



RESEARCH ARTICLE

Knowledge and perception on climatic variability among farming communities: An assessment in Bundelkhand region, India

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Abstract

Agricultural communities, especially those having marginal and small landholdings, are more vulnerable to the impacts of climate change. Among the Southeast Asian nations, India is highly susceptible to meteorological catastrophes such as droughts and floods. This research, conducted during 2022–2023, aims to investigate farmers' perceptions of climatic hazards, their choice of adaptation techniques and the factors that influence decisions regarding adaptation measures in the Bundelkhand region. A household survey was conducted to collect primary data from 180 agricultural households across 8 blocks in the districts of Banda, Hamirpur and Mahoba in the Bundelkhand region of India. A structured questionnaire served as the instrument for data collection from the targeted farmers in the study locations. Multiple regression analysis was employed to evaluate participants' perceptions of climatic variability and to identify the drivers that influence the choice for adaptation options adopted by respondents to address climate variability. The findings indicated that farmers know that climate variability exists (96.70 %) and know that it means temperature fluctuations in all climate parameters (90.00 %). A large proportion of respondents (83.90 %) were aware that climate variability leads to an increase in vector-borne diseases in animals. Whereas 70.60 % perceive that climate change harms the preservation of milk and milk-based products and 80.56 % perceive that climate variability decreases the fertility of the livestock. Regression analysis shows the model fit ($R^2 = 0.817$) and the variables influencing were age, education, family type, family size, occupation and experience were significantly influenced the perception of the farmers. These findings are significant as they highlight that climate adaptation strategies in semi-arid regions like Bundelkhand cannot be 'one-size-fits-all' but must be demographic-specific. To enhance resilience, policymakers should prioritise the integration of livestock health management into climate blueprints and invest in rural education to bridge the perception-adaptation gap.

Keywords: adaptation; climate change; farmers; knowledge; perception; strategies

Introduction

Climate change has negatively impacted all sectors worldwide, adversely affecting natural and socio-economic systems, particularly in developing countries (1, 2). Rising global temperatures, precipitation anomalies and sea levels have intensified climate-related risks in recent decades, with further increases anticipated in the near future (3, 4). Climate variations, particularly increasing temperatures, can significantly affect a nations' economy, leading to soil degradation, diminished agricultural yields, food insecurity,

poverty and heightened vulnerability of agrarian communities (5, 6). Climate change, characterised by heightened vulnerability for developing nations, is anticipated due to climate unpredictability and meteorological forecasts. Small and marginal farmers, lower subsistence farmers and rural communities are significantly affected by climate variability due to their limited adaptive capacity. Temperatures are projected to increase by 1.7–2.1 °C by 2050 and 2.7–3.4 °C by 2080 (7). Numerous studies have shown that the frequency and spatial extent of droughts have increased over the

past few decades and are expected to continue (8). In India, climate change poses a serious threat to agricultural sustainability and rural livelihoods. One of the most vulnerable regions is the Bundelkhand region, characterised by recurrent droughts, erratic rainfall, land degradation and chronic water scarcity. These climatic stresses, combined with socio-economic constraints such as small landholdings, low income levels and limited institutional support, make farm households in Bundelkhand highly susceptible to climate risks. Despite several government initiatives and adaptation efforts, the region continues to experience significant agricultural instability and livelihood insecurity. Effective risk reduction for climatic threats necessitates the understanding of climate variability by impoverished households. The IPCC forecasts that climate change will have a greater impact on agriculture and socioeconomic development. Emerging regions are especially susceptible to climate change due to inadequate adaptation (9, 10). Implementing timely adaptation strategies can help developing regions mitigate climate-related threats and severe weather. Although climate change adaptation initiatives are adopted globally, there is still a notable gap in the literature with respect to adaptation in India (11). Extreme weather events continue to rise, posing an adverse impact on livestock, agriculture and rural farming communities (12). The innovative and timely adaptation methods and agricultural practices are essential for sustainable development, poverty alleviation and food security.

Although a growing body of literature exists on climate change adaptation globally, empirical studies focusing on location-specific vulnerabilities and farmer-level adaptation behaviour in regions like Bundelkhand remain limited. Most existing studies emphasise either macro-level climate trends or general adaptation strategies, with insufficient attention to farmers' perceptions, decision-making processes and constraints influencing adaptation choices at the household level. This creates a critical research gap in understanding how vulnerable farming communities perceive climate risks and respond through adaptation practices. Addressing this gap is essential for designing context-specific and effective adaptation interventions. Therefore, the present study aims to examine farm households' perceptions of climate change, assess their vulnerability and analyse their adaptation strategies in response to climatic risks in the Bundelkhand region. The study is guided by the following hypothesis: H_0 : Socio-economic and institutional factors significantly affect farmers' perception of climate change. The findings of this study will contribute to the existing body of knowledge by providing insights into farm households' perceptions, vulnerabilities and adaptation decisions in the context of climate change. The results are expected to assist policymakers and development practitioners in designing targeted interventions to enhance climate resilience and promote sustainable agricultural practices in vulnerable regions.

