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Exploring Perceived Weather Uncertainty among Indian Farmers: Insights from Micro-level Analysis and Interpretations

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

India's economy relies heavily on farming, which is crucial for growth, jobs, and survival. However weather uncertainties like droughts, floods, and heatwaves make farming challenging. These uncertainties lower crop yield and quality, causing financial problems for farmers. Despite farmers' efforts, unpredictable weather still hurts crop management. Understanding how farmers feel about these uncertainties is vital for adapting to climate change and reducing risks. The present study was conducted in three villages: Bhomrapara, Mitrapur, and Maniktala of Haringhata block of Nadia district of West Bengal, India, from 2021 to 2022. Nadia district was purposively selected as it comes under the new alluvial zone (NAZ), which has decent productivity in terms of agriculture. A

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hundred farmers with good farming experiences were identified from the sampling frame, and responses were collected through a structured interview schedule. The study explores the diverse perspectives of Indian farmers on climate-related uncertainty, reveals that factors such as age, education, and landholding size significantly influence these views. Experienced farmers and those with more extensive landholdings perceive more significant uncertainty, with irrigation practices, crop yield, and cultivation costs play crucial roles. The study emphasizes the urgency of proactive risk reduction and resilience enhancement to avoid severe implications for agriculture and food security.

Keywords: Climate change; extreme climatic events; farmers perception; uncertainty; weather.

1. INTRODUCTION

Indian economy predominantly depends on the agricultural sector as almost two-thirds of the nation directly or indirectly depends upon it [1]. A significant percentage of the population receives employment, financial support, and nourishment from it [2,3], and makes a significant contribution to trade, economic and social growth of the community [4,5]. Even though the irrigated system depends on monsoon rainfall [6] and most agricultural lands are rainfed [7], the sector is very vulnerable to the hazards associated with climate change, particularly to drought [8]. Flooding is also a considerable issue in many regions of the nation, particularly in the east, where floods occur frequently [9]. Furthermore, heat waves in the middle and northern regions, cyclones along the eastern coast, and frost in the northwest equally wreak chaos. Recently, the incidence of these climatic extremes has increased due to the rising air temperature, increasing the possibility of significant losses in crop production [10]. Both direct and indirect effects of climate change on crops, soils, livestock, and pests can impact agriculture [11]. Increased atmospheric carbon dioxide affects agricultural fertility in several ways, including crop length, respiration rates, photosynthesis, evapotranspiration, and fertilizer use efficiency [12]. Successful farming relies on weather, land quality, irrigation, and crop management [13]. Even with farmers doing their best, there are things beyond their control. These unpredictable factors, which can affect farming and make it hard to foresee income or outcomes, are called uncertainty [14]. Weather uncertainty is the most significant uncertainty in agriculture among all categories. Climatic events like droughts, floods, and extremely high or low temperatures are unpredictable weather patterns, and its severity can majorly impact livestock production and limited scale of agricultural production, underscoring the importance of weather in agriculture [15]. Weather conditions play a crucial role in determining the quality of crop output as it gets moved from the field to storage and then to the market [16]. Adverse weather conditions can harm the quality of crops, whether they are left outside, stored indoors, or transported [17], which can ultimately damage the viability and strength of seeds and planting materials when stored [18]. Farmers generally want to mitigate unfavourable weather conditions, as they can result in substantial financial losses. However, achieving flawless coordination between crop production and meteorological circumstances is enormous. Weather patterns exhibit inherent unpredictability and can demonstrate significant year-to-year variability [19]. Although farmers make diligent attempts to strategize and minimize risks, they cannot exert complete control or accurately forecast the weather [20]. The absence of predictability in agricultural operations creates uncertainty, which hinders the consistent adjustment of crop quality and production [21]. The present study investigates the factors influencing farmers' perceptions of weather-related uncertainty and their contributions and interconnections. This study provides vital insights into how farmers manage the difficulties caused by uncertainty and adjust their methods in response to changing environmental circumstances. The study aims to illuminate the complexities of decision-making in agricultural environments by examining the nuances of farmers' perceptions and the underlying causes that influence them. Gaining a comprehensive understanding of these processes is essential for formulating efficient strategies and interventions to assist farmers in reducing risks and enhancing their ability to withstand unpredictable weather patterns and broader patterns related to climate change.

