Indian Research Journal of Extension Education

RESEARCH ARTICLE

Climate Change Adaptation Strategies and Vulnerabilities of Indian Farmers: A Systematic Literature Review (ROSES Approach)

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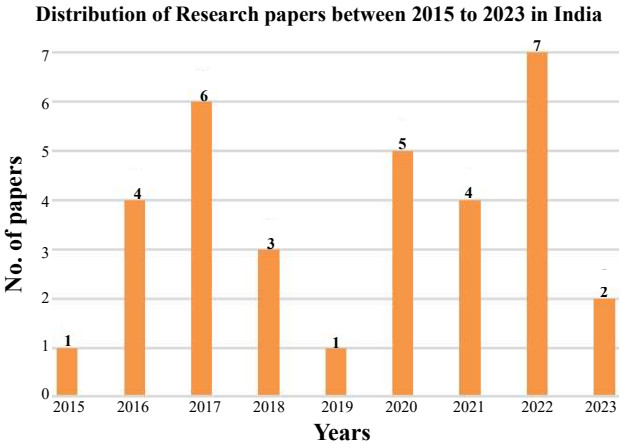
HIGHLIGHTS

- This study identified climate change adaptation strategies followed in India.
- Assessed the vulnerabilities of farmers to climate change.
- The farmers were mostly moderately affected by climate change and very few studies conducted on farmers vulnerability.

GRAPHICAL ABSTRACT



ARTICLE INFO

Editors:

Dr. B S Meena
Dr. J.K Chauhan

Key words:

Adaptations, Climate change, Farmers, India, Strategies, Vulnerabilities

Received : 15.07.2024
Accepted : 18.09.2024
Online published : 01.10.2024

doi:10.54986/irjee/2024/oct_dec/01-11

IRJEE METRICS

Google citations	- 9424
h-index	- 44
i10-index	- 304
NAAS rating	- 4.99

ABSTRACT

Context: Climate change is one of the most threatening. Such, a challenge is not going unnoticed and is being combated by the farmers by taking up adaptation strategies. Indian farmers' adaptation strategies to determine which ones are practical and effective for them to use in the field.

Objectives: The objectives drawn for the study were-To identify the adaptation strategies and practices taken up by Indian farmers, and, To assess the vulnerability of Indian farmers to climate change.

Methods: To achieve the stated objectives, reporting standards for Systematic Evidence Syntheses (ROSES) method of Systematic Literature Review was employed. Total 162 were identified, from which 115 were selected after the screening. To further determine their eligibility, the title and abstract were manually read, of which 63 articles were deemed eligible. On further scrutiny of the articles only 33 were included for the final appraisal.

Result & discussion: The results of the study depicted the adaptation strategies adopted by the farmers into 6 themes- crop management, soil management, water management, livestock management, financial management and livelihood diversification. While most farmers were moderately vulnerable to climate change.

Significance: Policy makers and climate change advocates and extension functionaries can benefit from this study by focusing on adaption measures that farmers support. Also, it calls for more studies to be conducted on assessing the vulnerabilities of farmers.

Agriculture in addition to feeding the people, also employs a portion of them. Over the 1960s, the amount of food produced worldwide more than quadrupled, but the amount of land used for agriculture grew by less than 15% (OECD, n.d.). United Nations Framework Convention on Climate Change, 1992 defines "climate change" as variations in the global temperature that occur additionally to natural climatic variability seen over similar time periods and that are ascribed, either directly or indirectly, to human activity that modifies the composition of the atmosphere. The dangers associated with less productive crops, fisheries, and livestock; disruption of food supply chains; and diminishing water supplies for crops and grasslands are particularly pertinent to agriculture (UN., n.d.).

Owing to its vast population, lack of arable land, reliance on agriculture and monsoon-dependent farming, and lack of financial and technological improvements for climate change adaptation (Birthal e*t al*., 2014). India is estimated to have one of the largest agricultural losses in the world as a ramifications of climate change (Guntukula, 2020, as cited in Datta and Behera, 2021). Farmers concurred climate change have raised the cost of cultivation (Kumari *et al.,* 2020).

Operationally speaking, adaptation strategies are the reworking or adjusting of farming practices or methods, such as altering crop yield, controlling water and soil, managing floods, controlling- land use, labour, livestock, finances, and families for minimizing losses or profit from climate change (Shanabhoga *et al*., 2020). Furthermore, adaptation varies by region (Begum and Mahanta, 2017). Assessing the adaptation strategies employed by Indian farmers can aid in mitigating and minimizing climate change risks.