Materials and Methods

The Bundelkhand region of India was selected due to its long history of recurrent droughts. Drought has historically affected up to 70 % of crops and adversely affected the livelihoods of small, marginal and subsistence farmers in this region. Bundelkhand, spanning parts of Uttar Pradesh and Madhya Pradesh, is highly vulnerable to climate variability and more sensitive than many other regions of India. Droughts transpired every 16 years during the 18th and 19th centuries, but their frequency increased three fold

from 1968–1992, presently occurring annually (13). From 2004–2017, the average yearly precipitation in the region was subnormal. The severity of low precipitation resulted in 40 % of land being fallow from the total net planted area, subsequently leading to a drop of approximately 30 % in overall farm output. A multistage sampling design was adopted for the study. Three districts, namely Banda, Mahoba and Hamirpur, were purposively selected from the 13 districts of Bundelkhand due to their high drought vulnerability (Fig. 1). From each district, two blocks were randomly selected, resulting in a total of six blocks (Badhokhar Khurd, Tindawari, Maudaha, Sumerpur, Kabari and Charkhari). Further, two villages were randomly selected from each block, making a total of 12 villages. From each village, 15 farm households were selected using simple random sampling, resulting in a total sample size of 180 households. The sample size of 180 households was determined based on resource constraints and to ensure adequate representation across selected districts, blocks and villages. Multiple regression models were used to find the perception of the farming community towards climate change. Primary data were collected through a household survey utilising face-to-face interaction from February to June 2023, employing simple random sampling. The interview schedule was validated through expert review and pilot testing with a small sample of respondents to ensure clarity, relevance and reliability of the questions. Data handling, cleaning and analysis were carried out using MS Excel 2021 and SPSS version 21.

Results

In the research region, most farmers were between 35 and 55 years old (66.11 %), with 20.55 % under 35 and 13.34 % over 55. Farm households' age affects their adaptation decisions to climate change (6). About half of the farmers were middle-aged (14). Our study found that farmers in the investigated areas are illiterate and only 36 (20.00 %) are graduates. 149 (82.77 %) had joint families and medium families (4–10 members) throughout the home survey. The majority of respondents were dairying and crop farming (163; 90.55 %), 62 (34.44 %) owned less than 1/hectare farms, 114 (63.34 %) had medium annual income, relied on mass media for information (165; 91.66 %) and 119 (66.11 %) had 10 to 27 years of farming experience and 112 (62.23 %) farm households had 3–7 dairy animals.

Farmers' knowledge of climate change and its effects on crops

The majority of respondents (96.70 %) noted variability in climate, indicating a high level of awareness among farm households in the Bundelkhand region (Table 1). While 90 % of the respondents knew that climate variability is a fluctuation in climatic parameters. Farmers also demonstrated a relatively good knowledge of visible and locally experienced causes and effects, like 80.00 % identifying deforestation and 78.90 % recognising crop residue burning as contributors to climate variability. Similarly, 71.12 % of respondents correctly perceived erratic rainfall patterns over the years, indicating strong experiential awareness due to direct exposure to climatic changes in the region. A significant knowledge gap was also observed in more technical and scientific aspects of climate change. A majority of respondents lacked correct knowledge regarding the impact of decreasing rainy days and increasing dry days on crop productivity, indicating confusion about the relationship between climate variables and agricultural outcomes. Awareness about

