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# Mapping Global Research on Farmers' Climate Resilience and Agricultural Extension: A Bibliometric Analysis

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## HIGHLIGHTS

- Global research on farmers' resilience and agricultural extension grew 40.62% annually, increasing nearly fifty-fold from 2015-2026.
- Keyword mapping reveals 2 clusters, with agricultural extension viewed as one adaptation strategy rather than a standalone research field.
- Author collaboration remains regionally concentrated, with limited cross-regional links, highlighting opportunities for broader international partnerships.
- Ethiopian universities dominate institutional output, while recent research increasingly emphasizes household survey based studies over extension theory.

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## ABSTRACT

The study mapped global research on farmers' climate resilience and agricultural extension through a bibliometric analysis of 353 Scopus-indexed publications published between 2015 and 2026. Bibliometric data were analysed using Biblioshiny in the Bibliometrix package. The results revealed rapid publication growth, with an annual growth rate of 40.62%, increasing from two documents in 2015 to 100 in 2025. The literature received an average of 17.86 citations per document, indicating growing scholarly interest. Research output was concentrated in Ethiopia, India, China, the United States, Ghana, and the United Kingdom, while Ethiopian universities accounted for five of the ten most productive institutions. Author keyword analysis identified two dominant thematic clusters centred on climate adaptation, resilience, and agricultural systems. Thematic evolution showed a shift from livelihood-oriented studies toward resilience and adoption-focused research. Although collaboration networks remained fragmented, publication output continued to expand. A key finding was that agricultural extension remained conceptually embedded within broader climate adaptation and resilience research rather than emerging as an independent thematic domain. The study provided future research directions for strengthening the theoretical and empirical integration of agricultural extension interventions to enhance farmers' resilience under changing climatic conditions, particularly in Southeast Asia and Latin America.

## INTRODUCTION

Climate change has stimulated rapid growth in research on farmers' resilience, adaptive capacity, vulnerability, and climate adaptation over the past decade. Following the adoption of the Paris Agreement and the Food and Agriculture Organisation's Climate Smart Agriculture (CSA) framework in 2015, scholarly attention has increasingly focused on understanding how farming households

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respond to climate-related risks through technological innovation, institutional support, and livelihood adaptation. Agricultural extension has emerged as a central mechanism for strengthening farmers' adaptive capacity by facilitating knowledge exchange, providing climate information services, and disseminating innovations. Raghuvanshi and Ansari (2020) demonstrated that farmers' vulnerability is closely associated with awareness, adaptive capacity, and extension support. Evidence from Pathak et al. (2024) indicates that farmers who actively accessed extension services and climate-related information were generally better prepared to respond to climate change. This underscores the continuing role of agricultural extension in supporting farmers' adaptation and resilience.

The rapid expansion of this literature has produced a highly fragmented and multidisciplinary knowledge base spanning agricultural extension, rural sociology, agricultural economics, climate science, sustainability, disaster risk reduction, and development studies. Although this diversity has enriched resilience research, it has also made it increasingly difficult to obtain a comprehensive understanding of the field's intellectual structure, collaboration patterns, and thematic evolution. Conventional narrative and systematic reviews provide valuable syntheses of empirical evidence but offer limited insights into the dynamics of scientific knowledge production and the evolution of research domains.

Bibliometric analysis has become an established approach for systematically mapping scientific knowledge through publication trends, citation performance, collaboration networks, and thematic evolution (Aria & Cuccurullo, 2017; Donthu et al., 2021). Baraj et al. (2024) mapped the literature on climate change, resilience, adaptation, and sustainable agriculture in India, revealing rapid scientific growth and evolving thematic structures. Similarly, Mukherjee et al. (2025) analysed global research on ICT-based agricultural extension and advisory services, highlighting the increasing prominence of digital extension and knowledge-sharing systems. However, these studies focused on specific research domains and did not examine the broader intellectual relationship between agricultural extension and farmers' climate resilience. Roy et al. (2024) while analysing Indian Journal of Extension Education, identified several intervention areas, a further improvement in those will enable this only Scopus-indexed journal on Agricultural Extension from Indian origin to provide Extension Researchers with a strong global platform. Thus, the findings not only confirm existing knowledge but also uncover unique situations, providing researchers and stakeholders with valuable perspectives for future exploration and engagement in extension education and related fields.

More importantly, no previous bibliometric study has explicitly investigated the position of agricultural extension within the global knowledge structure of farmers' climate resilience. As resilience research has expanded beyond technological adaptation to encompass adaptive capacity, institutional support, social learning, livelihood resilience, climate information services, and disaster preparedness, agricultural extension has become an increasingly important component of resilience-building. Nevertheless, it remains unclear whether agricultural extension has evolved into an independent research domain or continues to function primarily as a supporting theme within resilience research. Addressing this gap is essential for clarifying the intellectual development of agricultural extension and identifying future research priorities.

## METHODOLOGY

Bibliographic data were retrieved from the Elsevier Scopus database, with the search conducted on 5 May 2026. Scopus was selected because of its broad multidisciplinary coverage, comprehensive citation indexing, and extensive representation of agricultural, environmental, and social science journals. Consistent with recent bibliometric studies in agricultural extension (Chandra et al., 2026), a single database was used to ensure dataset consistency, avoid duplicate records, and harmonise metadata associated with merging multiple databases. The search was performed in the TITLE-ABS-KEY field using three concept groups representing farmers, climate resilience, and agricultural extension: TITLE-ABS-KEY ((“farmer” OR “smallholder” OR “agriculture”) AND (“resilience” OR “climate change adaptation” OR “adaptive capacity” OR “vulnerable”) AND (“agricultural extension” OR “advisory service” OR “climate-smart agriculture”)).

The initial search retrieved 2,091 records. Following the PRISMA 2020 framework (Page et al., 2021), records were sequentially refined using predefined Scopus filters. Publications were limited to the period 2015-2026 (n = 2.017), the subject areas Agricultural and Biological Sciences and Social Sciences (n = 722), document types articles and reviews (n = 532), final publication stage (n = 510), journal sources (n = 431), and English-language publications (n = 353). As all records originated from a single database, no duplicate records were identified. Titles and abstracts of the remaining publications were subsequently checked to confirm their relevance to farmers' climate resilience and agricultural extension, resulting in a final dataset of 353 peer-reviewed publications. The complete identification and screening process is presented in Figure 1.

The bibliometric analysis was conducted using Biblioshiny, the web interface of the Bibliometrix R package (Aria & Cuccurullo, 2017), a widely adopted platform for science mapping (Donthu et al., 2021). Performance analysis included annual publication and citation trends, as well as the most productive authors, journals, institutions, and countries. The intellectual and conceptual structure of the field was explored through author keyword (DE) co-occurrence analysis, co-authorship networks, strategic thematic mapping, thematic evolution, trend-topic analysis, and word cloud visualisation. Author Keywords (DE) were selected instead of Keywords Plus (ID) because they more accurately represent the thematic focus of individual publications. Thematic evolution was examined across four time periods (2015-2016, 2017-2019, 2020-2022, and 2023-2026) to identify changes in research themes.

