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Farmers' perception of climate change and livelihood vulnerability: a comparative study of Bundelkhand and Central regions of Uttar Pradesh, India

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Received: 20 August 2023 / Accepted: 1 February 2024
Published online: 05 February 2024

Abstract
Indian farmers are vulnerable to changing climate with unpredictable rainfall distribution, rising temperature, and complex socioeconomic conditions. The present study aims to assess livelihood vulnerability of farmers in two regions of the most populous State of Uttar Pradesh namely Bundelkhand and Central region. By using multistage random sampling technique, a total of 480 samples from 16 villages, 8 development blocks, 4 districts, and 2 regions were selected to elicit grass-root information on farmers' perception of climate change, their sensitivity and adaptive capacity to changing climate, and determinants of livelihood vulnerability. Further, this study has adopted methodology mentioned in the Intergovernmental Panel on Climate Change's fourth Assessment Report for the development of climate vulnerability index. The results show that farmers in Jhansi district were highly vulnerable to changing climate, while farmers in Barabanki district were relatively less vulnerable. The elevated degree of vulnerability to livelihood in Jhansi district attributed to its comparatively higher exposure and sensitivity to climatic change. The Binary Logistic Regression results show that illiterate farmers are relatively more vulnerable than literate farmers. On the contrary, higher income, assured irrigation, the use of certified seeds, and crop insurance are negatively associated with the LVI. In other words, farmers who have income from non-farm sources, use certified and recommended seed varieties, and avail themselves of crop insurance are relatively less vulnerable to climate change than those who do not have the aforesaid facilities. Hence, the present study suggests that farmers, must adapt to climate change to reduce its negative impact and reap the benefits of adaptation which can be achieved through capacity building, skill development (i.e., use of ultra-modern techniques), and capacity to strengthen the farmers' ability to adapt. Further, there is also a need to sensitize government officials on the dangers of climate change and to provide appropriate technical support to farmers for their adaptation.

Keywords Adaptive capacity · Central region · Climate change · Farmers perception · India · Indicator approach · Livelihood vulnerability index · Rainfed region · Sensitivity · Semi-arid

1 Introduction

Changes in the global climate, which have caught the attention of experts in every discipline, might have far-reaching consequences for human civilization [1]. The effect is varied in various places of the world [2] but negative effects are predicted to be more severe in tropical and subtropical climates, especially in developing nations like India [3]. The

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average global temperature in 2022 was about 1.5 ℃ above from the average temperature in 1850–1900 [4]. Further, the annual mean global near-surface temperature for each year between 2023 and 2027 is predicted to be between 1.0 ℃ and 1.8 ℃ higher than the 1850–1900, with human activity being the primary driver of the observed warming as observed by the World Meteorological Organization. According to the Intergovernmental Panel on Climate Change [5], between 20 and 40% of the world's population has already experienced warming of more than 1.5 ℃ on a regional basis. This has significant impact on agricultural productivity.

Consequently, the implications of climate change and the associated risks in developing countries like India is of a greater magnitude. Furthermore, it has been reported [6, 7] that a significant proportion of Indian farmers (i.e., 85%) have little financial resilience to deal with changing climate. In addition, there exists a significant socio-economic disparity in the vulnerability of farmers to fluctuations in monsoon patterns [1]. Farmers with low-quality soil or unfavourable location of fields or don't have access to irrigation are more at risk of crop failures brought on by dry spells [8]. Reductions in agricultural productivity have been linked to dry periods that occur during critical phases of plant development [3]. When it comes to minimizing production, gaps brought on by dry periods in India, Sikka et al. [9] stressed upon the need of securing irrigation and retaining soil moisture.

Despite significant reductions in greenhouse gas emissions as a component of a climate mitigation plan, it is anticipated that adverse impacts of climate change would persist and intensify in the next decades, hence, necessitating the implementation of adaptation measures [10, 11]. Further, objectives, scope, and the degree to which the findings of climate vulnerability assessments may be put into practice can vary greatly amongst studies [12–14]. The evaluations might be done to monitor changes in vulnerability or to identify existing or prospective hotspots as entry sites for climate adaptation action [1], while the mapping may be done on a scale ranging from a nation to a village in particular.

A circular rather than a linear relationships exist between vulnerability, adaptive capability, and adaptation [14]. It has been suggested that vulnerability and adaptability are linked, with the former depending on the latter [15]. People are less likely to be impoverished and hungry if they have access to stable income and a varied diet, for instance. This, in turn, increases their capability to react to pressures by shifting resource allocations or migrating to safe regions depending on the severity of the threats they face. For instance, in the event that individuals depend on credit schemes to acquire drought-resistant crops and crop varieties as a component of the essential adaptive measures to mitigate the impact of drought, a complete loss of crops would not only lead to food insecurity but will also burden them with insurmountable debts. Hence, the implementation of credit schemes and the cultivation of novel crops may need the provision of "weather insurance," as has been experimentally assessed in many developing countries [16]. Moreover, Kelly & Adger [15] asserted that the evaluation of individuals' genuine vulnerability is unattainable until adaptation has been implemented. Farmers have a crucial role in addressing climate change and possess a unique advantage in implementing adaptation strategies to mitigate the effect of climate change on their agricultural systems.

The recognition of climate change has been widely acknowledged as a fundamental need for implementing any kind of adaptation measures. According to Alam et al. [17], farmers who possess knowledge on the actualities of climate change and its significant ramifications are more likely to express support for government measures. In order to evaluate the vulnerability of farmers to climate change and their subsequent adaptation strategies, it is important to first examine their perception on this issue. The challenge of decision-making under constraints is exacerbated for farmers due to the time lag between information gathering and implementation. Several scholars, including Madison [18], Bryan et al. [19], Nhemachena and Hassan [20], and Singh [1], have highlighted the importance of understanding farmers' perceptions towards climate change within the framework of farm-level adaptation. The climatic components include several phenomena, such as the occurrence of localised climate extremes, including floods and droughts and fluctuations in average temperatures and precipitation in different geographical areas. Tripathi and Mishra [21] reported that the views of climate change among farmers are influenced by the prevailing weather conditions. Consequently, it is important to conduct research and ascertain the specific climatic factors that farmers consider in their assessments. Due to climate uncertainty, farmers place more weight on recent climatic occurrences as information [11]. Short-term observations reveal increasingly chaotic and unpredictable inter-annual temperature and climatic extremes. Historically, farmers have been worried with seasonal climate projections because to the short reaction time and narrow decision window afforded by such shifts. Earlier research also claims that farmers' perceptions of climatic events may not ensure adaptation strategies [19], since a number of variables may compromise their adaptability. Farmers' cognitive abilities differ from one another and are affected by factors such as age, education, gender, and geography [11, 22, 23].