Study area map of Bundelkhand region

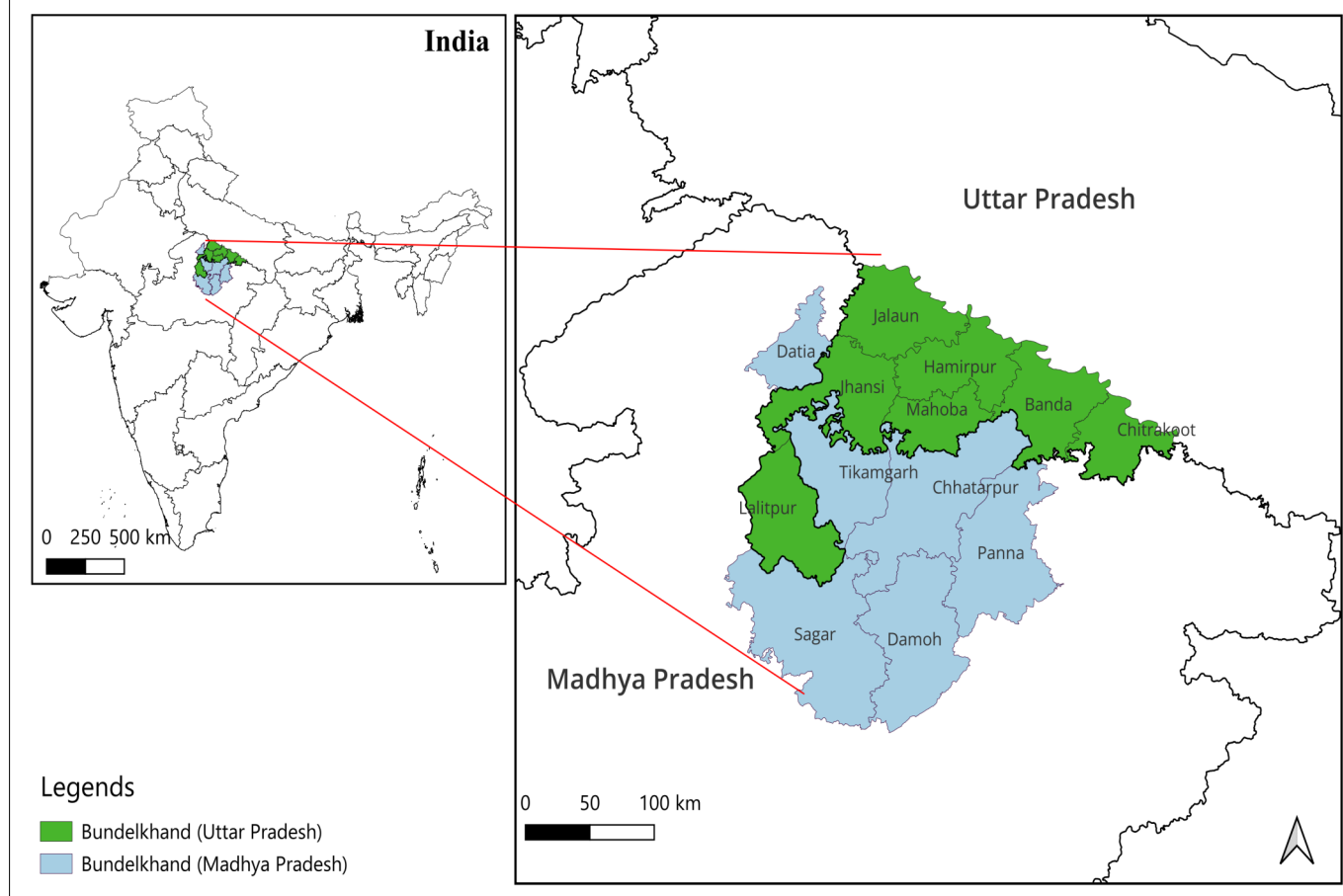


Fig. 1. Location of Bundelkhand region in India (left) and detailed map of the study area showing selected districts in Uttar Pradesh and Madhya Pradesh (right) (Source: QGIS version 3.40.14.).

Table 1. Distribution of respondents based on their knowledge of climate variability and its effects on the crops (n = 180)

Knowledge of respondents' climate variability and its effects on crops	Knowledge of respondents			
	Correct knowledge		Incorrect knowledge	
	Frequency	Percentage	Frequency	Percentage
Have you heard about climate variability	174	96.70	6	3.30
Climate variability means temperature fluctuations in all climate parameters	162	90.00	18	10.00
Deforestation is the human-induced cause of climate variability	144	80.00	36	20.00
Erratic rainfall over the years	128	71.12	52	28.88
Destruction and crop burning/fodder residues, grains and other ingredients in the field are also contributing to climate variability	142	78.90	38	21.10
Does a decrease in the number of rainy days lead to an increase in crop productivity?	66	36.70	114	63.30
Do you know that an increase in the number of dry days reduces crop productivity?	55	30.60	125	69.40
Do you know that the burning of fossil fuels causes climate change?	21	11.70	159	88.30
Less rainfall and high temperatures are the main causes of climate change	25	13.90	155	86.10
Climate change leads to a shift in the onset of the monsoon over the years	20	11.10	160	88.90
Changes in rainfall patterns occur due to climate change, which harms crop production	19	10.60	161	89.40
Does extreme climate affect the duration of crop growth?	21	11.70	159	88.30
Do you think that climate change has affected the onset of the monsoon?	31	17.20	149	82.80
Is there a change in the frequency of hot days during the summer months?	30	16.70	150	83.30
Do you know that the number of warm nights has increased nowadays?	31	17.20	149	82.80
Do you know that climate change results in heat stress on crop plants?	17	9.40	163	90.60
Do you know that high relative humidity promotes the growth of mould and bacteria in crops?	20	11.10	160	88.90

general causes such as fossil fuel emissions (11.70 %) and climatic factors like high temperature and low rainfall (13.90 %) was particularly low. Understanding of specific climate-related impacts, such as changes in monsoon season, rainfall variability affecting crop production, duration of crop growth and increased frequency of hot days and warm nights was also limited among respondents. Knowledge regarding physiological and biological impacts, including heat stress on crops and the role of high relative humidity in promoting mould and bacterial growth, was notably poor. The findings also show that while farmers possess relatively good awareness of observable and experience-based aspects of climate variability, their understanding of scientific causes and detailed impacts remains inadequate. As shown in Fig. 2, overall the majority of the respondents (58.33 %) had medium-level knowledge of climate variability and its effects on crops, while 21.11 and 20.56 % fell in the categories of low and high levels of knowledge respectively.

Knowledge of farmers about climate change and its effects on livestock

The majority of the respondents (Fig. 3) indicate that a large proportion of respondents (83.90 %) were aware that climate variability leads to an increase in vector-borne diseases in animals. Similarly, 80.00 % of respondents perceived that the incidence of

temperature-related illnesses in dairy animals would increase in the long run, whereas 20.00 % were not aware of such long-term impacts. 81.70 % also recognised that crossbred dairy animals are more sensitive to climate variability compared to indigenous breeds, while 71.10 % expressed a preference for rearing indigenous breeds due to their higher tolerance to heat stress. Whereas 72.80 % of respondents reported that climate stress negatively affects the reproductive performance of dairy animals, indicating awareness of the physiological impacts of climatic stress. Knowledge regarding specific and long-term consequences of climate variability was relatively limited among respondents. Less than half (42.80 %) were aware that climate change may lead to increased overgrazing in community grazing lands, while only 28.90 % recognised that indigenous breeds possess greater disease resistance under adverse climatic conditions. Similarly, a smaller proportion of respondents reported that heat stress reduces feed intake (21.70 %) and affects milk production (25.60 %), indicating gaps in understanding of productivity-related impacts. Awareness regarding resource-related constraints was also low, with only 18.30 % of respondents perceiving long-term shortages of feed and fodder, 16.10 % recognising the potential decline in water resources such as ponds and 14.40 % acknowledging the reduction in grazing and pasture land due to climate change. Farmers demonstrate a