## RESULTS

### Overview of the bibliometric dataset

Table 1 summarises the principal descriptive parameters of the dataset. The 353 documents were published across 198 distinct sources, mostly peer-reviewed journals all of which are peer-reviewed Scopus-indexed journals, over the 2015-2026 timespan,

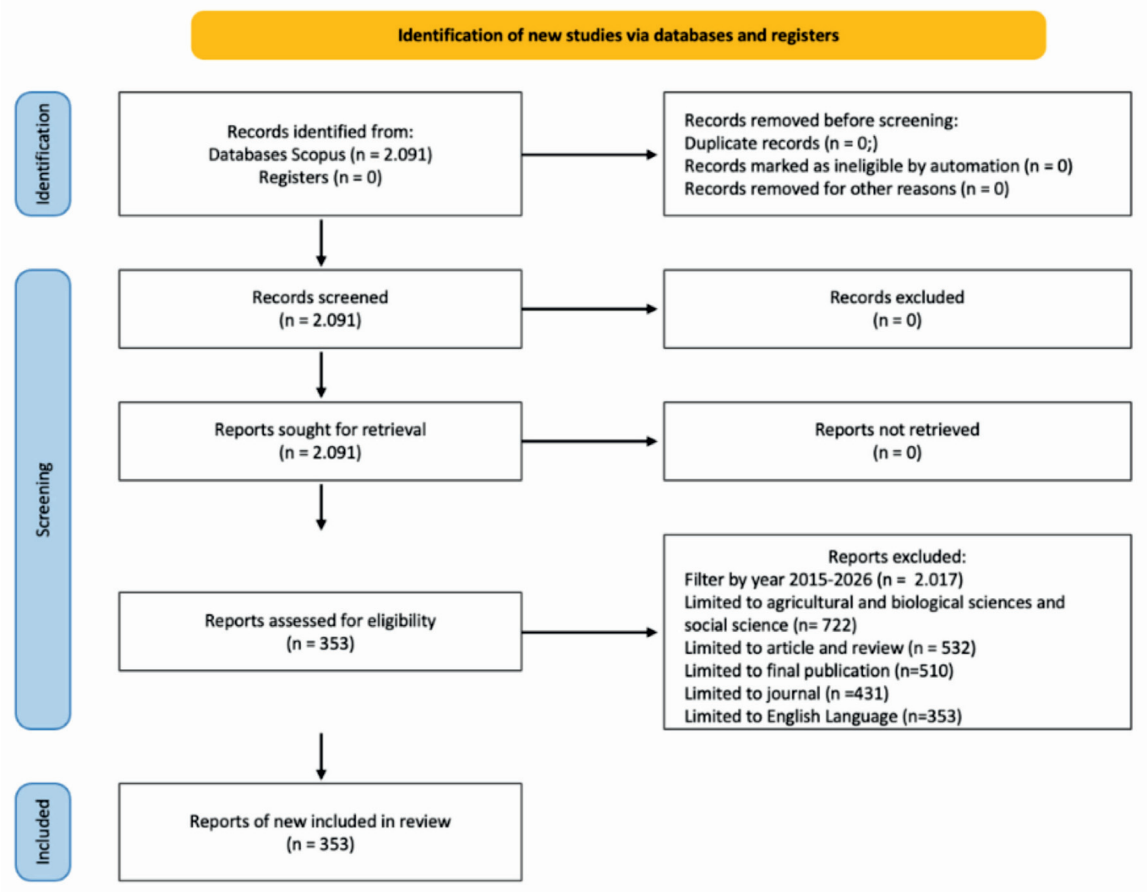


**Figure 1.** PRISMA flow diagram

**Table 1.** Main bibliometric information about the dataset (2015-2026)

| Description | Result |
|---|---|
| Timespan | 2015-2026 |
| Sources (journals) | 198 |
| Documents | 353 |
| Annual growth rate (%) | 40.62 |
| Document average age (years) | 2.41 |
| Average citations per document | 17.86 |
| Keywords Plus (ID) | 1,360 |
| Author's Keywords (DE) | 1,087 |
| Authors | 1,636 |
| Authors of single-authored documents | 19 |
| Single-authored documents | 20 |
| Co-authors per document | 5.07 |
| International co-authorship (%) | 43.91 |
| Document type: Article | 309 (87.5%) |
| Document type: Review | 44 (12.5%) |

comprising 309 articles (87.5%) and 44 reviews (12.5%). The annual growth rate of 40.62% indicates a rapid increase in publication output over the study period. In addition, the average document age was 2.41 years, calculated as the mean interval between each publication year and the data collection year (2026), following the descriptive bibliometric indicators implemented in the Bibliometrix package (Aria & Cuccurullo, 2017). Although no universally accepted threshold exists for document age, values below approximately 3-5 years generally indicate that a research field is characterised by recent and actively growing literature. Together, these indicators suggest that farmers' climate resilience and agricultural extension constitute a relatively young and rapidly expanding research area. A total of 1,636 authors contributed to the dataset, with only 19 publishing as sole authors and 20 documents being single-authored; the mean of 5.07 co-authors per document and an international co-authorship rate of 43.91 per cent point to a field that is collaborative and globally networked at the level of individual papers.

### Trends in annual scientific production

The annual distribution of publications (Figure 2) shows a marked increase in research output across the study period. During the initial years of the analysed timeframe (2015-2017), publication volumes remained relatively low, with two, two, and four documents, respectively. This pattern reflects the limited number of publications captured within the selected observation period rather than the origin of the broader climate resilience research field. Publication output increased gradually between 2018 and 2020 (12, 11, and 14 documents), suggesting growing scholarly attention to the intersection of farmers' resilience and agricultural extension. From 2021 onward the field entered a phase of sustained, accelerating output to 29 documents in 2021, a modest dip to 26 in 2022, 29 in 2023 and 39 in 2024, before output more than doubled to 100 documents in 2025.

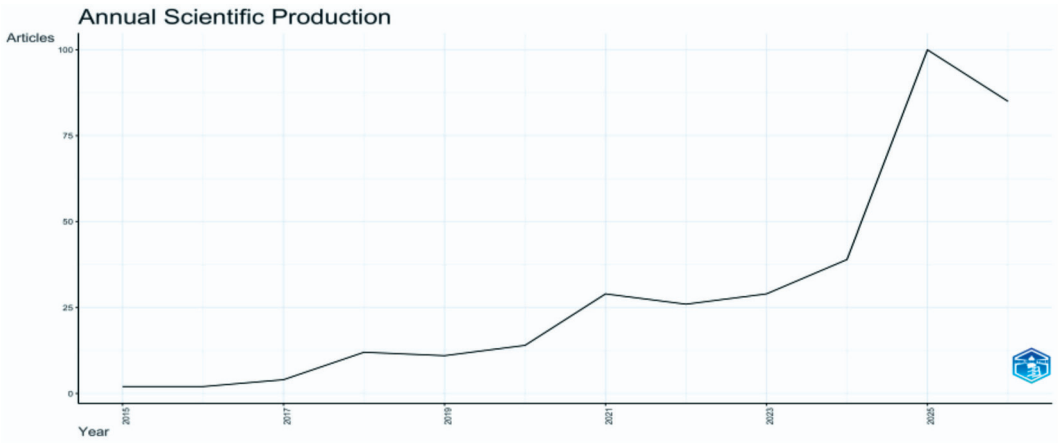


**Figure 2.** Annual scientific production on farmers' resilience to climate change and agricultural extension (2015-2026).

**Field maturity: a growth-curve projection**

To situate the observed growth within the broader life cycle of a research field, a non-linear diffusion model was fitted to the annual publication series (Figure 3), achieving a strong fit ($R^2$ = 0.885) and projecting an inflection point the year of peak annual output, around 2028-2029. The corresponding cumulative growth curve (Figure 4) indicates that the literature has, as of 2026, covered only a modest share of its projected eventual volume, well short of the 50 per cent mark, let alone the 90 or 99 per cent saturation thresholds typically associated with a mature field. Read together with the keyword and collaboration patterns discussed below, this places the resilience-extension literature firmly in an emergent-to-growth stage rather than a mature one: the underlying knowledge base is still being assembled, theoretical consolidation is incomplete, and a substantial share of the eventual literature has yet to be written. This projection should be interpreted with caution, as it extrapolates from a comparatively short time series and assumes a continuation of current policy and funding conditions; abrupt shifts in global climate governance or research funding could shift the timing of the projected peak in either direction.