Vulnerability is the tendency or predisposition to be adversely affected by climate-related health effects, and encompasses three elements: exposure, sensitivity or susceptibility to harm, and the capacity to adapt to or to cope with change (Gamble, 2016). It is accepted that the agricultural sector is more sensitive to several climatic factors than the industrial or service sectors, making the farming community more vulnerable to climate change (Sarkar *et al.*, 2021). Assessment of the vulnerability of farm-based livelihood systems to climate shocks can assist in defining and identifying measures to strengthen their resilience and satisfy the sustainable development goals (SDGs) (Lokonan, 2017). As a result, identifying and comprehending the agricultural community's vulnerabilities is essential to a safe and secure future of building a resilient agriculture system. With such importance of adaptation strategies and vulnerabilities in relation to climate change the following objectives are drawn-

1. To identify the adaptation strategies and practices taken up by Indian farmers.
2. To assess the vulnerability of Indian farmers to climate change.

Since the study focuses on Indian agriculture, only Indian research is included. This comprehensive research might inform scientific investigations on Indian farmers' shortcomings and adaptive tactics. This report provides an overview of Indian farmers' practical and potential practices. Understanding farmer risks helps policymakers and stakeholders construct a climate-resilient agriculture future. We believe this viewpoint and review will help the scientific community make informed vulnerability and adaptation strategy research decisions.

METHODOLOGY

The review of the current and available records was done by following the ROSES protocol. Reporting Standards for Systematic Evidence, or ROSES Maps and syntheses created especially for the subject of environmental management and systematic reviews (Haddaway *et al.*, 2018 as cited in Shaffril *et al*., 2020). According to the ROSES website the whole process is divided into three phases- 1. Searching, 2. Screening, 3. Critical Appraisal and Synthesis. The flow diagram of ROSES protocol is given in figure 1.

Searching : As per the ROSES protocol the search string is in the form of Boolean-style. The search strings or search words for identification of records were- “climate change” and “vulnerability” and “India” and “farmers” and “adaptation” and “strategies” or “practices”. The search string were the inputs into the main database- ScienceDirect and Indian Research Journal of Extension Education. And for web-based search engines, Google Scholar was chosen for its provision of documents from various scholarly publishers. The total records identified from the three databases were 162.

Screening : At this stage, the papers' eligibility is assessed. Criteria for the records' inclusion and deletion have been set in order to further evaluate their quality and appropriateness for the review. The selection process was based only on research articles

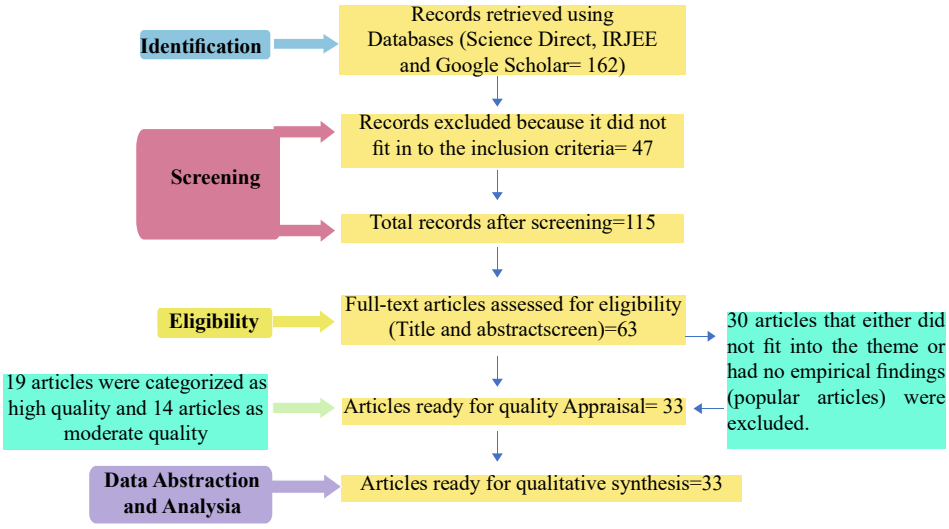


Figure 1. Flow Diagram of the ROSES Approach

with solid and empirical backing, written in English with an Indian foundation. Since the establishment of the Sustainable Development Goals in 2015, research has strongly emphasised the need to address climate change. As a result, the study's time span was established for 2015–2023. Furthermore, as the evaluation was completed in 2023, it was included in the later bracket for that time period. Only open access publications were included in the review; no papers that needed payment for access or inaccessible were considered.

