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Determinants of Farmers' Adaptation Strategies to Climate Change in the Hyper-Arid Partially Irrigated Western Plain of Rajasthan, India

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Authors' contributions

This work was carried out in collaboration among all authors. Author TG designed the study, performed the statistical analysis and wrote the first draft of the manuscript. Authors VS and SS helped in the manuscript writing. Authors SS and NKS helped in the data collection and statistical analysis. All authors read and approved the final manuscript.

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ABSTRACT

Climate change is a global environmental threat to all economic sectors, mainly the agricultural sector is highly vulnerable to the negative impact of climate change. Using cross-sectional data of 120 farmers collected from three blocks of the Jaisalmer district of the hyper-arid partially irrigated western plain of Rajasthan, this study investigates farmers' adaptation measures to climate change and their determinants of adaptive strategies. The study used a logistic model to analyze the relationship between binary dependent variables and other explanatory variables. According to logistic regression results, factors such as land area, farming experience, and household income are positively related to climate change adaptation strategies. The marginal effects for the land area (0.040), farming experience (0.004), and household income (0.00). Further, the result of the study also shows the basic adaptation measures adopted by the farmers are mulching, changing in the crop, changing in sowing date, changing in cultivation practices, changing in water management and changing in input management. According to the study's findings, farmers' well-being will be improved by more significant investment in farmer education, farmers' training through Krishi Vigyan Kendra (KVK), and financial inclusion through Kisan Credit Card (KCC) for climate change adaptation.

Keywords: Climate change; logistic model; marginal effects; adaptation strategies.

1. INTRODUCTION

"The effects of climate change have been an ongoing problem that has long-term effects on the world. The gradual changes in temperature, precipitation patterns, and rising sea levels are just some of the many consequences of this phenomenon. Both developed and underdeveloped countries are impacted by climate change. But compared to developed countries, developing countries are more vulnerable to climate change" Soro et al. [1]. "There are numerous other factors that make developing countries more vulnerable, such as slow technical development and a lack of resources to mitigate the adverse effects of climate change on agriculture" Kumar and Sharma [2]; Saravanakumar et al. [3]. The IPCC report confirms that climate change has a negative impact on various societal sectors and the ecosystem IPCC [4]), and several research studies show that agriculture is particularly vulnerable to climate change in developing countries because they depend so heavily on their natural resources IPCC [5]; Yazdanpanah et al. [6], [7]; Limantol et al. [8]) and because a larger proportion of their population depends on agriculture for a living [9]. Agriculture, as a climate-sensitive sector, requires adaptation to ensure global food security and mitigate the impacts of climate change Loboguerrero et al. [10]; Aryal et al. [11]. "The vulnerability of agriculture in developing countries to climate change is a pressing issue that requires immediate attention and adaptation strategies. High variations in climatic variables such as temperature and rainfall negatively affect crop growth, and certain crops get positively affected due to changes in these environmental factors. Thus, changes in climatic variables may have positive and negative impacts on agricultural productivity and the food security situation in the economy" Greg et al. [12].

"Rajasthan is situated in the western portion of the Indian subcontinent. It is currently the largest State of India covering nearly 10.4 percent of the total geographical area of the country. Nearly 65% of its population (56.5 million) is dependent on agriculture. The State is presently divided into 33 administrative districts and has 10 agro-climatic zones. The average rainfall of Rajasthan is 574 mm compared to the all-India average of 1,100 mm and a significant variation is seen across different regions. In western Rajasthan, the average annual rainfall ranges from less than 100 mm in the north-western part of Jaisalmer (lowest in the state) to over 400 mm in Sikar, Jhunjhunu, Pali region and along the western periphery of the Aravali range. Rajasthan is a water deficit state. It is the driest state with nearly 70 percent of the area classified as arid and semi-arid region" [13]. The Hyper-Arid Partially Irrigated Zone of Rajasthan is a challenging and unique agro-climatic region in India characterized by extremely low annual rainfall and limited access to water resources. With an average annual rainfall ranging from 100 to 300 millimeters, the zone faces a hyper-arid climate with erratic rainfall patterns and frequent drought conditions. Agriculture in this region relies primarily on rainfed practices, and farmers face significant challenges in sustaining agricultural production due to water scarcity and the adverse impacts of climate change. The zone's vulnerability to climate change remains a significant concern, with rising temperatures, altered precipitation patterns, and increased frequency of extreme weather events posing additional challenges to farmers. To cope with the climate change impacts, farmers in the region employ various adaptation strategies Sarwary et al. [14]. These strategies may include cultivating drought-resistant crops, adopting traditional agricultural practices, and exploring innovative water management techniques. Adaptation to climate change is changing or modifying systems to minimize negative impacts and maximize positive impacts [15]. Furthermore, adaptation could occur at several levels of government, such as regional, national, sub-national, and local. Local adaptation is the most significant issue since local actors are the first to recognize the seriousness of climate change. (UNFCCC, 2009).