2. METHODOLOGY

The present study envisages the relationship between the critical factors of uncertainty in farming and the socio-ecological variables. An *ex-post facto* research design [22] was followed to conduct the study. The study was conducted by randomly selecting three villages, namely Bhomrapara, Mitrapur, and Maniktala, of the Haringhata block of Nadia district in West Bengal. Nadia district of West Bengal comes under the New Alluvial Zone (NAZ), characterized by highly fertile, productive land and high cropping intensity [23,24]. Despite that, the farmers are not facing easy farming due to uncertainty. A score of 100 respondents has been selected through a random sampling method. Data are collected between August 2021 and May 2022 through a structured interview schedule using face-to-face interactions. The data were collected in terms of independent and dependent variables. Twenty-three socio-ecological variables are identified as independent variables based on the review of literature and pilot study for the study. In assessing uncertainty in agriculture, perceived weather uncertainty (PWU) is considered the primary factor which is quantified using a ten-point rating scale. Five validated statements related to weather uncertainty were developed based on expert opinion and a pilot study. The overall PWU is calculated as the average of these individual statements:

$$PWU=\frac{(WUS1+WUS2+WUS3+WUS4+WUS5)}{5}$$

where WUS = weather uncertainty statement

where WUS represents each weather uncertainty statement. A score of ten indicates the highest perception of uncertainty, whereas a score of zero indicates the lowest. This method aims to capture the range of possible outcomes regarding weather-related uncertainty in agriculture. The collected data are analysed through both descriptive and multivariate analysis. Statistical Package for the Social Science v23.0 (SPSS) of IBM and online statistical tool OPSTAT [25] are used for analysing the coefficient of correlation, stepwise regression analysis, and path analysis.

3. RESULTS AND DISCUSSION

Farmers' perceptions and responses to climate-related uncertainties significantly impact agricultural resilience and food security. High levels of perceived uncertainty regarding extreme weather events, droughts, or long-term climate shifts may deter farmers from investing in costly adaptation measures or making strategic adjustments to their farming practices. Consequently, this hesitancy can increase their vulnerability to adverse outcomes, such as crop failures, livestock losses, and reduced yields. Conversely, a comprehensive understanding of the sources and characteristics of climate uncertainty can enable farmers to make more informed decisions, access pertinent support services, and implement effective risk management strategies. Fig. 1 presents three weather parameters i.e. annual rainfall, minimum temperature and maximum temperature of the last fifteen years (2006 to 2022) (Gridded data collected from India Meteorological Department, Pune) [26,27]. The data indicates that, in case of annual rainfall, there is an increasing trend, whereas in case of minimum and maximum temperature, the trend is flattened over the years. Although there is some variability present in all three weather parameters over the year. Fig. 2 depicts the cropped area damaged due to climatic events in the last seven years throughout the entire state of West Bengal.

It has been reported that about 34 lakh hectares of cropped area of the state is damaged from the year 2015 to 2022 with an average of about 4.86 lakh hectare area damaged per year. With the increasing pressure of crop production per unit area of crop land it becomes crucial to reduce the loss of crop due to climate related hazards or extreme climatic events.

At the same time, 51 percent and 43 percent of farmers had perceived very low uncertainty about the chances of thunderstorms and the amount of precipitation, respectively. The study suggests that the farmers have a broad understanding of the uncertainty of different climate events, ranging from very low to very high. A similar study also reveals that the participant has a good appreciation of the uncertainty of weather forecasts. However, they tend to avoid forecasts based on low probabilities for their decisions [29].

3.1 Relation between PWU and Selected Socio-Ecological Variables

Weather uncertainty is a condition where an uncertain weather event can be seen that directly impacts farming. Farmers can perceive uncertain weather conditions by achieving some socio-ecological attributes. Table 1 envisages the association between the dependent variable, PWU, and selected socio-ecological variables using Pearson’s multiple correlation coefficients. It has been found that variables age (x1), education (x2), dependency ratio (x6), cultivated land (x7), landholding (x9), irrigated land (x11), crop diversity index (x13), yield of crop (x14), cost of cultivation (x15), information seeking behaviour (x21) have recorded significant correlation with PWU. among them, the following variables age (x1), landholding (x9), and cost of cultivation (x15) have recorded positive correlations, whereas education (x2), dependency ratio (x6), cultivated land (x7), irrigated land (x11), crop diversity index (x13), yield of crop (x14), information seeking behavior (x21) have recorded negative correlation with PWU.