**Figure 3.** Fitted diffusion (life-cycle) curve of annual publication counts, with a projected peak near 2028-2029.

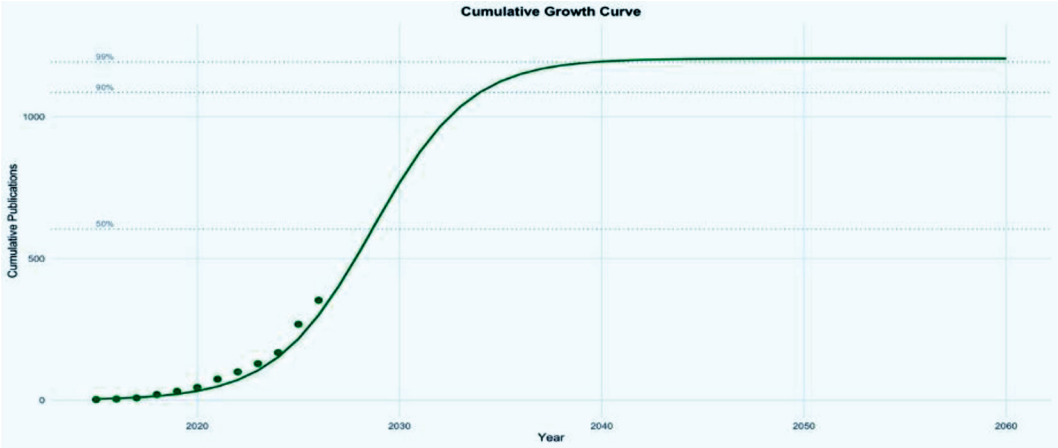


**Figure 4.** Cumulative growth curve of the literature, indicating the field has not yet approached saturation.

### Citation impact and the most globally cited documents

Citation analysis (Figure 5, Table 2) shows that the most influential document in the dataset is Makate et al. (2016), which examined crop diversification and adaptive management among smallholder farmers in Zimbabwe and has accumulated 308 citations. It is followed by Schmidt et al. (2018) on long-term cover-cropping and soil microbial resilience (221 citations) and Heeb et al. (2019) on climate-smart pest management (204 citations). Notably, several of the most-cited documents address the determinants of climate-smart agricultural practice adoption are; Abegunde et al. (2020) in South Africa (198 citations), Zakaria et al. (2020) in Ghana (149 citations) and Bedeke et al. (2019) in Ethiopia (126 citations). In each case extension or training access emerges as a significant explanatory variable rather than the principal object of study. Zakaria et al. (2020), for instance, demonstrates that farmer participation in extension training programmes is a strong predictor of climate-smart agriculture adoption in Ghana, illustrating how extension surfaces as an enabling mechanism even within a citation landscape dominated by agronomic and adoption-economics framing. With an average document age of only 2.41 years against an average of 17.86 citations per document, the field's citation profile is still maturing; the apparent prominence of pre-2021 documents in the top-cited list partly reflects citation lag, and the influence of the much larger 2023-2026 publication cohort is likely to become more visible as those documents continue to accrue citations.

### Leading source journals

The 353 documents were distributed across 198 journals, although a relatively small group of multidisciplinary sustainability and food-system journals accounted for a substantial share of the output (Table 3). Sustainability (Switzerland) was the leading source with 20 documents, followed by Frontiers in Sustainable Food Systems (13), Discover Sustainability and Environment, Development and Sustainability (nine each), Climate Services and Cogent Food and Agriculture (eight each), and Climate (seven). In

**Table 2.** Top ten most globally cited documents on farmers' resilience to climate change and agricultural extension

| Authors | Year | Title | Source | Citations |
|---|---|---|---|---|
| Makate, C. et al. | 2016 | Crop diversification and livelihoods of smallholder farmers in Zimbabwe: Adaptive management for environmental change | SpringerPlus | 308 |
| Schmidt, R. et al. | 2018 | Long-term use of cover crops and no-till shift soil microbial community life strategies in agricultural soil | PLoS ONE | 221 |
| Heeb, L. et al. | 2019 | Climate-smart pest management: building resilience of farms and landscapes to changing pest threats | Journal of Pest Science | 204 |
| Abegunde, V.O. et al. | 2020 | Determinants of the adoption of climate-smart agricultural practices by small-scale farming households in South Africa | Sustainability (Switzerland) | 198 |
| Zakaria, A. et al. | 2020 | Adoption of climate-smart agricultural practices among farm households in Ghana: the role of farmer participation in training programmes | Technology in Society | 149 |
| Bedeke, S.B. | 2023 | Climate change vulnerability and adaptation of crop producers in sub-Saharan Africa: a review on concepts, approaches and methods | Environment, Development and Sustainability | 144 |
| Bedeke, S. et al. | 2019 | Adoption of climate change adaptation strategies by maize-dependent smallholders in Ethiopia | NJAS -Wageningen Journal of Life Sciences | 126 |
| Ahmed, Z. et al. | 2021 | Climate change risk perceptions and agricultural adaptation strategies in vulnerable riverine char islands of Bangladesh | Land Use Policy | 125 |
| Nkiaka, E. et al. | 2019 | Identifying user needs for weather and climate services to enhance resilience to climate shocks in sub-Saharan Africa | Environmental Research Letters | 122 |
| Ma, W. & Rahut, D.B. | 2024 | Climate-smart agriculture: adoption, impacts, and implications for sustainable development | Mitigation and Adaptation Strategies for Global Change | 121 |

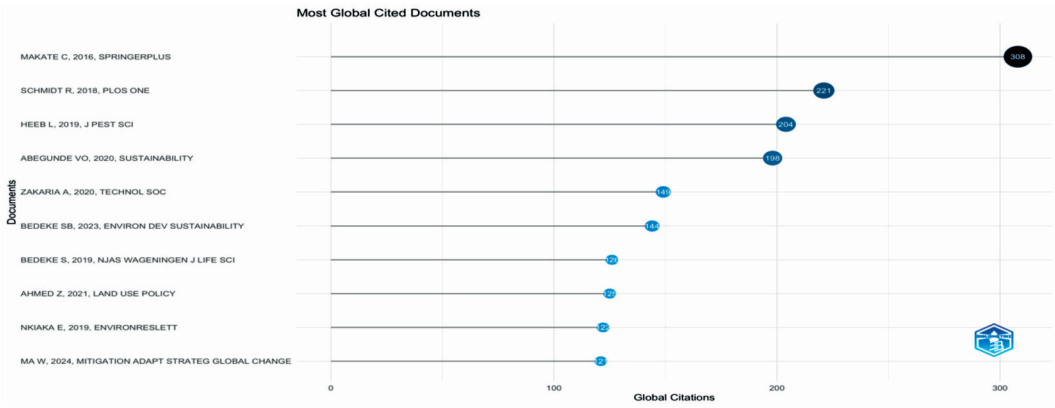


**Figure 5.** Most globally cited documents in the dataset.

contrast, specialised agricultural extension journals, including the South African Journal of Agricultural Extension and the Journal of Agricultural Education and Extension, contributed only a small proportion of publications.

The prominence of Sustainability reflects the increasingly interdisciplinary nature of climate resilience research. Farmers' resilience is no longer examined solely from the perspective of agricultural production or extension education but is increasingly framed within broader sustainability challenges, including climate adaptation, food security, sustainable livelihoods, environmental governance, and the Sustainable Development Goals. Consequently, multidisciplinary sustainability journals provide a broader platform for integrating environmental, social, economic, and institutional dimensions of resilience than discipline-specific agricultural journals.

This publication pattern also has important implications for agricultural extension research. Rather than emerging as an independent field, agricultural extension is predominantly treated as an enabling mechanism that supports climate adaptation, technology adoption, knowledge exchange, and resilience building within wider sustainability research. The limited representation of extension journals therefore suggests that extension research remains embedded within interdisciplinary climate and sustainability studies instead of developing as a distinct conceptual domain. This finding is consistent with the keyword co-occurrence and thematic analyses, which show that agricultural extension is closely linked to adaptation and resilience themes but does not form an independent thematic cluster.

Bradford's Law further (Figure 6) confirms the concentration of publications within a limited group of core journals. Sustainability (Switzerland) occupies the leading position, followed by Frontiers in Sustainable Food Systems, Discover Sustainability, Environment, Development and Sustainability, and several climate, and food-system-oriented outlets. The composition of the core zone indicates that research on farmers' climate resilience is primarily disseminated through multidisciplinary sustainability and climate journals rather than specialised agricultural extension outlets. This pattern reinforces the finding that agricultural extension remains embedded within broader adaptation and resilience scholarship.