1.1 Livelihood vulnerability assessment

Vulnerability assessment has been considered in several settings, such as the World Food Programme's (WFP) vulnerability assessment and mapping tool, specifically for the purpose of directing food assistance via the Famine Early Warning System (FEWS). Vulnerability assessment techniques have been used for diverse geographic assessments, as well as for integrating data on health status, poverty, biodiversity, and globalisation. A fundamental component of assessing climate change and vulnerability is quantifying the multi-dimensional vulnerability via the use of several indicators. Indicators are consolidated into a composite index in this particular evaluation, whereby many factors are merged [24]. For instance, the Human Development Index (HDI) integrates many indicators and sub-indicators, such as health, life expectancy, education, and quality of living, in order to get a comprehensive assessment of a nation's overall well-being. Additionally, the Sullivan technique [25] is used to calculate the Water Poverty Index (WPI) in order to evaluate the adequacy of water distribution and determine any deviations from a predetermined benchmark. Both the WPI and HDI are regarded as exemplary instances of composite indices, which are computed by using weighted averages of distinct individual indicators. Occasionally, these weighted approaches have a tendency to fluctuate. Some researchers have used the equal weight approach, while others have utilised either the judgmental or statistical weight technique [12].

Climate vulnerability assessment has become a crucial technique in quantifying the degree to which communities are exposed to changing environmental circumstances and how they will adapt to these changes. In order to address these shifting climate circumstances, several scholars and novel approaches have endeavoured to reconcile the disparities across natural, physical, and social sciences. A majority of these studies and researchers largely depend on the operational definition of IPPC for assessing climate vulnerability- Vulnerability is determined by the combined factors of exposure, sensitivity, and adaptive capability, as stated by the IPCC [26]. Vulnerability refers to the susceptibility of both natural and human systems to be impacted by and their capacity to react to the stress caused by climate change. In this context, "exposure" refers to the length of time during which a climate-related event, such as a shift in precipitation or a drought, occurs, as well as the intensity or extent of that event. Sensitivity refers to the extent to which a system is impacted by exposure. The IPCC defines the system's ability to tolerate or recover from exposure as adaptive capacity.

The evaluation of climate vulnerability also indicates the necessity of incorporating both long-term and short-term planning into sustainable future agricultural development policies. This involves integrating knowledge of climate change and understanding in order to effectively address the challenges posed by a changing climate. Climate change exerts a negative effect, resulting in decreased agricultural yields and limited opportunities for livelihood. Additionally, it is exacerbating issues such as food instability, decreased supply of fuel, wool, and fodder, loss of biodiversity, and increased out-migration of people.

The scope of this study has been broadened to include supplemental irrigation planning on a watershed scale. Therefore, it is necessary to be able to identify and map relative vulnerability. Investments in life-saving irrigation access may be directed toward farmers who are more at risk of experiencing crop losses due to dry spells. This is true not just for India, but also for the worldwide phenomenon of more unpredictable rainy seasons in dryland rainfed areas. There is no method that can be used to determine how dry season vulnerability may be conceptualized and computed at the level of a farm, at the same time, mapped for all farmers at an aggregate scale such as a village in order to facilitate the implementation of policies. This research gap is addressed in this study. The objectives of this study are: (i) to analyse perception of farmers on climate change, (ii) to develop a livelihood vulnerability index for different surveyed districts, (iii) to determine the factors that contribute to livelihood vulnerability in the Bundelkhand and Central regions of Uttar Pradesh, and (iv) compare the farmers perception of climate change, and vulnerability status of surveyed districts.

2 Methods and materials

2.1 Study area

The Bundelkhand region consists of 13 districts: six districts in Madhya Pradesh and seven in Uttar Pradesh. The region is a semi-arid zone, is probe to drought of moderate intensities and is very susceptible to climate change. The region is renowned for its socio-economic backwardness [27]. Approximately 60% of the population consists of workers and labourers. The forest area in the Bundelkhand region spans 1.24 million hectares, accounting for about 17.62% of the total geographical area, but a bulk of the forests in the region is characterised by tropical dry deciduous and thorn forests. The region has a fluctuating climate, which has been exacerbated by inconsistent rainfall, significant evapo-transpiration losses, high run-off in the catchment areas and inadequate soil water conservation practices. Additionally, there are extensive expanses of barren and uncultivated land in the region [28]. The populace relies mostly on agriculture and farming for sustenance. According to Samra [29], a majority of rural income in the Bundelkhand area is derived from agriculture, animal husbandry, and seasonal out-migration. The predominant impact of climate change has compelled individuals to relocate to urban areas in pursuit of sustenance and means of living. According to the Census [30], around 6000 people are migrating from this area on a daily basis. The area is under additional stress due to the progressive disappearance of traditional water harvesting practises and the lack of suitable water-harvesting infrastructure [31]. The expanding population and corresponding rise in the need for natural resources have made agricultural and water resources in the area vulnerable to escalating climate change hazards, which are impacting the well-being of local residents. The south-west monsoon is crucial for sowing in the fields, but it has been experiencing significant fluctuations in recent years, resulting in substantial losses for farmers.