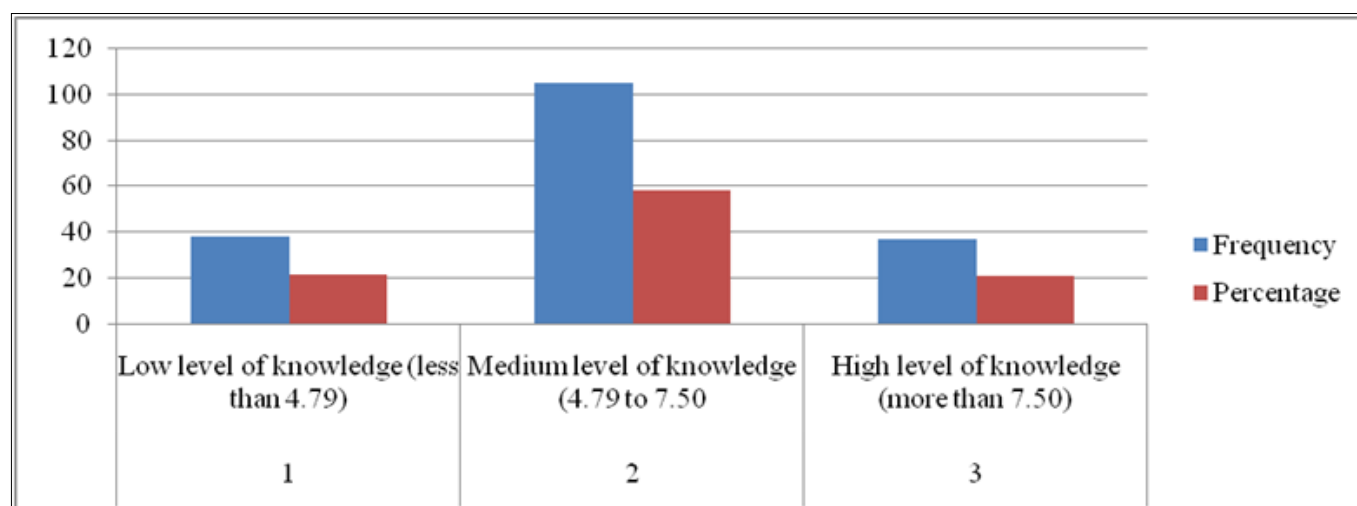


Fig. 2. Distribution of respondents based on their level of knowledge on climate variability and its effects on the crops (n = 180).

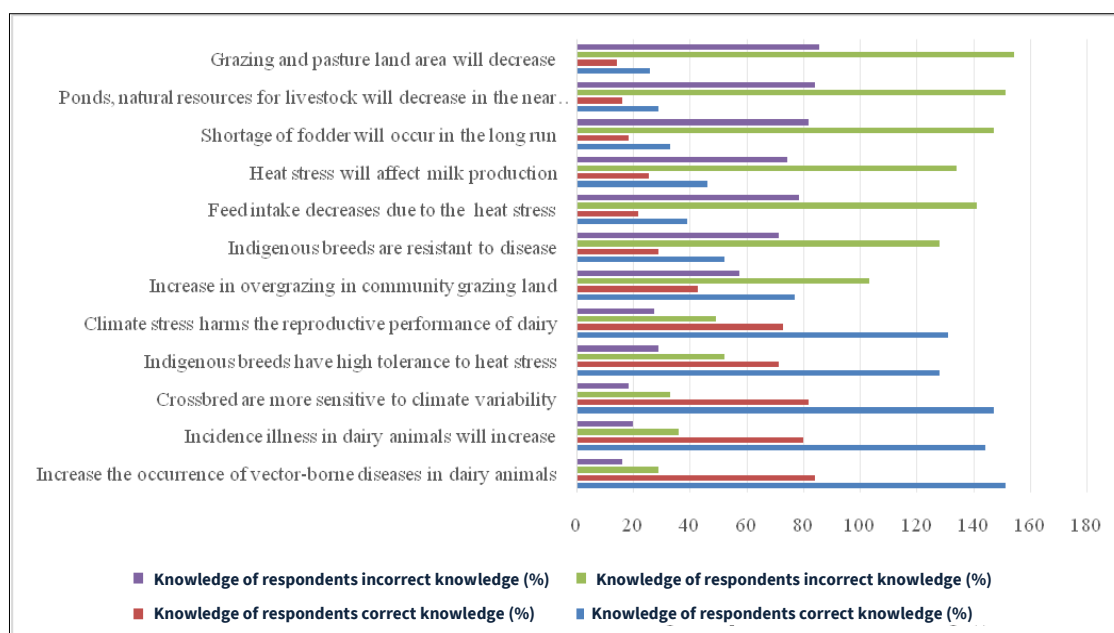


Fig. 3. Distribution of the respondents based on their knowledge of climate variability and its effects on livestock (n = 180).

relatively high awareness regarding visible and immediate impacts of climate variability, such as disease incidence and animal sensitivity; their understanding of indirect, long-term and resource-related effects remains limited, highlighting the need for targeted extension interventions and climate education programmes. The results revealed that less than half of the respondents (45 %) had medium-level knowledge of climate variability and its effects on farm animals, while (31.11%) and (23.89%) had low and high levels of knowledge categories, respectively (Fig. 4).

