that are near to agricultural institutions and other extension services use mixed cropping and construct farm ponds because they have access to financial resources and quality seeds. Distance from the farmland is another important determinant that negatively influences adaptation strategies such as using different crop varieties, mixed cropping, and selling livestock, because when the farmland is far away it costs the farmers time and money and they are reluctant to introduce new strategies that require time and effort.

Table 2: Factors determining households' adaptation strategies (marginal effect)

Variables	Usage of variety of crops	Mixed cropping	Livestock selling	Fertilizers	Pesticides	Trees plantation	Crop rotation	Farm ponds
Educational status of HH head	0.04***	0.04***	-0.18	0.04**	-0.03	0.03**	0.07	0.07
Number of years farming	0.02	-0.03**	0.03	0.07***	0.04*	-0.04**	-0.02	-0.03
External support	0.19***	0.18***	-0.22***	-0.05	0.18***	0.09**	0.02	0.14***
Agricultural Training	-0.02	0.01	-0.07	-0.03	-0.04	0.11***	-0.17	0.04
Land size	-0.03**	0.02*	-0.01**	-0.001	-0.02*	-0.01	-0.02*	0.03**
Agricultural income	-0.05	0.05	0.08	0.05	-0.12***	-0.04	0.07*	-0.03
Agricultural Institutions	-0.13	0.15***	-0.03	-0.06	-0.04	0.06	0.04	0.03**
Farmland distance	-0.06***	-0.53***	-0.05***	-0.04	-0.04	0.03	1.06***	0.06
Storage	-0.06	-0.61	0.90**	-0.11**	0.06	0.03	0.05	-0.01

Note: * indicates significance at 0.1%, ** indicates significance at .05%, *** indicates significance at .01%

Source: Primary Data

4.3 Livelihood vulnerability index

The livelihood vulnerability index has 8 major components: economic wellbeing and stability, gender discrimination, dependency burden, interconnectivity, susceptibility to environmental change, housing quality, awareness level, and institutional and infrastructure environment. These components are divided into sub-components. Weights are assigned to each sub-component and their value is calculated. Table 3 shows the variables and the weights assigned to them.

Table 3: Variables under study

Sub-Indices (min–max)	**Indicators (min–max)**	**Values/Weights**	**Explanation**
Economic wellbeing and stability	Total Household Assets (1–4)	1 for <5 2 for 5–10 3 for 10–15 4 for >15	Types of assets the households own
	Land rights (0–2)	0 if no land 1 if shared/leased 2 if land is owned	Whether the household possess any land rights
	Income diversification (0–1)	0 for no income diversification 1 for income diversification	Whether the households are engaged in any off–farm activities.
	Healthy household members (0–3)	0 if none 1 if only 1 2 if 2–4 3 if >5	Number of household member healthy enough to work.
	Female participation (0–3)	0 if no participation 1 if 2–3 days working 2 if 3–5 days working 3 if 7 days working	Whether the women in the households are working or not.

Gender Discrimination	Women's land rights (0–1)	0 if no 1 if yes	Whether woman in the household has any land rights
	Decision-making power (0–1)	0 if no 1 if yes	Whether woman in the household has any decision–making power
	Women's health (0–1)	0 if no 1 if yes	Whether women are allowed to visit the doctor
	Women's skills (0–1)	0 if no 1 if yes	If the woman in the household possesses any skills
	Women's responsibility as caregivers (0–2)	0 if women do not fetch water 1 if women fetch water 2 if both men and women fetch water	The household member who fetches water for the household
	Strategies during crop failure (0–1)	0 if no strategy 1 if there is a strategy	If any strategies are being used by the woman in the household
Dependency Ratio	Household members with terminal illness (0–2)	0 if none 1 if 1 2 if >2	Number of household members with terminal illness
	Non-working household members (0–2)	0 if none 1 if <3 2 if >4	Number of household members not working