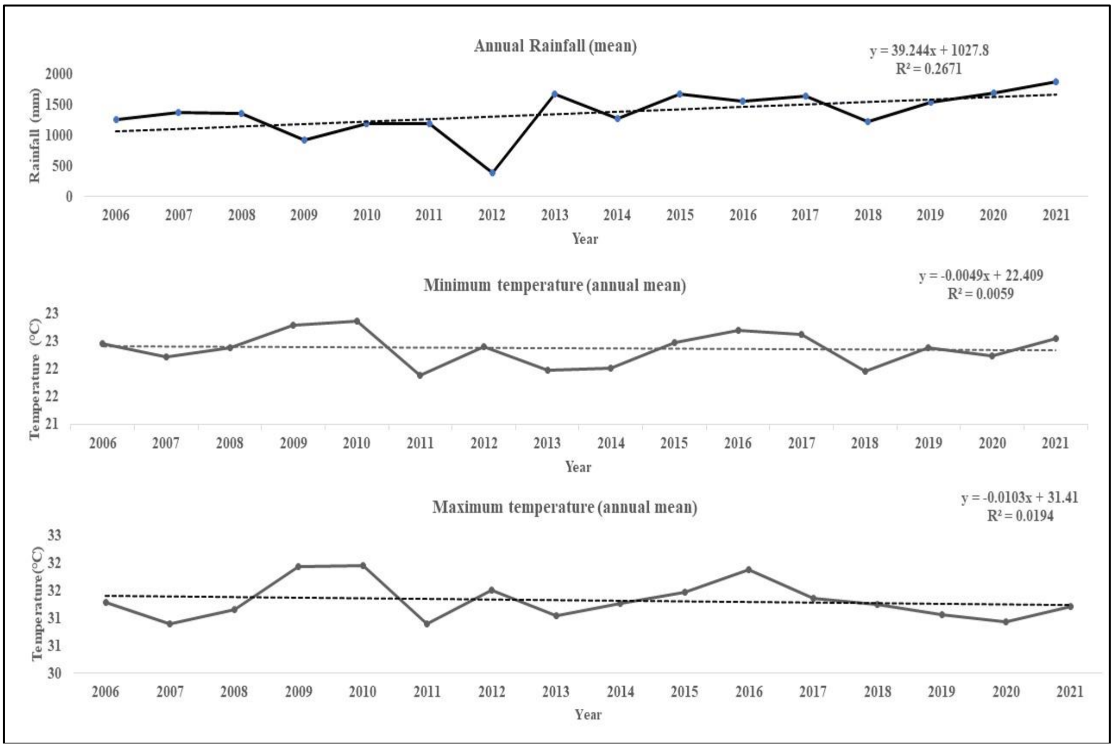

Fig. 1. Weather data of the selected study locale from 2006 to 2021 (IMD, Pune)

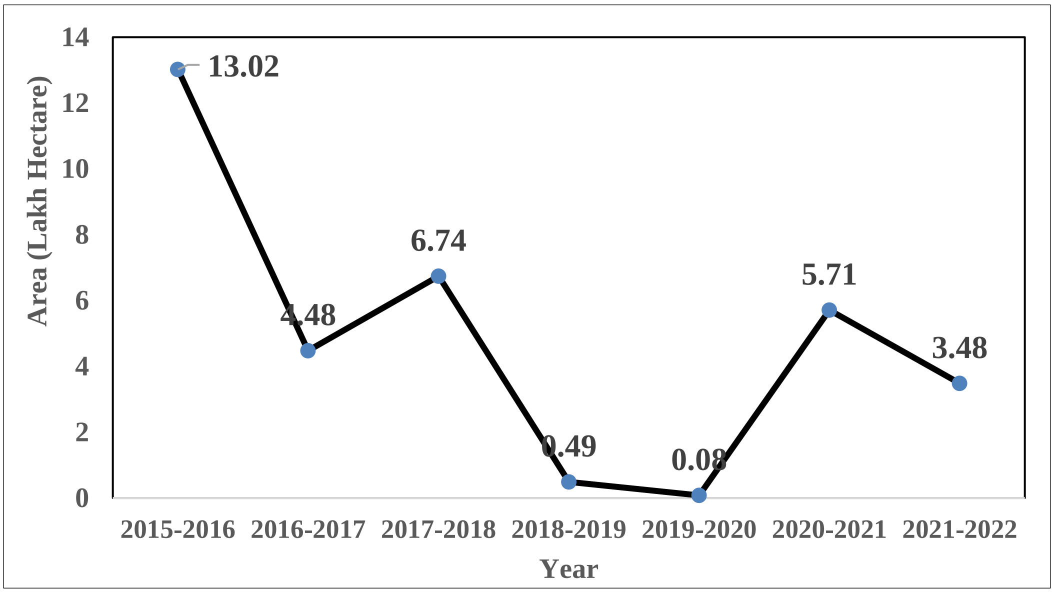

Fig. 2. Cropped area damaged due to Hydro Meteorological Calamities/Hazards in West Bengal (2015-2016 to 2021-2022) [28]

