**REVIEW ARTICLE**

# A systematic literature review on factors influencing the adaptation behaviour of climate variability in agriculture

**Sakeel Ganesh M[1], Sriram N[2*], Balasubramaniam P[3], Vijayabhama M[4], Mohammed Ghouse L[1] & G A Dheebakaran[5]**

[1]Department of Agricultural Extension, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India
[2]Directorate of Research, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India
[3]Directorate of Open and Distance Learning, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India
[4]Department of Physical Sciences and Information Technology, AEC & RI, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India
[5]Agro Climatic Research Centre, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

*Correspondence email - ns73@tnau.ac.in

## Abstract

Climate variability adaptation encompasses measures implemented to adjust to the impacts of climate variability, aiming to minimize associated risks and vulnerabilities. It entails creating plans to shield economies, ecosystems and people from the negative effects of climate variability. Reducing the negative effects of climatic variability, safeguarding livelihoods and promoting sustainable development are crucial. It enhances resilience, reduces vulnerabilities and protects infrastructure, ecosystems and human welfare. Analyzing factors affecting adaptation behaviour aids in identifying challenges and potential opportunities for successful response strategies. This paper analyzes climate variability in agriculture, explored the factors influencing adaptation behaviour. A systematic literature review was conducted in published papers (i.e., over the last ten years) from the Scopus database using PRISMA methodology. This review identified 40 articles that answered three important questions: What trends are emerging in the global literature to explain climate variability adaptation? What factors are considered when shaping climate variability adaptation? Which elements can be regarded as critical to advancing adaptation mainstreaming in policy and practice? Thematic analysis showed that decision making, farmers' perspective, environmental policy and agricultural extension were the most important elements influencing climate variability adaptation. Food security plays a modest role in climate variability adaptation. Strong governance, policy integration, stakeholder involvement and proper financing have all been identified as critical components for furthering climate variability adaptation mainstreaming.

**Keywords:** adaptation; climate variability; determinants; factors

## Introduction

Agriculture has been highly influenced by climate variability, making it increasingly difficult to maintain traditional practices in crop cultivation, livestock rearing and fish farming. Climate change, along with other evolving environmental and socio-economic factors, has significantly impacted agricultural production and productivity (1). Agriculture has been adversely affected by climate variability and farmers have been negatively impacted by both climate change and variability, posing significant risks to their livelihoods (2, 3). The frequency and intensity of extreme weather events have been contributing to the devastating effects of climate change and significantly altering the lives of vulnerable and isolated groups (4, 5). For example, recurrent droughts in sub-Saharan Africa have led to severe crop failures, reducing food availability and pushing smallholder farmers into deeper poverty. Similarly, intensified cyclones in coastal South Asia have displaced farming communities and

damaged critical agricultural infrastructure. These events highlight how extreme weather disproportionately affects marginalized populations with limited adaptive capacity.

The vulnerability of individuals in poor countries has increased due to the amplification of these events, especially for those primarily engaged in subsistence farming and livelihoods dependent on natural resources that are susceptible to climate change (6). Climate change has adversely impacted future livelihoods, reducing farmers' income by nearly 30 % in dry climates and 20 % in wet climates (7).

Farmers' livelihoods have been severely impacted by various climate-related events, including heat waves, droughts, storms, floods, insect pest outbreaks and increasingly unpredictable and intense rainfall, along with a notable rise in temperatures. Additionally, future climate projections indicate continued uncertainty in climatic patterns, complicating the prediction and management of

climate extremes (8). The awareness of climate change and variability is becoming a rising factor among people and who consider it a serious threat, which would induce adaptation strategies among farmers (9).

The capital and adaptability relationship are determined in a significant way by climatic and non-climatic factors. Farmers could be obliged to adopt adaptive measures due to unfavourable weather conditions since the likelihood of adaptation is marginally increased when climatic elements rise. Despite having adequate resources, the rise in non-climatic factors (socio-economic, institutional and demographic characteristics) reduces the adaptability. Capital refers to farmers' available resources, including financial assets, social networks, human skills, natural resources and physical infrastructure, which influence their capacity to adapt to climate variability (10). Farmers proactively aware of climate change tend to implement more management techniques and the likelihood that farmers will enhance their climate change adaptation tactics is greatly increased by financial support, such as availability of credit and access to the produce market (11).

There is a substantial negative correlation between risk assessment and actual adaptation behaviour, indicating that higher perceived risks do not always lead to immediate action. However, both risk assessment and coping appraisal positively influence farmers' behavioural intention to adopt climate change adaptation strategies. In developing countries, this intention is further shaped by social judgment, highlighting the role of community norms and peer influence in adaptation decisions (12).

Researchers and extension specialists may have the greatest influence through specialized techniques that support both adaptation and mitigation. These may include climate-smart agriculture, early warning systems and tailored decision-support tools. Farmers' adaptation behaviour, however, appears to be primarily driven by the direct consequences of climate change rather than by efforts to mitigate it (13). Mitigating the adverse effects of climate change and variability may involve implementing new technologies and improved seeds, expanding land cultivation, lowering trade barriers and altering farming techniques (14).

Farmers in hilly terrain and alluvial plains appear to be the most adaptive. Farmers described their strategies for adapting to climate change as including short-season crops, drought-tolerant crops, irrigation, rearranging planting dates and planting trees. The adverse effects of a changing climate remain unnoticed by smallholder farmers, who have responded appropriately to variations in rainfall, temperature and wind (15, 16).

Farmers' adoption of climatic variability adaptation measures was highly influenced by age, gender, education level and agricultural experience (17). The adaptation behaviour was significantly influenced by education and innovativeness; therefore, it is necessary to educate farmers on the significance of climate change adaptation (18). The adoption of sustainable agricultural practices helps reduce the impacts of climate variability (19). The farm size was inversely related to adoption of adaptation behaviour, small farm size leads to higher adoption of strategies (20).

## Drivers of adaptation

Farmers with higher farm income did not have the stimulus to adopt adaptation strategies and farmers with lower farm income have a higher stimulus to adopt adaptation strategies (21). Farmers adopted traditional farming practices to mitigate climate change and variability (22).

Based on their perceptions of climate variability, farmers can make investment decisions according to the assistance of indigenous knowledge (23). Farmers' perceptions of climate change were found to be positively correlated with their awareness of it, misinformation or the absence of accurate data may cause perceptions to become distorted (24, 25). Evidence from the reviewed literature reveals significant variation in farmers' adaptation behaviour based on geographic and economic contexts. In low-income countries and arid regions, limited access to resources and institutional support amplifies reliance on traditional knowledge and reactive strategies. Conversely, farmers in high-income countries and humid zones are more likely to adopt proactive, technology-based adaptations, influenced by better infrastructure and risk awareness. Climate variability leads to a decrease in the length of the crop growing season and chemical fertilizers were used to overcome this barrier (26). To enhance farming methods, skills training in climate change adaptation and mitigation could be implemented (27). The most prevalent ways to mitigate the short-term effects of climate variability were to alter growing seasons (sowing and harvesting), as well as to apply fertilizers and pesticides (28).

Farmers' perceptions of climate change risks and their beliefs in the efficacy of adaptation measures significantly impact their willingness to adopt adaptive strategies (29).

## Role of institutions

Access to financial resources, credit facilities and markets can either facilitate or hinder adaptation efforts. Farmers with higher incomes and better market access are more likely to implement adaptive strategies (30). Support from local government leaders and the presence of robust governance structures are vital. Lack of support from local government elected leaders is a significant barrier to municipal adaptation (31).

Societal norms, cultural beliefs and individual behaviors influenced adaptation actions. Engaging with these aspects was crucial for effective adaptation strategies (32). Attributes such as age, gender, household size and education level significantly influenced adaptation decisions. For example, younger farmers with higher education levels were more likely to adopt innovative adaptation strategies (33). Income levels, farm size and access to financial resources play pivotal roles. Farmers with larger landholdings and higher incomes have greater capacity to implement adaptation measures (34).

Individuals' awareness and understanding of climate change risks influence their willingness to adapt. Those who perceive higher risks are more proactive in adopting the adaptation strategies (35). Regular interactions with

agricultural extension services provide farmers with information and support, facilitating the adoption of appropriate adaptation practices (36). Effective governance, policy frameworks and institutional coordination enhance the implementation of adaptation measures. Skilful project management and improved institutional coordination are key elements for successful adaptation interventions (37). Community engagement and social norms significantly impact adaptation decisions. Strong social networks can facilitate the sharing of knowledge and resources necessary for adaptation (38).

### Barriers to adaptation

Availability of natural resources, such as water and fertile land, determines the feasibility of certain adaptation strategies (39). Cultural beliefs and practices can either facilitate or hinder adaptation efforts. Understanding local cultural contexts is essential for designing effective adaptation strategies (40). Past experiences with climate-related events shape individuals' risk perceptions and influence their adaptation behaviours (41). Prevailing social norms can either facilitate or hinder adaptation efforts. It emphasized the importance of aligning adaptation policies with local social norms to ensure their effectiveness (42). Engagement with agricultural extension services, training programs and weather-related information enhances the adoption intensity of climate change adaptation practices among farmers (43, 44).

Understanding the factors affecting climate change adaptation aids in designing practical approaches that align with local contexts, ensuring successful adaptation measures. Insights into adaptation determinants enable efficient distribution of resources, ensuring support reaches areas where it's most needed (45). Understanding these factors could inform strategies to increase support for adaptation policies, facilitating their implementation (46).