The selected districts—Jhansi and Lalitpur and the villages falling in these districts are diverse in terms of agro-ecological and socio-economic conditions. While, Lalitpur district is relatively rich in terms of water resource availability, Jhansi district has poor soil cover with numerous rock outcrops and water scarcity for both agriculture and domestic purposes. The districts of Lucknow and Barabanki districts fall under the central region of Uttar Pradesh. The region receives on an average 979 mm of rainfall [32]; the climate ranges from dry sub-humid to semi-arid, the soil is alluvium calcareous sandy loam. About 62% of the land is cultivated of which only 56% is irrigated [30]. Lucknow (123 m above sea level) the capital of Uttar Pradesh covers an area of 3, 244 square kilometres. About 75% of the total rainfall is realized during June to September. The summers in Lucknow are very hot and winters very cold [32]. Similar conditions are also reported in the Barabanki district, which is relatively vulnerable to several climate induced hazards including heat waves. Heat waves are dangerous especially for vulnerable populations such as the elderly, young children, those with underlying health conditions and people living in extreme poverty. In totality, both regions (i.e., Central and Bundelkhand) are highly vulnerable to changing climate change; hence, it is a prerequisite to assess the livelihood vulnerability status of the regions for the development of an appropriate risk aversion policy.

2.2 Sampling technique and sample size

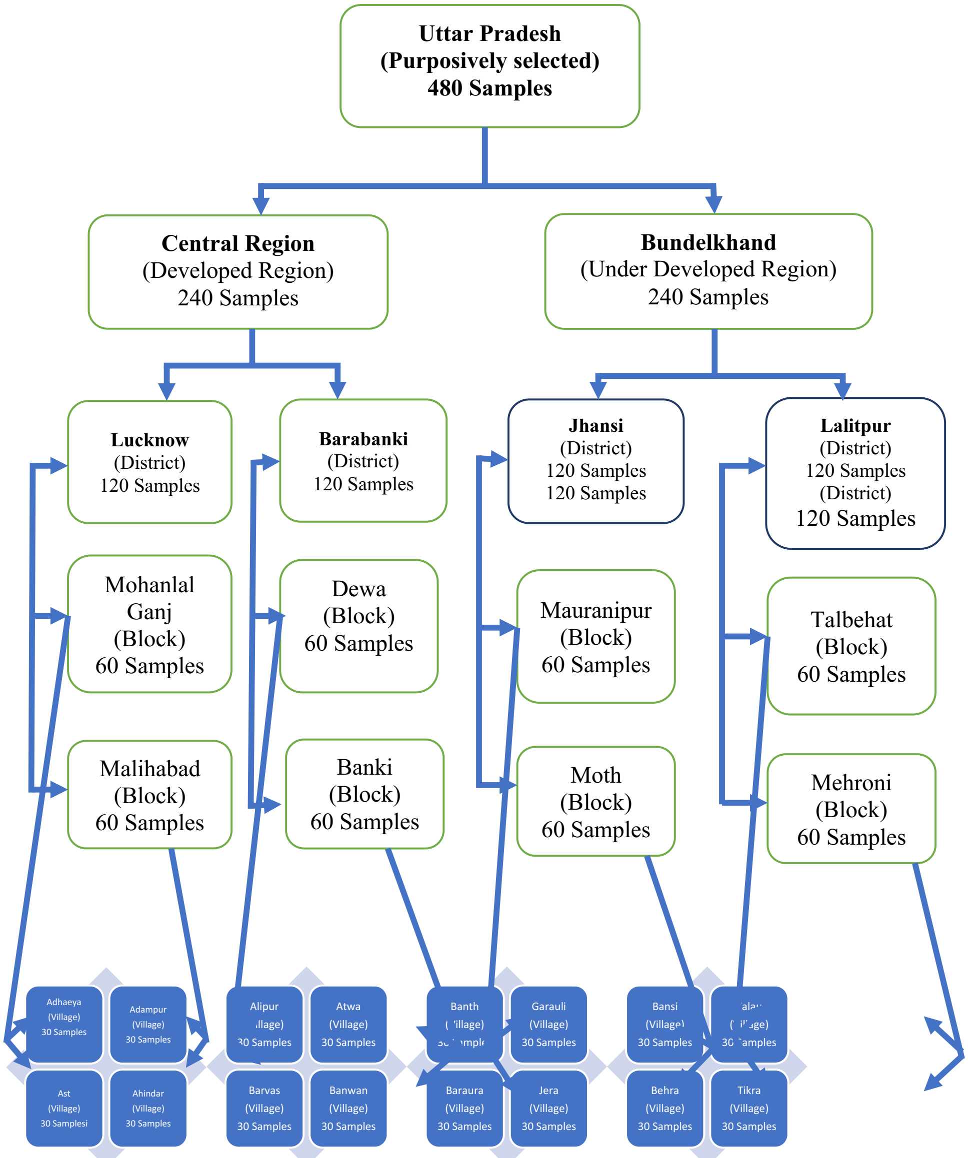
To collect field survey data, a multistage random sampling procedure was followed. Field survey was conducted in the months of August and September 2022. In the first step, Uttar Pradesh was selected and in the second step, two regions were purposely selected to identify the drivers of livelihood vulnerability—an under-developed region- Bundelkhand and a developed region—Central Uttar Pradesh. In the third step, two districts from each region were selected. From the Bundelkhand region, Jhansi and Lalitpur districts and from the Central region, Lucknow and Barabanki districts were selected. In the fourth step, two Development Blocks from each district were selected. In the fifth step, two villages (micro administrative unit) from each Development Block were selected. Finally, 30 samples from each village were selected. Thus, 2 regions, 4 districts, 8 Development Blocks, 16 villages, and 480 samples were selected to capture farmers' perception of climate change and to identify the drivers of livelihood vulnerability in most populous state of India (Fig. 1).

2.3 Estimation method: indicator approach

The present study employs an indicator-based methodology to compute a livelihood vulnerability index for the sampled farmers. The indicator approach is widely employed and has numerous advantages that has facilitated its extensive use in the planning process and policy communication. One key advantage is its ability to condense a substantial amount of intricate information into a manageable format [33]. Additionally, this approach allows for the utilization of data at various levels, ranging from individual to national, in order to construct a livelihood vulnerability index. Moreover, in situation where original data is unavailable, proxy data can be used. This approach also enables the identification, prioritization, and ranking of the climate vulnerable districts, thereby aiding in the identification of potential barriers to district development. Lastly, the indicator approach is valuable for monitoring and evaluating the effectiveness of interventions [11].

