# Sectoral vulnerabilities and adaptations to climate change: insights from a systematic literature review

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## Article Info

## ABSTRACT

Climate change is an urgent global issue impacting various life sectors, including health, agriculture, and infrastructure. This systematic literature review (SLR) aims to provide a comprehensive synthesis of research on sectoral vulnerabilities and adaptation strategies to climate change. Utilizing bibliometric analysis, the review identifies key themes and research gaps, highlighting the successes and challenges in implementing adaptation strategies. Key findings reveal that topics such as climate change, adaptive management, agriculture, public health, and food security are central to the research discourse. However, areas like health equity, sanitation, and agricultural worker adaptation remain under-researched. The analysis underscores the necessity for holistic, context-specific, and innovative approaches to policy-making, Scopus integrating sustainable development and public health to enhance resilience and adaptive capacity in vulnerable regions. This review offers valuable insights for researchers and policymakers aiming to develop effective adaptation strategies and address the multifaceted challenges of climate change.

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## 1. INTRODUCTION

Climate change has become an urgent global issue, with widespread impacts across various life sectors. The increase in global temperatures, changes in precipitation patterns, and the rising frequency of extreme weather events are phenomena increasingly attributed to climate change. According to the Intergovernmental panel on climate change (IPCC), the global surface temperature has risen by approximately 1.09 °C from 1850 to 1900 to 2011 to 2020, primarily due to human activities such as fossil fuel combustion and deforestation. These changes affect not only natural ecosystems but also human systems, including health, agriculture, and infrastructure. For instance, a study by Dastour *et al.* [1]. indicated a significant relationship between wildfire patterns in Alberta, Canada, and climate variables such as temperature and humidity These impacts threaten not only human well-being but also ecosystem stability and economic sustainability, compelling nations to develop more effective adaptation and mitigation strategies. Research by Lavoie *et al.* [2] emphasizes the importance of comprehensive climate data portals to support evidence-based decision-making in addressing these challenges. Therefore, understanding and addressing the impacts of climate change are crucial for ensuring future sustainability and resilience.

Vulnerability to climate change varies across sectors and regions, reflecting differences in exposure, sensitivity, and adaptive capacity. The health, agriculture, and infrastructure sectors are particularly vulnerable to these changes, given their reliance on stable climatic conditions. For example, research by Kelly and Radler [3] found a significant correlation between energy consumption in Africa and climate change, suggesting that rising temperatures and climate variability could affect energy resilience in the region. In the agricultural sector, climate change can reduce crop productivity and increase pest incidents, as reported by Li [4] in a study on rice production in Japan. Infrastructure, including drainage systems and water supply, also faces significant challenges due to the increasing occurrence of extreme weather events, such as floods and droughts, which can damage facilities and disrupt essential services. Vulnerability and adaptation studies are vital for identifying these risks and developing effective mitigation strategies.

This research aims to conduct a systematic review of vulnerability and adaptation strategies to climate change in the health, agriculture, and infrastructure sectors. Therefore, what adaptation strategies have been implemented in the health, agriculture, and infrastructure sectors, and how effective are these strategies? By gathering and analyzing relevant literature, this study seeks to provide comprehensive insights into how these sectors are affected by and adapt to climate change. The study also aims to identify common patterns and trends in the literature and explore various approaches used to address climate change challenges. For example, Sangsefidi et al. [5] investigated the impact of climate change on coastal drainage infrastructure and found that data-driven approaches can help plan and manage flood risks. Similar approaches can be applied to other sectors to enhance climate resilience.

This study contributes to the literature by identifying common patterns and trends in vulnerability and adaptation across various sectors. By understanding the factors influencing vulnerability and the success of adaptation strategies, this research can assist policymakers, academics, and practitioners in designing more effective strategies to cope with the impacts of climate change. For instance, research by Godwin et al. [6] showed that the phenological phases of carrot plants have different sensitivities to climate change, indicating that adaptation strategies need to be tailored to specific crop growth cycles. Additionally, this systematic review highlights existing knowledge gaps and provides recommendations for further research. For example, Rosenberg et al. [7] found that sentiment analysis on Twitter data can offer insights into public perceptions of climate actions, which can be used to design more effective awareness campaigns.