Understanding adaptation behaviour is increasingly vital as climate variability poses significant risks to agricultural productivity and livelihoods. Farmers' responses to these challenges are shaped by complex socio-economic, environmental and institutional factors. Without insight into these behaviours, adaptation strategies may fail to be effective or equitable. This review systematically examines the key factors influencing adaptation behaviour in agriculture to inform targeted and sustainable interventions.

Considering the above discussion, this paper seeks to explore three primary questions:

(a) What trends are emerging in the global literature to explain climate variability adaptation? (b) What factors are conceptualized in shaping climate variability adaptation? (c) Which elements can be considered key to advancing adaptation mainstreaming in policy and practice?

## Methodology

### Review structure

To assess the relevant scholarly literature on factors affecting climate variability adaptation, we employed the 15-step Systematic Quantitative Literature Review method (47). This highly structured approach is robust and reproducible, supporting transparency in the review process and reporting of key findings. We followed the protocols of the Preferred Reporting Items for Systematic Review Recommendations (PRISMA) (48).

The impact of climate variability and change was analysed through Systematic Literature Review (SLR) method (49, 50). We used the SLR technique to systematically compile, describe and categorize relevant literature (51). It entails scanning information sources and making a mind map (conceptual framework). We used VOSviewer software to construct a bibliographic review, generating maps, cross-references and co-occurrence analyses based on bibliographic connections.

### Search terms, database searches and article selection

The Scopus database was used to search the literature published over the last ten years (2015-2024) since there was a rise in literature post-Paris Agreement during this period. The keyword combinations used for the database search are shown in Table 1. The search for research publications involves the use of a variety of search strategies related to climate variability and its adaptation behaviour. The search strategies utilised keyword combinations from all categories were shown in   Table 1.

The Scopus search strategy employed Boolean operators and wildcards to ensure comprehensive coverage of relevant literature. The search string used was: ("climate variability" OR "climate change") AND (adapt* OR "coping strategy" OR "resilience") AND (agriculture OR farming) AND (behaviour OR behaviour OR "decision-making"). A search using keywords related to climate variability, agriculture, adaptation behaviour and influencing variables yielded 375 publications in the Scopus database (Table 1). This highlights the importance and ongoing study interest in these interrelated subjects, which are reflected in the substantial

**Table 1.** Combination of keywords used and the total number of publications from databases

| Databases | Search terms | Numbers of articles |
|---|---|---|
| Scopus | "climate variability" AND "agriculture" AND "adaptation behaviour" AND "factors" OR "determinants" | 375 |

amount of literature that has been written about them in this database.

### Primary screening

A total of 375 articles were identified as potentially relevant (Fig. 1). Preliminary screening removed 158 articles. The preliminary screening was based on automation filters such as non-English, review paper and restricted access, published year (2015 to 2024). These filters were applied to maintain consistency, accessibility and relevance within the review scope. Excluding non-English and restricted-access articles ensured that selected studies were both comprehensible and openly available for analysis. Limiting the publication years to 2015-2024 focused the review on recent findings reflecting current climate-agriculture dynamics and policy contexts.

### Quality screening

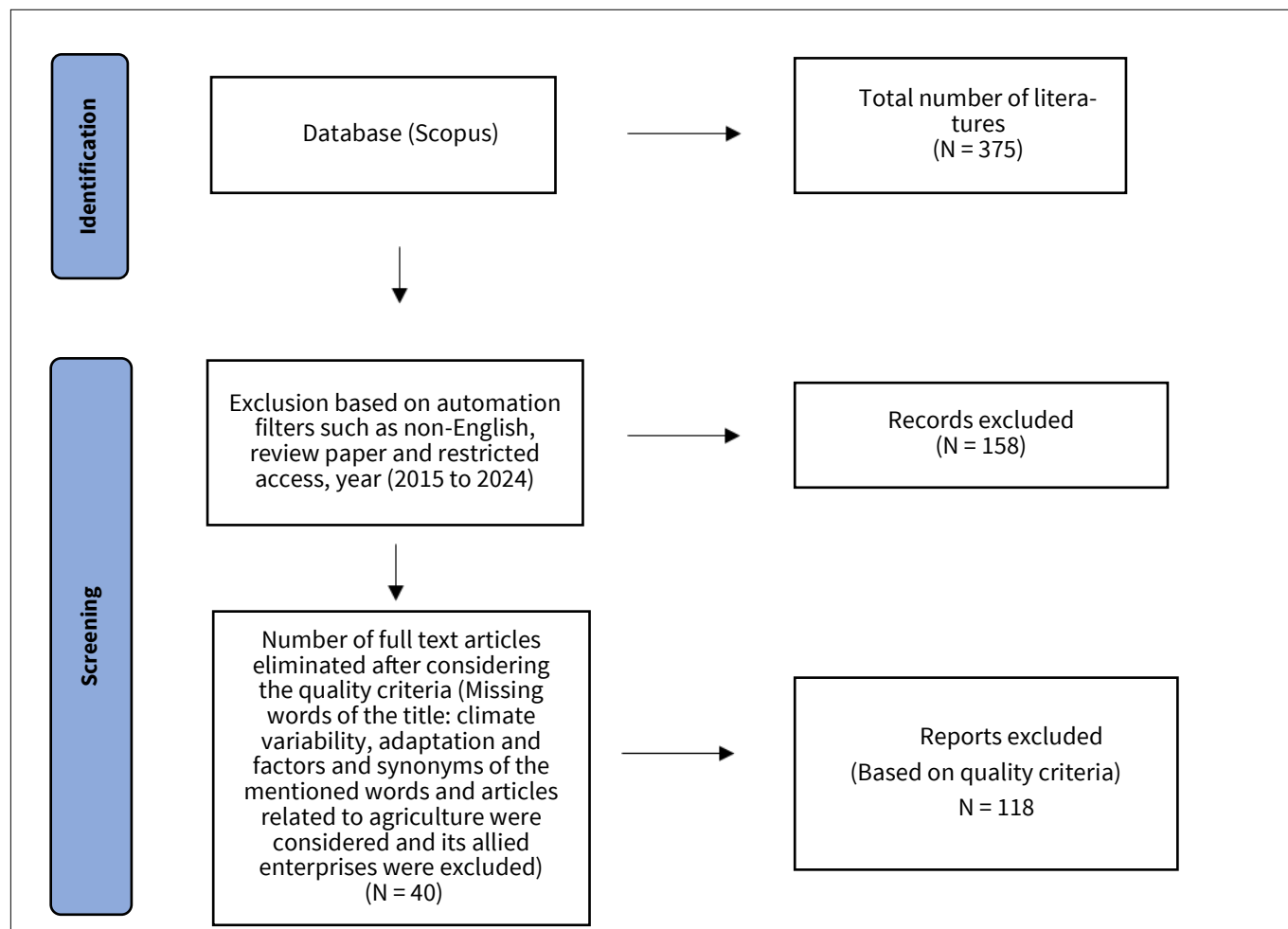The remaining 217 articles were taken to the inclusion-

**Fig. 1.** PRISMA flowchart depicting the number of studies inclusion and exclusion for identifying the determinants.

**Table 2.** Inclusion and exclusion criteria

| Criteria | Inclusion | Exclusion |
|---|---|---|
| Time span | 2015-2024 | <2015 |
| Subject area | Social science, Agricultural & biological science, Multidisciplinary and Environmental science | Earth and planetary science, Engineering, Economics, Econometrics and Finance<br>Biochemistry, Genetics and Molecular Biology, Energy, Medicine, Arts and Humanities, Computer Science, Business, Management and Accounting, Decision Sciences, Immunology and Microbiology, Chemical Engineering, Veterinary, Mathematics, Chemistry, Psychology, Physics and Astronomy, Materials Science, Neuroscience, Pharmacology, Toxicology and Pharmaceutics, Health Professions, Nursing |
| Document type | Article | Conference papers, Book chapters |
| Languages | English | Non-English |
| Source type | Journal | Trade journal |
| Publication stage | Final | Press |
| Open access | Open access | Restricted access |
| **Screening** | | |
| Title and abstract | Existence of predefined keywords in the title, abstract, or keywords part of the paper. Considered the climate variability, adaptation behaviour and factors as an outcome | |
| Full text | Included at least three determinants from climate variability, agriculture and adaptation behaviour | |

exclusion criteria (which were shown in Table 2). Based on the quality criteria outlined in Table 2, 118 articles were excluded. The 118 articles were excluded after full-text screening based on quality criteria to ensure methodological rigor and relevance. Studies lacking clear research design, insufficient data on adaptation behaviour, or weak analytical frameworks were removed. Articles with unclear target populations or unsupported conclusions were also excluded. This process ensured that the final selection reflected high-quality, evidence-based contributions to the topic. A total of 40 studies were chosen for quantitative analysis based on suitability, relevancy and clarity of addressing stress and coping variables.

## Findings

### Characteristics of global literature

#### Bibliometric Summary

A bibliometric summary of a Systematic Literature Review

(SLR) conducted on research published between 2015 and 2024 is shown in Table 3. It highlights key indicators such as the number of sources, documents, citations, author collaboration and keyword trends. The analysis provides insights into research growth, impact and global collaboration within the field studied.