The present study used differential data to compute the livelihood vulnerability index, thereby necessitating the consideration of the normalization procedure. Further, Excel software version 13 was used to analyze the data. The current investigation has used the min–max method [33] in order to normalize indicators to a uniform range (0, 1) based on their functional association with the dimension of interest, namely livelihood vulnerability. The use of min–max method

Fig. 1 Tree diagram of sampling technique



might facilitate the process of simplification of an intricate dataset related to climate exposure, specifically focusing on the perceptions of farmers on climate change, as well as the interconnectedness of sensitivity and adaptive capacity. The technique has significance in terms of providing information to the general public and policymakers on significant livelihood vulnerability [34] and the necessary measures for its mitigation [12, 34–36]. Equations 1 & 2 were used to represent indications of the 'larger-the-better' and 'smaller-the-worse' indicators, respectively.

$$Z_{ij} = \frac{X_{ij} - Min(X_{ij})}{Max(X_{ij}) - Min(X_{ij})} \tag{1}$$

$$Z_{ij} = \frac{Max(X_{ij}) - X_{ij}}{Max(X_{ij}) - Min(X_{ij})} \tag{2}$$

$$i = 1, 2, \ldots .I \text{ and } j = 1, 2, \ldots .$$

where, Z_{ij} is the variable index value, X_{ij} is the actual value, $Max(X_{ij})$ and $Min(X_{ij})$ is the maximum and minimum value of i^{th} indicator for the j^{th} household. In this way, the indicators normalized on a scale of 0 to 1.

The current study used normalized values of farmers' perception of climate change as proxy indicators in order to calculate an exposure index. Additionally, normalized socio-economic indicators are used to develop a sensitivity index, while normalized adaptation strategy indicators are utilized to construct an adaptive capacity index. (Table 1) using Eqs. (3–5) as follows.

$$Exposure\ Index(EI) = \frac{R + S + D + W}{4} \tag{3}$$

$$Sensitivity\ Index(SI) = \frac{F + DW + Ir + FHH + M + T + H + BPL + E + I}{10} \tag{4}$$

$$Adaptive\ Capacity\ Index(SI) = \frac{CPR + NF + JF + KKC + CWB + In + St + Tr + NPK + ASD + CD}{11} \tag{5}$$

where the variables on the right-hand side are the normalized version of the indicators listed in Table 1. Once the values for exposure, sensitivity and adaptive capacity for the household-level had been calculated, two contributing factors (exposure and sensitivity) were combined using Eq. 6 to obtain the household-level potential livelihood vulnerability index [13].

$$PLVI_h = Exposure\ Index_h - Sensitivity\ Index_h \tag{6}$$

where $PLVI_h$ is the potential livelihood vulnerability index score for the household h; $Exposure\ Index_h$ is the calculated exposure score for the household h; and $Sensitivity\ Index_h$ is the sensitivity score for the household h. further, adaptive capacity, represented by A_h in Eq. 7 was taken into consideration for the development of livelihood vulnerability index as follows:

$$LVI_h = \left(Exposure\ Index_h - Adaptive\ Capacity\ Index_h\right) * Sensitivity\ Index_h \tag{7}$$

PLVI and LVI were scaled so that -1 denotes the least vulnerable and 1 the most vulnerable.

2.4 Determinants of livelihood vulnerability: binary logistic regression model

In order to examine the determinants of livelihood vulnerability to climate change, this study has adopted binary logistic regression model because its underlying assumptions are less restrictive than those of other models and it is free from problems with the use of ordinary least square [1, 37]. It is assumed that if livelihood vulnerability index (LIV) value is more than 0.500 then household are relatively more vulnerable than those household livelihood vulnerability index values lower than 0.500. Therefore, the livelihood vulnerability index is the dichotomous dependent variable (Y) of this model having a binary value of one (1) if the households have LVI value more than 0.500, and zero (0) if otherwise. The model also assumes that the use of LVI is a log-linear function of the exogenous variables X_1, X_2 of the term.

$$L_i = In\frac{P_i}{1 - P_i} = Z_i = B_0 + B_1X_1 + B_2X_2 + \ldots\ldots\ldots..B_nX_n$$

That is L; the log of the odds ratio is not only linear in X_i but also linear in the parameters. Where, L = logit model, P = is the probability of vulnerable to climate change (LVI). Denote as

$$P = \frac{1}{1 + e^{-2}} = \frac{e^z}{1 + e^z}$$

where, $Z = B_0 + B_1X_1 + B_2X_2 + \ldots\ldots\ldots..B_nX_n$

Therefore, the probability of not vulnerable is:

$$1 - P = \frac{1}{1 + e^{-2}} * \frac{P}{1 - P} = \frac{1 + e^z}{1 + e^z}$$

Table 1 Rational Indicators for Livelihood Vulnerability Index

Component	Indicators	Functional relationship with livelihood vulnerability index	Source
Exposure	HHs perceived that rainfall declined (Rainfall)	Positive	[11, 41]
	HHs perceived that summer days become hotter (Summer Days)	Positive	[11, 42]
	HHs perceive those frequencies of drought has increased (Drought)	Positive	[11, 23]
	HHs perceive that water level has declined (Water Level)	Positive	[11, 47]
Sensitivity	HHs using only forest-based energy resources for cooking purposes (Forest)	Positive	[11, 45]
	HHs using hand-pump (untreated) water for drinking (Drinking Water)	Positive	[11, 46]
	HHs depends on government sources for irrigation (Irrigation)	Positive	[11, 46]
	Female- headed households (FHH)	Positive	[11, 47]
	HHs using 108 free medical facilities (Medical)	Negative	[11, 48]
	HHs do not have toilet facilities (Toilet)	Positive	[11, 48]
	HHs do not have all seasonal house (House)	Positive	[11, 48]
	HHs belong to Below Poverty Line category (BPL)	Positive	[11, 49]
	HHs do not have electricity connection (Electricity)	Positive	[11, 48]
	Head of Household does not attained school (Illiterates)	Positive	[11, 50]
Adaptive Capacity	HHs changes their cropping pattern (Cropping Pattern Change)	Negative	[11, 41]
	HHs switch to non-farm activities (Non- farm)	Negative	[11, 41]
	HHs live in joint family (Joint Family)	Negative	[11, 41]
	HHs using Kisan Call Centre for agro-advisory (KKC)	Negative	[11, 41]
	HHs started conservation of water bodies and soil to combat climate variability (CWB)	Negative	[11, 41]
	HHs secure their crop through crop insurance (Insurance)	Negative	[11, 41]
	HHs have storage capacity to procure agriculture products (Storage)	Negative	[11, 41]
	HHs have taken professional training on climate change combating (Training)	Negative	[11, 41]
	HHs aware about nitrogen, phosphorus, and potassium ratio (NPK)	Negative	[11, 41]
	HHs growing more than one cropping (Crop diversification)	Negative	[11, 51]