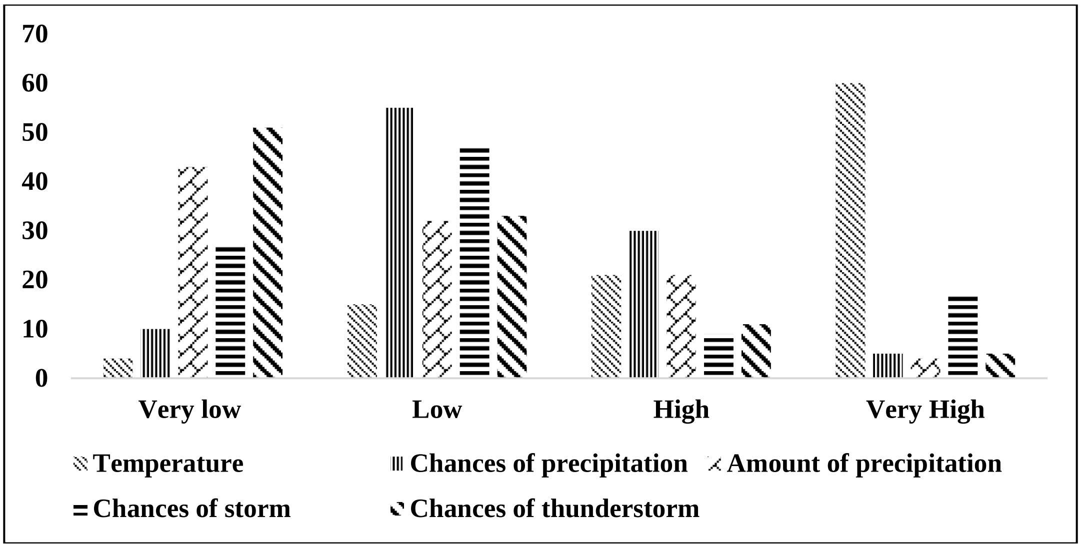

Fig. 3. Perceived uncertainty of different climate events by the farmers

Table 1. Association between PWU (y) and selected socio-ecological variables (x1-x23)

Sl. No.	Variables	'r' value	Remarks
1	Age (x1)	0.253	*
2	Education (x2)	-0.266	**
3	Family size (x3)	-0.053	
4	Sex ratio (x4)	-0.061	
5	Cost of energy consumption (x5)	0.083	
6	Dependency ratio (x6)	-0.426	**
7	Cultivated land (x7)	-0.206	*
8	Homestead land (x8)	0.039	
9	Landholding(x9)	0.482	**
10	Number of fragments (x10)	-0.156	
11	Irrigated land (x11)	-0.393	**
12	Cropping intensity (x12)	-0.059	
13	Crop diversity index (x13)	-0.389	**
14	Yield of crop (x14)	-0.292	**
15	Cost of cultivation (x15)	0.342	**
16	On-farm income (x16)	-0.134	
17	Off-farm income (x17)	0.011	
18	Income per year (x18)	-0.120	
19	Training received (x19)	-0.166	
20	Farming experience (x20)	0.133	
21	Information seeking behaviour (x21)	-0.406	**
22	Health status (x22)	0.110	
23	Stress (x23)	-0.070	

*N.B.**Correlation is significant at the 0.01 level; *Correlation is significant at the 0.05 level*