Level of inter connectivity	Geographical scope of social capital contacts and social categories a household relies on (0–1)	0 if no contacts 1 if there are contacts	Whether the household has any social connectivity
	Groups to which household belongs (0–1)	0 if no groups 1 if there are groups	Whether the household belongs to any social group or organization
Susceptibility to environmental change	Contribution of farming to household livelihood (0–3)	0 if not significant 1 if <30% 2 if 30–70% 3 if > 70%	The percentage of contribution of agriculture to annual income
	Cooking energy source (0–1)	0 if wood/kerosene/dung 1 if gas	Cooking energy source used by the household
	Source of drinking water (0–1)	0 if free source 1 if paid source	Source of drinking water
Housing quality	Quality of house (0–2)	1 if kutcha 2 if mixed 3 if pucca	The quality of the house
Awareness level	Ability to describe environmental change (0–1)	0 if no awareness 1 if there is awareness	If the household is aware of climate changes
Institutional and infrastructure environment	Access to institutions and organizations (0–1)	0 if no access 1 if there is access	Whether the household has access to social institutions and extension services

Source: Vincent (2007), modified by Mwamba (2013)

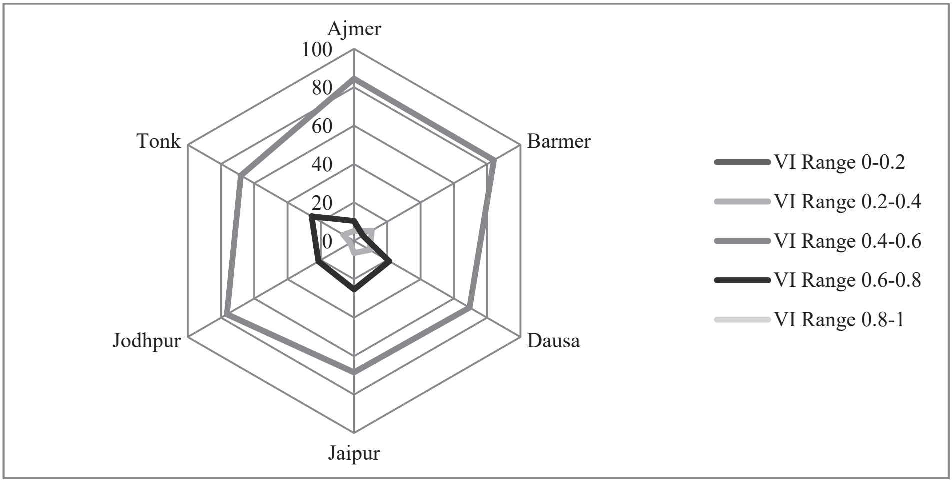
The vulnerability index analyses households' vulnerability with values of 0 to 1. There are five different levels of vulnerability: households that fall into the range of 0–0.2 are the least vulnerable, followed by less vulnerable (0.2–0.4), moderately vulnerable (0.4–0.6), highly vulnerable (0.6–0.8), and extremely vulnerable (0.8–1). Table 4 shows that most of the households are moderately vulnerable to climate change. No households fall into the least vulnerable or extremely vulnerable categories. The radar graph in Figure 9 compares the vulnerability of households in different districts. There is zero variation in the ranges 0–0.2 and 0.8–1, indicating that no households fall into these categories.

Table 4: District-wise vulnerability index values

District	VI Range 0–0.2	VI Range 0.2–0.4	VI Range 0.4–0.6	VI Range 0.6–0.8	VI Range 0.8–0.1
	Percent	Percent	Percent	Percent	Percent
Ajmer	–	5.19	84.41	10.39	–
Barmer	–	10.64	84.04	5.32	–
Dausa	–	9.41	69.41	21.18	–
Jaipur	–	6.31	68.42	25.26	–
Jodhpur	–	2.24	76.40	21.35	–
Tonk	–	6.34	68.09	25.53	–