Source: adopted from Jatav, 2020 and Field Survey Data, 2022

Now, P/(1-P) is simply the odds ratio in favor of LVI i.e., the ratio of the probability that livelihoods of household are vulnerable to changing climate to the probability that he/she will not. Thus, if P = 0.9, it means that odds are 0 to 1 in favor of LVI. If P goes from 0 to 1 (that is, as z varies from $(-X_i to + X_i)$ the logit, L goes from –X to + X. Although the probability lies between 0 and 1, the logit is not so bounded [1]. Finally, the study hypothesized that there are different socio-economic and demographic factors that determining livelihood vulnerability of farmers to climate change.

2.5 Selection of Rational Indicators for the development of Livelihood Vulnerability Index

The Intergovernmental Panel on Climate Change (IPCC) defines vulnerability, as stated in its fourth assessment report, as the probability of being susceptible to adverse conditions, as well as the challenges associated with adaptation and mitigation of the sudden risk, shocks, and undesirable events resulting from climate change and climate-induced hazards [38]. The adverse impacts of extreme events are closely associated with climate variability and gradual changes in key climatic factors such as mean temperature, rainfall, and climate-related hazards such as cyclones, storms surges, sea level rising, flooding, and coastal vulnerability. These impacts can be understood through three inter-connected dimensions: (i) adaptive capacity (the ability to cope with sudden risk), (ii) sensitivity (the extent to which a particular area or population is affected by an extreme event), and (iii) exposure (the intensity of climatic variability and the factors that contribute to vulnerability) [11, 39, 40].

Previous research has used farmers' perception of climate change as a means to approximate an exposure index [23, 40, 41]. According to Masud et a. [41] in Malaysia and Jatav [11] in Bundelkhand region, a significant majority (> 90%) of farmers have reported perceiving changes in the climate. Specifically, they have seen a notable rise in temperatures and a decrease in predictability of rainfall patterns. According to Shreshta et al. [42], farmers possess a comprehensive understanding of detrimental effects of climate change on agriculture and their overall livelihoods. However, their ability to adjust to these challenges is hindered by many factors such as limited access to advanced technologies, small land holdings, and persistent drought conditions.

Sensitivity refers to the extent to which a system is influenced, either negatively or beneficially, by climate-related stimuli [26] as well as the capacity of a system to adopt to climate change from socio-economic and ecological perspective [43]. The development of a sensitivity index for various districts in the Bundelkhand and Central regions was based on the use of socio-economic data outlined in Table 1.

While the system may exhibit a notable degree of susceptibility or responsiveness to environmental stress and shocks, it would be inaccurate to categorise it as susceptible [44]. The vulnerability of a system is influenced by its adaptive capacity, which in turn adjusts to both exposure and sensitivity [11]. The achievement and effectiveness of adaptation processes are influenced by the three crucial factors: (i) the prompt recognition and comprehension of climate variations and the corresponding requirement to implement adaptive measures; (ii) the presence of incentives and the capacity to adapt; and (iii) the necessity to modify agricultural practices in order to optimize benefits in response to changing climate conditions [22]. Additionally, Masud et al. [41] proposed that the implementation of climate change adaptation measures is essential in order to mitigate its adverse effects and capitalise on the advantages of adaptation. The authors further proposed that a greater level of adaption may be attained by implementing training programmes, fostering skill development, and enhancing the capability of farmers to adjust. Specialized training sessions have significant importance not just for farmers but also for government officials responsible for delivering suitable technical assistance to the farmers. Therefore, the adaptive capacity index was constructed using the extension education data provided in Table 1.

3 Results and discussion

3.1 Farmers' perception of climate change

The present study asked farmers, "Do you perceived that rainfall pattern has been changed in last decade". This inquiry aimed to gauge their perceptions on climate change. Previous studies in ethnographic research [52–54] have shown that individuals possess the ability to accurately discern changes in climate patterns over a span of ten years via their personal encounters. Consequently, this study has used the mental map methodology to quantitatively assess farmers' observations and perceptions of climatic fluctuations. Once they affirmed their agreement, they were then asked about the reduction in rainfall amount. The investigation also included the frequency with which farmers encountered adverse weather conditions and the subsequent impact on their agricultural yield during the preceding

Table 2 Farmers' Perception of Changing Climate

Indicators	Bundelkhand region		Central region	
	Jhansi	Lalitpur	Lucknow	Barabanki
Rainfall has declined over past 10 years	90.50	92.75	85.50	82.50
Drought frequency has increased over past 10 years	95.50	88.50	80.50	78.50
Summer days are become hotter over past 10 years	95.50	90.50	85.75	75.75
Water levels has declined over past 10 years	90.50	82.50	85.50	78.50
Weather extremes have become common phenomena over past 10 years	95.75	90.25	80.50	80.25
Late withdrawal of monsoon is now common phenomena	90.25	90.75	85.75	80.33
Rainfall distribution become erratic	92.75	90.25	89.25	82.25
Temperature has increased over past 10 years	95.25	92.50	90.27	89.25

Source: Field Survey, 2022. Note: all values are in percentage

Table 3 Adaptation strategies adopted by sampled farmers

Indicators	Bundelkhand region		Central region	
	Jhansi	Lalitpur	Lucknow	Barabanki
Cropping pattern change	79.25	82.25	60.25	72.50
Switch to non-farm activities	50.25	55.75	80.25	42.25
Improved irrigation facilities	55.75	60.25	40.25	35.25
Planted Trees surrounded fields	75.25	78.25	80.25	82.25
Early Maturing Varieties	80.75	75.27	76.50	70.25
Less water consuming crops	85.25	80.25	45.25	60.65
Crop diversification	45.25	42.25	45.75	48.25

Source: Field Survey, 2022. Note: values are in percent

ten-year period. The study area has been affected by droughts of varying intensities over the last decade and it was expected that the respondents would respond with confidence to this question.