## 2. METHOD
### 2.1. Databases and sources

This study was conducted using secondary data based on a systematic search carried out in May 2024 on articles published and available in databases that meet the standards and reputation of international journals, specifically Scopus. The search strategy employed a combination of keywords as shown in Table 1 related to climate change adaptation in the specified sectors. These keywords were combined using Boolean operators (AND, OR, NOT) to refine the search. The descriptor "Climate change" was used in all searches to ensure that all relevant articles were obtained.

This review was conducted in accordance with the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines [8]–[10]. The use of PRISMA aimed to enhance the quality of systematic review reporting and provide substantial transparency in the article selection process [11], [12]. Additionally, the reference lists of the obtained studies were manually searched to identify additional relevant studies. The search and selection of studies were organized following the population, intervention, comparison, outcome, study design (PICOS) strategy. As done by Kolaski et al. [13], Nishikawa-Pacher [14], and Amir-Behghadami and Janati [15], we used a search strategy based on their composition according to the PICOS method to find and compare various studies, as shown in Figure 1 and Table 2.

Table 1. Studies searches according to database (Scopus)

| Search terms |
| --- |
| Topic: *"Climate change adaptation" AND "health sector" AND (language:("English") AND type:("article")* |
| Topic: *"Climate change adaptation" AND "agriculture sector" AND (language:("English") AND type:("article")* |
| Topic: *"Climate change adaptation" AND "infrastructure sector" AND (language:("English") AND type:("article")* |
| Topic: *"Adaptation strategies" AND "climate change" AND "health" AND (language:("English") AND type:("article")* |
| Topic: *"Adaptation strategies" AND "climate change" AND "agriculture" AND (language:("English") AND type:("article")* |
| Topic: *"Adaptation strategies" AND "climate change" AND "infrastructure" AND (language:("English") AND type:("article")* |
| Topic: *"Mitigation policies" AND "climate change" AND (language:("English") AND type:("article")* |
| Topic: *"Innovative approaches" AND "climate change adaptation" AND (language:("English") AND type:("article")* |
| Topic: *"Effectiveness" AND "climate change adaptation strategies" AND (language:("English") AND type:("article")* |
| Topic: *"Comparative analysis" AND "climate change adaptation" AND (language:("English") AND type:("article")* |
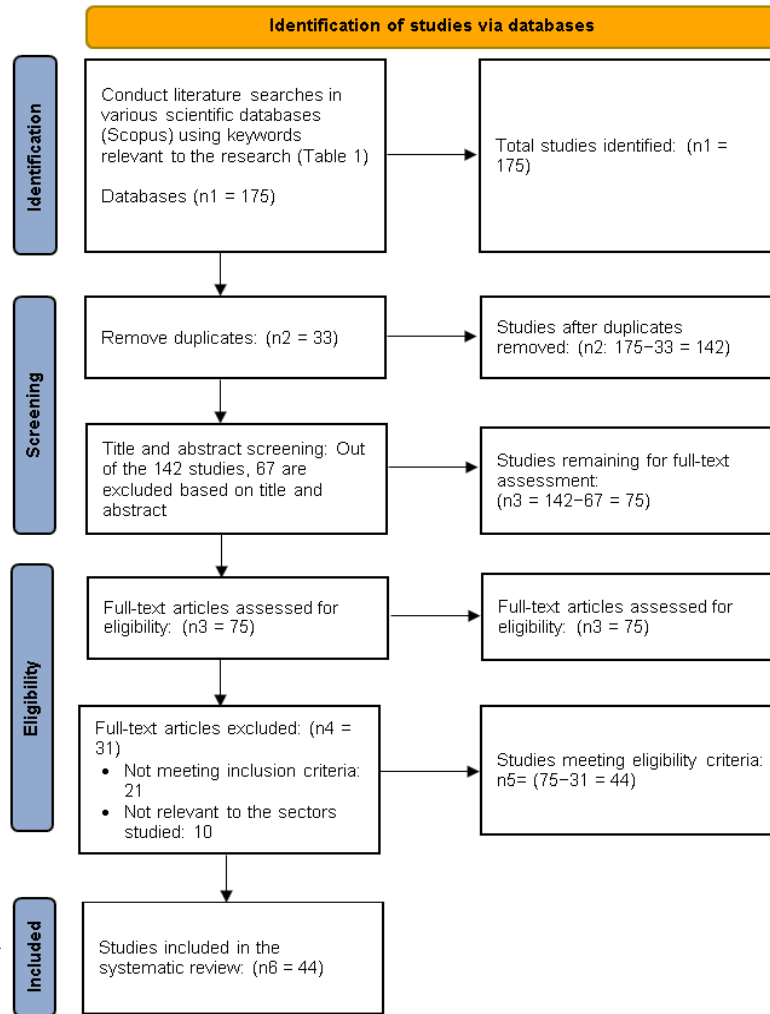
Figure 1. Study selection process using the PRISMA framework