**Table 3.** Leading source journals publishing on farmers' resilience to climate change and agricultural extension

| Source | Articles |
|---|---|
| Sustainability (Switzerland) | 20 |
| Frontiers in Sustainable Food Systems | 13 |
| Discover Sustainability | 9 |
| Environment, Development and Sustainability | 9 |
| Climate Services | 8 |
| Cogent Food and Agriculture | 8 |
| Climate | 7 |
| Mitigation and Adaptation Strategies for Global Change | 5 |
| Agricultural Systems | 5 |
| Frontiers in Climate | 5 |
| International Journal of Climate Change Strategies and Management | 5 |

## Geographic distribution of research

Analysis of author affiliations (Table 4) indicates that Ethiopia (50 affiliation records), India (43), China (40), the United States (37), Ghana (32), the United Kingdom (32), South Africa (29), Australia (27), Nigeria (25), and Kenya (18) are the countries with the highest numbers of author affiliations in the dataset. This distribution mirrors findings reported by Anuranj and Vishnu (2026), where African and South Asian case studies are often conducted through collaborations with European, North American, and Australian partners. While such partnerships facilitate

**Table 4.** Leading countries by author-affiliation frequency

| Country | Affiliation mentions |
|---|---|
| Ethiopia | 50 |
| India | 43 |
| China | 40 |
| United States | 37 |
| Ghana | 32 |
| United Kingdom | 32 |
| South Africa | 29 |
| Australia | 27 |
| Nigeria | 25 |
| Kenya | 18 |

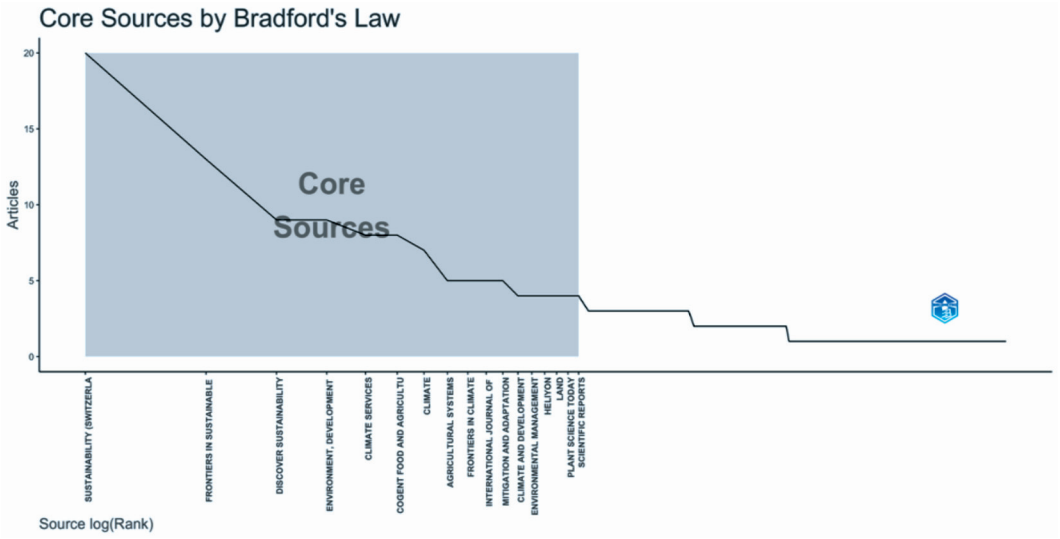


**Figure 6.** Bradford's Law

knowledge exchange and methodological development, they also raise questions about the extent to which Southern institutions lead the formulation of research agendas concerning their own farmers and extension systems. Latin America and Southeast Asia remain visibly under-represented relative to their own climate-vulnerability profiles, indicating a geographic imbalance that mirrors findings reported elsewhere in the climate-adaptation bibliometrics literature.

Institutional-level data (Table 5) further highlight Ethiopia's prominent contribution to the analysed literature. Bahir Dar University emerged as the most productive institution with 23 publications, followed by Tamil Nadu Agricultural University (19) and Kwame Nkrumah University of Science and Technology (16). Five Ethiopian universities: Bahir Dar, Addis Ababa, Haramaya, Hawassa, and Mekelle, collectively contributed 62 publications, indicating that research output was distributed across several national institutions rather than concentrated in a single university. Outside Ethiopia, Tamil Nadu Agricultural University was the leading institutional contributor from India, while Kwame Nkrumah University of Science and Technology and Universiti Putra Malaysia (11) represented important research centres in West Africa and Southeast Asia, respectively. The University of California (12) and the University of Florida (8) were the only institutions from outside the Global South among the ten most productive affiliations.

**Table 5.** Most relevant affiliations (institutions) in the dataset

| Affiliation | Articles |
|---|---|
| Bahir Dar University | 23 |
| Tamil Nadu Agricultural University | 19 |
| Kwame Nkrumah University of Science and Technology | 16 |
| Addis Ababa University | 13 |
| University of California | 12 |
| Universiti Putra Malaysia | 11 |
| Haramaya University | 10 |
| Hawassa University | 8 |
| Mekelle University | 8 |
| University of Florida | 8 |

### Author productivity and collaboration network

Table 6 identifies the most prolific authors in the dataset. Philip Antwi-Agyei and Andrew J. Dougill each contributed five publications, followed by Belay Simane and Frank Baffour-Ata with four publications. Several other authors, including Assefa A. Berhanu, Zewdu B. Ayele, Dessalegn C. Dagnew, Melusi Sibanda, P.P. Murugan, T.S. Amjath-Babu, Timothy J. Krupnik, Muhammad Ali Imran, Asghar Ali, and Azhar Abbas, each published three documents.

**Table 6.** Most productive authors in the dataset

| Author | Documents |
|---|---|
| Antwi-Agyei, Philip | 5 |
| Dougill, Andrew J. | 5 |
| Simane, Belay | 4 |
| Baffour-Ata, Frank | 4 |
| Berhanu, Assefa A. | 3 |
| Ayele, Zewdu B. | 3 |
| Dagnew, Dessalegn C. | 3 |
| Sibanda, Melusi | 3 |
| Murugan, P.P. | 3 |
| Amjath-Babu, T.S. | 3 |
| Krupnik, Timothy J. | 3 |
| Imran, Muhammad Ali | 3 |
| Ali, Asghar | 3 |
| Abbas, Azhar | 3 |

Temporal analysis of author productivity indicates that most leading contributors became active after 2020, coinciding with the rapid expansion of the literature. Andrew J. Dougill and Philip Antwi-Agyei exhibited the longest and most consistent publication trajectories, maintaining research output from 2019 to 2024. In contrast, Belay Simane, Frank Baffour-Ata, and Zewdu B. Ayele demonstrated more recent but intensive publication activity concentrated between 2021 and 2025. These patterns suggest that the recent growth of the field has been driven by both sustained contributions from established researchers and the emergence of new author groups.

The co-authorship network (Figure 7) reveals several well-defined regional collaboration clusters rather than a single integrated research community. The largest and most densely connected cluster is centred on Dougill, Antwi-Agyei, and Baffour-Ata, reflecting sustained collaboration on climate-smart agriculture, resilience, and

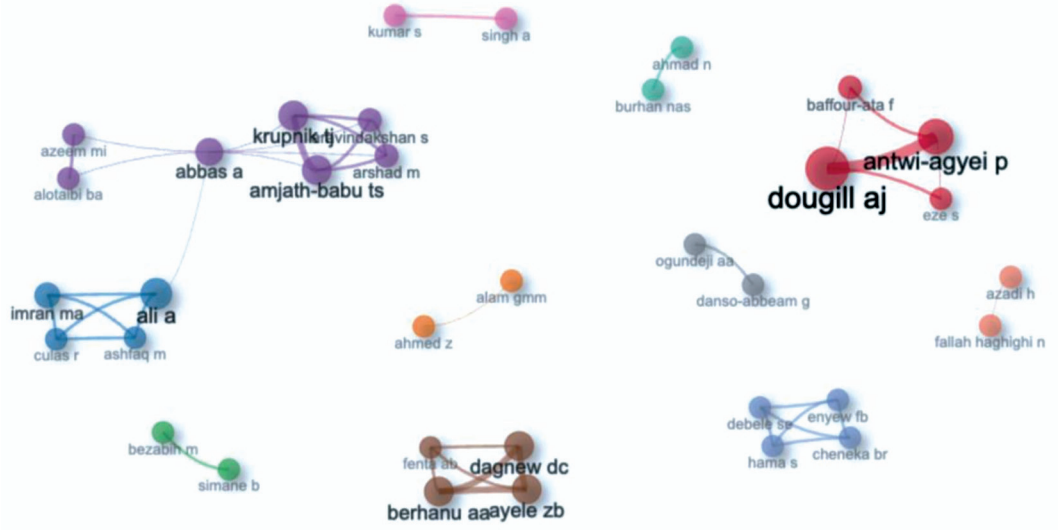


**Figure 7.** Co-authorship (collaboration) network among researchers publishing on farmers' resilience and agricultural extension

farmers' adaptive capacity in African farming systems (Dougill et al., 2021; Gyimah et al., 2024).