Several studies have been conducted on farmers' adaptation to climate change in India, but only a few have been conducted in Rajasthan. There have been no studies about adaptations to climate change in the hyper-arid partly irrigated western plain. This specific agro-climatic zone experiences extreme aridity and limited water resources, making it highly vulnerable to the impacts of climate change. However, there is a lack of comprehensive research that specifically investigates the determinants of farmers' adaptation practices in this hyper-arid region. Thus, this study will be helpful to develop effective agricultural adaptation policies in that agroclimatic region. This study has been conducted with the following research objectives; (1) to examine the key adaptation measures adopted by the farmers; (2) To analyze the factors influencing farmers' decision to adopt adaptation strategies.

2. REVIEW OF LITERATURE

Gbetibouo [16] examines "farmers' perception of climate change and variability in South Africa and found that 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".

Di Falco et al. [17] conducted "a study on climate change adaptation in Ethiopia. The findings highlighted the significant role of climate information from formal and informal sources, as well as access to credit, in influencing farm households' decisions to adapt. Moreover, non-adapting households displayed an inverted U-shaped pattern of rainfall behavior during the Meher season. The study also emphasized the importance of public policies in supporting adaptation efforts through provisions like access to credit, climate information, extension services, and adopting climate-resilient technologies and crop varieties".

In the study conducted by Mabe et al. [18] in "Northern Ghana, binary logistic regression was used to examine the determinants of farmers' choice in climate change adaptation strategies. The findings highlighted that factor such as farming experience, farm income, access to phones, mixed farming, perception of reduced rainfall, and access to weather information significantly influenced farmers' decisions. The study recommended strengthening agricultural extension services through adult education programs and establishing agroclimatic information centers in farming communities".

Abid et al. [19] explored "farmers' perceptions and adaptation strategies to climate change in Pakistan's Punjab province. The results of the binary logistic model revealed that education, farm experience, household size, land area, tenancy status, tube well ownership, access to market and weather information, and agricultural extension services influenced farmers' choices of adaptation measures. The results also underscored challenges such as information scarcity, financial constraints, resource limitations, and water shortages hindering effective climate change adaptation in the area".

Limantol et al. [20] 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 was inclined to vary crop type as their adaptation strategy.

In the Indian context, Dhaka et al. [21] analyzed "farmers' perceptions of and adaptation strategies to climate change. The results of the study revealed that farmers adapt to climate change by adjusting the cropping sequence, including changing the timing of sowing, planting, spraying, and harvesting. Larger farms are more likely to adapt to climate change than small farms. The results also indicated that the adaptation process is driven by a number of factors, including the experience of the farmer, the level of education, and the relationship between the Indian summer monsoon and the southern Oscillation".

Sahu and Mishra [22] analyzed "the perceptions and adaptability strategies of farmers to climate change in Odisha, India. The results of the study revealed that annual income, access to irrigation, access to credit facilities, and land holding size of farming households are the major factors influencing their behavior to adapt to climate change".

Choudhary et al. [23] assessed "the local perception of climate change and coping strategies in Chotanagpur Plateau of Eastern India. Results of the study revealed that farming communities of the Chotanagpur plateau had meager knowledge about climate-related change and its possible impact. It was also recorded that the farming communities of the Chotanagpur plateau have indigenous knowledge to handle the possible impact of climate change".

Mohapatra et al. [24] studied "vulnerability and adaptation to climate change in Rajasthan. The study found that the major determinants of adaptation strategy were the 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".

3. METHODS

3.1 Study Area

The study was carried out in the Jaisalmer district of the hyper-arid partially irrigated western plain of Rajasthan (Fig. 1). With an area of 32,401 sq km, Jaisalmer is the largest district in Rajasthan, and the third-largest in the country by area. The Jaisalmer district lies in the Thar Desert, which straddles the border of India and Pakistan. The district is located within a square lying between 26 °.4' – 28 °.23' north parallel and 69 °.20'- 72 °.42' east meridians.