Source: Primary Data

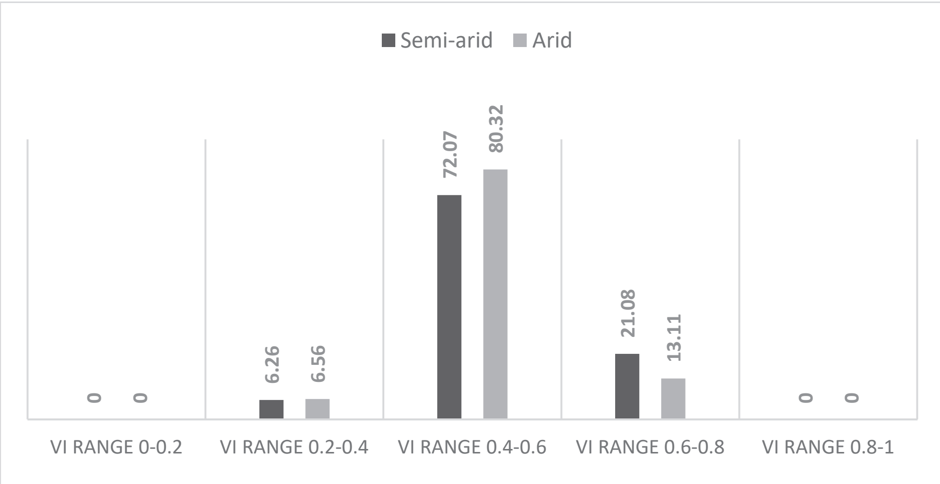
Figure 9: Radar graph of vulnerability



Source: Primary Data

Figure 10 shows the vulnerability to climate change of households in the arid and semi-arid regions. 80.32% of the arid households and 72.07% of semi-arid households are moderately vulnerable. The percentage of less vulnerable households is the same at approximately 6% of the total vulnerable population. Access to credit, availability of agricultural machinery, improved awareness and education, quality seed varieties, extensive government support, and cheap loans account for the lower vulnerability in these areas. However, the percentage of households falling into the highly vulnerable category is higher in the semi-arid region (21.08%) than in the arid region (13.11%). This implies that households in the arid regions are adapting to climate change by employing several strategies, making them less vulnerable.

Figure 10: Region-wise vulnerability



Source: Primary Data

5. CONCLUSION

Increasing temperatures, erratic rainfall patterns, and rising sea levels due to climate change are now an existential threat. Agriculture is a climate-sensitive sector, involving much uncertainty and many risk factors that negatively affect agricultural households. This study analyses agricultural households' perception of climate change and the major adaptation strategies undertaken to mitigate climate change in the arid and semi-arid regions of Rajasthan, and identifies the factors acting as barriers to adaptation. The majority of the households perceive the existence of climate change and have noticed long-term changes such as increased temperature, decreased rainfall intensity, and decreased rainfall events. Their perception is entirely analogous to the meteorological data for Rajasthan. The respondents identify deforestation, changing living standards, increased population, urbanisation, and industrialisation as major factors causing climate change. The major factors that have a significant influence on the farmers' perception are gender, social responsibility, the household head's literacy status and education, years of farming experience, household size, access to institutions, and visits by an extension officer.

The major adaptation strategies of the agricultural households include crop diversification, applying fertilizer, constructing farm ponds, mixed crop farming, crop rotation, planting trees, and selling off livestock. The major determinants of adaptation strategy are found to be educational status of the household head, farming experience, external support, training, land size, agricultural income, access to agricultural institutions, farmland distance, access to crop insurance, social capital, and storage. A vulnerability index measuring adaptive capacity shows that most of the households are moderately vulnerable to climate change.

Based on the above analysis, policy addressing the issues facing rural households needs to be improved to include providing information on climate change, agricultural training, and an efficient weather forecasting system, so that farmers can adapt. Households should receive specific training on the management of climatic stress. Financial support in terms of cheap and easy access to credit should be facilitated, and farmers should receive information about smart agricultural practices. Farmers should be made aware of the benefit of crop insurance schemes such as the Fasal Bima Yojana or Kisan Credit Card. Community-based organisations that include women, and agricultural extension services should function to extend support to farmers during climatic stress.