Table 2. Article criteria using the PICOS framework

| PICOS framework | Description |
| --- | --- |
| Population | Health, agriculture, and infrastructure sectors; Geographical studies impacted by climate change; and Research with stakeholders like governments, communities, and institutions. |
| Intervention | Adaptation strategies in health, agriculture, and infrastructure sectors; Climate mitigation policies; and Technology use in climate adaptation. |
| Comparison | Analysis of adaptation strategies across sectors; Effectiveness comparison across regions; and Evaluation of different adaptation approaches. |
| Outcome | Identification of effective adaptation strategies; Insights on adaptation implementation; and Policy recommendations and best practices; and Research gaps and further research suggestions. |
| Study design | Systematic review of climate change adaptation in health, agriculture, and infrastructure; Study selection with inclusion/exclusion criteria; and Data analysis and synthesis from various studies. |

## 2.2. Inclusion and exclusion criteria

This comprehensive approach ensures that the selected studies are relevant, current, and provide a thorough examination of adaptation strategies to climate change in the specified sectors. By focusing on studies published between 2010 and 2024 and including various stakeholders, the review aims to capture the most recent and pertinent data. The exclusion of studies not directly related to the topic, those not available in full text, and those published before 2010 ensures a focused and high-quality dataset for analysis. By adhering to these inclusion and exclusion criteria, the review aims to provide a comprehensive and focused synthesis of the literature on climate change adaptation strategies. This structured approach ensures that the selected studies are relevant, current, and offer valuable insights into effective adaptation measures across the health, agriculture, and infrastructure sectors.

Figure 1 depicts the study selection process using the preferred reporting items for systematic reviews and meta-analyses (PRISMA) flowchart, outlining stages from identification to inclusion in the review. In the identification stage, literature searches in databases such as Scopus using relevant keywords yielded 175 studies. During the screening stage, 33 duplicate studies were removed, leaving 142 studies. Further title and abstract screening excluded 67 irrelevant studies, resulting in 75 studies for full-text assessment. In the eligibility stage, 75 full-text articles were assessed, and 31 were excluded, with 21 not meeting the inclusion criteria and 10 being irrelevant. This left 44 studies meeting the eligibility criteria. Finally, in the inclusion stage, these 44 studies were included in the systematic review.