Table 3 reveals that the time span (2015-2024) indicates that the research covers an eight-year period, highlighting recent advancements in the field. The increasing number of studies suggests growing academic interest and relevance over time. The sources and documents analyzed include 33 different publication sources and 40 research papers, demonstrating a diverse range of scholarly contributions. This variety enhances the comprehensiveness of systematic review. The annual growth rate of 21.9 % suggests a steady rise in research output, reflecting increasing engagement from researchers. The average document age of 4.08 years indicates that most studies are relatively recent and contribute to current scientific discussions. The average citation count per document (27.85) highlights the high impact and influence of the studies included in this review. The total of 3004 references signifies a strong research foundation, showing that the field is well-supported by existing literature.

The keyword analysis reveals 307 Keywords Plus and 153 Author Keywords, reflecting a broad and multidisciplinary scope of research. This diversity in keywords suggests the interconnected nature of the topic across various disciplines. The authorship analysis shows that 191 researchers contributed to the 40 papers, indicating significant academic participation. The presence of only three single-authored papers suggests that research in this field is predominantly collaborative.

Regarding collaboration patterns, the co-authorship per document (4.9) indicates that studies typically involve multiple researchers, enhancing the depth of research. The international co-authorship rate of 42.5 % reflects strong global research networks and cross-border collaborations. The document type analysis confirms that all 40 studies are journal articles, ensuring that the research has undergone rigorous peer review. This enhances the credibility and reliability of the findings presented in systematic review.

**Most relevant sources**

According to the number of documents published, the most pertinent sources in the topic of climate variability are highlighted in Fig. 2. The most notable source is "Sustainability (Switzerland)" with four contributions, followed by "Climate Risk Management" with three. "Heliyon" and "Climate and Development" each make two contributions, suggesting that they are somewhat significant. Some sources, such as "Agriculture (Switzerland)" and "Agriculture, Ecosystems and Environment," provide a single document that reflects a more focused or limited focus in the context of studies on climate change. This distribution highlights how multidisciplinary journals like "Sustainability" are dominant in this field.

The dominance of multidisciplinary journals like "Sustainability" (Switzerland) suggests that climate variability research requires integrated approaches, covering environmental, social and economic aspects. Journals such as "Climate Risk Management" focus on adaptation and mitigation strategies, making them key contributors. Specialized journals like "Agriculture, Ecosystems and Environment" publish fewer studies because they target specific climate impacts on agriculture and ecosystems. This distribution highlights the broad and interdisciplinary nature of climate variability research, requiring contributions from multiple fields.

**Most relevant affiliations**

Most relevant affiliations among the selected articles are

**Table 3.** Bibliometric summary (2015-2024)

| S. No | Description | Results |
|---|---|---|
| I. | **Main information about data** | |
| 1. | Time span | 2015-2022 |
| 2. | Sources (Journals, Books, etc) | 33 |
| 3. | Documents | 40 |
| 4. | Annual Growth Rate % | 21.9 |
| 5. | Document Average Age | 4.08 |
| 6. | Average citations per doc | 27.85 |
| 7. | References | 3004 |
| II. | **Document contents** | |
| 8. | Keywords Plus (ID) | 307 |
| 9. | Author's Keywords (DE) | 153 |
| III. | **Authors** | |
| 10. | Authors | 191 |
| 11. | Authors of single-authored docs | 3 |
| IV. | **Authors collaboration** | |
| 12. | Single-authored docs | 3 |
| 13. | Co-Authors per Doc | 4.9 |
| 14. | International co-authorships % | 42.5 |
| V. | **Document types** | |
| 15. | Article | 40 |
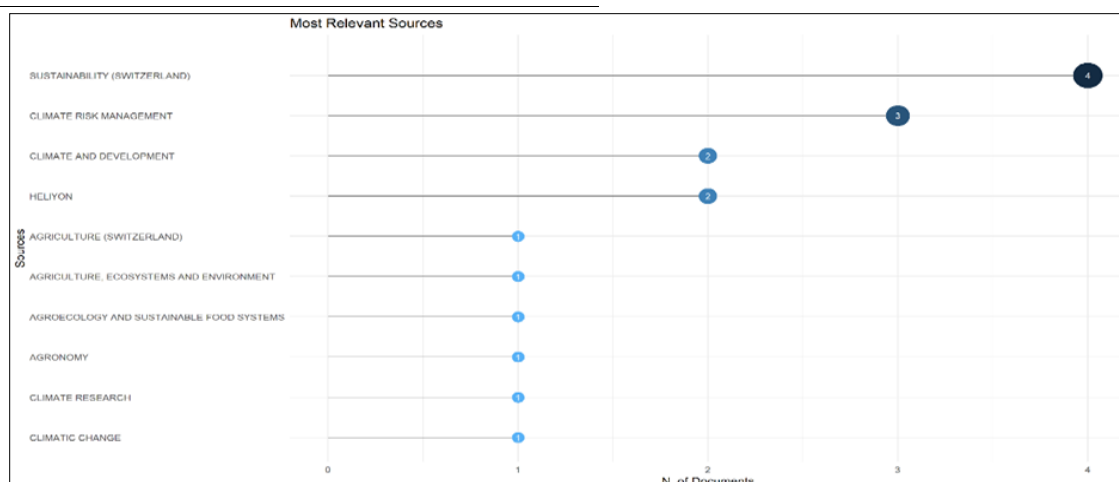


**Fig. 2.** Most relevant sources (R studio).

shown in Fig. 3. It was found that five articles were contributed by organizations including the American University of Beirut, Department of Economics and Social Sciences (University of Natural Resources) and the University of Vermont. Significant international cooperation and institutional interest in climate variability and adaptation research are highlighted by the variety of affiliations, especially from agricultural and multidisciplinary academic centres.

The dominance of Sichuan Agricultural University and Indiana University underscores their leading role in adaptation behaviour. The agriculture was adversely affected the research. The contributions from diverse institutions reflect global collaboration and multidisciplinary interest in the field. Agricultural and environmental sciences play a crucial role in shaping adaptation strategies. This highlights the need for continued cross-institutional efforts to address climate challenges.

### Country scientific production

The worldwide scientific output associated with the subject area is shown in Fig. 4, with darker tones signifying higher contributions. Due to their substantial research output and emphasis on climate variability and associated subjects, nations like the United States, China and India are notable contributors. Countries in Europe, Australia and certain portions of Africa have moderate contributions, suggesting a spread interest. The graphic highlights the value of international cooperation in tackling the problems associated with climate variability.

### Most global cited articles

Globally cited articles are shown in Fig. 5. With 152 citations, the paper by Niles, 2015 (20) in Agricultural Ecosystems & Environment is the most globally cited work in the subject. Li, 2017 (52) in Journal of Environmental Management trails with 122 citations. Other significant works that make substantial contributions to the conversation on climate variability and adaptation are Singh, 2020 (53) and Mitter, 2019 (54). These articles' substantial influence on furthering knowledge and research in this field is demonstrated by their high citation counts.
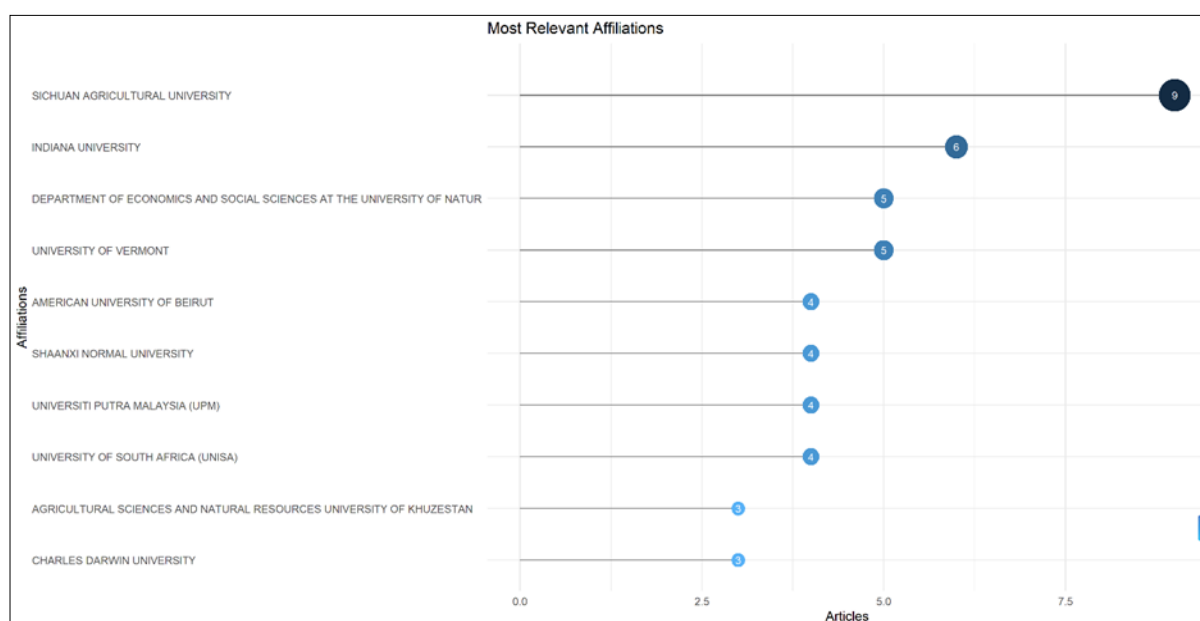
### Cocitation network