The current study has attempted to understand the micro-level perception, vulnerability, and adaptation strategies of agricultural households. A limitation of the study is that it only considers the arid and semi-arid belts; future research could consider the vulnerabilities, perception, adaptation, and barriers to adaptation in other agroecosystems. The study's vulnerability index only measures adaptive capacity: future studies might compute vulnerability based on all its respective components; i.e., exposure, sensitivity, and adaptive capacity.

Acknowledgments

Research Funding: The paper is based on a survey conducted under the research project "Measuring the Vulnerability of Agricultural Households to Climate Change in Arid and Semi-Arid Regions of Rajasthan: A Capacity to Adapt Perspective." The project was financially supported under the IMPRESS scheme by the ICSSR (Ministry of Human Resource Development), Government of India (File no. IMPRESS/P2383/635/2018-19/ ICSSR).

Conflict of interest

The authors declare that they have no conflicts of interest.

REFERENCES

Abid, M., Scheffran, J., Schneider, U. A., & Elahi, E. (2018). Farmer perceptions of climate change, observed trends and adaptation of agriculture in Pakistan. *Environmental Management*, 63(1), 110–123. https://doi.org/10.1007/s00267-018-1113-7

Adu, D. T., Kuwornu, J. K. M., Anim-Somuah, H., & Sasaki, N. (2018). Application of livelihood vulnerability index in assessing smallholder maize farming households' vulnerability to climate change in Brong-Ahafo region of Ghana. *Kasetsart Journal of Social Sciences*, 39(1), 22–32. https://doi.org/10.1016/j.kjss.2017.06.009

Adzawla, W., Azumah, S. B., Anani, P. Y., & Donkoh, S. A. (2020). Analysis of farm households' perceived climate change impacts, vulnerability and resilience in Ghana. *Scientific African*, 8. https://doi.org/10.1016/j.sciaf.2020.e00397

Ahmed, Z., Guha, G. S., Shew, A. M., & Alam, G. M. M. (2021). Climate change risk perceptions and agricultural adaptation strategies in vulnerable riverine Char islands of Bangladesh. *Land Use Policy*, 103, 105295. https://doi.org/10.1016/j.landusepol.2021.105295

Alauddin, M., & Sarker, M. A. (2014). Climate change and farm-level adaptation decisions and strategies in drought-prone and groundwater-depleted areas of Bangladesh: An empirical investigation. *Ecological Economics*, 106, 204–213. https://doi.org/10.1016/j.ecolecon.2014.07.025

Asfaw, A., Bantider, A., Simane, B., & Hassen, A. (2021). Smallholder farmers' livelihood vulnerability to climate change-induced hazards: Agroecology-based comparative analysis in Northcentral Ethiopia (Woleka sub-basin). *Heliyon*, 7(4). https://doi.org/10.1016/j.heliyon.2021.e06761

Banerjee, R., Kamanda, J., Bantilan, C., & Singh, N. P. (2013). Exploring the relationship between local institutions in SAT India and adaptation to climate variability. *Natural Hazards*, 65(3), 1443–1464.

Bose, M. M., Abdullah, A. M., Harun, R., Jamalani, M. A., Elawad, R. E., & Fallah, M. (2014). Perception of and adaptation to climate change by farmers in the semi-arid zone of north-eastern Nigeria. *IOSR Journal of Environmental Science Toxicology and Food Technology*, 1(8), 52–57.

Boyer, A.-L., Le Lay, Y.-F., & Marty, P. (2021). Coping with scarcity: The construction of the water conservation imperative in newspapers (1999–2018). *Global Environmental Change*, 71, 102387. https://doi.org/10.1016/j.gloenvcha.2021.102387

Das, Abhinandan. (2010). *Farmers' Perception of Climate Change in the Semi-Arid Topic Region of India*. Report Submitted to International Crops Research Institute for the Semi-Arid Tropics.