The results indicate that about 90.50% (highest) of farmers in Jhansi and 82.50% (lowest) perceived that rainfall has declined over past 10 years (Table 2). A majority of farmers perceived that rainfall distribution had become erratic and unpredictable over past 10 years. A majority of farmers also perceived that temperatures have increased and summers days are now hotter over the past 10 years. The comparative analysis across the districts indicates the farmers in Jhansi district are well aware of changing rainfall and temperature pattern, while farmers in Barabanki are less aware. The results align with the data published by the Indian Meteorological Department, Government of India [32]. The temperature data for Uttar Pradesh indicate a notable upward trend in yearly temperature levels, with an average rise of around 0.01^{0}C per year seen between the years 1980 and 2020.

3.2 Adaptation strategies in surveyed area

Adaptation strategies adopted by sample farmers in both Bundelkhand and Central regions of Uttar Pradesh is presented in Table 3. The study has identified seven modes of incremental adaptations: (i) cropping pattern change, (ii) switch to non-farm activities, (iii) improved irrigation facilities, (iv) planted trees surrounded fields, (v) early maturing varieties, (vi) less water consuming crops, and (vii) crop diversification. Non-farm activities, improved irrigation facilities and less water consuming were key adaptation strategies adopted by the farmers in Bundelkhand region. Planting trees surrounding the fields, using early maturing varieties of seeds and crop diversification were identified as adaptation strategies for climate change. When faced with modification in planting operations, adjusting the sowing dates is often used as a technique. Typically, there is a self-regulated adjustment in altering the timing of planting activities in accordance with the commencement of monsoon season. Following the occurrence of crop failure during the *Kharif* season as a result of unpredictable rainfall patterns, it was noticed that a subset of farmers opted to augment their agricultural intensity during the subsequent *Rabi* season. The farmers who encountered an early- season setback proceeded to plant either the same or other crops in the same field. In order to save money, farmers reported hiring more members of their own families to work on their farms.

Farmers also reported to have made systemic adaptation by switching to early-maturing variety of seeds and climate-resistant crop varieties. Different drought-tolerant and less water-consuming crops were favoured by farmers in the rainfed (Bundelkhand region) and semi-arid (Central region) regions, where droughts are common. Farmers have shifted to high-yield, short-duration crop varieties to get assured yields and increase income. It was also observed that certain effective harvesting and water management measures were used, such as the use of drip irrigation, sprinklers, and the construction of rainwater harvesting structures. However, the extent to which these ideas were incorporated was modest. However, the farmers are myopic in their view of sustainable use of water, and they cared exclusively for short term profits.

The other frequently documented systemic adaptation methods in farming practices were crop rotation, crop diversification, inter-cropping, and mixed cropping to enhance agricultural activity. According to Tripathi and Mishra [21], diversification of crops in agricultural practices has been shown to reduce sample households' susceptibility to adverse weather conditions and unpredictable monsoon patterns. This is attributed to the provision of supplementary income opportunities compared to monoculture. The results from Table 3 indicate that farmers have adopted different adaptation strategies to maximize farm returns across the districts. Nearly 80% of farmers in Jhansi district have changed their cropping pattern from water-intensive crop i.e., wheat to less water consuming crop like chickpea to deal with climate change and save water, while only 60.25% of farmers in Lucknow district have changed their cropping pattern. Further, non-farm employment opportunities ensure regular income. Since Lucknow district is the headquarters of Uttar Pradesh and has better non-farm employment opportunities, more than 80% of farmers have diversified their occupation patterns and switched to non-farm activities, while only 42.50% of farmers in Barabanki have diversified their occupation patterns. Improving irrigation systems along with conservation of water bodies ensures water even on hot summer days and it was observed that more than 60% of farmers in Lalitpur have improved their irrigation facilities, while only 35.25% of farmers in Barabanki have improved their facilities. Also, it is observed that more than 75% of farmers across the regions have planted Eucalyptus trees to maximize farm returns. More than 80% of farmers in Jhansi are concerned about water use in agriculture since the Bundelkhand region is affected by continuous droughts. Hence, they have used early maturing and less water-consuming varieties to deal with the changing climate, while the corresponding figure for Barabanki district was only 70.25%. Lastly, since crop diversification is a viable solution to combat changing climate, it was observed that nearly half of the farmers have diversified their cropping patterns in the sampled districts.

3.3 District wise exposure index

Farmers' perception of climate change was used to develop an exposure index which is a key part of livelihood vulnerability index. Further, exposure indices were calculated using Eqs. 1 and 2 (as explained in the previous section) for different districts of Bundelkhand and Central regions of Uttar Pradesh. The indicators mentioned in Table 1 were used to develop an exposure index for different districts. Questions were asked in a systematic manner to capture farmers' perceptions of climate change like, "Do you perceive that rainfall has declined over the past 10 years?" Then the rainfall indicator of the exposure index was calculated. The results indicate that Jhansi district was the most exposed district in the Bundelkhand region, while Lucknow was the most exposed district in the Central region (Table 4). Long summer days result in heatwaves and dry spells, which are responsible for drastic reductions in crop production. The calculated indices

Table 4 District wise Exposure Index in surveyed area

Indicators	Bundelkhand region		Central region	
	Jhansi	Lalitpur	Lucknow	Barabanki
Rainfall	0.91	0.87	0.77	0.76
Summer	0.81	0.79	0.79	0.79
Drought	0.87	0.81	0.90	0.83
Water level	0.84	0.88	0.78	0.83
Exposure index	0.86	0.83	0.81	0.80

Source: Field Survey, 2022

show that farmers of Jhansi district are highly exposed to heatwaves and high summer temperatures in the Bundelkhand region, while mixed results were observed in districts in the central region. Further, drought is responsible for crop failure in both the regions. The calculated index value shows that farmers (about 87.30%) in Jhansi district confirmed that frequencies of droughts have increased over the past 10 years, while 90% of farmers in Lucknow district also perceived that frequent drought incidence is responsible for higher climate exposure.