Overall level of knowledge of farmers about climate change (n = 180)

The findings indicate that 52.22 % of the farmers had a medium level of overall (crop + livestock) knowledge regarding climate variability, while 25.56 % and 22.22 % had a low and high level of knowledge categories, respectively (Fig. 5).

Perception of respondents towards climatic variability and their effects on crops

The results regarding perception of respondents towards climatic variability and their effects on crops indicate that 46.67 % of respondents perceived an increase in the length of the agricultural season, while 10.55 % reported an increase in the harvest season and 42.78 % observed no change (Fig. 6). A majority of respondents (61.67 %) reported a decrease in annual rainfall, whereas 13.88 % perceived an increase and 24.45 % reported no change. Similarly, 56.11 % of respondents indicated that the duration of the rainy season had decreased, while 18.89 % reported an increase and 25 % observed no change. Half of the respondents (50.00 %) perceived an increase in the duration of dry periods, while 32.80 % reported no change and 17.20 % observed a decrease. A majority of

respondents (58.33 %) reported an increase in maximum temperature and the number of hot days, whereas 22.22 % perceived a decrease and 19.45 % reported no change. With respect to groundwater levels, 73.30 % of respondents reported a decline, while 21.10 % observed no change and 5.60 % perceived an increase. Regarding rainfall characteristics, 47.80 % of respondents reported a decrease in rainfall intensity and pattern, while 35.00 % perceived an increase and 17.20 % observed no change. More than half of the respondents (55.00 %) perceived an increase in crop pest and disease incidence, whereas 39.40 % reported a decrease and 5.60 % observed no change. A majority of respondents (53.90 %) reported an increase in the frequency of droughts, while 27.20 % perceived a decrease and 18.90 % reported no change. Changes in farm management practices were reported by 40.00 % of respondents, while 33.30 % perceived a decrease in such adjustments and 26.70 % reported no change. Furthermore, 71.11 % of respondents reported an increase in crop losses due to climate variability, whereas 16.11 % perceived a decrease and 12.78 % observed no change.

Perception of respondents towards climatic variability and its effects on livestock

The findings shown in Table 2 revealed that 49.44 % of respondents perceived a change in the feeding schedule of dairy animals, while 27.78 % reported a decrease and 22.78 % observed no change. Also, a majority of respondents (82.20 %) reported a decrease in herd size, whereas 12.20 % perceived no change and 5.60 % reported an increase. Similarly, 80.56 % of respondents perceived a decrease in livestock fertility, while 18.89 % perceived an increase and 0.55 % reported no change. Regarding milk production, 76.70 % of respondents reported a decrease, whereas 8.30 % perceived an

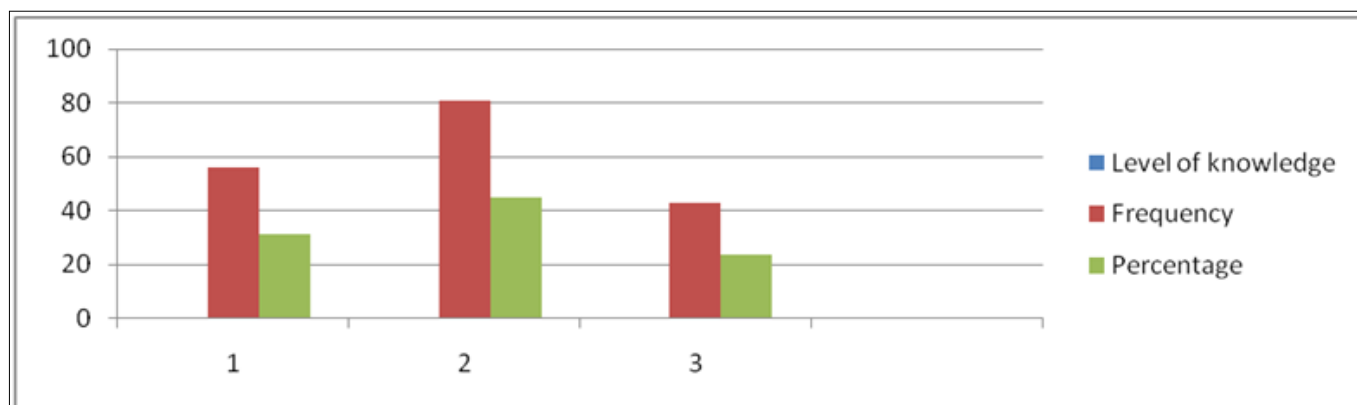


Fig. 4. Distribution of respondents based on their level of knowledge on climate variability and its effects on the Livestock (n = 180).