A total of 115 articles met the requirements for further screening after searching using all the parameters. Manual evaluation of the abstract and title was done to further ascertain the articles' eligibility and make sure they met the requirements. Of the 115, 63 articles were further inspected, of which 33 articles got excluded again for not having empirical findings. Overall, only 33 articles were selected after full screening.

Critical appraisal and synthesis : Experts rank the remaining articles into high, moderate, and low categories. Review of only high and moderately rated items is recommended (Petticrew and Robert as cited in Shaffril *et al.,* 2020). To assess the articles' level of quality, the experts concentrated on their methods. 19 articles were conferred to be of high quality while 14 were considered to be moderate.

Table 1. Inclusion and exclusion criteria

Criteria	Inclusion	Exclusion
Document type	Research Article	Article review, book chapters, book, Conference/ symposium proceeding
Language	English	Non-English
Region	India	Other countries
Time	2015-2023	<2015
Access	Open access	Closed/ paid

RESULTS

The results help in identifying the strategies practiced most by the farmers in the country. The beauty of systematic literature review is the coverage of diverse cultures, people practicing different agriculture systems and growing crops of manifold types. Though it has been stated by many that farmers are the most vulnerable group to climate change, post analysis it became clear that studies on vulnerabilities are lacking in the country.

Distribution of studies conducted on Adaptation Strategies and Vulnerabilities of Farmers across Indian states is presented in figure 2.

Two of the studies included in the analysis have been conducted in two states- first in Arunachal Pradesh and Assam while the second study in - Manipur and Sikkim. Another in three states- Arunachal Pradesh, Manipur and Meghalaya. While one of the studies have not specified the location stating ‘locations representing arid, semi-arid, sub-humid, and humid zones of India’.

Adaptation strategies to climate change : Of the 33 articles, 28 have been identified and enlisted the various adaptation strategies practiced by the farmers all over India. 6 major themes were identified from the 28 articles after the analysis of the adaptation strategies. The themes identified in the analysis were- Crop