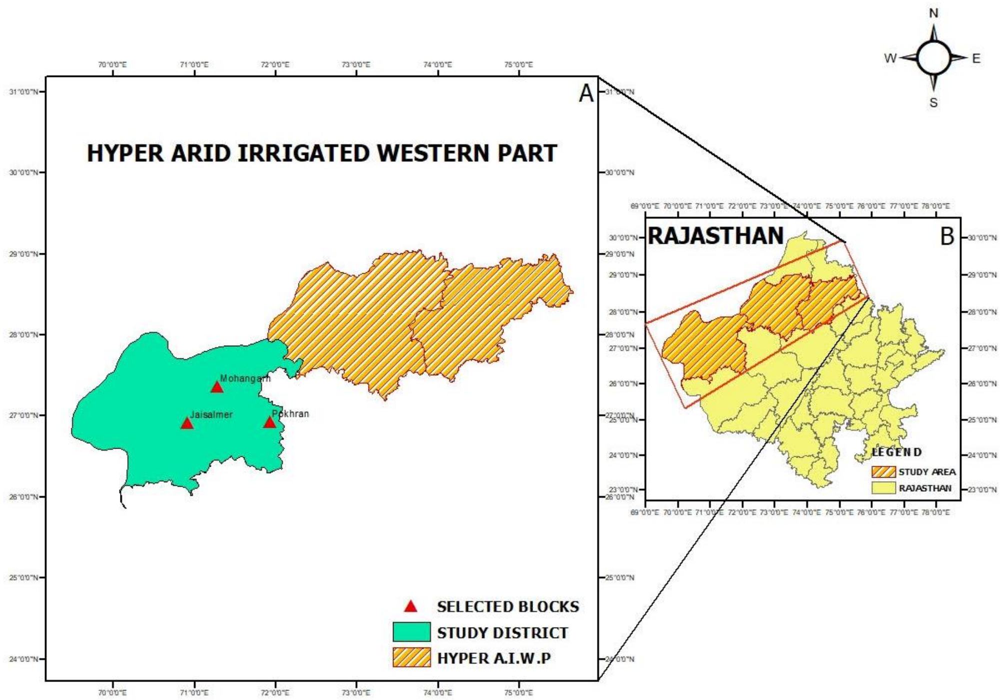

Fig. 1A. Map of hyper-arid irrigated western plain showing study district. 1B. Map of Rajasthan showing hyper-arid irrigated western plain

The climate of Jaisalmer during the winter season remains cold and dry. Throughout the winter, the temperature stays low. The upmost temperature marked during the winter is 24 degrees Celsius, with overnight lows of 7 or 8 degrees. The winter season lasts between the months of November and February. The upmost temperature recorded throughout the day in the summer is 42 degrees Celsius. The temperature drops to 25 degrees Celsius at night-time. The summer starts in Jaisalmer at the end of June and ends in September. The summer months are June, July, August, and September. The average annual rainfall is only 160 mm and is distributed sporadically. The main occupation of people living in Jaisalmer is agriculture and animal husbandry. Guar, Guar, Groundnut, Moong, Castor, and Til are the main crops cultivated in the Kharif season, while Mustard, Cumin, Gram, Isbgol, and Taramira are the main crops grown in the Rabi season. Sandy and sandy loam soil predominate in that area.

3.2 Sampling and Data Collection

A multi-stage random sampling approach was applied to choose the study site and sample farm households in the study area. In the first stage, the Jaisalmer district was selected as the overall study area because it is the largest district in terms of area than the other districts in Rajasthan's hyper-arid partially irrigated western plain. In the second stage, three blocks were randomly selected from the district. In the third stage, from each block, three villages were randomly selected to administer the questionnaire survey. In the fourth stage, 20 farmers were selected randomly from each village to be interviewed about climate change adaptation methods in their farming and socioeconomic status.

The study took place from January to April of 2023. For the data collection, about 120 farmers were interviewed irrespective of gender, farm size, or tenancy status through a farm household survey. A completely organized questionnaire was used to collect data on socioeconomic factors, land tenure, access to various institutional services, current adaptation measures, and adaptation barriers.

3.3 Dependent and Independent Variables

Based on the literature review and past studies, the following were selected as independent variables: age, land area (ha), education, farming experience, household income, household size, access to farm credit, and agriculture extension services. Dependent variables related to farmers' adaptation strategies included mulching, mixed cropping, change in the crop, change in Variety, change in cropping pattern, change in sowing/planting date Change in cultivation practices, change in livestock breed, and change in livestock management practices.