## 3. RESULTS AND DISCUSSION

### 3.1. Insights into the successes and challenges in implementing adaptation strategies

#### 3.1.1. Co-occurrence network

The image presents a network map of keywords in climate change research, with "climate change" as the central, most connected node. This keyword is closely linked to topics such as "adaptive management," "agriculture," "human," and "humans," highlighting the main focus of research on adaptive management, the agricultural sector, and the impact of climate change on humans. The red cluster indicates the direct impacts of climate change, including "global warming," "vulnerability," and "risk assessment," while the blue cluster emphasizes human aspects and adaptive management, such as "food supply" and "ecosystem." The green cluster, which includes keywords like "livestock" and "Himalayas," points to specific contexts or regional case studies. The following flow can be seen in Figure 2.
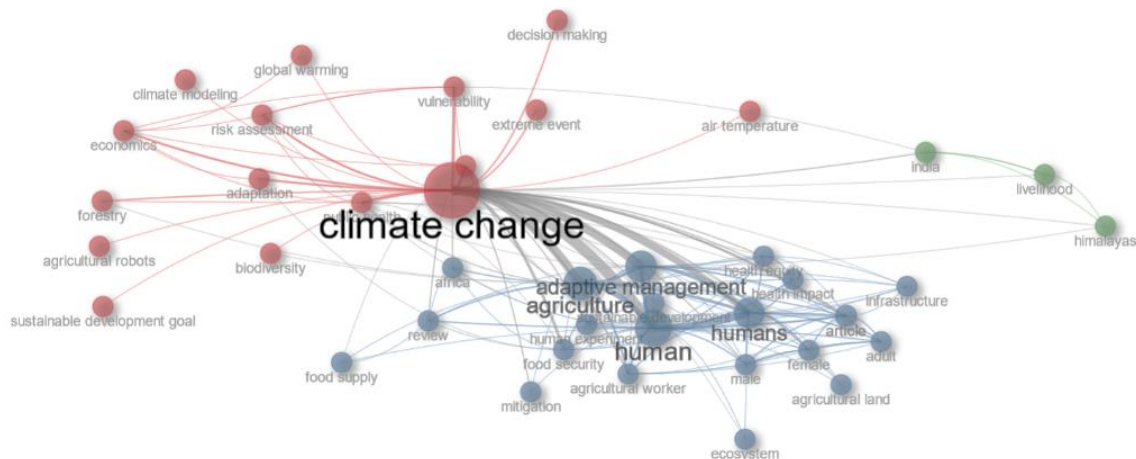


Figure 2. Co-occurrence network

This map reveals several key successes and challenges. Successes are evident in the implementation of adaptive management and improvements in food security within the agricultural sector, where flexibility and responsiveness are crucial. However, significant challenges arise from human vulnerability to climate change, particularly among vulnerable populations, and from the need to enhance decision-making processes and risk assessments. Moreover, these successes and challenges are heavily influenced by local and regional contexts, as illustrated by the focus on the Himalayas and the livestock sector. Thus, the image provides valuable insights into the focus of climate change research, highlighting key areas for intervention and improvement in adaptation strategies.

Table 3 provides quantitative insights into the significance of various keywords in climate change research based on metrics such as Cluster, Betweenness, Closeness, and PageRank. The keyword "climate change" stands out as the central node with the highest Betweenness, Closeness, and PageRank values, underscoring its pivotal role in connecting diverse research topics. Keywords like "public health," "vulnerability," and "adaptation" in Cluster 1 highlight the main focus of studies on the impacts of climate change and adaptive strategies. Cluster 2, containing terms such as "agriculture," "human," "adaptive management," and "food security," emphasizes adaptation efforts in the agricultural sector and the broader implications for human populations. Additionally, specific regional and contextual focus areas are reflected in Cluster 3, with keywords like "infrastructure" and "India." The high Betweenness values for keywords like "public health" and "drought" indicate their critical roles in linking various research topics. Similarly, the

significant Closeness values for "climate change," "public health," and "agriculture" suggest these topics' proximity to others, enabling quick connections within the research network. Overall, the high PageRank values for these keywords affirm their relative importance and centrality in climate change literature, aligning with the earlier visualization that demonstrated the research focus on adaptive management, agricultural impacts, and human vulnerability. This analysis highlights the interconnected nature of these research areas and the necessity for targeted interventions to address the multifaceted challenges of climate change adaptation.