When districts experience continuous drought, longer summer periods, and erratic rainfall distribution pattern, it motivates the farmers to dig deeper bore wells to extract groundwater for irrigation and domestic purposes. This results in a further decline in water level. The calculated water level indices show that Lalitpur district in the Bundelkhand region is highly exposed among the districts in both regions. Finally, the calculated exposure index for all four districts and two regions shows that farmers in Jhansi district in the Bundelkhand region and Lucknow in the Central region are highly exposed to changing climates.

3.4 District wise sensitivity index

Using the socio-economic data mentioned in Table 1, a sensitivity index was calculated for the surveyed districts. The calculated results show that farmers in Jhansi district in the Bundelkhand region and farmers in Lucknow district in the Central region were highly sensitive to changing climates (Table 5). Farmers are highly dependent on non-renewable forest resources for cooking, drinking untreated water, and living below the poverty line. Further, limited access to electricity and sanitation facilities is adding an additional layer of sensitivity to the system. The descriptive and cross-indicator analyses show that more than 90% of farmers in Jhansi districts are dependent on forest resources for cooking fuel, while only 61.80% of farmers in Barabanki are dependent on forest resources.

Safe drinking water helps farmers deal with health-related issues. It is observed that 92% of farmers in Jhansi district used hand pumps for drinking water, while only 43.90% of farmers used hand pumps in Barabanki district. Nearly 90% of farmers are dependent on the government for irrigation, since the Bundelkhand region has the largest coverage of canal irrigation in Uttar Pradesh, while the corresponding figure for Barabanki was only 32.50%. It means farmers in Barabanki have the highest irrigation security. The reason behind is that due to higher coverage of irrigation, farmers in Barabanki have highest irrigation security among the surveyed districts. Further, lower irrigation security in the Bundelkhand region, while it has the largest coverage of irrigation, is that water is not sufficiently available in rivers like Betwa and Yamuna for irrigation. Dhasan, Singh Betwa and Ken are the major tributaries of the Yamun River almost dry in the summer season. Likewise, more than 80% of households are headed by females in Jhansi district, while only 40% of households are headed by females in Barabanki district. In total, farmers belonging to Jhansi district are highly sensitive, while farmers belonging to Barabanki district are less sensitive among the surveyed districts.

Table 5 District wise sensitivity index in surveyed area

Indicators	Bundelkhand region		Central Region	
	Jhansi	Lalitpur	Lucknow	Barabanki
Cooking source	0.91	0.80	0.76	0.61
Hand pump	0.92	0.77	0.56	0.43
Irrigation	0.89	0.56	0.47	0.32
Female-headed	0.83	0.74	0.62	0.40
Free medical facility	0.73	0.56	0.39	0.27
Sanitation facility	0.90	0.85	0.78	0.67
Nature of house	0.95	0.78	0.66	0.57
Below poverty line	0.92	0.87	0.75	0.59
Electricity access	0.93	0.89	0.81	0.77
Education level	0.96	0.92	0.86	0.80
Sensitivity index	0.89	0.77	0.66	0.54

Source: Field Survey, 2022

3.5 District wise adaptive capacity index

Changes in cropping patterns, diversification of crops, early planting and late harvesting, increased storage capacity, expert agricultural training, and water conservation are some of the climate risk management strategies that farmers have implemented in the sampled districts. Most efforts were made without official government involvement, although fertilizer and water supplies were two notable exceptions. Subsidized farm pond digging was linked to both drought mitigation and job creation efforts, along with assistance for drip irrigation from the state horticulture department. However, due to economies of scale, these plans were usually successful only for big farms [11].

The calculated adaptive capacity indices for different surveyed districts indicate that farmers of Barabanki district have the highest adaptive capacity, while those in Jhansi district have the lowest adaptive capacity to deal with a changing climate (Table 6). The cross-indicator analysis shows that about 12% of farmers belonging to the Barabanki district have changed their cropping pattern, while only 2% of farmers belonging to the Jhansi district have changed their cropping pattern. Likewise, about 26% of farmers belonging to the Barabanki district have diversified their occupation patterns by involving themselves in non-farm activities, while only 10% of farmers belonging to the Jhansi district are involved in non-farm activities.

Further, joint family structure provide a safety net against any disaster, including climate change and it also ensures regular unpaid family labor, which was always available for work in agriculture. It is observed that about 31% of farmers of Barabanki district lived in a joint family structure, while the corresponding figure for Jhansi district was only 6%. More than 25% of farmers in Barabanki district consulted agricultural experts to deal with the climate, while the corresponding figure for Jhansi district was only 4%.

It was also observed that farmers in Barabanki are highly motivated and aware of the conservation of water bodies and more than 25% of farmers conserved water bodies, while the corresponding figure for Jhansi district was only 9%. Crop insurance is an *ex-post* adaptation strategy against changing climate and more than 30% of farmers in Barabanki district have taken crop insurance, while only 9% of farmers in Jhansi district have taken this insurance. Similarly, more than 30% of farmers have storage capacity to store farm produce in Barabanki district, while only 13% of farmers in Jhansi district have storage capacity.

Furthermore, about 37% of farmers have taken agriculture training at *Kisan Vikas Kendras* about modern tools and techniques in agriculture, while the corresponding figure for Jhansi district was only 21%. Balanced use of fertilizers is important for sustainable farming and survey data reveals that about 30% of farmers in Barabanki district used the recommended fertilizer ratio, while only 8% of farmers in Jhansi district did so. More than 30% of farmers in Barabanki have adjusted sowing dates to deal with climate change, while the corresponding figure is only 12% in Jhansi district. In total, farmers belonging to the Barabanki district have the highest adaptive capacity, while those in the Jhansi district have the lowest adaptive capacity to deal with a changing climate.