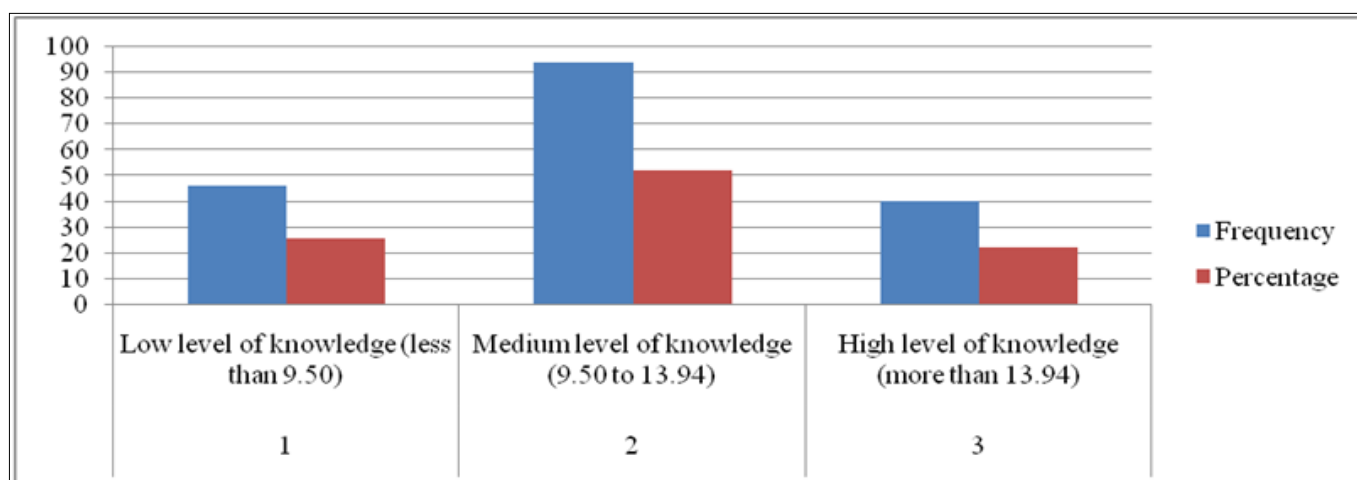


Fig. 5. Distribution of respondents based on their overall knowledge level on climate variability (n = 180).

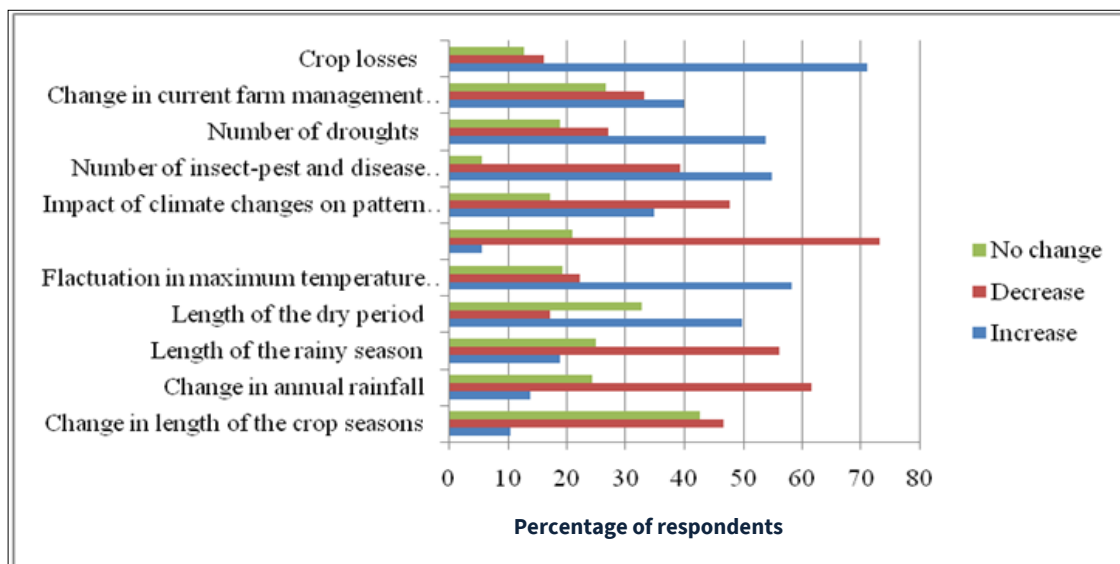


Fig. 6. Distribution of respondents based on perception of climatic variability and its effect on crop.

Table 2. Distribution of respondents based on perception towards climatic variability and their effects on livestock (n=180)

Particulars	Response					
	Increase		Decrease		No change	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
Change in the feeding schedule of farm animals	89	49.44	50	27.78	41	22.78
Herd size	10	5.60	148	82.20	22	12.20
Livestock fertility	34	18.89	145	80.56	1	0.55
Amount of milk produced by dairy animals	15	8.30	138	76.70	27	15.00
Impact of climate change on green fodder availability	27	15.00	99	55.00	54	30.00
The proliferation of microbes and the rapid fermentation of milk	95	52.80	36	20.00	49	27.20
Insect-pest and disease infection in dairy animals	106	58.90	21	11.70	53	29.40
Climate change negative impact on the preservation of milk and milk-based products	127	70.60	20	11.10	33	18.30

increase and 15.00 % observed no change. As of green fodder availability, 55.00 % of respondents perceive a decrease, while 15.00 % perceive an increase and 30.00 % observed no change. More than half of the respondents (52.80 %) reported an increase in microbial proliferation and fermentation of milk and milk-based products, whereas 20.00 % perceived a decrease and 27.20 % observed no change. Similarly, 58.90 % of respondents reported an increase in insect-pest and disease incidence in dairy animals, while 11.70 % perceived a decrease and 29.40 % reported no change. A majority of respondents (70.60 %) believe that climate variability negatively affects the preservation and shelf life of milk and milk-based products, whereas 11.10 % perceived a decrease in such effects and 18.30 % reported no change. The results revealed that respondents believed that climate variability had adverse effects on livestock productivity and related aspects.