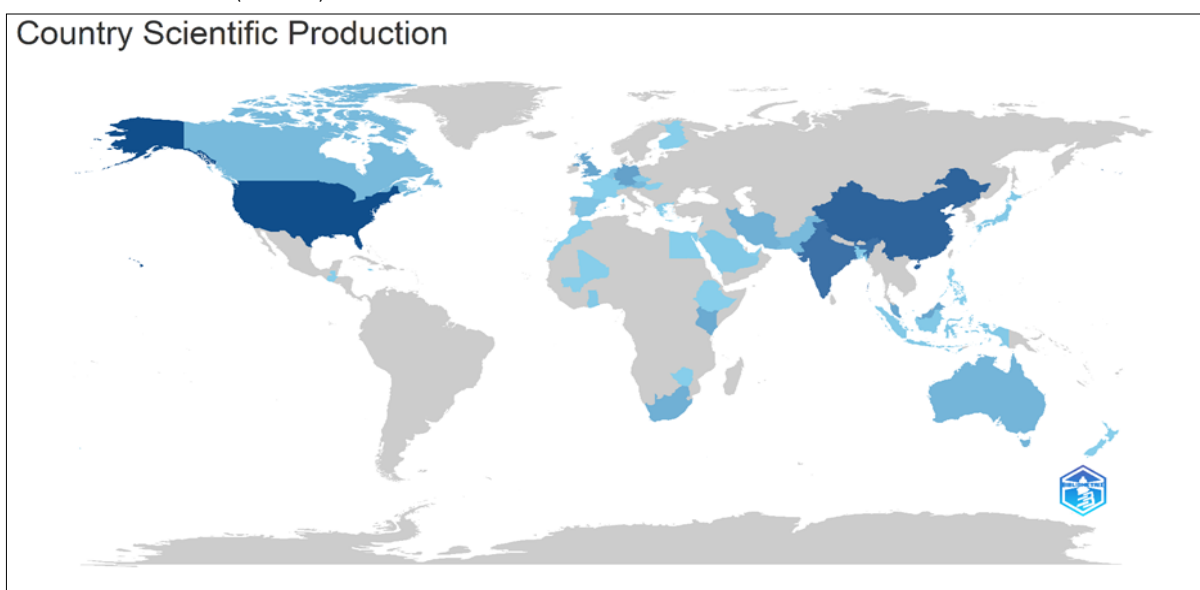**Fig. 3.** Most relevant affiliations (R studio).



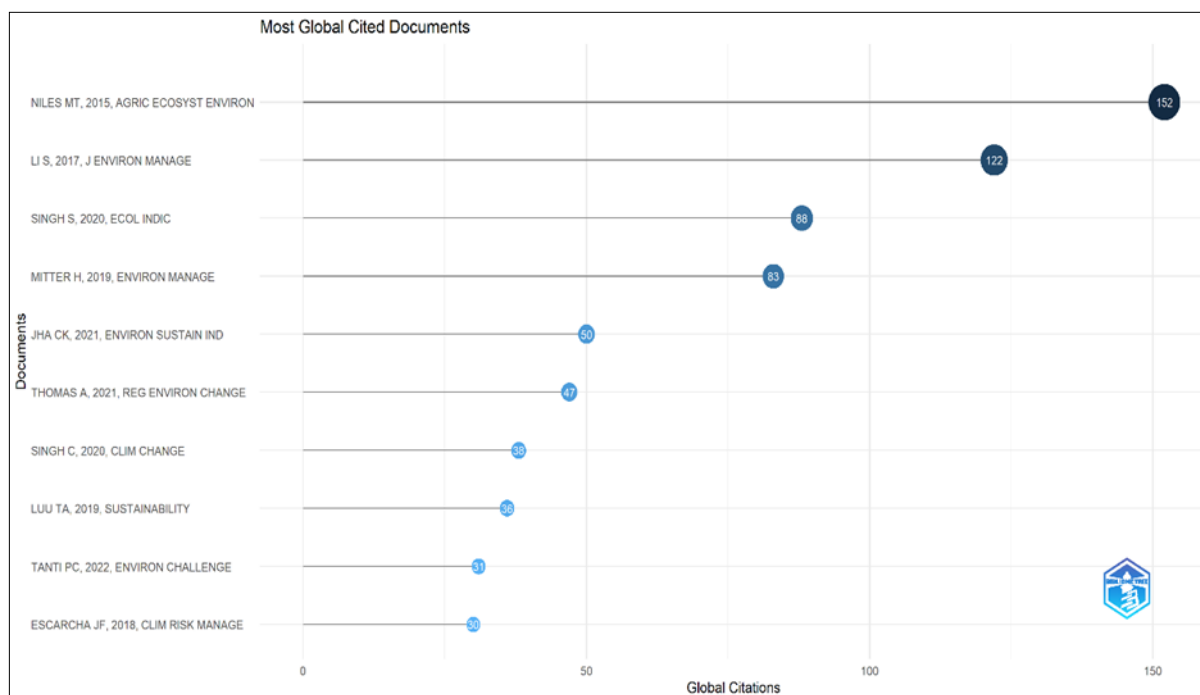**Fig. 4.** Country scientific production (R studio).

The co-



**Fig. 5.** Most global cited articles (R studio).

authorship relationships in climate variability and adaptation studies are depicted in the network visualization shown in Fig. 6. Important writers like Smit B, Adger WN and Deressa TT are prominent, demonstrating their substantial impact and cooperation in this area. The clustering of nodes into discrete clusters is indicative of regional partnerships or thematic research areas. Strong cooperation networks are indicated by the density of connections inside clusters, whereas writers with few co-authorship ties are represented by isolated nodes. The multidisciplinary and cooperative character of the research community tackling climate variability is highlighted by this graph.

### Trending topics

Trending topics covered in the selected articles are shown in Fig. 7. The graph shows the temporal trends in the use of important phrases such as "climate change," "adaptation," "agriculture," and "perception" in published studies. The terms "climate change" and "adaptation" have remained prominent across time, reflecting their basic significance in research. The consistent prominence of the terms "climate change" and "adaptation" highlights their foundational role in framing agricultural resilience research. These core concepts capture the urgency of environmental shifts and the necessity of strategic responses within farming systems. Their recurrence across time indicates sustained scholarly attention and policy relevance. This trend reflects ongoing global efforts to understand and enhance adaptive capacity in agriculture.

### Co-occurrence keywords network

The co-occurrence keywords network among the selected articles is shown in Fig. 8. The analysis focuses on major research terms and their relationships within the conceptual map. "Climate change" is the most influential term, with 135 links and 31 occurrences, average 0.92 normalized citations. "Climate change adaptation" has a high influence, with 68.5 average citations and 1.89 normalized citations. Terms like "adaptation," "decision making," and "perception" show
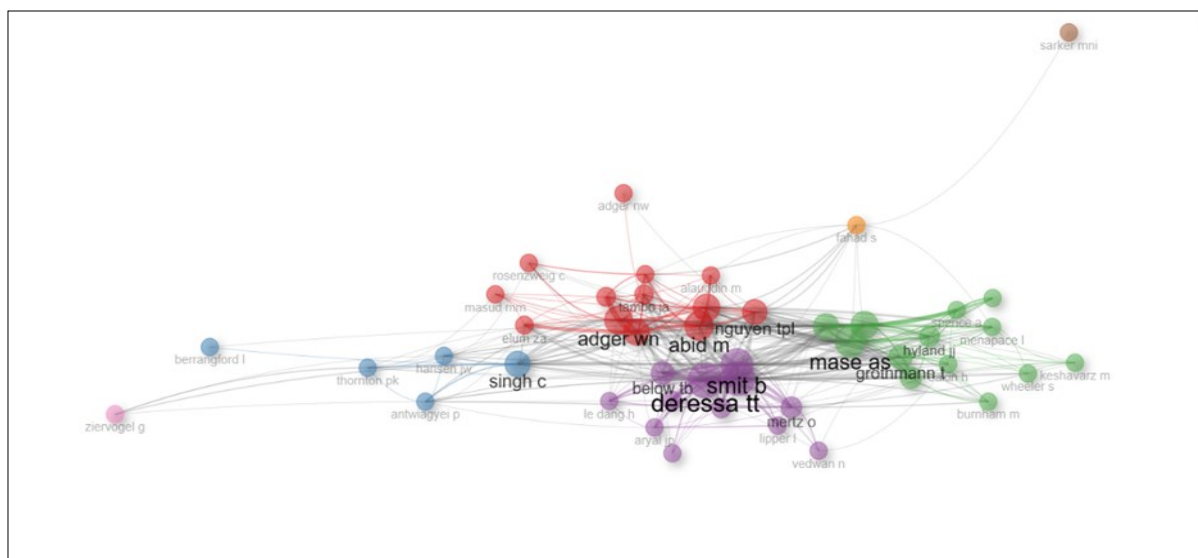
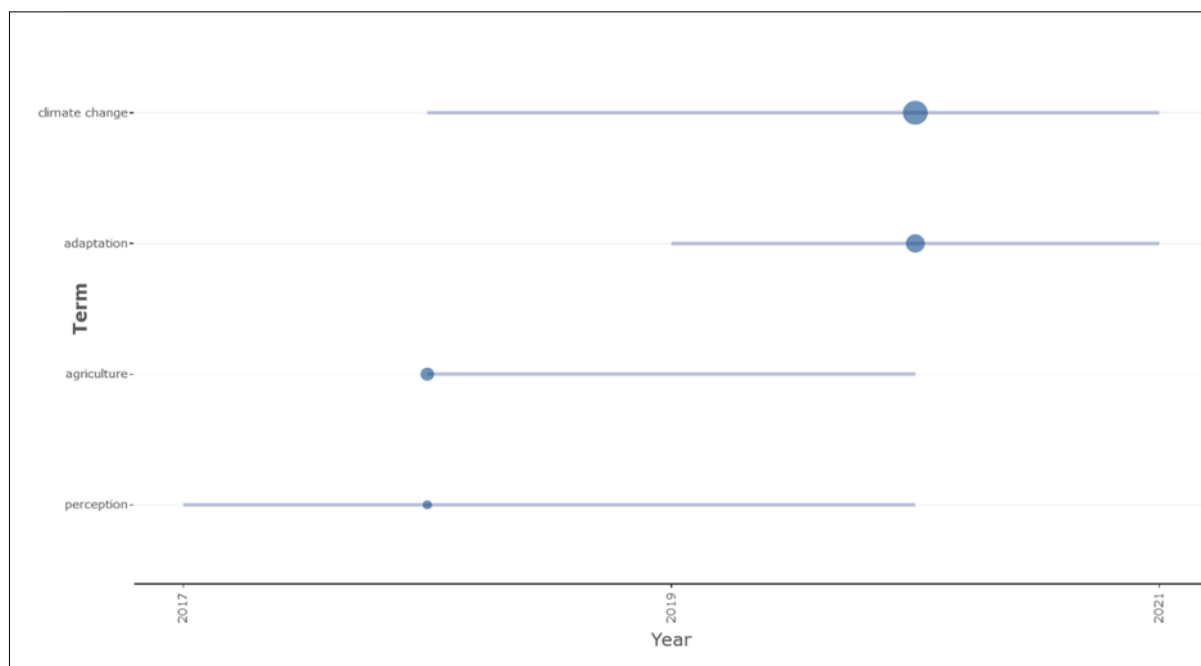