Dendir, Z., & Simane, B. (2019). Livelihood vulnerability to climate variability and change in different agroecological zones of Gurage administrative zone, Ethiopia. *Progress in Disaster Science*, 3, 100035. https://doi.org/10.1016/j.pdisas.2019.100035

Dessai, S., Adger, W. N., Hulme, M., Turnpenny, J., Köhler, J., & Warren, R. (2004). Defining and Experiencing Dangerous Climate Change. *Climatic Change*, 64(1/2), 11–25. https://doi.org/10.1023/b:clim.0000024781.48904.45

Deressa, T. T., Hassan, R. M., Ringler, C., Alemu, T., & Yesuf, M. (2009). Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Global Environmental Change*, 19(2), 248–255. https://doi.org/10.1016/j.gloenvcha.2009.01.002

Dhaka, B. L., Chayal, K., Poonia, M. K., & Kendra, K. V. (2010). Analysis of farmers' perception and adaptation strategies to climate change. *Libyan Agriculture Research Center Journal International*, 1(6), 388–390.

Dhanya, P., & Ramachandran, A. (2016). Farmers' perceptions of climate change and the proposed agriculture adaptation strategies in a semi-arid region of south India. *Journal of Integrative Environmental Sciences*, 13(1), 1–18.

Gbetibouo, Glwadys Aymone, (2009). Understanding farmers' perceptions and adaptations to climate change and variability: The case of the Limpopo Basin, South Africa. *IFPRI discussion papers 849*, Washington DC: International Food Policy Research Institute.

Getahun, A. B., Ayal, D. Y., Ture, K., & Zeleke, T. T. (2021). Determinants of climate variability adaptation strategies: A case of Itang special district, Gambella Region, Ethiopia. *Climate Services*, 23, 100245. https://doi.org/10.1016/j.cliser.2021.100245

Guo, R., Li, Y., Shang, L., Feng, C., & Wang, X. (2021). Local farmer's perception and adaptive behavior toward climate change. *Journal of Cleaner Production*, 287, 125332. https://doi.org/10.1016/j.jclepro.2020.125332

Guodaar, L., Bardsley, D. K., & Suh, J. (2021). Integrating local perceptions with scientific evidence to understand climate change variability in northern Ghana: A mixed-methods approach. *Applied Geography*, 130, 102440. https://doi.org/10.1016/j.apgeog.2021.102440

Fahad, S., Inayat, T., Wang, J., Dong, L., Hu, G., Khan, S., & Khan, A. (2020). Farmers' awareness level and their perceptions of climate change: A case of Khyber Pakhtunkhwa province, Pakistan. *Land Use Policy*, 96, 104669. https://doi.org/10.1016/j.landusepol.2020.104669

Hallegatte, S., Bangalore, M., Bonzanigo, L., Fay, M., Kane, T., Narloch, U., Rozenberg, J., Treguer, D., & Vogt-Schilb, A. (2016). *Shock Waves: Managing the Impacts of Climate Change on Poverty*. Washington, DC: World Bank. doi:10.1596/978-1-4648-0673-5.

Hoang, H. D., Momtaz, S., & Schreider, M. (2020). Assessing the vulnerability of small-scale fishery communities in the estuarine areas of central Vietnam in the context of increasing climate risks. *Ocean & Coastal Management*, 196, 105302. https://doi.org/10.1016/j.ocecoaman.2020.105302

Horne, L., De Urioste-Stone, S., Seekamp, E., Rahimzadeh-Bajgiran, P., & Rickard, L. (2021). Determinants of visitor climate change risk perceptions in Acadia National Park, Maine, USA. *Journal of Outdoor Recreation and Tourism*, 35, 100401. https://doi.org/10.1016/j.jort.2021.100401

Jamal, A. M., Antwi-Agyei, P., Baffour-Ata, F., Nkiaka, E., Antwi, K., & Gbordzor, (2021). Gendered perceptions and adaptation practices of smallholder cocoa farmers to climate variability in the Central Region of Ghana. *Environmental Challenges*, 5, 100293. https://doi.org/10.1016/j.envc.2021.100293

Kattumuri, R., Ravindranath, D., & Esteves, T. (2017). Local adaptation strategies in semi-arid regions: study of two villages in Karnataka, India. *Climate and Development*, 9(1), 36–49.