3.4 Empirical Model

The Logit model, commonly known as the Logistic Regression model, is a popular statistical technique for describing the connection between a binary dependent variable and one or more independent variables Deressa et al. [25]; Zhai et al., 2018). The binary dependent variable is whether farmers either implemented adaptation measure(s) or did not adopt any adaptation measures. In this case, Y_i is the dummy variable, Y_i =1 denotes the farmer adopted adaptation measure(s), and Y_i =0 denotes the farmer did not adopt any measures (Bhattacharyya, 2004). The relationship between the farmers' decision to take adaptation measures and independent variables is constructed as follows:

$$P(X) = \frac{e^{\beta_0+\beta_i X}}{1+e^{\beta_0+\beta_i X}}, m = 0,1 \quad (1)$$

Where P denotes the probability that a farmer with characteristics X takes adaptation strategies, Y denotes the dependent variable, indicating whether farmers adopt adaptation measures, X denotes a set of explanatory variables influencing farmers' adaptation decision-making, and β_0 is the intercept, β_i denote the vector of regression coefficients.

The Logit model can also be expressed using the following equation:

$$ln\left(\frac{P(Y=1)}{P(Y=0)}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_i X_i \quad (2)$$

Where P(Y=1) is the probability of adopting the climate change adaptation strategy; P(Y=0) is the probability of not adopting the climate change adaptation strategy; β_0 is the intercept; β_1, β_2,..., β_i are the vector of regression coefficients; X_1, X_2,...,X_i are the set of explanatory variables influencing farmers' adaptation decision-making Greene, [26]; Wooldridge, [27]; A Colin Cameron & Trivedi, [28]; J Scott Long & Freese [29].

The marginal effect provides the change in the probability of the adoption of a climate change adaptation strategy for a one-unit change in the independent variable. The marginal effect for the independent variables X_i can be calculated as:

$$ME_{X_i} = \frac{dP(Y=1)}{dX_i} = \beta_i \times P(Y=1) \times \left(1 - P(Y=1)\right) \quad (3)$$

Where the notation $\frac{dP(Y=1)}{dX_i}$ represents the derivative of the probability P(Y=1) with respect to the independent variables X_i Greene, [26]; Adrian Colin Cameron & Trivedi, [30]; Wooldridge [27;31].

4. RESULTS AND DISCUSSION

4.1 Socio-Economic Characteristics of Sample Respondents (n=120)

The respondent farmers' socioeconomic characteristics are shown in Table 1. The respondents' average age was 42, and they had an average of 12 years of farming experience. The mean household size is 5 members per household. The average amount of land that each household possessed was 3.8 Hectares. 94 of the 120 farmers who were interviewed had interaction with agricultural extension agencies, while 111 of the 120 farmers had access to credit facilities. The household's total average income from farming and non-farming sources was 2,38,889. The farmers surveyed had an average of 5 years of education.

4.2 Adaptation Strategies Employed by the Farmers

The various adaptation strategies being used by farmers in response to changing climatic are presented in Fig. 2. Analyzing adaptations made by all respondents revealed that the change in input management viz. uses of fertilization practices, uses of pesticides etc. was considered to be one of the most important adaptations in response to climate change. To cope with climate variability, farmers have developed a wide range of management practices such as mulching, change in cropping pattern, change in livestock breed, and change in crop type. Farmers were also found making suitable efforts to conserve water through change in water management techniques.

4.3 Results of the Binary Logistic Model

Table 2 displays the results of the logit regression model and the marginal effects of the independent variables. The dependent variable used in the analysis is the adoption of the climate change adaptation strategy followed by the respondent farmers in the study area.

From the results of the logistic model, land area (Ha) has positively and significantly at 5 percent implying that as the land area increased by one unit the probability of willingness to adopt the adaptation measures increased by 4 percent since large farm size has more capacity to adopt new technology and adaptation measures. The negative and significant coefficient of household size indicates that as the household size increases, the probability of adoption decreases. The marginal effect of household size indicated that the probability of willingness to adopt the adaptation measures decreased by 2.2 per cent.
The coefficient of farming experience is positive and significant indicating as the farming experience increases, the probability of adoption of adaptation measures increases. A unit increase in the Farming experience results in a 0.4% increase in the probability of willingness to

Table 1. Socioeconomic characteristics of sample farmers and description of independent variables

Factors	Explanatory variables	Mean	SD
Socio-economic factors	Age (Years)	42.35	8.42
	Land Area (Ha)	3.81	1.87
	Household size (Numbers)	5.47	1.78
	Farming Experience (Years)	12.25	11.29
	Household Income (Rs.)	238888	90553
	Education (Years)	6.73	4.92
Institutional factors	Access to farm credit (1= Yes, 0=No)	0.64	0.48
	Agriculture extension services (1=Yes, 0=No)	0.77	0.41