**Fig. 6.** Co-citation network (R studio).
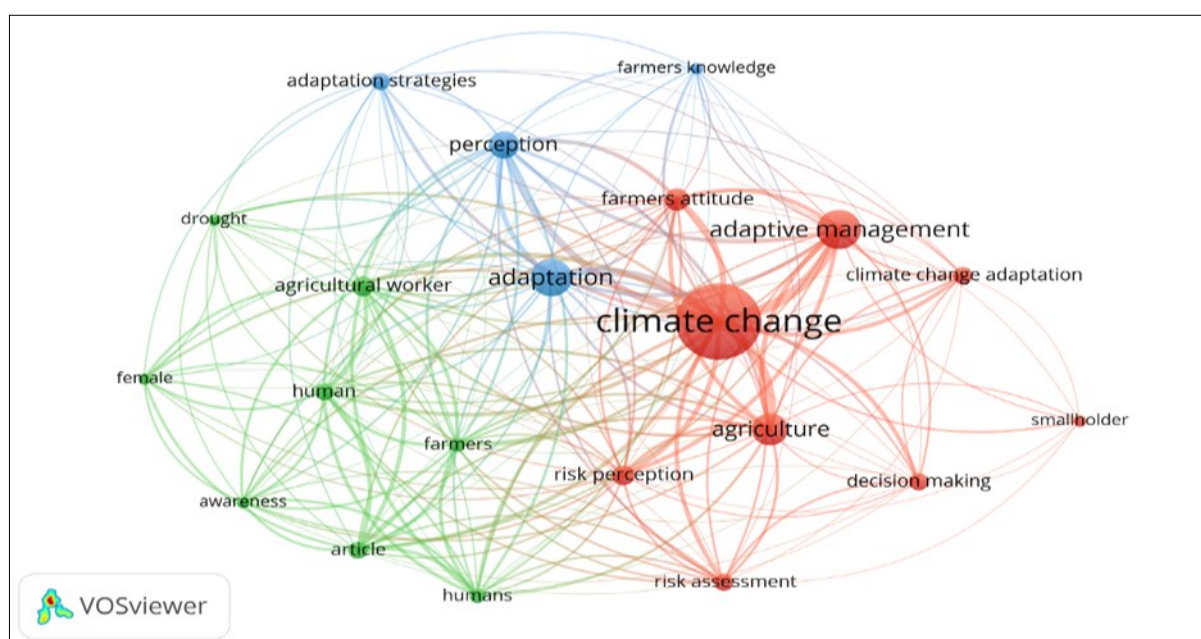
**Fig. 7.** Trending topics (R studio).



**Fig. 8.** Co-occurrence keywords network (VOSviewer).

considerable linkage and influence, emphasizing their importance in the study network. This study demonstrates the significance of adaptation and decision-making in climate change research.

### Factors affecting climate variability adaptation

Thematic analysis among the selected articles provides the factors that are affecting climate variability adaptation. It is a qualitative method for detecting, evaluating and interpreting patterns or themes in a body of scholarly work. It entails being acquainted with the literature, coding essential concepts or phrases and organizing these codes into larger themes that convey key ideas. These topics are then examined, improved and properly defined to ensure they are appropriate for the study environment. This strategy facilitates the synthesis of varied material, the discovery of patterns and the identification of research gaps, resulting in a structured narrative that captures the field's essential discoveries and theoretical underpinnings.

The result of thematic analysis is depicted in Fig. 9. It identifies "climate change" as the most impactful and well-connected issue, with major contributions from clusters such as "decision making" and "adult." Other clusters, such as "environmental policy" and "agricultural extension," provide specialized insights, although peripheral subjects like "data set" and "food security" have little significance. This analysis demonstrates the importance of climate-related themes and their interconnection within the research framework.

It can be understood from thematic analysis that "decision making", "adult" (farmers' perspectives), "environmental policy" and "agricultural extension" were the major factors affecting climate variability adaptation.

### Decision making

Decision-making was considered a crucial factor in climate variability adaptation because it directly influenced the effectiveness and sustainability of adaptive strategies.
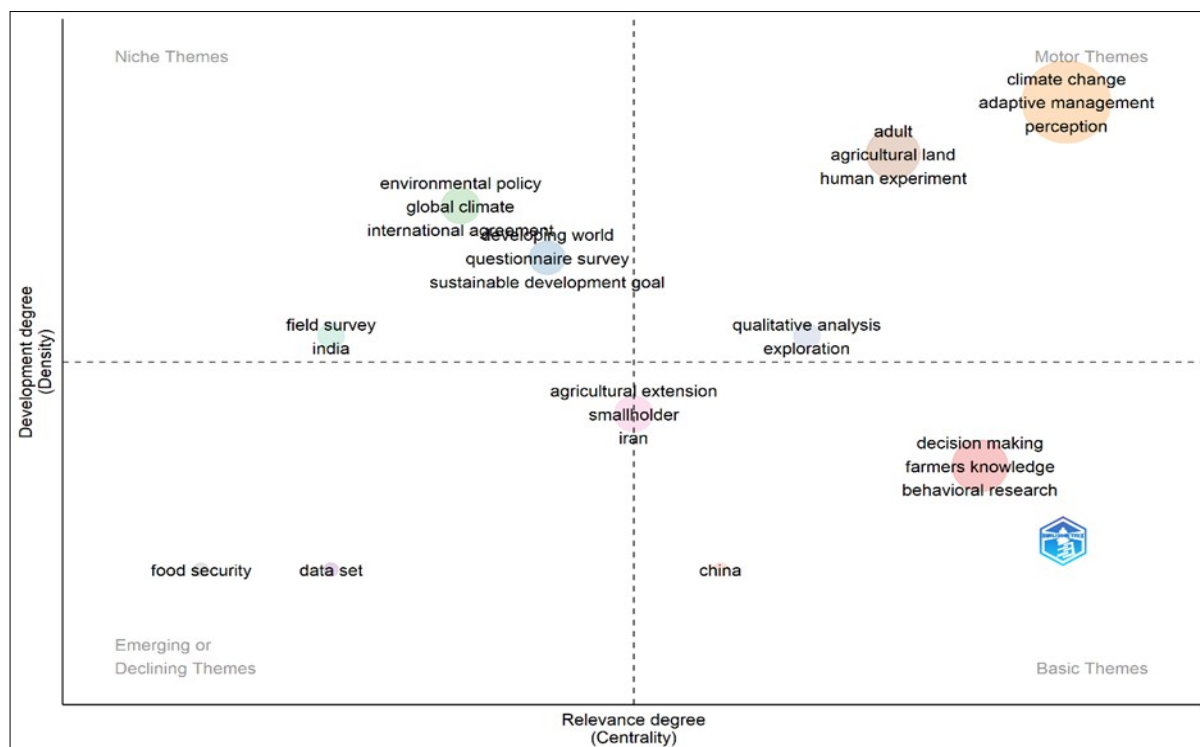
**Fig. 9.** Thematic map (R studio).

Farmers' decisions were shaped by their risk perception, knowledge and available resources, which determined how well they adapted (53, 55). Different types of decision-making responses to climate risks impacted long-term resilience (56). Uncertainty and access to climate information significantly shaped adaptation choices (57, 58). Inclusive decision-making, particularly women's participation, enhanced adaptation outcomes, proving that well-informed and inclusive decision-making was key to successful climate adaptation (59).

## Perception of farmers

Farmers' perception was considered an important factor in adaptation of climate variability because it directly influenced their willingness to adopt adaptive strategies. Farmers' awareness and attitudes determined how they responded to climate risks (60). Farmers' perception was shaped by social networks, experience and available resources, which impacted their decision-making (61). The perception of water scarcity drove farmers to modify their agricultural practices (62). Farmers' perception was strengthened by institutional support, enhancing adaptation capacity (63). Farmers who perceived climate change as a serious threat were more likely to adopt sustainable practices, making perception a key driver of climate resilience (54, 64).