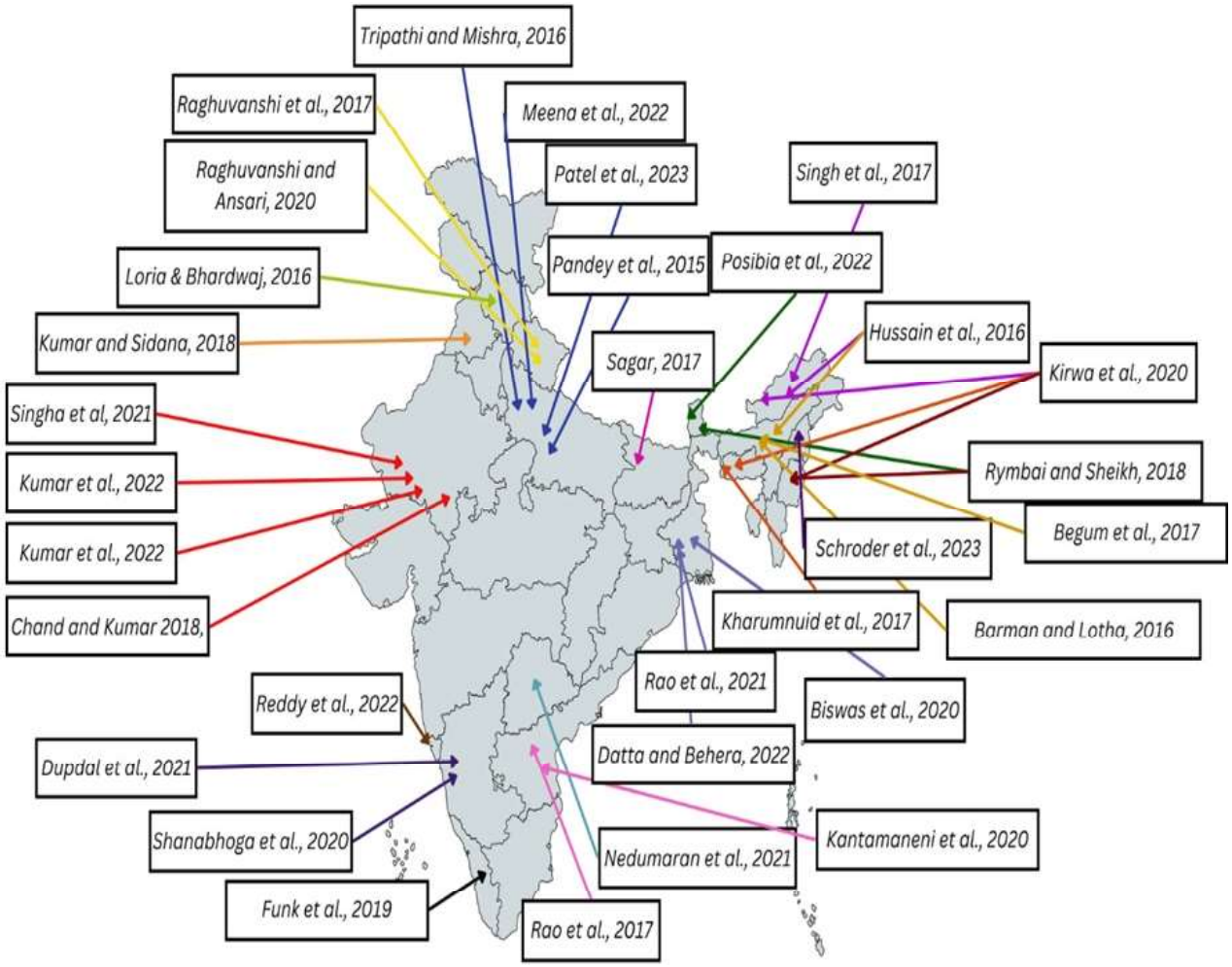


Figure 2. Distribution of Research studies in India

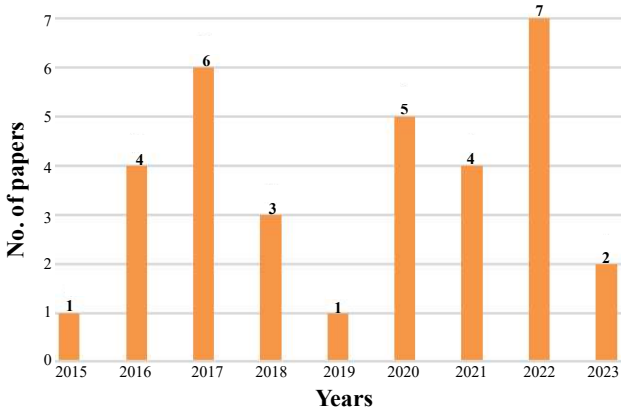


Figure 3. Distribution of Research papers between 2015 to 2023 in India

Management, Water Management, Soil Management, Livestock Management, Financial Management and Livelihood Diversification (Figure 3). These themes were more common in the reports, while certain adaptation strategies were only mentioned in certain articles. Only 18 primary adaption techniques were frequent.

Crop management : Among the adaptation strategies, crop management related practices had the highest rate of adoption by the farmers is presented in the Table 2. Other practices mentioned in the studies which fall under crop management theme but do not fall under any sub theme are- use of seed drill (Rao *et al.*, 2017), increased application of pesticide, planting woody tree (Datta and Behera, 2022), Earthing up and land preparation in traditional way (Kharumnuid *et al.*, 2017), direct seeded rice, zero till wheat (Kumar and Sidana, 2018), using plant protection chemicals, Planting trees in surrounding fields (Singha *et al,* 2022), intercropping with legumes, Cover crops 14% (Schroder *et al.,* 2023) and planting fruit trees/other trees (Biswas *et al*., 2020), mix cropping (Tripathi and Mishra, 2016).

Soil management : The next theme with greater importance in relation to the adaptation strategies is soil management is presented in the Table 3.