A second major cluster links Krupnik, Amjath-Babu, Abbas, and Arshad, whose collaborative research focuses on climate variability and yield risk in South Asia's rice-wheat systems (Arshad et al., 2017, 2018). A related but separate cluster involving Imran, Ali, Ashfaq, and Culas examines the livelihood implications of climate-smart cotton production in Punjab (Imran et al., 2018). Another cluster, comprising Dagnew, Berhanu, Ayele, and Fenta, focuses primarily on smallholder coping strategies and the hydrological dimensions of climate resilience in Ethiopia (Berhanu et al., 2024). Smaller collaboration pairs, including Bezabih-Simane and Ahmed-Alam, remain relatively isolated with limited connections to other research groups, reflecting work on livelihood vulnerability in Ethiopia and climate-risk perception in Bangladesh, respectively (Ahmed et al., 2021).

Despite a relatively high mean of 5.07 co-authors per document and an international co-authorship rate of 43.91% (Table 1), the collaboration network remains fragmented. Most collaborations occur within regional or institutional groups, whereas cross-cluster collaboration remains relatively limited.

Author productivity broadly follows Lotka's Law (Figure 8), with the overwhelming majority of researchers contributing only one documents and progressively fewer authors producing two or more documents. The observed proportion of single documents authors is higher than the theoretical distribution, while the proportion of authors with multiple papers declines more sharply than expected. This pattern indicates a dispersed and still-emerging research community in which sustained authorship is concentrated among a small group of scholars.

**Keyword co-occurrence and thematic structure**

Author keyword co-occurrence analysis identified "climate change" as the most frequently occurring keyword, appearing 219 times, more than three times the frequency of "food security" (64 occurrences), the second most common term. Other prominent author keywords included "agriculture" (61), "smallholder" (52), "adaptation" (47), "climate-smart agriculture" and "resilience" (42 each), "adaptive management" (37), and both "livelihood" and "smallholder farmers" (34 each) (Table 7; Figure 13). Notably, neither "climate resilience" nor "farmers' resilience" appeared among the most frequently used author keywords. Instead, researchers predominantly adopted broader concepts related to climate adaptation, agricultural sustainability, and resilience, suggesting that climate resilience remains conceptually embedded within these wider research themes rather than functioning as a distinct keyword domain. The author keyword co-occurrence network organised these terms into two major clusters linked through the central "climate change" node. The larger cluster comprised keywords related to food security, resilience, adaptation, climate-smart agriculture, agricultural extension, adaptive capacity, farming systems, and sustainable development, together with geographically focused terms such as Ethiopia, Ghana, Pakistan, and Sub-Saharan Africa. This cluster represents the policy and adaptation-oriented core of the literature, where resilience and extension-related themes are most closely interconnected. The second cluster included agriculture, productivity, adoption, drought, crop production, agroforestry, and demographic descriptors (e.g., female, male, and human), reflecting the predominance of empirical, survey-based studies in the field.

Within the first, substantive cluster, "agricultural extension" sits close to "agricultural management" and "adaptation strategies" rather than forming an independent sub-cluster of its own. This pattern suggests that agricultural extension is largely embedded within broader adaptive-management discussions rather than conceptualized as a distinct resilience-building mechanism. This finding aligns with recent calls to redefine extension beyond information delivery toward facilitation, coordination, and co-learning roles (Knook et al., 2020; Mburu et al., 2024; Maka, 2025). The relative absence of a dedicated extension sub-cluster, despite extension's frequent appearance as an explanatory variable in the most-cited documents, is one of the clearest knowledge gaps this bibliometric mapping identifies.

The strategic thematic map (Figure 9) provides a complementary view of the conceptual structure by positioning keyword clusters according to two dimensions: centrality, which reflects a theme's importance and connectivity within the overall research field, and density, which indicates its level of internal development and conceptual maturity. Based on these dimensions, themes are classified into four quadrants: Motor Themes (high

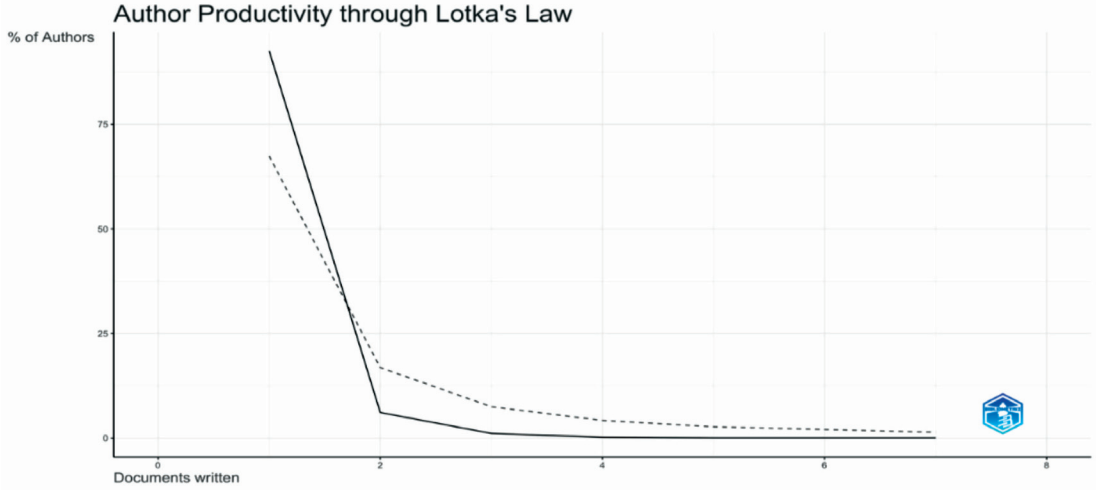


**Figure 8.** Lotka's Law

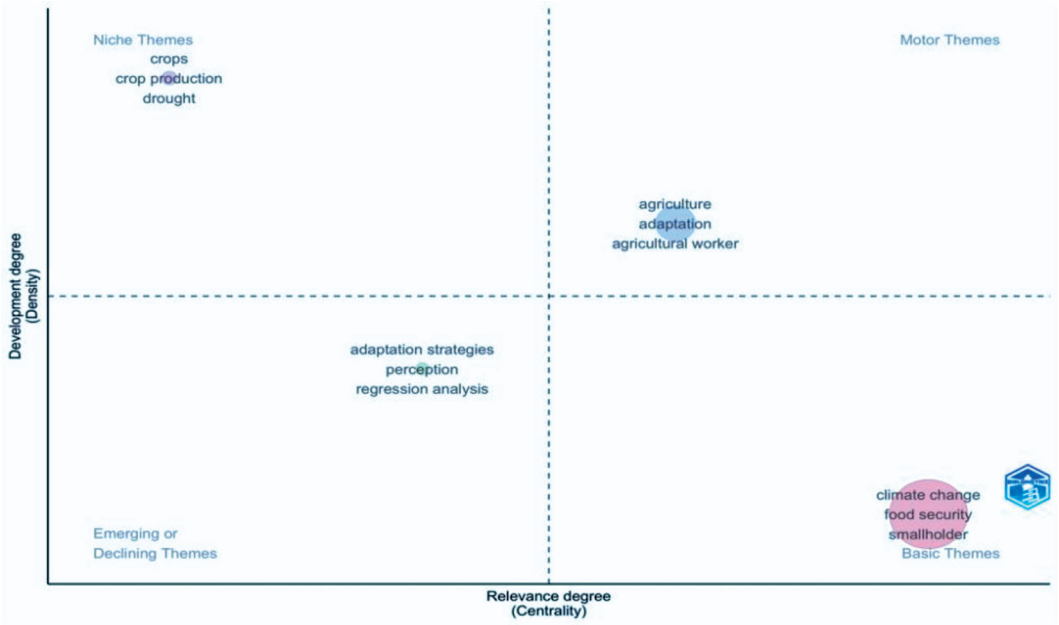


**Figure 9.** Thematic strategic diagram

centrality and high density), representing well-developed themes that drive the field; Basic Themes (high centrality but low density), representing fundamental topics that underpin the literature but remain comparatively less developed; Niche Themes (low centrality but high density), representing specialised and internally mature topics with limited influence on the broader field; and Emerging or Declining Themes (low centrality and low density), representing either newly developing topics or areas experiencing declining scholarly attention.