## Environmental policy

Environmental policy plays a crucial role in climate change variability by shaping strategies and frameworks that enhanced resilience. It was found that integrating adaptation policies with existing environmental policies improved their effectiveness and sustainability. This alignment ensured that adaptation efforts were not isolated but were part of a comprehensive governance approach (65). However, adaptation measures also had unintended environmental consequences. Incorporating environmental impact

assessments into adaptation planning was essential to mitigate negative effects (66). Overall, well-structured environmental policies that promoted integration and careful impact evaluation were key to ensuring effective and sustainable climate variability adaptation.

## Agricultural extension

Agricultural extension services play a pivotal role in enhancing farmers' capacity to adapt to climate change by disseminating vital information and innovative practices. Extension agents often rely on traditional media like radio and television for climate information, highlighting the need for capacity building in technical skills and communication methods to effectively convey climate-smart agricultural practices (67). Access to agricultural extension services significantly enhances farmers' awareness of climatic changes and facilitates the adoption of appropriate management practices. These services, along with timely climate information, enable farmers to perceive climatic variations accurately and adjust their agronomic practices, accordingly, thereby improving their adaptive capacity.

## Results of thematic analysis

The thematic map is a visual depiction of research themes organized by relevance (centrality) and development (density). The quadrants assist in defining the nature and relevance of these themes within the study framework:

**Quadrant 1: Motor Themes (High Centrality and High Density) :** This quadrant contains well-developed and highly related themes that are crucial to the research area. The main concepts are "climate change," "adaptive management," "perception," "adult," "agricultural land," etc. "human experiment." These themes have significant conceptual and practical implications and they serve as the foundation of the research network. For example, "climate change" and "adaptive management" are important components of

environmental and sustainability research, which is driving the network's expansion.

The phrase "human experiment" may initially seem out of place among terms like "climate change," "adaptive management," and "agricultural land," but it likely refers to research exploring human behaviour, decision-making and adaptation strategies in response to climate change. In this context, "human experiment" could encompass studies that assess how individuals or communities adapt their agricultural practices, resource management, or behaviours based on perceived risks, climate information and policy interventions. Understanding these human responses is crucial for designing effective adaptive management strategies, as it bridges the gap between environmental change and human action. Thus, while not a traditional environmental or agricultural term, "human experiment" fits within this quadrant by highlighting the behavioural and social dimensions of climate adaptation research.

The strong interconnection between "climate change" and "adaptive management" reflects the growing recognition that effective climate adaptation requires proactive and flexible strategies in response to environmental shifts. These themes are central to advancing sustainable agricultural practices, which are essential for addressing the vulnerabilities of farming systems to climate variability.

**Quadrant 2: Niche Themes (Low Centrality, High Density) :** Although the themes in this quadrant are well developed and specialized, they are not effectively integrated into the larger research network. Themes such as "environmental policy," "global climate," "international agreements," "developing world," "questionnaire survey," along with "sustainable development goals." Though they are separated, these themes offer insightful information within their domains, suggesting that they serve as supporting or context-specific regions rather than as the major drivers of study.

While the themes in this quadrant are well-developed, their limited integration into the broader research network indicates that they focus more on specific contexts rather than on universal frameworks for climate adaptation. Themes like "environmental policy" and "global climate" provide crucial insights but often remain isolated due to their focus on governance and international perspectives.

**Quadrant 3: Emerging or Declining Themes (Low Centrality, Low Density) :** Underdeveloped issues with no impact on the present research framework are represented by this quadrant, which may indicate new or out-of-date subjects. Topics like "food security" and "data set" fit into this category, indicating a lack of impact or a shift in the field of study.

The themes in this quadrant, such as "food security" and "data set," are underdeveloped within the current research framework because they either represent outdated concepts or are no longer central to contemporary climate adaptation discussions. As the field evolves, these topics may be overshadowed by more pressing issues like climate resilience or behavioural adaptation.

**Quadrant 4: Basic Themes (High Centrality, Low Density) :** Though they need to be further developed to increase their density and robustness, the themes in this quadrant are

essential to the research network. A few noteworthy themes are "decision making," "behavioural research," "farmers' knowledge." In order to enhance their theoretical and practical contributions, these themes underscore the necessity for further investigation into the fundamental ideas that underpin the network's structure.

Themes like "decision making," "behavioural research," and "farmers' knowledge" are pivotal to understanding how adaptation strategies are formed and implemented at the ground level. Despite their current low density, these themes hold high strategic value, as they directly influence the success of climate adaptation practices. Strengthening research in these areas will deepen theoretical foundations and improve the practical relevance of adaptation frameworks across diverse agricultural contexts.

## Key elements for advancing climate variability adaptation mainstreaming in policy and practice

Advancing the mainstreaming of climate variability adaptation into policy and practice involves several key elements identified in this paper. Two overarching factors were found in a study: the authority to adapt and the capacity to adapt. The authority to adapt refers to the mandate from higher levels of government or local leadership that empowers municipal administrations to implement adaptation actions. The capacity to adapt encompasses access to resources, professional networks and supportive organizational systems and culture that enable effective adaptation efforts (68). Policy integration also plays a crucial role in mainstreaming adaptation. Aligning adaptation policies with existing institutional systems and capacities enhances their effectiveness. This alignment ensures that adaptation efforts are cohesive and sustainable within the broader policy framework (69).

Leadership and agenda-setting are vital components as well. Factors such as public opinion, community expectations, issue salience and the presence of policy entrepreneurs influence whether adaptation was prioritized on municipal policy agendas. Leaders' networks of influence could be leveraged to support climate mainstreaming and engaging with leaders' mindsets and receptiveness to adaptation was essential for successful integration (70).

## Discussion

### Characteristics of global literature

The dominance of multidisciplinary journals in climate adaptation research is due to the interconnected nature of climate change, requiring inputs from agriculture, economics and environmental sciences. Strong institutional affiliations and international collaborations arise from the global urgency to address climate variability, prompting joint research efforts. The significant contributions from countries like the U.S., China and India reflect their large agricultural sectors, vulnerability to climate change and research investments. Highly cited works and influential authors indicate the maturity of climate adaptation research, with foundational studies shaping ongoing discussions. The frequent use of keywords like "decision-making" and "perception" highlights the importance

of behavioural and policy aspects in effective climate adaptation strategies.

Additionally, the increasing emphasis on climate adaptation in agricultural research reflects the recognition that effective solutions must be context-specific, accounting for diverse environmental, socio-economic and cultural factors. As climate change impacts are felt differently across regions, the global discourse benefits from region-specific research, which helps tailor adaptation strategies to local realities. The integration of technological advancements and local knowledge in research further enhances the adaptability of agricultural systems.

### Factors affecting climate variability adaptation

The importance of decision-making in climate variability adaptation arises from its role in determining the effectiveness and sustainability of responses, as farmers rely on their risk perception and available resources to make informed choices. Farmers' perception influences adaptation because it shapes their willingness to adopt strategies, which is reinforced by social networks, institutional support and access to knowledge. Environmental policies are crucial as they provide a structured framework for integrating adaptation strategies into governance, ensuring sustainability while mitigating unintended consequences. Agricultural extension services are vital for adaptation as they facilitate knowledge transfer, enhance awareness and enable farmers to make informed decisions based on timely climate information. Overall, these factors collectively strengthen adaptive capacity by improving decision-making, perception, policy support and access to critical information.

Moreover, the role of technology and innovation in decision-making cannot be overlooked, as advancements in climate prediction tools, resilient crop varieties and sustainable practices empower farmers to adapt more effectively. The increasing involvement of local communities in decision-making processes ensures that adaptation strategies are more contextually relevant and culturally acceptable.

### Key elements for advancing climate variability adaptation mainstreaming in policy and practice

The integration of climate variability adaptation into policy and practice relies on governance structures, as authority and institutional capacity determine the effectiveness of adaptation measures. Aligning adaptation policies with existing frameworks enhances coherence, preventing disjointed efforts. Leadership and public demand drive political will, ensuring adaptation remains a policy priority. Effective mainstreaming requires strong governance, adequate resources and proactive leadership for long-term success.

Policymakers should prioritize integrating climate services into agricultural extension platforms to provide farmers with real-time climate information and tailored adaptation strategies. Additionally, promoting gender-inclusive governance ensures that adaptation strategies account for the different roles and needs of women and men in farming communities. Strengthening public-private partnerships can enhance the dissemination of innovative technologies and climate-smart practices. Finally, fostering participatory decision-making processes will ensure that local knowledge and priorities are effectively integrated into climate adaptation policies.

## Conclusion

This review highlights the multifaceted factors influencing climate adaptation behaviour, including decision-making, farmers' perceptions, environmental policies and agricultural extension services. Effective decision-making plays a crucial role in determining the sustainability and success of adaptation strategies, while farmers' perceptions significantly shape their willingness to adopt adaptive measures. The integration of well-structured environmental policies ensures that adaptation efforts are aligned with broader governance frameworks, enhancing long-term resilience. Additionally, agricultural extension services facilitate knowledge dissemination and capacity building, enabling farmers to respond effectively to adaptation behaviour. The global literature on adaptation behaviour reflects a strong emphasis on multidisciplinary research, institutional collaboration and regional contributions, particularly from high-research-output nations. Furthermore, mainstreaming climate adaptation into policy and practice is driven by factors such as institutional authority, resource capacity and leadership. Aligning adaptation policies with existing governance structures enhances coherence and implementation effectiveness. Strengthening institutional support, fostering international cooperation and ensuring inclusive decision-making processes remain critical for advancing adaptation behaviour at both policy and practice levels.