The practices which were not categorized under the themes were- soil test-based fertilizer application

Table 2. Adaptation strategies for crop management

Adaptation strategies	Authors
Change of Crop Variety	Loria and Bhardwaj, 2016; Tripathi and Mishra, 2016; Kharumnuid et al., 2017; Rao et al., 2017; Kumar and Sidana, 2018; Biswas et al., 2020; Raghuvanshi and Ansari, 2020; Shanabhoga et al., 2020; Dupdal et al., 2021; Singha et al., 2021; Datta and Behera, 2022; Mohapatra et al., 2022; Posibia et al., 2022; Reddy et al., 2022; Patel et al., 2023
Crop Diversification	Hussain et al, 2016; Loria and Bhardwaj, 2016; Singh et al., 2017; Tripathi and Mishra, 2016; Raghuvanshi et al., 2017; Begum and Mahanta, 2017; Datta and Behera, 2022; Sagar, 2017; Kharumnuid et al., 2017; Raghuvanshi and Ansari, 2020; Dupdal et al., 2021; Reddy et al., 2022
Shifting of date	Barman and Lotha, 2016; Loria and Bhardwaj., 2016; Tripathi and Mishra, 2016; Begum and Mahanta, 2017; Sagar, 2017; Kharumnuid et al., 2017; Rymbai and Sheikh, 2018; Dupdal et al., 2021; Singha et al., 2021; Paramesh et al., 2022; Patel et al., 2023
Change of crops	Hussain et al., 2016; Raghuvanshi et al., 2017; Rymbai and Sheikh, 2018; Datta and Behera, 2022; Patel et al., 2023
Crop rotation	Begum and Mahanta, 2017; Singha et al., 2021; Mohapatra et al., 2022
Leaving land fallow	Rymbai and Sheikh, 2018; Reddy et al., 2022

Table 3. Adaptation strategies for soil management

Adaptation strategies	Authors
Use of fertilizer	Begum and Mahanta, 2017; Raghuvanshi et al., 2017; Sagar, 2017; Raghuvanshi and Ansari, 2020; Mohapatra et al., 2022
Bund construction	Rao et al., 2017; Shanabhoga, 2020; Datta and Behera, 2022; Kumar et al., 2022; Reddy et al., 2022
Soil conservation schemes	Loria and Bhardwaj, 2016; Raghuvanshi et al., 2017; Shanabhoga et al., 2020; Paramesh et al., 2022
Use of organic manure	Kharumnuid et al., 2017; Schroder et al., 2023

Table 4. Adaptation strategies for water management

Adaptation strategies	Authors
Water harvesting	Loria and Bhardwaj., 2016; Raghuvanshi et al., 2017; Kirwa et al., 2020; Kharumnuid et al., 2017; Dupdal et al., 2021; Singha et al., 2021; Mohapatra et al., 2022; Schroder et al., 2023
Building irrigation systems	Barman and Lotha, 2016; Begum and Mahanta, 2017; Sagar, 2017; Kirwa et al., 2020; Datta and Behera, 2022; Patel et al., 2023

methods (Rao *et al.,* 2017), mulching (Schroder *et al.,* 2023) and soil testing (Patel *et al*., 2023).

Water management : The next major sub theme identified is Water Management (Table 4). Water is essential for the growth of crops and hence its management is one of the key components in crop production. The improvement of irrigation facilities (Kumar and Sidana, 2018), Bore well digging (Singha *et al.*, 2021), more use of ground water for irrigation and use of PVC pipes to carry water on farms (Tripathi and Mishra, 2016) were the practices that did not suit any sub themes.

Livestock management : Rearing of livestock like poultry and cattle help in diversifying the income and dietary sources. Adaptation strategies for livestock management is presented in Table 5.

Other practices mentioned only one in one study each were- use of crop as livestock fodder (Shanabhoga *et al.*, 2020), livestock supported farmers during dry seasons in earning income (Begum *et al.*, 2017), the rearing of crossbreds, growing green fodder in the off season mainly to ensure year-round availability of energy and fiber sources, using electric fans/coolers during summer to relieve heat ,higher prophylactic measures against disease infestation, rearing of improved fingerling, the introduction of new species, adoption of managed ponds to reduce seepage loss (Paramesh *et al*., 2022) and reducing livestock (Loria and Bhardwaj, 2016).

Table 5. Adaptation strategies for livestock management and financial management

Adaptation strategies	Authors
Llivestock management	
Diversification of rearing livestock	Loria and Bhardwaj, 2016; Kharumnuid et al., 2017; Singh et al., 2017; Funk et al., 2019; Shanabhoga et al., 2020; Raghuvanshi and Ansari, 2020; Reddy et al., 2022
Fodder preservation	Chand and Kumar, 2018; Shanabhoga et al., 2020; Raghuvanshi and Ansari, 2020
Financial management	
Selling of assets	Reddy et al., 2022; Biswas et al., 2020; Mohapatra et al., 2022
Crop loans	Funk et al., 2019; Reddy et al., 2022

Financial management : Farmers also took up strategies that would ensure financial stability in case of any unforeseen calamity.