Table 6 District wise Adaptive Capacity Index in surveyed area

Indicators	Bundelkhand region		Central region	
	Jhansi	Lalitpur	Lucknow	Barabanki
Cropping pattern change	0.02	0.06	0.10	0.12
Switch to non-farm	0.10	0.12	0.23	0.26
Joint family	0.06	0.10	0.24	0.31
KKC	0.04	0.11	0.12	0.25
CWB	0.09	0.12	0.19	0.26
Crop insurance	0.09	0.19	0.20	0.31
Storage capacity	0.13	0.23	0.26	0.30
Training	0.21	0.24	0.29	0.37
Use of balance fertilizers	0.08	0.12	0.15	0.30
Sowing dates	0.12	0.21	0.30	0.33
Crop diversification	0.08	0.18	0.26	0.32
Adaptive capacity index	0.09	0.15	0.21	0.28

Source: Field Survey, 2022

Table 7 District wise Potential and Livelihood Vulnerability Index

Indicators	Bundelkhand Region		Central Region	
	Jhansi	Lalitpur	Lucknow	Barabanki
Exposure index	0.86	0.84	0.81	0.80
Sensitivity index	0.89	0.77	0.67	0.55
Adaptive capacity index	0.09	0.15	0.21	0.28
Potential livelihood vulnerability index	1.75	1.61	1.48	1.35
Livelihood vulnerability index	0.68	0.53	0.40	0.28

Source: Field Survey, 2022

Table 8 Factors determining Household's Livelihood Vulnerability to Climate Change

Explanatory variables	Coefficient	Odds Ratio
Education (illiterates = 1, otherwise = 0)	0.0357	1.25
Land Size (marginal = 1, otherwise = 0)	0.0964	3.21
Social group (scheduled caste and scheduled tribe = 1, otherwise = 0)	0.5470	2.21
Income (continuous)	− 0.457	0.28
Irrigation (Yes = 1, otherwise = 0)	− 0.054	2.23
Use of certified seed (yes = 1, otherwise = 0)	− 0.034	3.41
Crop insurance (Yes = 1, otherwise = 0)	− 0.072	4.24
Constant	0.2764	0.28
LR chi2	23.65	
Prob > chi	0.0049	
Pseudo R	0.9548	
Log likelihood	− 75.26	
No. of observations	480	

Source: Field Survey, 2022

3.6 District wise livelihood vulnerability index

Using Eq. 6, the potential livelihood vulnerability index for different districts in Bundelkhand and the Central regions was calculated and the results show that farmers in the Bundelkhand region were relatively more exposed and sensitive to changing climate compared with the Central region (Table 7). On the contrary, farmers belonging to the Bundelkhand region had the least adaptive capacity compared with farmers in the Central region. In total, farmers in the Bundelkhand region are relatively more vulnerable than farmers in the Central Region. The main reason of higher livelihood vulnerability in the Bundelkhand region was correlated with their lowest adaptive capacity. Lastly, among the four surveyed districts and 480 sample farmers, farmers belonging to the Jhansi district were relatively highly exposed, sensitive, and had the least adaptive capacity to deal with changing climates, whereas farmers belonging to the Barabanki district were relatively less exposed, sensitive, and had a higher adaptive capacity. In other words, Barabanki district was the least vulnerable to a changing climate among the surveyed districts.

3.7 Determinants of household livelihood vulnerability

The estimated parameters of the empirical Binary Logistic Regression (BLR) model are mentioned in Table 8, which indicates that the BLR predicted about 95% of the responses correctly. The model fits the data at ($p < 0.001$) as indicated by the chi-square ($Prob > Chi^2$) goodness of fit demonstrated that the variables captured in this study are valid. Study results also reject the null hypothesis and accept the alternative hypothesis stating a significant relationship between the captured variables and livelihood vulnerability of sampled farmers. The BLR results show that illiterate farmers are relatively more vulnerable than literate farmers. In other words, education has a vital role to play in reducing livelihood vulnerability. Likewise, farmers having less than 2 hectares of land are relatively more vulnerable than farmers having more than 2 hectares of land. It is documented that farmers belonging to the backward social groups (i.e., marginalised sections of society) are more likely to be vulnerable [1] than farmers belonging to the general and other backward classes (i.e., the upper class in India). Similar results were also reported from this study (Table 8).

On the contrary, higher income, assured irrigation, use of certified seeds, and crop insurance are negatively associated with the LVI. In other words, farmers who have income from non-farm sources, use certified and recommended seed varieties, and avail themselves of crop insurance are relatively less vulnerable to climate change than those who do not have the aforesaid facilities.

4 Conclusion and policy recommendations

Farmers in Bundelkhand and the Central region, which are recognised as economically disadvantaged and environmentally susceptible areas, have expressed their apprehensions on the repercussions of climate change. Farmers held the belief that climate change poses a significant challenge to agriculture and the livelihoods of farmers and expressed a desire to engage in partnerships with the government and non-governmental organizations (NGOs) in order to effectively adapt and reduce their vulnerability to the impacts of climate change. It was observed that making use of extension services and having a higher level of education (above secondary level) help farmers to deal with changing climate. Further, higher income levels were the most significant economic indicator in minimising sensitivity to climate change and its consequences on livelihoods. Farmers have been taking measures to adapt to climate change in the study area by installing new irrigation systems, shifting planting dates, altering their cropping patterns, diversifying their crops, and using less water-intensive seed varieties.

Therefore, this study has clearly indicated that farmers, particularly those residing in developing countries such as India, must undertake measures to adjust to climate change with an aim to alleviate its adverse impacts and capitalise on its potential benefits. Now is the moment to help farmers to better understand climate change adaptation and to implement effective adaptation methods to mitigate its negative effects. The farmers' adaptability might be improved by the establishment of training programs, skill development, and capacity building. However, Government authorities need information from the field to devise appropriate programs and suitable implementation to provide farmers the right kind of technical assistance. Policymakers ought to strategically devise and implement suitable adaptation strategies to mitigate the adverse consequences of climate change. These strategies may encompass technological advancements aimed at enhancing irrigation and weather forecasting systems, cost reduction of agricultural inputs, facilitation of information, availability, provision of agricultural subsidies to farmers, and augmentation of access to agricultural markets.

Author contributions S.S.J reviewed of literature, collected & analysed data and wrote the paper.

Funding There is no funding received for this paper.

Data availability The data that used in this study collected from the field surveyed. Data will made available as when requested.

Declarations

Ethics approval and consent to participate The verbal consent from the respondents was taken during field survey and all the respondents agreed to use their socioeconomic and climate response data for the research purpose. Further, No approval from the research ethics committee was required to accomplish the goals of this study because it collected data from the field and no human experiments were conducted.

Consent for publication This study collected field survey data, and verbal informed consent was obtained prior to the interview of respondents.

Competing interests The author declares no competing interests for this paper.

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