Kalungu, J. W., & Harris, D. (2013). Smallholder farmers' perception of the impacts of climate change and variability on rain-fed agricultural practices in semi-arid and sub-humid regions of Kenya. *Journal of Environment and Earth Science*, 3(7), 129–140.

Kehler, S., & Birchall, S. J. (2021). Social vulnerability and climate change adaptation: The critical importance of moving beyond technocratic policy approaches. *Environmental Science & Policy*, 124, 471–477. https://doi.org/10.1016/j.envsci.2021.07.025

Kihupi, M. L., Chingonikaya, E. E., & Mahonge, C. (2015). Smallholder farmers' perception of climate change versus meteorological data in semi-arid areas of Iringa District, Tanzania. *Journal of Environment and Earth Science*, 5(2), 137–147.

Khan, N. A., Qiao, J., Abid, M., & Gao, Q. (2021). Understanding farm-level cognition of and autonomous adaptation to climate variability and associated factors: Evidence from the rice-growing zone of Pakistan. *Land Use Policy*, 105, 105427. https://doi.org/10.1016/j.landusepol.2021.105427

Mairura, F. S., Musafiri, C. M., Kiboi, M. N., Macharia, J. M., Ng'etich, O. K., Shisanya, C. A., Okeyo, J. M., Mugendi, D. N., Okwuosa, E. A., & Ngetich, F. K. (2021). Determinants of farmers' perceptions of climate variability, mitigation, and adaptation strategies in the Central Highlands of Kenya. *Weather and Climate Extremes*, 34, 100374. https://doi.org/10.1016/j.wace.2021.100374

Mekonnen, A., Tessema, A., Ganewo, Z., & Haile, A. (2021). Climate change impacts on household food security and farmers' adaptation strategies. *Journal of Agriculture and Food Research*, 6, 100197. https://doi.org/10.1016/j.jaf r.2021.100197

Moroda, G. T., Tolossa, D., & Semie, N. (2018). Perception and adaptation strategies of rural people against the adverse effects of climate variability: A case study of Boset District, East Shewa, Ethiopia. *Environmental Development*, 27, 2–13. https://doi.org/10.1016/j.envdev.2018.07.005

Mwamba, L.O. (2013). Vulnerability and Adaptability: Modelling the Adaptive Capacity of Rural Households to Environmental Changes. (Doctoral dissertation, University of Leipzig, Germany). Retrieved from https://ul.qucosa.de/api/qucosa%3A11873/attachment/ATT-0/

Nguyen, Y. T., & Leisz, S. J. (2021). Determinants of livelihood vulnerability to climate change: Two minority ethnic communities in the northwest mountainous region of Vietnam. *Environmental Science & Policy*, 123, 11–20. https://doi.org/10.1016/j.envsci.2021.04.007

Ojo, T. O., & Baiyegunhi, L. J. S. (2021). Climate change perception and its impact on net farm income of smallholder rice farmers in south-west, Nigeria. *Journal of Cleaner Production*, 310, 127373. https://doi.org/10.1016/j.jclepro.2021.127373

Owusu, V., Ma, W., Emuah, D., & Renwick, A. (2021). Perceptions and vulnerability of farming households to climate change in three agro-ecological zones of Ghana. *Journal of Cleaner Production*, 293, 126154. https://doi.org/10.1016/j.jclepro.2021.126154

Qazlbash, S. K., Zubair, M., Manzoor, S. A., ul Haq, A., & Baloch, M. S. (2021). Socioeconomic determinants of climate change adaptations in the flood-prone rural community of Indus Basin, Pakistan. *Environmental Development*, 37, 100603. https://doi.org/10.1016/j.envdev.2020.100603

Prasad, R., Pandey, A. K., Newaj, R., Dhyani, S. K., Saroj, N. K., Tripathi, V. D. (2014). Risk and vulnerability due to climate change and adaptation initiatives for agricultural resilience in Panna district of Madhya Pradesh, central India. *Range Management and Agroforestry*, 35(1), 157–162.