Three keyword clusters: climate change, food security, and smallholder are located in the Basic Themes quadrant, indicating that they constitute the conceptual foundation of the literature despite remaining less internally developed. A second cluster comprising agriculture, adaptation, and agricultural worker appears in the Motor Themes quadrant, suggesting that these topics are both well developed and central to current research. In contrast, crops, crop production, and drought occupy the Niche Themes quadrant, indicating specialised research areas with strong internal development but relatively limited influence on the wider resilience literature. Another cluster consisting of adaptation strategies, perception, and regression analysis falls within the Emerging or Declining Themes quadrant, suggesting either newly developing research directions or topics receiving diminishing scholarly attention. Notably, agricultural extension does not emerge as a distinct thematic cluster in any quadrant.

The three-field plot (Figure 10) connects the principal research topics, leading authors, and their countries of affiliation. Climate change forms the dominant thematic stream and is linked to most of the leading authors and national research communities. Agricultural extension appears as a smaller thematic flow, connecting selected authors and countries rather than forming a broadly distributed research stream. Ethiopia, India, Pakistan, the United Kingdom, and Ghana account for the strongest author-country linkages, confirming the geographical concentration identified in the country and institutional analyses. Overall, the plot demonstrates that the field's leading authors are primarily associated with climate adaptation, livelihoods, smallholder farming, and vulnerability, whereas extension-specific scholarship remains comparatively limited.

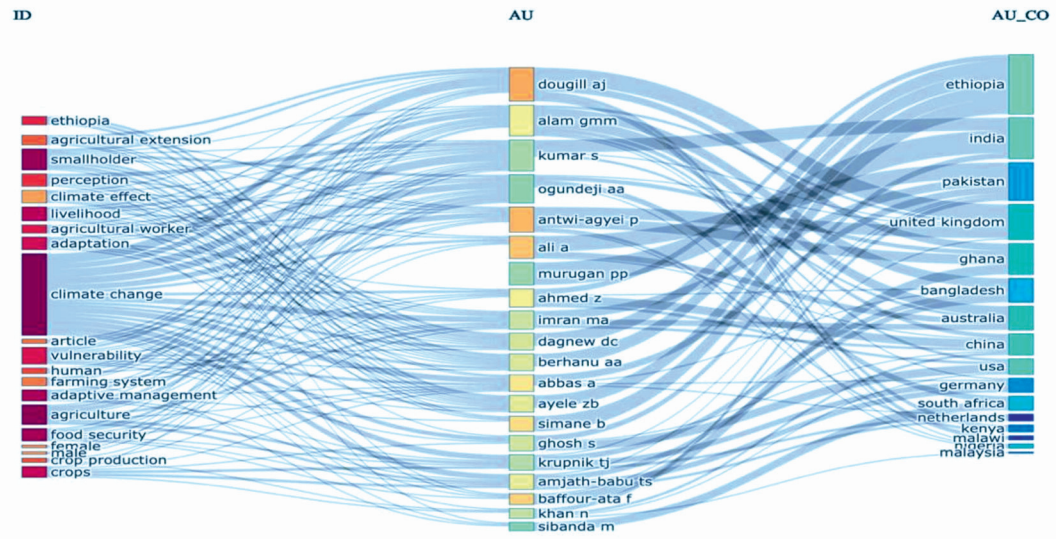


**Figure 10.** The three-field plot

The trend topics analysis (Figure 11) adds a temporal perspective to the thematic structure of the literature. Early keywords such as zea mays, Malawi, and agricultural land peaked between 2018 and 2020, reflecting the prominence of location- and commodity-specific case studies during the initial stage of research development. Between 2021 and 2023, attention shifted toward methodological and analytical themes, including farming system, decision making, regression analysis, adaptive management, mitigation, and crop production. This period broadly corresponds to the adoption-determinants phase identified in Table 8.

More recently, climate change, agriculture, and adaptation reached their highest frequencies around 2024 and remain the dominant themes in the field. The newest keywords to emerge are smallholder, smallholder farmers, food security, household, household survey, and climate, all peaking during 2025-2026. This pattern suggests a growing emphasis on household-level empirical research and survey-based analysis. Notably, extension-related terms do not appear among the emerging frontier topics. This finding is consistent with the co-occurrence and thematic-map analyses, indicating that agricultural extension is primarily examined within broader adaptation and resilience studies rather than as a distinct conceptual research domain.

A word cloud based on Author Keywords (DE) was generated to visualise the relative frequency of keywords in the dataset, with larger words indicating higher occurrence frequencies (Figure 12). Although this study focuses on farmers' climate resilience, the author keyword analysis reveals that the literature is predominantly organised around broader concepts such as "climate change", "adaptation", and "resilience", rather than the explicit term "climate resilience" (Table 7). This finding suggests that climate resilience remains a conceptually fragmented construct that is operationalised through multiple related themes rather than consistently represented by a single keyword.

Local impact analysis complements the productivity ranking by showing that documents output does not always correspond

**Table 7.** Most frequent author keywords in the dataset

| Term | Frequency |
|---|---|
| climate change | 219 |
| food security | 64 |
| agriculture | 61 |
| smallholder | 52 |
| adaptation | 47 |
| climate-smart agriculture | 42 |
| resilience | 42 |
| adaptive management | 37 |
| livelihood | 34 |
| smallholder farmers | 34 |

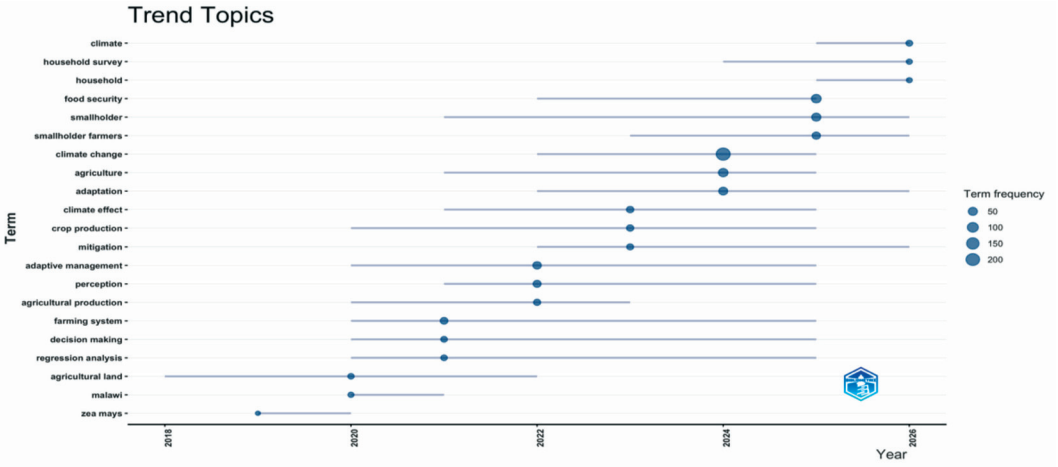


**Figure 11.** Trend topics showing the period of peak usage and relative frequency of leading author keywords, 2015-2026.