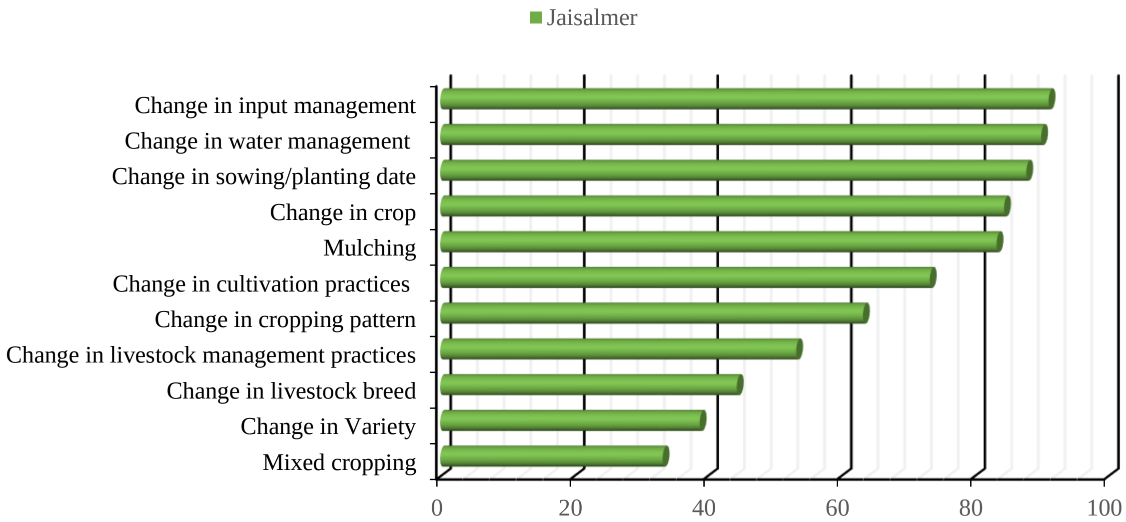

Fig. 2 Adaptations to climate change by respondents' farmers (n=120)

Table 2. Results of the logistic model

Explanatory variables	**Model (1): logit model**	**Marginal Effects (ME)**	**Odds Ratio**
	Adoption of adaptation measures (Yes=1; no=0)		
	Coefficients	**Coefficients**	
Age	0.003	0.000	1.003
Land Area (Ha)	0.203**	0.040**	1.226
Household size	-0.112***	-0.022***	0.894
Farming Experience	0.024**	0.004**	1.024
Household Income	0.000*	0.000**	1.000
Education	-0.128	-0.025	0.880
Access to farm credit	0.117	0.23	1.125
Agriculture extension services	-0.710	-0.141*	0.492
Constant	0.137	-	-
Log-likelihood	-105.14	-	-
LR x^2	26.28	-	-
Prob > x2	0.0009	-	-
Pseudo R^2	0.111	-	-
Overall ME	-	0.914	-

****, ** and * are significant at 1%, 5% and 10%, respectively*

adopt the adaptation measures. The income of the households surveyed has a positive and significant impact on adoption of adaptation measures. The results are similar to the work on climate change adaptation strategies done by Deressa et al. [25], Mignouna et al. [32], Abid et al. [19], Maddison [33], Gbeibouo [16]; Uddin et al. [34-36].

Overall, the marginal effects indicated that the probability of prediction was 91.4 percent for willingness to adopt the adaptation strategies. The results of the odds ratio for those variables which have one or more than one indicates that the probability of happening the event on willingness to adopt the adaptation measures will be more than the non-happening of event. The variables which are having one or more than one odds ratio were age (1.003), land area (1.22), farming experience (1.02), household income (1.0), and access to farm credit (1.12) increases the chances of the probability of sample farmers for willingness to adopt the adaptation measures.

5. CONCLUSION AND POLICY SUGGESTION

The study analyzed the determinants of farmers' adaptation strategies to climate change. Both socioeconomic characteristics and institutional factors influence farmers' adaptation strategies to climate change. Land area, household size, farming experience, and household income are the most influential factors affecting the adoption of farmers' adaptation strategies to climate change. There were several potential policy implications from the results of this study. Farmers with more years of education were adopting climate change adaptation strategies so, supporting farmers' education, farmers' training and easy access to information policies should be implemented by the government. Access to agricultural extension services should be given importance by the government. For farmers with less income, the government may want to consider price support to increase their ability to adapt to climate change by investing in capital and technology in agriculture. Also, financial inclusion through Kisan Credit Card, and short-term loan should be given to farmers through financial institution. Farmers with higher incomes should be guided by the government to take further innovative measures to address climate change. The government should give focus on the adoption of technological innovation viz., drought tolerance varieties, improved irrigation systems, and building farm infrastructures (greenhouses & poly houses) to mitigate the adverse impact of climate change.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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