Other strategies related to financial management (Table 5) were- borrowing from other people (Reddy *et al.,* 2022), insurance (Paramesh *et al.*, 2022) and use credit services to cope up the adverse effect of climate change (Biswas et al., 2020).

Livelihood diversification : The last theme common among the strategies is Livelihood diversification. Farmers usually take up non farming activities for diversifying their livelihood (Hussain *et al.*, 2016; Loria and Bhardwaj, 2016; Tripathi and Mishra, 2016; Kharumnuid *et al.*, 2017; Biswas *et al,* 2020; Kirwa *et al.,* 2020; Raghuvanshi and Ansari, 2020; Singh *et al.*, 2021; Kumar *et al*., 2022; Patel *et al.*, 2023. A synonymous type of diversification was observed in the study of Singh *et al.* (2017) where the women farmers made handicrafts, accessed forest-based resources, fished, hunted while poor farmers also bartered their products with people from outside their networks.

Vulnerabilities : Of the 33 articles selected, only 9 were found to have conducted vulnerability study in India. 3 of the vulnerability studies were done with the assessment of adaptation strategies while 6 were purely on Vulnerability of farmers.

6 of the studies determined the vulnerability level of the farmers. Meena *et al.* (2022), Raghuvanshi and Ansari (2020) and Mohapatra *et al.* (2022) found that majority of the respondents fall under moderately vulnerable group. In contrast, Kumar *et al.* (2022) in their study found that a majority of the respondents (about 55%) were in highly vulnerable group, while only 1% was in moderately vulnerable group. The study conducted in Telangana concluded that most of the marginal, small, semi-medium, medium was extremely vulnerable while resilient households majorly consisted of large and most affluent group of farm households (Nedumaran *et al.*, 2021). The bulk of respondents (about 55%) belonged to the extremely vulnerable category, followed by the vulnerable group (around 44%) and the moderately susceptible group (only 1%) (Kumar *et al.*, 2022).

The Climate Vulnerability Index value of households practicing Agroforestry was lower than

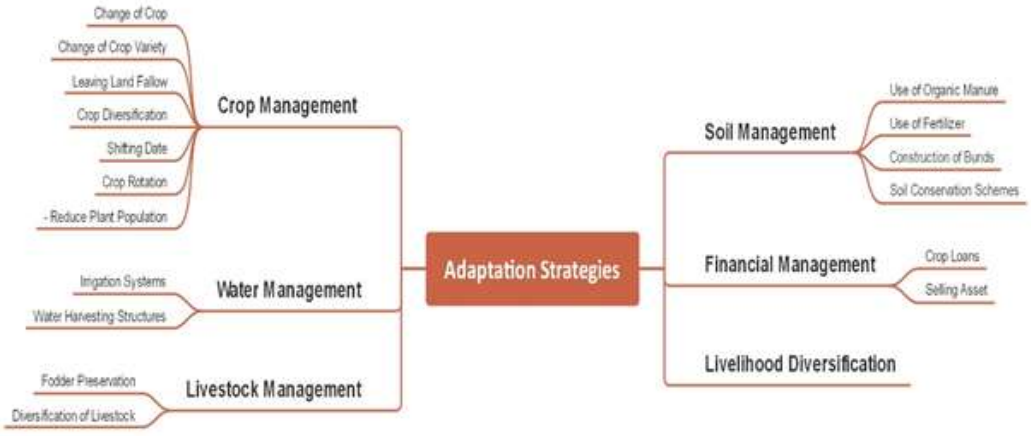


Figure 4. Major climate change adaptation strategy themes

non-Agroforestry households which depicts that the agroforestry households were less prone to climate change (Pandey *et al.,* 2015). While households practicing farming systems- 1) Crops without Livestock, 2) Crops with Small Ruminants and 3) Crops with Dairy were assessed. The households in the Crops without Livestock system exhibited the highest level of vulnerability among the three farming systems (Rao *et al.,* 2021).