## Authors' contributions

SGM conceptualized, formulated the manuscript and analysed the data. SN guided the research by formulating the research concept and approved the final manuscript. BP contributed by developing the ideas, reviewed the manuscript and helped in procuring research grants. VM helped in summarizing and statistical analysis of data. MGL helped in editing and reviewing the original draft. DGA helped in collecting the data.

## Compliance with ethical standards

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

**Ethical issues:** None

# References

1. Patel RS, Zala PH, Patel AA. Weather forecasting, climate variability and change. Advances in Agronomy; 2023. p. 69-82.

2. Agbenyo W, Jiang Y, Jia X, Wang J, Ntim-Amo G, Dunya R, et al. Does the adoption of climate-smart agricultural practices impact farmers' income? Evidence from Ghana. International Journal of Environmental Research and Public Health. 2022;19(7):3804-28. https://doi.org/10.3390/ijerph19073804

3. Bulla B, Steelman T. Farming through change: Using photovoice to explore climate change on small family farms. Agroecology and Sustainable Food Systems. 2016;40(10):1106-32. https://doi.org/10.1080/21683565.2016.1225623

4. Al Dirani A, Abebe GK, Bahn RA, Martiniello G, Bashour I. Exploring climate change adaptation practices and household food security in the Middle Eastern context: A case of small family farms in Central Bekaa, Lebanon. Food Security. 2021;13(4):1029-47. https://doi.org/10.1007/s12571-021-01188-2

5. Belay A, Oludhe C, Mirzabaev A, Recha JW, Berhane Z, Osano PM, et al. Knowledge of climate change and adaptation by smallholder farmers: Evidence from southern Ethiopia. Heliyon. 2022;8 (12):e12089. https://doi.org/10.1016/j.heliyon.2022.e12089

6. Gerling C, Drechsler M, Keuler K, Leins JA, Radtke K, Schulz B, et al. Climate–ecological–economic modelling for the cost-effective spatiotemporal allocation of conservation measures in cultural landscapes facing climate change. Q Open. 2022;2(1):qoac004. https://doi.org/10.1093/qopen/qoac004

7. Habib-ur-Rahman M, Ahmad A, Raza A, Hasnain MU, Alharby HF, Alzahrani YM, et al. Impact of climate change on agricultural production; Issues, challenges and opportunities in Asia. Frontiers in Plant Science. 2022;13:925548. https://doi.org/10.3389/fpls.2022.925548

8. Yazd SD, Wheeler SA, Zuo A. Understanding the impacts of water scarcity and socio-economic demographics on farmer mental health in the Murray-Darling Basin. Ecological Economics. 2020;169:106564. https://doi.org/10.1016/j.ecolecon.2019.106564

9. Mobeen M, Kabir KH, Schneider UA, Ahmed T, Scheffran J. Sustainable livelihood capital and climate change adaptation in Pakistan's agriculture: Structural equation modeling analysis in the VIABLE framework. Heliyon. 2023;9(11):e20818. https://doi.org/10.1016/j.heliyon.2023.e20818

10. Mustafa G, Alotaibi BA, Nayak RK. Linking climate change awareness, climate change perceptions and subsequent adaptation options among farmers. Agronomy. 2023;13(3):758-78. https://doi.org/10.3390/agronomy13030758

11. Feng Q, Zhao W, Fu B, Ding J, Wang S. Ecosystem service trade-offs and their influencing factors: A case study in the Loess Plateau of China. Science of the Total Environment. 2017;607:1250-63. https://doi.org/10.1016/j.scitotenv.2017.07.079

12. Lane D, Murdock E, Genskow K, Rumery Betz C, Chatrchyan A. Climate change and dairy in New York and Wisconsin: Risk perceptions, vulnerability and adaptation among farmers and advisors. Sustainability. 2019;11(13):3599-622. http://dx.doi.org/10.3390/su11133599

13. Alvi S, Khayyam U. Mitigating and adapting to climate change: Attitudinal and behavioural challenges in South Asia. International Journal of Climate Change Strategies and Management. 2020;12 (4):477-93. https://doi.org/10.1108/IJCCSM-08-2019-0054

14. Akhtar R, Afroz R, Masud MM, Rahman M, Khalid H, Duasa JB. Farmers' perceptions, awareness, attitudes and adaptation behaviour towards climate change. Journal of the Asia Pacific Economy. 2018;3(2):60-76. https://doi.org/10.1080/13547860.2018.1442149

15. Alidu AF, Man N, Ramli NN, Haris NBM, Alhassan A. Smallholder farmers access to climate information and climate smart adaptation practices in the northern region of Ghana. Heliyon. 2022;8(5):9513-21. https://doi.org/10.1016/j.heliyon.2022.e09513

16. Kamau MW, Ndung'u CK, Felista WN. Factors influencing farmers' adaptations to climate variability and extreme events in dry Kitui, Kenya. International Journal of Environmental Sciences & Natural Resources. 2020;24(1):556126. https://doi.org/10.19080/IJESNR.2020.23.556126

17. Vasanthi C, Sahana S, Sudheendra M. Socio-economic factors influencing the adoption of coping mechanism to climate change by the farmers. Asian Journal of Agricultural Extension, Economics & Sociology. 2018;27(1):1-11. https://doi.org/10.9734/AJAEES/2018/39896

18. Ndamani F, Watanabe T. Determinants of farmers' climate risk perceptions in agriculture—A rural Ghana perspective. Water. 2017;9 (3):210-23. https://doi.org/10.3390/w9030210

19. Mu L, Fang L, Liu Y, Wang C. Identifying barriers and enablers for climate change adaptation of farmers in semi-arid North-Western China. Sustainability. 2020;12(18):7494-514. https://doi.org/10.3390/su12187494

20. Niles MT, Lubell M, Brown M. How limiting factors drive agricultural adaptation to climate change. Agriculture, Ecosystems & Environment. 2015;200:178-85. https://doi.org/10.1016/j.agee.2014.11.010

21. Rautela P, Karki B. Impact of climate change on life and livelihood of indigenous people of higher Himalaya in Uttarakhand, India. American Journal of Environmental Protection. 2015;3(4):112-24. https://doi.org/10.12691/env-3-4-2

22. Mamba SF. Factors influencing perception of climate variability and change among smallholder farmers in Swaziland. Indian Journal of Nutrition. 2016;3(2):138-42.

23. Madaki MY, Muench S, Kaechele H, Bavorova M. Climate change knowledge and perception among farming households in Nigeria. Climate. 2023;11(6):115-31. https://doi.org/10.3390/cli11060115

24. Azadi Y, Yazdanpanah M, Forouzani M, Mahmoudi H. Farmers' adaptation choices to climate change: A case study of wheat growers in Western Iran. Journal of Water and Climate Change. 2019;10(1):102-16. https://doi.org/10.2166/wcc.2018.242

25. Bagagnan AR, Ouedraogo I, Fonta WM. Perceived climate variability and farm level adaptation in the central river region of the Gambia. Atmosphere. 2019;10(7):423-34. https://doi.org/10.3390/atmos10070423

26. Paramesh V, Kumar P, Shamim M, Ravisankar N, Arunachalam V, Nath AJ, et al. Integrated farming systems as an adaptation strategy to climate change: Case studies from diverse agro-climatic zones of India. Sustainability. 2022;14(18):11629. https://doi.org/10.3390/su141811629

27. Engler A, Rotman ML, Poortvliet PM. Farmers' perceived vulnerability and proactive versus reactive climate change adaptation in Chile's Maule region. Sustainability. 2021;13(17):9907-21. https://doi.org/10.3390/su13179907

28. Nguyen-Thi-Lan H, Fahad S, Nguyen-Anh T, Tran-Thi-Thu H, Nguyen-Hong C, To-The N. Assessment of farm households' perception, beliefs and attitude toward climatic risks: A case study of rural Vietnam. PLoS One. 2021;16(12):e0258598. https://doi.org/10.1371/journal.pone.0258598

29. Marie M, Yirga F, Haile M, Tquabo F. Farmers' choices and factors affecting adoption of climate change adaptation strategies: Evidence from northwestern Ethiopia. Heliyon. 2020;6(4):e03867. https://doi.org/10.1016/j.heliyon.2020.e03867

30. Rogers NJ, Adams VM, Byrne JA. Factors affecting the mainstreaming of climate change adaptation in municipal policy and practice: A systematic review. Climate Policy. 2023;23(10):1327-44. https://doi.org/10.1080/14693062.2023.2208098

31. Singh C. Human dimensions of climate change adaptation: Gaps and knowledge frontiers. Dialogues on Climate Change. 2024;2 (1):71-81. https://doi.org/10.1177/29768659241297772

32. Mwinkom FX, Damnyag L, Abugre S, Alhassan SI. Factors influencing climate change adaptation strategies in North-Western Ghana: Evidence of farmers in the Black Volta Basin in Upper West region. SN Applied Sciences. 2021;3:1-20. https://doi.org/10.1007/s42452-021-04503-w

33. Al-Amin AQ, Masud MM, Sarkar MSK, Leal Filho W, Doberstein B. Analysing the socioeconomic and motivational factors affecting the willingness to pay for climate change adaptation in Malaysia. International Journal of Disaster Risk Reduction. 2020;50:101708. https://doi.org/10.1016/j.ijdrr.2020.101708

34. Gemeda DO, Korecha D, Garedew W. Determinants of climate change adaptation strategies and existing barriers in Southwestern parts of Ethiopia. Climate Services. 2023;30:100376. https://doi.org/10.1016/j.cliser.2023.100376