Determinants of farmers' perception towards climate variability

The results of the multiple regression analysis indicate that the selected independent variables explain 81.70 % of the variation in respondents' perception of climate variability (Table 3). The model demonstrated a good overall fit, with a high coefficient of determination ($R^2 = 0.817$). The model was statistically significant, with an F-value of 75.437 and a relatively low standard error of estimate (2.479), suggesting a good level of precision in prediction. Among the independent variables, age showed a negative and statistically significant effect on perception ($B = -0.045$; $p < 0.05$). Education exhibited a positive and highly significant influence ($B = 0.799$; $p < 0.01$). Family type was found to have a negative and significant relationship ($B = -2.247$; $p < 0.01$), while family size showed a positive and highly significant effect ($B = 0.706$; $p < 0.01$). Occupation also had a positive and significant influence on

Table 3. Multiple regression analysis of independent variables concerning respondents' perceptions of climatic variability (n = 180)

Coefficients						
Sl. No.	Model	Unstandardised coefficients		Standardised coefficients		p-value (sig.)
		B	Std. error	Beta	t	
	(Constant)	23.613	1.818		12.990	"0.000"
1.	Age	-0.045	0.022	-0.105	-2.020	0.045*
2.	Education	0.799	0.186	0.292	4.295	0.000**
3.	Family type	-2.247	0.708	-0.151	-3.173	0.002**
4.	Family size	0.706	0.109	0.359	6.496	0.000**
5.	Occupation	0.973	0.459	0.071	2.118	0.036**
6.	Landholding	0.339	0.216	0.065	1.573	0.118
7.	Herd size	-0.232	0.192	-0.099	-1.208	0.229
8.	Milk production	0.147	0.098	0.127	1.500	0.136
9.	Annual income	1q1dqare2rq2dsdqfd2xc4	0.000	0.006	0.122	0.903
10.	Experience	0.206	0.032	0.423	6.490	0.000**
	R²	0.817	Adjusted R²	0.803	F-statistic	75.437

perception ($B = 0.973$; $p < 0.05$). Similarly, farming experience demonstrated a strong positive and highly significant effect ($B = 0.206$; $p < 0.01$). In contrast, variables such as landholding ($B = 0.339$; $p > 0.05$), herd size ($B = -0.232$; $p > 0.05$), milk production ($B = 0.147$; $p > 0.05$) and annual income ($B = 2.3447$; $p > 0.05$) were found to be non-significant. The results suggest that demographic and socio-economic characteristics, particularly education, family structure, occupation and experience, play a significant role in shaping farmers' perception of climate variability, while farm size and income-related variables do not show a statistically significant influence.

Discussion

The results of the study provide a comprehensive understanding of farmers' knowledge, perception and determinants of farmers' perception of climate variability in the Bundelkhand region. The socio-economic characteristics of respondents play an important role in shaping perception and adaptation behaviour, as livelihood dependence on climate-sensitive sectors increases farmers' exposure to climatic risks (6, 14). The profile of respondents indicates that the majority of farmers were middle-aged, engaged in mixed farming (crop and livestock) and belonged to joint families with medium-sized landholdings and farming experience.

The study revealed that farmers have a high level of knowledge regarding climate variability, particularly for observable changes such as erratic rainfall, temperature fluctuations and visible human-induced causes like deforestation and crop residue burning. This high level of knowledge is due to their direct and repeated exposure to climatic stress, especially droughts and irregular rainfall of the Bundelkhand region (15). Most farmers rely heavily on experiential learning and indigenous knowledge systems, which allow them to recognise climate changes based on their experiences; the results are in agreement with the previous studies (16–18). However, despite this general awareness, significant knowledge gaps were observed regarding scientific causes and technical aspects of climate change, such as fossil fuel emissions, crop physiological responses and long-term climatic processes. This gap may be due to limited access to formal education, inadequate extension services and insufficient dissemination of scientific climatic information. Farmers often rely on indigenous knowledge and personal observations rather than formal training, resulting in partial awareness of climate processes (19). A similar pattern was also observed in the context of livestock-related knowledge. Farmers demonstrated a strong awareness regarding immediate and visible impacts, such as an increase in vector-borne diseases, heat stress and sensitivity of crossbred animals due to climatic variability. Respondents' preference for indigenous breeds also reflects their adaptive behaviour based on previous experience, as local breeds are perceived to be more resilient to heat stress and harsh environmental conditions. Whereas, knowledge regarding indirect and long-term impacts such as resource degradation, reduced feed intake, decline in water availability and changes in grazing pattern was limited. These results suggest that farmers' understanding is limited to short-term and observable impacts, while systemic and long-term consequences of climate variability are less recognised. The findings of the other researchers also confirmed and revealed that the majority were well informed on the life cycles of crops, emergence of new insect-pests and diseases and natural hazards (19, 20).