Schlingmann, A., Graham, S., Benyei, P., Corbera, E., Martinez Sanesteban, I., Marelle, A., Soleymani-Fard, R., & Reyes-García, V. (2021). Global patterns of adaptation to climate change by indigenous peoples and local communities. A systematic review. *Current Opinion in Environmental Sustainability*, 51, 55–64. https://doi.org/10.1016/j.cosust.2021.03.002

Sertse, S. F., Khan, N. A., Shah, A. A., Liu, Y., & Naqvi, S. A. (2021). Farm households' perceptions and adaptation strategies to climate change risks and their determinants: Evidence from Raya Azebo District, Ethiopia. *International Journal of Disaster Risk Reduction*, 60, 102255. https://doi.org/10.1016/j.ijdrr.2021.102255

Shah, K. U., Dulal, H. B., Johnson, C., & Baptiste, A. (2013). Understanding livelihood vulnerability to climate change: Applying the livelihood vulnerability index in Trinidad and Tobago. *Geoforum*, 47, 125–137. https://doi.org/10.1016/j.geoforum.2013.04.004

Shahid, R., Shijie, L., Shahid, S., Altaf, M. A., & Shahid, H. (2021). Determinants of reactive adaptations to climate change in semi-arid region of Pakistan. *Journal of Arid Environments*, 193, 104580. https://doi.org/10.1016/j.jaridenv.2021.104580

Shreevastav, B. B., Tiwari, K. R., Mandal, R. A., & Nepal, A. (2021). Assessing flood vulnerability on livelihood of the local community: A case from Southern Bagmati corridor of Nepal. *Progress in Disaster Science*, 12, 100199. https://doi.org/10.1016/j.pdisas.2021.100199

Suresh, K., Khanal, U., Wilson, C., Managi, S., Quayle, A., & Santhirakumar, S. (2021). An economic analysis of agricultural adaptation to climate change impacts in Sri Lanka: An endogenous switching regression analysis. *Land Use Policy*, 109, 105601. https://doi.org/10.1016/j.landusepol.2021.105601

Tesfahunegn, G. B., Mekonen, K., & Tekle, A. (2016). Farmers' perception on causes, indicators and determinants of climate change in northern Ethiopia: Implication for developing adaptation strategies. *Applied Geography*, 73, 1–12. https://doi.org/10.1016/j.apgeog.2016.05.009

Udmale, P., Ichikawa, Y., Manandhar, S., Ishidaira, H., Kiem, A. S. (2014). Farmer'' perception of drought impacts, local adaptation and administrative mitigation measures in Maharashtra State, India. *International Journal of Disaster Risk Reduction*,10, 250–269.

Van der Linden, S. (2015). The social-psychological determinants of climate change risk perceptions: Towards a comprehensive model. *Journal of Environmental Psychology,* 41, 112–124.

Webber, H., Gaiser, T., & Ewert, F. (2014). What role can crop models play in supporting climate change adaptation decisions to enhance food security in sub-Saharan Africa? *Agricultural Systems*, 127, 161–177. https://doi.org/10.1016/j.agsy.2013.12.006

Whitmarsh, L., & Capstick, S. (2018). Perceptions of climate change. *Psychology and Climate Change*, 13–33.

Wing, I. S., De Cian, E., & Mistry, M. N. (2021). Global vulnerability of crop yields to climate change. *Journal of Environmental Economics and Management*, 109, 102462. https://doi.org/10.1016/j.jeem.2021.102462

Received: June 14, 2022
Accepted: September 18, 2022