The study reveals that older farmers have a heightened perception of weather uncertainty due to their extensive farming experience. Farmers with larger land areas under cultivation may encounter more uncertain weather events, leading to increased cultivation costs due to unfavorable conditions. Conversely, farmers with lower levels of education tend to view weather uncertainty more negatively. Higher education and better training may mitigate the impact of weather uncertainty. Those who rely more on other family members' earnings often face more significant weather uncertainty. Farmers with small Landholdings are particularly vulnerable to extreme weather events. Regions with less irrigation suffer more from weather uncertainty, as irrigation can mitigate extreme weather effects. Weather uncertainty significantly affects crop yields. Seeking more weather information helps reduce uncertainty. Larger farms experience more pronounced effects from weather uncertainty. Similar studies also reveal that the factors affecting different categories of climate change perceptions depend upon a series of factors, including both socio-economic and psychological considerations, *viz*. gender, age, education, soil fertility status, climate change information, and access to credit services [12], being located in an area with external water supply, owning fields with salinization issues, cultivating drought or salt-sensitive crops, farm revenue, drought risk experience, and perceived control [30,31].

3.2 Envisioning Perceived Weather Uncertainty Based on Selected Socio-Ecological Variables

Table 2 presents the stepwise regression analysis for screening out the most dominant causal variable impacting weather uncertainty (y). It has been found that the following variables, Landholding(x9), irrigated land (x11), yield of crop (x14), crop diversity index (x13), dependency ratio (x6), cost of cultivation (x15) have been retained at the last step. These six variables (dominant) together have contributed 70.90 percent variance embedded in the dependent variable PWU. Interestingly, these six variables have made a net contribution of 91.60 percent of the total variance explained. These six variables have tremendous strategic importance. Weather uncertainty and landholding size are closely associated. The more land under irrigated farming, the less impact weather has on generating uncertainty. Irrigated land provides higher security and less uncertainty due to controlled management and consistent income. Crop yield serves as a strong predictor and indicator of weather uncertainty. Yield fluctuations are directly linked to weather variations. Crop diversity is essential for estimating weather uncertainty intensity and mitigating its effects. Dependency ratio usage affects both costs and risk perception. When costs increase, risk implications are amplified, creating a ripple effect. Cultivation costs serve as a standard indicator for assessing uncertainty levels. Information seeking and sharing are crucial for addressing uncertainty and are logically connected to the dependency ratio. Several similar studies also support that the availability of specific and agro-ecologically relevant weather forecasts is essential to overcome perceptual problems and to support effective adaptation [32] along with the provision of climate change-related information through various outlets may be helpful to distribute timely and relevant information to farmers. Institutional measures and arrangements, such as improved agricultural extension services, can have an increased impact in facilitating information exchange and motivating farmers to take necessary action in due course time [33]. It is also essential to adequately reduce the problem of lack of money, resource constraints, and shortage of irrigation water to adapt the mitigation strategies related to weather-related uncertainties [34].

Table 3 presents the path analysis wherein the total effect of the dependent variable has been decomposed into direct, indirect and residual effects of selected independent variables. Yearly income has exerted the highest direct effect on PWU. The higher the weather uncertainty, the poorer the income. Again, On-farm income has come out with an intensive associative property to characterize the weather uncertainty by a clandestine maundering of the role and Contribution of other variables. The residual effect of 22.8 percent is to conclude that even

Table 2. Stepwise regression analysis: PWU (y) *vs.* selected socio-ecological variables (x1-x23)

Sl. No.	Variables	*B*	*SE B*	β	*t*
1	Landholding(x9)	0.394	0.066	0.394	5.931
2	Irrigated land (x11)	-0.423	0.068	-0.423	-6.264
3	Yield of crop (x14)	-0.186	0.074	-0.186	-2.502
4	Crop diversity index (x13)	-0.169	0.079	-0.169	-2.139
5	Dependency ratio (x6)	-0.320	0.073	-0.320	-4.363
6	Cost of cultivation (x15)	0.281	0.092	0.281	3.045
R square: 70.90 percent; The standard error of the estimate: 0.556					

N.B. B: Unstandardized beta; SE B: Standard error of unstandardized beta; β: Standardized beta; *t*: t test statistics

Table 3. Decomposition of Total Effect of PWU (y) on selected socio-ecological variables (x1-x23)