The perception analysis further supports these findings, as a majority of respondents reported changes in climatic parameters such as decreased rainfall, shortened rainy seasons, increased dry spells, rising temperatures and declining groundwater levels. Similar perceptions regarding climate variability on crops were also observed in similar previous studies (21, 22). These perceptions align closely with the climatic conditions of the semi-arid regions of the Bundelkhand region and indicate that farmers are highly sensitive to environmental changes that directly affect agricultural productivity. The reports of an increase in crop pest and disease incidence, along with higher crop losses, may be linked to changing temperature and humidity conditions that favour pest outbreaks and interrupt the crop cycle. Previous studies have shown that farmers could correctly discern changes in patterns of climatic variability over the years through their personal experiences (23–28). Similarly, changes in farm management practices among a section of farmers suggest adaptive responses to climatic stress, although a considerable proportion reported limited or no changes, possibly due to constraints such as lack of resources, knowledge, or institutional support. In the case of livestock, respondents largely perceived that climate variability is harming productivity, health and product quality. The reported decline in herd size, fertility, milk production and fodder availability can be a result of heat stress, reduced feed intake, water scarcity and deterioration of grazing resources (29, 30). The increase in disease incidence and microbial activity affecting milk quality further reflects the impact of rising temperatures and humidity on livestock systems (31). These findings highlight the vulnerability of livestock-based livelihoods to climatic stress, particularly in regions with limited adaptive capacity. Findings of other researchers also confirmed that lesser rainfall had a severe impact, reduced fertility, less grazing land and led to going long distances to access the pasture and water (20, 32, 33). Contrary to the present study, respondents endorsed supernatural forces (45 %), natural processes (33 %) and deforestation (16 %) as the main climate change causes (21). The regression analysis provides the model fitting of the dependent variable over various independent variables. Before using regression analysis, diagnostic checks were conducted to validate the regression model. Multi-collinearity was assessed using the variance inflation factor (VIF) and no serious multi-collinearity was detected ($VIF < 5$). The Durbin-Watson statistic indicated no autocorrelation among residuals. Residual plots confirmed homoscedasticity and normality of residuals was verified using histograms and P-P plots. Influential observations were examined using Cook's distance and no extreme outliers were found. Therefore, the regression model satisfies the key assumptions and is considered reliable. The regression analysis indicates that socio-demographic and experiential variables have a more significant role than economic variables. The negative relationship between age and perception suggests that younger farmers are more responsive to climate variability, possibly due to greater exposure to information sources and higher adaptability (34). Education is also a strong positive predictor, showing the importance of knowledge and awareness in shaping perception. Farming experience also positively influenced perception, as long-term engagement in agriculture helps farmers to observe and interpret gradual climatic changes (35, 36). The positive effect of family size may be related to increased information sharing and collective decision-making within households, while occupation reflects the role of livelihood dependence on climate-sensitive activities. Whereas variables such

as landholding, herd size and income were non-significant, indicating that resource endowment alone does not necessarily enhance perception and knowledge. These constructs are more closely linked to human capital and information access and are consistent with previous studies highlighting the importance of education, experience and socio-demographic factors in influencing climate perception among farmers.

The study highlights that farmers' perception of climate variability is largely formed by experiential knowledge, socio-demographic characteristics and exposure to climatic events. While knowledge of immediate and observable impacts is relatively high, there is a clear gap in understanding of scientific causes and long-term implications. This highlights the need for strengthening extension services, improving dissemination of climatic information and promoting targeted awareness programmes to enhance farmers' understanding and adaptive capacity. Bridging the gap between experiential and scientific knowledge is essential for enabling informed decision-making and fostering effective climate change adaptation in vulnerable regions like Bundelkhand. (37–41).

Conclusion

The study shows the knowledge and perception of the farming community and appropriate information intervention, highlighting the farmers' adaptation benefits on crops and livestock. The study suggests that a unique measure of adaptation must be promoted for attracting farmers' support, especially among those who are already in favour of mitigation efforts. Considering the pressing need to combat the adverse effects of climate change and its impact on agriculture and livestock through adaptation and mitigation, this research is unique and a timely contribution to augment the scientific know-how of climate change adaptation-mitigation strategies and how farmers think, reflect and act upon them. The paper illuminates adaptation measures and their benefits and emphasises risk-mitigating measures investment. Policymakers should prioritise extension worker climate change awareness initiatives. Endowments like services and alternative livelihoods can help poor agricultural households. Strengthening extension systems with targeted climate change awareness programmes and improving access to timely, location-specific climate advisories can enhance farmers' adaptive responses. Additionally, promoting livelihood diversification and institutional support mechanisms can help reduce vulnerability among small and marginal farmers. These results move us one step nearer to understanding the relationship between adaptation-mitigation as well as how climate change communication can be designed in the agricultural and livestock context. Future studies should focus on integrating advanced analytical approaches to examine the interaction between perception, adaptation and resilience outcomes across different agro-climatic regions. Longitudinal and comparative studies are also needed to better understand the dynamic nature of farmers' adaptation behaviour over time.

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Authors' contributions

APV contributed to conceptualisation and participated in writing the original draft. BKG and BPM contributed to conceptualisation. DK contributed to methodology and analysis; and assisted in review and editing of the manuscript. DM and DP contributed to methodology and analysis. GS assisted in writing the original draft. RY assisted in writing the original draft; and contributed to review and editing of the manuscript. UC, TV, PKO and VKP contributed to review and editing of the manuscript. All authors have read and approved the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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