**Figure 12.** Word cloud of the most frequent author keywords in the dataset.

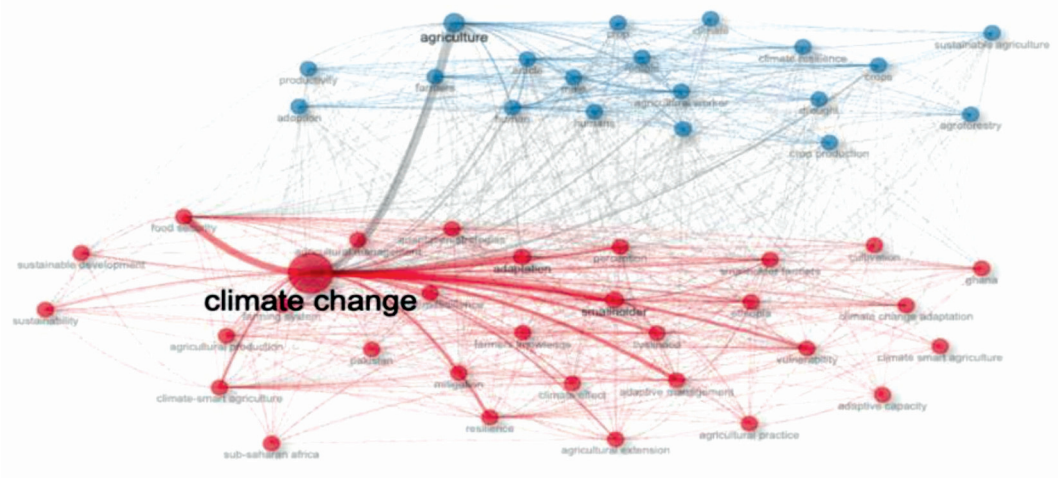


**Figure 13.** Keyword co-occurrence network showing the substantive (red) and methodological/demographic (blue) thematic clusters.

directly to citation influence within the dataset. Andrew J. Dougill recorded the highest local H-index (h = 7), followed by Philip Antwi-Agyei (h = 5) and Asghar Ali (h = 4). Azhar Abbas, Frank Baffour-Ata, S. Ghosh, Muhammad Ali Imran, A.A. Ogundeji, and Belay Simane each recorded a local H-index of three. These results identify Dougill and Antwi-Agyei as both productive and consistently influential contributors to the field.

### Thematic evolution and synthesis of the resilience-extension research focus

The thematic evolution analysis (Figure 14) confirms the developmental trajectory of the field across four periods (2015-2016, 2017-2019, 2020-2022, and 2023-2026). The earliest period was dominated by only two keywords, farmers and adaptive, reflecting the limited number of documents during these years. These themes evolved into a broader vocabulary during 2017-2019, including climate, livelihood, resilience, adoption, farming, and variability. This pattern aligns with the early focus on livelihood vulnerability and adaptation determinants.

During 2020-2022, the thematic structure became more diverse. New keywords such as coastal, south, rice, and adaptations emerged alongside established themes including resilience, climate, agriculture, and awareness. This shift reflects the expansion of research into new geographic contexts and empirical applications, while maintaining a strong emphasis on climate adaptation and farmer resilience.

During 2023-2026, the thematic structure became more consolidated around four dominant themes: climate, agriculture, resilience, and adoption. Notably, Ethiopia emerged as a distinct thematic node rather than merely a geographic reference. This finding complements the country- and institution-level analyses (Tables 4 and 5), indicating that Ethiopia has become both a major contributor to and a substantive focus of the literature.

Taken together, the thematic evolution map, strategic diagram (Figure 9), and trend-topics analysis (Figure 11) reveal a clear

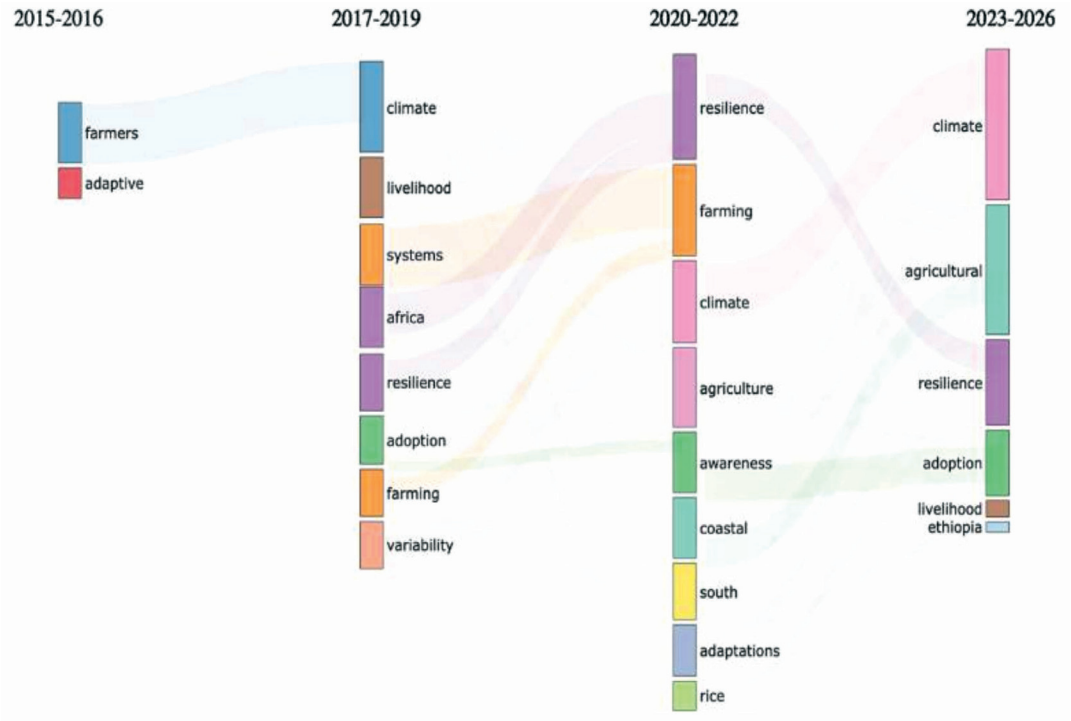


**Figure 14.** Thematic evolution of author-keyword vocabulary across four periods, 2015–2026.

**Table 8.** Evolution of the farmers' resilience–agricultural extension research focus

| Period | Dominant focus | Representative evidence |
|---|---|---|
| 2015-2016 | Initial, narrowly empirical framing of farmers' adaptive behaviour | Makate et al. (2016) |
| 2017-2019 | Conceptual framing of livelihood vulnerability and early climate-smart agriculture operationalisation | Akrofi-Atitianti et al. (2018); Bedeke et al. (2019); Heeb et al. (2019) |
| 2020-2022 | Geographic and methodological diversification; quantifying determinants of climate-smart practice adoption, with extension/training access as a recurrent factor | Abegunde et al. (2020); Zakaria et al. (2020); Ahmed et al. (2021); Setsoafia et al. (2022) |
| 2023-2026 | Thematic consolidation around climate, agriculture, resilience and adoption, anchored in Ethiopian evidence; extension–resilience synergy and digital/AI-enabled advisory services | Bedeke (2023); Thottadi & Singh (2024); Berhanu et al. (2024); Billah et al. (2025); Singh et al. (2025); Mkuna (2026) |

developmental trajectory. The field evolved from broad livelihood-oriented studies (2015-2019) to a period of geographic and methodological diversification (2020-2022), before converging on climate adaptation, resilience, and adoption research in recent years (2023-2026). Despite this evolution, agricultural extension never emerged as a distinct thematic cluster. Instead, it remained embedded within broader adaptation and resilience research, highlighting a persistent knowledge gap in the literature.

## DISCUSSION

This bibliometric mapping confirms the rapid growth of research on farmers' resilience to climate change since 2015. The annual growth rate of 40.62%, the young average document age of 2.41 years, and the diffusion-curve projection indicating a documents peak around 2028-2029 suggest that the field remains in an active stage of development. The marked acceleration in publication output after 2021 likely reflects broader scientific and policy developments rather than a continuation of historical publication trends. Growing international attention to climate adaptation following the implementation of the Paris Agreement, together with heightened concerns over food-system resilience during and after the COVID-19 pandemic, has stimulated research on farmers' resilience. At the same time, increasing investments by governments and international development agencies in climate adaptation, climate-smart agriculture, and agricultural extension programmes have expanded research opportunities and strengthened scholarly interest in institutional mechanisms that support farmers' adaptive capacity. Although the bibliometric data do not establish causal relationships, these developments are consistent with the sustained publication growth observed in this study. Despite this youth, the average document has already accumulated 17.86 citations, suggesting strong and immediate uptake of the literature by the wider research community. Consequently, this review captures a literature whose intellectual structure is still evolving, and future bibliometric analyses may reveal a more consolidated and theoretically integrated research landscape.

The geographic and collaboration patterns identified in this study are consistent with findings from the extension-climate-smart agriculture literature (Anuranj & Vishnu, 2026). Research activity is concentrated in climate-vulnerable regions, particularly Ethiopia, Ghana, Nigeria, South Africa, and South Asia. However, a substantial share of co-authored documents involves institutions from the United States, the United Kingdom, Australia, and continental Europe, indicating their continued influence on the field's analytical framing. Such partnerships have unquestionably supported methodological capacity-building and resource mobilisation (Cobon et al., 2021; Nkiaka et al., 2019), but the fragmented, regionally siloed structure of the collaboration network (Figure 7) suggests that this support has not yet translated into a single, integrated global research community; rather, several parallel bilateral or small-group partnerships coexist with comparatively little cross-fertilisation. Strengthening South-South collaboration and ensuring that Southern institutions lead, rather than merely host, the framing of research questions would help convert the field's rapid growth into more cumulative and contextually grounded knowledge.