Sl. No.	Variables	TE	DE	IE	HIE
1	Age (x1)	0.253	0.078	0.175	0.143 (x15)
2	Education (x2)	-0.266	-0.023	-0.243	-0.125 (x18)
3	Family size (x3)	-0.053	-0.393	0.340	0.677 (x16)
4	Sex ratio (x4)	-0.061	0.124	-0.185	-0.618 (x18)
5	Cost of energy consumption (x5)	0.083	0.282	-0.199	0.641 (x16)
6	Dependency ratio (x6)	-0.426	-0.315	-0.111	-0.087 (x9)
7	Cultivated land (x7)	-0.206	-0.175	-0.031	1.137 (x16)
8	Homestead land (x8)	0.039	0.152	-0.113	0.658 (x16)
9	Landholding (x9)	**0.482**	0.336	0.146	-0.223 (x16)
10	Number of fragments (x10)	-0.156	-0.138	-0.018	1.003 (x16)
11	Irrigated land (x11)	-0.393	-0.392	-0.001	-0.085 (x16)
12	Cropping intensity (x12)	-0.059	0.021	-0.080	-0.669 (x18)
13	Crop diversity index (x13)	-0.389	-0.177	-0.212	-0.132 (x15)
14	Yield of crop (x14)	-0.292	-0.188	-0.104	-0.100 (x15)
15	Cost of cultivation (x15)	0.342	0.227	0.115	-0.115 (x16)
16	On-farm income (x16)	-0.134	1.215	**-1.349**	-1.198 (x18)
17	Off-farm income (x17)	0.011	0.388	-0.377	-0.558 (x18)
18	Income per year (x18)	-0.120	**-1.231**	1.111	1.182 (x16)
19	Training received (x19)	-0.166	-0.026	-0.140	0.154 (x16)
20	Farming experience (x20)	0.133	0.047	0.086	0.511 (x16)
21	Information seeking behaviour (x21)	-0.406	0.001	-0.407	-0.222 (x9)
22	Health status (x22)	0.110	-0.058	0.168	0.092 (x18)
23	Stress (x23)	-0.070	-0.037	-0.033	0.117 (x16)

NB. TE= Total Effect; DE= Direct Effect; IE= Indirect Effect; HIE= Highest Indirect Effect; Residual effect: 0.228

with a combination of 23 causal variables, around 23 percent of variants in consequent variables and around 23 percent of variants in PWU could not be explained. The variable irrigated land has the highest indirect effect of 11 other causal variables to characterize the PWU. The following study underscores the multifaceted nature of perceived weather uncertainty among the farming community. Economic stability, especially annual income, plays a crucial role in reducing perceived weather uncertainty, while dependency on agriculture escalated. It is also evident that the net farm income of smallholder farmers is dependent on small shifts in precipitation and temperature. In particular with regard to smallholder farmers, government policies and investment strategies should be focused on supporting education, strengthening farmers' cooperatives, providing financial options, and disseminating information about climate change [35,36].

On the other hand, land use practices and their indirect effects also have an influence in this dynamic which points to the need for integrated strategies that consider economic diversification, land management and climate resilience to address the challenges of weather uncertainty among the farming community. A similar study also suggested that designing smart land tenure interventions based on improved understanding of (local) interactions between farmers and weather support systems can help farmers in effectively addressing the adverse effects of weather uncertainty [37,38,39].

4. CONCLUSION

Uncertainty is an intrinsic characteristic of any system characterized by multiple contradictory factors that remain unpredictable or incomprehensible. In such situations, the system's complexity level is inversely proportional to its ability to withstand and recover from disruptions. Farmers, whose livelihoods depend on the success of their crops, are acutely aware of the potential destruction that irregular weather patterns can inflict. Variations in precipitation and temperature may cause severe impacts on crop production, leading to a subsequent decrease in food supply. The findings indicate that farmers have a wide range of views of uncertainty, which differ depending on the specific climate occurrences. age, education, and landholding size are important socio-demographic factors that majorly impact these beliefs. Elderly farmers and those with more extensive landholdings tend to experience increased uncertainty. Factors such as irrigation practices, crop yield, and cultivation costs are solid determinants of weather uncertainty. The study also reveals the complex interaction between these variables, highlighting income per year as a significant direct contributor. Although causal factors have been thoroughly examined, a substantial percentage of the uncertainty variation remains unexplained, indicating the complex nature of weather-related challenges. This instability weakens farmers' endeavours and makes it highly challenging to rationalize any modifications to their current farming techniques. These observations emphasize the necessity of implementing specific interventions and policy actions to strengthen the ability of agriculture to withstand the uncertainties caused by climate change. The complex interaction of uncertainties in the Indian agricultural production system highlights the pressing requirement for proactive actions to reduce risks and enhance resilience. Neglecting to tackle these difficulties comprehensively could result in significant implications, impacting not only the agricultural sector but also the country's overall food security.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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