Because their adaptation tactics have up to now relied on rainfed systems and forest resources—both of which are increasingly impacted by climate variability and extreme weather events—poorer farmers—especially women—are expected to become even more susceptible (Singh *et al.,* 2017). While social of worsening fluctuations in climatic conditions are leading to many young farmers becoming middle-aged bachelors (Kantamaneni *et al.,* 2020).

Figure 4. Major climate change adaptation strategy themes

DISCUSSION

This study is one of the minuscule attempts to understand climate change through the farmers' lens in India. By rigorous screening and selection 33 articles were analyzed. Of which 28 and 9 articles had assessed the adaptation strategies and vulnerabilities of farmers all around India, respectively.

Crop yields might rise by 12 per cent if sowing and variety adaptations are made as opposed to non-adaptation (Doody, 2023). The popularity of new cultivars with advantageous characteristics, such as those that are heat- or drought-resistant, short-duration, early ripening, or higher yielding is responsible for the shift in crop variety. Changing the timing of sowing, transplanting, planting, and/or harvesting in order to mitigate the impact of disease (Kharumnuid *et al.*, 2017), maintain long-term revenue (Dupdal *et al.*, 2021), and prepare for eventual dry periods or terminal droughts (Paramesh *et al.,* 2022) are some of the reasons for taking up this strategy. The shift in the dates for planting, transplanting, and harvesting can be linked to climatic variations. Growing entirely new crops in place of previously cultivated ones is known as a "change of crops." Cash and commercial crops provide a greater price than other crops, therefore farmers are drawn to producing them. One of the most often used techniques for raising the productivity of the land is crop rotation. Allowing land to remain fallow promotes the land's recovery of health and fertility. according to Shanabhoga *et al*. (2020).

The use of fertilizer increased which is in trend with the rise in global usage of fertilizer. In 2021 the global consumption was 195.38 million tons compared to the 46.3 million metric tons in 1965 (Statista Research Department, 2023). Bund construction in essence is a soil conservation schemes, by preventing runoff of soil. Training farmers in bund construction produced higher-quality work (Kumar, 2023). While use of organic manures by farmers is a positive sign of sustainability of agriculture in the area.

Water harvesting structures have been widely accepted by the farmers in India as one of the adaptation strategies against climate change. Panwar *et al.* (2023) presented 12 case studies from various climatic conditions throughout India, which showed that harvesting water may improve the land utilization index, crop diversification index, fertilization index, and revenue enhancement. The other common water management strategy is building irrigation systems in the farms which is an encouraging direction for the farmers in the long run. As Kalli *et al.* (2024) concluded that irrigated paddy cultivators outperformed their rain-fed counterparts.

Building resilience in farmers against risk is necessary in face of an uncertain future. Diversification in crop and livestock was shown to improve family food security in a way that was statistically significant (Danso-Abbeam *et al.,* 2021). The other adaptation is preservation of fodder. By saving fodder for dry and lean seasons, the farmers ensure a continuous supply of feed for their livestock. The failed crops are also used as fodder for the livestock.

Other than providing food and nutritional security to the farm households, livestock also provide financial security. Although livestock and their product can fetch them good prices, some of the farmers have been driven to distress selling of their livestock. Such cases are witnessed usually in the event of any unforeseen calamities like droughts, failure of crops and others. National Bank For Agriculture And Rural Development reported a 5.34 lakh crore rise in Small and Marginal loan distribution from 2015–16 to 2016–17. SF/MF accounts supported by all agencies rose from 60.07 percent in 2015–16 to 72.06 percent in 2016–17. This can imply that farmers are able to access financial assistance such as Crop Loans and subsidies, strengthening the farmers' financial security.

As is apparent from the review, crop loan is a strategy taken up by the farmers in the country.

Livelihood diversification is a process by which household members construct a diverse portfolio of activities and social support capabilities in their struggle for survival and to improve their standards of living (Ellis 1998, as cited in Abera *et al.,* 2021). The farmers used several alternate livelihood strategies to deal with lower agricultural yields (Jyothi and Venkata, 2020). Off farm activities served as an- alternative to meet their livelihood (Loria and Bhardwaj, 2016), a reliable source of income for the farmers; (Patel *et al*., 2023) while others worked as daily paid laborers in different field like building construction, leather factory, jewelry factory, cloth making factory nearby or by going to different states (Funk *et al.*, 2019). Off farm activities diverges the dependence of rural people from agriculture to other activities to sustain their livelihood (NABARD, 2020). The poor farmers had less opportunity for intensification due to their limited resources (Singh *et al.*, 2017).