The thematic analysis carries a more specific implication for agricultural extension scholarship. Although extension-related variables, training participation, advisory access, and extension contact frequency recur as significant predictors across many empirical studies (Zakaria et al., 2020; Bedeke et al., 2019), agricultural extension does not constitute an independent thematic cluster within the keyword network; instead, it is embedded within a broader adaptive-management discourse. This finding suggests that extension continues to be treated primarily as an explanatory factor supporting adaptation outcomes rather than as a distinct field of theoretical inquiry. This interpretation is consistent with longstanding critiques that extension research is often positioned within adoption and adaptation studies instead of being conceptualised as an independent resilience-building discipline (Knook et al., 2020; Witinok-Huber et al., 2021). Recent empirical evidence from Indonesia nevertheless demonstrates that agricultural extension significantly strengthens farmers' climate resilience, both directly and indirectly, by improving livelihood capitals, adaptive capacity, and farming sustainability (Azhari et al., 2025a). These findings therefore reinforce the argument that, despite its peripheral intellectual position in the bibliometric structure, agricultural extension plays a fundamental role in strengthening farmers' resilience to climate change. Recent systematic reviews focused specifically on extension's role in climate-smart agriculture (Billah et al., 2025; Thottadi & Singh, 2024) and emerging work on the usability of climate information for extension officers themselves (Wiréhn, 2024) suggest the beginnings of a more dedicated research front, but this study's network evidence indicates that such work remains a secondary current within the wider resilience literature rather than its mainstream.

The bibliometric patterns identified in this study are broadly consistent with previous science-mapping studies on climate

adaptation and agricultural sustainability, while also revealing several distinctive characteristics of the resilience-extension literature. Similar to the bibliometric review of climate adaptation research in agricultural systems by Jiang et al. (2023), this study confirms that documents output has accelerated markedly since the mid-2010s, reflecting growing scientific and policy attention following the Paris Agreement and the expansion of climate adaptation initiatives. Likewise, Baraj et al. (2024) found that climate change, adaptation, sustainable agriculture, and resilience constitute the dominant conceptual pillars of agricultural climate research, a pattern also observed in the present keyword co-occurrence network. However, unlike these earlier bibliometric studies, our analysis explicitly demonstrates that agricultural extension remains embedded within broader adaptation and resilience themes rather than emerging as an independent research domain. This finding extends previous bibliometric evidence by identifying the relatively peripheral intellectual position of extension despite its acknowledged practical importance for strengthening farmers' adaptive capacity.

The observed thematic structure reflects the ongoing evolution of agricultural extension from the traditional technology-transfer paradigm toward facilitation-oriented and agricultural innovation system (AIS) approaches. Contemporary extension theory no longer conceptualizes extension professionals solely as disseminators of agricultural technologies but increasingly recognizes them as facilitators of collective learning, innovation brokers, and coordinators of adaptive decision-making under conditions of climatic uncertainty. Accordingly, the absence of agricultural extension as a distinct thematic cluster should not be interpreted as evidence of diminishing relevance. Instead, it indicates that extension has become embedded within broader resilience-building processes encompassing climate information services, social learning, institutional coordination, and innovation support. This interpretation is consistent with recent studies suggesting that modern extension systems strengthen farmers' climate resilience primarily by enhancing adaptive capacity, facilitating knowledge exchange, fostering collaborative learning, and supporting innovation, rather than merely promoting technology adoption (Knook et al., 2020; Mukherjee et al., 2025). Empirical evidence from Indonesia further shows that resilience-oriented extension becomes substantially more effective when integrated with livelihood capitals and pluralistic advisory approaches, enabling improvements in farmers' resilience capacity and long-term farming sustainability (Azhari et al., 2025b).

The findings also align closely with the broader climate adaptation literature, which increasingly recognises resilience as a multidimensional process shaped by interactions among institutional support, livelihoods, social learning, and governance rather than by technological interventions alone. Recent climate adaptation studies have consistently shown that adaptive capacity depends not only on farmers' access to technologies but also on extension services, climate information, financial resources, and institutional arrangements. The predominance of keywords related to food security, adaptive management, livelihoods, and smallholder farming observed in this study therefore reflects the evolution of resilience research from hazard-centred analyses toward integrated socio-ecological adaptation frameworks. At the same time, the limited visibility of extension-specific concepts suggests that future research should more explicitly examine how extension contributes to resilience through advisory systems, participatory learning, digital services, and innovation platforms. Such a shift would strengthen the theoretical integration between agricultural extension and climate adaptation research.

These findings have important practical implications for agricultural extension systems. Rather than focusing primarily on technology dissemination, extension organisations should adopt facilitation-oriented advisory approaches that promote collective learning, climate-informed decision-making, innovation co-creation, and stronger multi-stakeholder collaboration. Recent evidence further indicates that strengthening extensionists' participatory, pluralistic, entrepreneurial, and gender-sensitive facilitation capacities substantially improves the effectiveness of extension programmes and enhances the ability of farmer groups to respond to increasingly complex climate and livelihood challenges (Amanah et al., 2026).

The observed geographical concentration of documents in Ethiopia, India, and China reveals persistent regional disparities in scientific knowledge production, despite the widespread exposure of many developing regions to climate-related risks. This finding suggests the need for policy interventions that strengthen agricultural extension research and climate adaptation capacity in underrepresented regions, particularly Southeast Asia and Latin America. Governments, funding agencies, and international development organisations should prioritise investments that support cross-regional research collaboration, institutional capacity building, and knowledge-sharing networks. Such policies would contribute to a more geographically balanced evidence base while enabling the development of locally relevant extension systems and resilience strategies tailored to diverse agroecological and socio-economic contexts.

Future bibliometric studies could broaden database coverage by integrating multiple indexing sources, such as Web of Science and Dimensions, thereby improving the comprehensiveness and robustness of scientific mapping. Furthermore, longitudinal analyses incorporating co-citation, bibliographic coupling, and thematic evolution techniques would provide deeper insights into the intellectual development and theoretical maturation of agricultural extension within climate resilience research. Beyond bibliometric investigations, future empirical studies should examine the mechanisms through which agricultural extension strengthens farmers' adaptive capacity, with particular attention to digital extension, climate advisory services, innovation platforms, and social learning processes across diverse agroecological and socio-economic contexts. Such research would contribute to a more nuanced understanding of how extension systems facilitate long-term climate resilience among farming communities.

## CONCLUSION

Research on farmers' resilience to climate change has expanded rapidly since 2015 and remains in a growth phase. The literature is largely concentrated in climate-vulnerable regions of Sub-Saharan Africa and South Asia, although collaboration networks remain fragmented across regions. Agricultural extension is consistently

identified as an important factor supporting resilience and adaptation, yet it has not developed into a distinct research theme and is still embedded within broader adaptation and livelihood studies. Future research should strengthen cross-regional collaboration, develop stronger theoretical and empirical frameworks explaining how extension enhances resilience through facilitation, co-learning, and digital advisory services, and expand empirical evidence from underrepresented regions such as Latin America and Southeast Asia. Addressing these priorities will help align resilience research more closely with the evolving role of agricultural extension in climate adaptation.

## DECLARATIONS

Ethics approval and informed consent: Not applicable. This study is based exclusively on secondary bibliometric metadata retrieved from the Scopus database and does not involve human or animal subjects.

Conflict of interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The authors declare that during the preparation of this work, they thoroughly reviewed, revised, and edited the content as needed. The authors take full responsibility for the final content of this publication.

Data availability: The Scopus BibTeX export and the Biblioshiny-generated outputs (descriptive tables, annual production, keyword and collaboration network visualisations) analysed in this study are available from the corresponding author on reasonable request.

Declaration of generative AI and AI-assisted technologies in the writing process: During the preparation of this work, the authors used AI to improve the readability and language of the manuscript. After using this tool, the authors carefully reviewed and edited the manuscript and take full responsibility for its content.

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