35. Thinda KT, Ogundeji AA, Belle JA, Ojo TO. Understanding the adoption of climate change adaptation strategies among smallholder farmers: Evidence from land reform beneficiaries in South Africa. Land Use Policy. 2020;99:104858. https://doi.org/10.1016/j.landusepol.2020.104858

36. Pacillo G, Nguyen N, Paustyan E, Cavatassi R, Astralaga M, Läderach P. What drives the success and failure of climate change adaptation projects? A qualitative comparative analysis. Mitigation and Adaptation Strategies for Global Change. 2024;29(8):1-27. https://doi.org/10.1007/s11027-024-10186-6

37. Smart LS, Seekamp E, Van Berkel D, Vukomanovic J, Smith JW. Socio-spatial factors influence climate change adaptation decisions of rural coastal landowners. Landscape Ecology. 2023;38(12):4365-83. https://doi.org/10.1007/s10980-023-01734-7

38. Esfandiari M, Khalilabad HRM, Boshrabadi HM, Mehrjerdi MRZ. Factors influencing the use of adaptation strategies to climate change in paddy lands of Kamfiruz. Land Use Policy. 2020;95:104628. https://doi.org/10.1016/j.landusepol.2020.104628

39. Noll B, Filatova T, Need A. How does private adaptation motivation to climate change vary across cultures? Evidence from a meta-analysis. International Journal of Disaster Risk Reduction. 2020;46:101615. https://doi.org/10.1016/j.ijdrr.2020.101615

40. Wu W, Xu Y. Factors affecting climate adaptation behavior among grain farmers in China. Environment, Development and Sustainability. 2024;1-14. https://doi.org/10.1007/s10668-024-04　500-0

41. Puig D, Adger NW, Barnett J, Vanhala L, Boyd E. Improving the effectiveness of climate change adaptation measures. Climate Change. 2025;178(1):1-15. https://doi.org/10.1007/s10584-024-03838-8

42. Upendram S, Regmi HP, Cho SH, Mingie JC, Clark CD. Factors affecting adoption intensity of climate change adaptation practices: A case of smallholder rice producers in Chitwan, Nepal. Frontiers in Sustainable Food Systems. 2023;6:1016404. https://doi.org/10.3389/fsufs.2022.1016404

43. Ebhuoma EE, Simatele MD, Leonard L, Ebhuoma OO, Donkor FK, Tantoh HB. Theorising indigenous farmers' utilisation of climate services: Lessons from the oil-rich Niger Delta. Sustainability. 2020;12(18):7349-66. https://doi.org/10.3390/su12187349

44. Tun Oo A, Cho A, Yan Naing S, Marin G. Determining factors and barriers to the uptake of climate change adaptation strategies of agriculture and aquaculture farm households in Myanmar. International Journal of Climate Change Strategies and Management. 2024;16(2):253-72. http://dx.doi.org/10.1108/IJCCSM-12-2023-0154

45. Harris BS, Howe PD. What factors are associated with public support for climate change adaptation policy in the US? Environmental Research Communications. 2023;5(9):091003. https://doi.org/10.1088/2515-7620/acf4e1

46. Pickering C, Byrne J. The benefits of publishing systematic quantitative literature reviews for PhD candidates and other early-career researchers. Higher Education Research & Development. 2014;33(3):534-48. https://doi.org/10.1080/07294360.2013.841651

47. Moher D, Liberati A, Tetzlaff J, Altman DG, Prisma Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. International Journal of Surgery. 2010;8(5):336-41. https://doi.org/10.1016/j.ijsu.2010.02.007

48. Pham Y, Reardon-Smith K, Mushtaq S, Cockfield G. The impact of climate change and variability on coffee production: a systematic review. Climatic Change. 2019;156:609-30. https://doi.org/10.1007/s10584-019-02538-y

49. Shaffril HAM, Krauss SE, Samsuddin SF. A systematic review on Asian's farmers' adaptation practices towards climate change. Science of the Total Environment. 2018;644:683-95. https://doi.org/10.1016/j.scitotenv.2018.06.349

50. Wu Y, Meng S, Liu C, Gao W, Liang XZ. A bibliometric analysis of research for climate impact on agriculture. Frontiers in Sustainable Food Systems. 2023;7:1191305-19. https://doi.org/10.3389/fsufs.2023.1191305

51. Jha CK, Gupta V. Do better agricultural extension and climate information sources enhance adaptive capacity? A micro-level assessment of farm households in rural India. Ecofeminism and Climate Change. 2021;2(2):83-102. http://dx.doi.org/10.1108/EFCC-10-2020-0032

52. Li S, Juhász-Horváth L, Harrison PA, Pintér L, Rounsevell MD. Relating farmer's perceptions of climate change risk to adaptation behaviour in Hungary. Journal of environmental management. 2017;185:21-30. https://doi.org/10.1016/j.jenvman.2016.10.051

53. Singh C, Ford J, Ley D, Bazaz A, Revi A. Assessing the feasibility of adaptation options: methodological advancements and directions for climate adaptation research and practice. Climatic Change. 2020;162:255-77. https://doi.org/10.1007/s10584-020-02762-x

54. Mitter H, Larcher M, Schönhart M, Stöttinger M, Schmid E. Exploring farmers' climate change perceptions and adaptation intentions: Empirical evidence from Austria. Environmental Management. 2019;63:804-21. https://doi.org/10.1007/s00267-019-01158-7

55. Lai CH, Liao PC, Chen SH, Wang YC, Cheng C, Wu CF. Risk perception and adaptation of climate change: An assessment of community resilience in rural Taiwan. Sustainability. 2021;13(7):3651-65. https://doi.org/10.3390/su13073651

56. Reddy KV, Paramesh V, Arunachalam V, Das B, Ramasundaram P, Pramanik M, et al. Farmers' perception and efficacy of adaptation decisions to climate change. Agronomy. 2022;12(5):1023-40. https://doi.org/10.3390/agronomy12051023

57. Waldman KB, Todd PM, Omar S, Blekking JP, Giroux SA, Attari SZ, et al. Agricultural decision making and climate uncertainty in developing countries. Environmental Research Letters. 2020;15(11):113004. https://doi.org/10.1088/1748-9326/abb909

58. Van Aelst K, Holvoet N. Climate change adaptation in the Morogoro Region of Tanzania: women's decision-making participation in small-scale farm households. Clim Dev. 2018;10(6):495-508. https://doi.org/10.1080/17565529.2017.1318745

59. Schattman RE, Méndez VE, Merrill SC, Zia A. Mixed methods approach to understanding farmer and agricultural advisor perceptions of climate change and adaptation in Vermont, United States. Agroecology and Sustainable Food Systems. 2018;42(2):121-48. https://doi.org/10.1080/17565529.2017.1318745

60. Hou L, Huang J, Wang J. Farmers' perceptions of climate change in China: the influence of social networks and farm assets. Climate Research. 2015;63(3):191-201. https://doi.org/10.3354/cr01295

61. Leroy D. Farmers' Perceptions of and adaptations to water scarcity in Colombian and Venezuelan Páramos in the context of climate change. Mountain Research and Development. 2019;39(2):21-34. https://doi.org/10.1659/MRD-JOURNAL-D-18-00062.1

62. Mahmood N, Arshad M, Mehmood Y, Shahzad MF, Kächele H. Farmers' perceptions and role of institutional arrangements in

climate change adaptation: Insights from rainfed Pakistan. Climate Risk Management. 2021;32:100288. https://doi.org/10.1016/j.crm.2021.100288

63. Makate C, Makate M, Mango N. Smallholder farmers' perceptions on climate change and the use of sustainable agricultural practices in the Chinyanja Triangle, Southern Africa. Social Sciences. 2017;6 (1):30-42. https://doi.org/10.3390/socsci6010030

64. Juhola S, Bouwer LM, Huggel C, Mechler R, Muccione V, Wallimann-Helmer I. A new dynamic framework is required to assess adaptation limits. Global Environmental Change. 2024;87:102884. https://doi.org/10.1016/j.gloenvcha.2024.102884

65. Berrang-Ford L, Sietsma AJ, Callaghan M, Minx JC, Scheelbeek PF, Haddaway NR, et al. Systematic mapping of global research on climate and health: a machine learning review. Lancet Planet Health. 2021;5(8):514-25. https://doi.org/10.1016/S2542-5196(21)00179-0

66. Antwi-Agyei P, Stringer LC. Improving the effectiveness of agricultural extension services in supporting farmers to adapt to climate change: Insights from northeastern Ghana. Climate Risk Management. 2021;32:100304. https://doi.org/10.1016/j.crm.2021.100304

67. Pathak H. Impact, adaptation and mitigation of climate change in Indian agriculture. Environmental Monitoring and Assessment. 2023;195(1):52-74. https://doi.org/10.1007/s10661-022-10537-3

68. Braunschweiger D, Pütz M. Climate adaptation in practice: how mainstreaming strategies matter for policy integration. Environmental Policy and Governance. 2021;31(4):361-73. https://doi.org/10.1002/eet.1936

69. Rauken T, Mydske PK, Winsvold M. Mainstreaming climate change adaptation at the local level. Local Environment. 2015;20(4):408-23. https://doi.org/10.1080/13549839.2014.880412

70. Kim YJ, Shin J. Evaluating sectoral pathways and barriers in mainstreaming climate change adaptation. Climate Risk Management. 2024;45:100627. https://doi.org/10.1016/j.crm.2024.100627

## Additional information