Other strategies like intensifying the agricultural activities on irrigated land, diversifying of labor use from crop to livestock, employing labor-saving implements for cultivation, reducing the number of waged labors used on the farm (Shanabhoga *et al.,* 2020). While changing the size of land under cultivation (Raghuvanshi and Ansari, 2020) like farming in small area (Datta and Behera, 2022) and increasing the extent of land put into agriculture (Sagar, 2017) was also observed. Incorporation of modern technology as strategy against climate change seemed to be lesser in practice from the reviewed studies as is evident in the case of Singha *et al.* and Datta and Behera i.e- Use of ultramodern wireless-based monitoring system and ICT respectively. Other systematic reviews had discussed about social participation and contact (Shaffril *et al.,* 2018) in adaptation of strategies but contact with cooperatives and self-help group (Datta and Behera, 2022) was mentioned in only one case.

In case of vulnerability, majority of farmers were found to be moderately vulnerable to climate change (Meena *et al.,*2022; Raghuvanshi and Ansari, 2020; Mohapatra *et al.,* 2022). It can be attributed to the farmers likely taking up adaptation strategies by their own experience and the need to change with time. Farmers were able to perceive change in the climate (Parganiha and Sharma, 2017; Kumari *et al.* 2020). Nedumaran *et al.* (2021) concluded that extremely vulnerable group consisted mostly of the marginal, small, semi-medium, medium households while resilient households majorly consisted of large and most affluent group of farm households. The marginal, small, semi-medium, medium farm households lack access to resources while the opposite is true for the large households. Application of indigenous and scientific knowledge along with climate-smart methods in agriculture and related systems can alleviate the effects of climate change (Devi *et al.*, 2022).

In the studies of Pandey et al. (2015) and Rao *et al.* (2021) it is clear that farmers practicing Integrated Farming System (IFS) like Agroforestry and Crop-Livestock production were less prone to climate change risks. By diversifying the farming system farmers are insured of their income and dietary sources. Therefore, farmers should be encouraged to take up IFS. Farmers suggested 'Provision of financial support' would be a major propelling factor for adoption of Integrated Farming System (Kumar *et al.*, 2022). Socially, the implications of climate change is concerning as poor and women farmers are found to be more vulnerable than other social groups. Also, farming has been considered to be risk influenced therefore the farming as an occupation itself is in danger. Farmers are not considered as eligible suitors for marriage. Hence, reducing the status of farmers in the society.

CONCLUSION

The undertone of climate studies has always been dark. By taking up this study, we try to understand how farmers of India have coped with the changing times and climate. The necessity to understand the vulnerability of farmers in relation to climate change has also been highlighted. After the review of the articles, the adaptation strategies were categorized in to 6 themes- Crop Management, Soil Management, Water Management, Livestock Management, Financial Management and Livelihood Diversification. Crop Management theme included adaptation strategies taken up by the farmers to improve the health and yield of crops. Soil Management practices intends to ameliorate the soil health and fertility. While Water Management directs to take up practices that can improve water supply and application in the farms. Livestock Management theme included practices that aimed to intensify the production of livestock. Financial Management adaptation strategies were the actions taken up by the farmers for handling their home

finances. And the last theme identified was Livelihood Diversification, which oversaw the off-farm activities taken up by the farmers to spread their income generation web. However, in contrast to adaptation strategies the vulnerabilities of farmers were less studied. The farmers were mostly moderately affected by climate change. And farmers with access to more resources were more resilient compared to others.

With this study the path for climate change adaptation strategies and vulnerabilities studies can take direction in the needed one. Policy makers can also apply the findings on the types of adaptation strategies to be targeted, for building a climate resilient agriculture system in India. There is also a dire need for studying the vulnerabilities of farmers across the nation, as the climate change effects the varying parts of the country differently.

Funding: There was no funding support from any source.

Declaration of competing interest: The authors have no known competing interest to declare.

Data availability: Data would be made available on request

Authors' contribution: First author conceptualized, initial literature review, outlined the paper's structure, and coordinated the collaboration among the authors. Second author critically evaluated the selected papers, including revisions and edits of the manuscript. Third and fourth author contributed to writing – review and editing.

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