Table 3. *CoWord_Network_Analysis*

| Node | Cluster | Betweenness | Closeness | PageRank |
|---|---|---|---|---|
| Climate change | 1 | 495.8485033 | 0.025641026 | 0.163417873 |
| Public health | 1 | 3.157273292 | 0.014925373 | 0.027528525 |
| Drought | 1 | 0.693802512 | 0.014084507 | 0.021328255 |
| Vulnerability | 1 | 0.793859649 | 0.01369863 | 0.019020984 |
| Adaptation | 1 | 0.142857143 | 0.013333333 | 0.011787689 |
| Biodiversity | 1 | 0 | 0.013157895 | 0.007412488 |
| Decision making | 1 | 0 | 0.012987013 | 0.006684617 |
| Economics | 1 | 2.399392097 | 0.014084507 | 0.021938642 |
| Extreme event | 1 | 0 | 0.012987013 | 0.006684617 |
| Global warming | 1 | 0 | 0.013157895 | 0.008037392 |
| Risk assessment | 1 | 0.441798112 | 0.013888889 | 0.019050691 |
| Air temperature | 1 | 0 | 0.012987013 | 0.005706411 |
| Climate modeling | 1 | 0 | 0.012987013 | 0.005706411 |
| Forestry | 1 | 0 | 0.013333333 | 0.010262633 |
| Sustainable development goal | 1 | 0 | 0.012987013 | 0.005706411 |
| Agricultural robots | 1 | 0 | 0.012987013 | 0.005706411 |
| Agriculture | 2 | 35.00950532 | 0.017857143 | 0.068243062 |
| Human | 2 | 41.89596313 | 0.018181818 | 0.078746419 |
| Adaptive management | 2 | 22.29126859 | 0.017241379 | 0.061112286 |
| Food security | 2 | 3.272154597 | 0.015151515 | 0.030601577 |
| Humans | 2 | 11.89174017 | 0.016393443 | 0.057568918 |
| Africa | 2 | 0 | 0.01369863 | 0.014651423 |
| Sustainable development | 2 | 0 | 0.013333333 | 0.010850809 |
| Agricultural worker | 2 | 0 | 0.014492754 | 0.025328205 |
| Health equity | 2 | 0.515758301 | 0.014925373 | 0.027362439 |
| Article | 2 | 2.416617542 | 0.015384615 | 0.035871366 |
| Ecosystem | 2 | 0 | 0.013333333 | 0.008990233 |
| Adult | 2 | 0 | 0.014492754 | 0.024363961 |
| Female | 2 | 0 | 0.014492754 | 0.024363961 |
| Food supply | 2 | 0 | 0.013513514 | 0.011026294 |
| Health impact | 2 | 0.515758301 | 0.014925373 | 0.027362439 |
| Human experiment | 2 | 0.222107508 | 0.014705882 | 0.022926897 |
| Infrastructure | 2 | 0 | 0.014285714 | 0.017531301 |
| Male | 2 | 0 | 0.014492754 | 0.024363961 |
| Mitigation | 2 | 0 | 0.013333333 | 0.010043396 |
| Review | 2 | 0.520075758 | 0.014084507 | 0.019611036 |
| Agricultural land | 2 | 0 | 0.013513514 | 0.010665893 |
| India | 3 | 0.660714286 | 0.013513514 | 0.016447192 |
| Livelihood | 3 | 0 | 0.013333333 | 0.012719718 |
| Himalayas | 3 | 0.31085044 | 0.013513514 | 0.013267168 |

### 3.1.2. Thematic map

The thematic map in Figure 3 reveals the development and relevance of various themes in climate change research, offering key insights into the successes and challenges of implementing adaptation strategies. Motor themes such as "sustainable development," "mitigation," "climate change," "human," and "agriculture" are positioned in the upper right quadrant, indicating that these topics are highly developed and very relevant. This reflects significant success in integrating adaptation strategies into sustainable development policies and agricultural practices. However, basic themes like "food security," "extreme event," "health equity," "drought," "vulnerability," and "adaptation," located in the lower right quadrant, while very relevant, still face substantial challenges in implementation. This underscores the importance of focusing on food security, health equity, and vulnerability reduction as areas that require more attention to overcome existing barriers. The following flow can be seen in Figure 3.

On the other hand, niche themes such as "decision making," "climate modeling," and "ecosystems," found in the upper left quadrant, show that these topics are highly developed but less relevant in the broader research context. This suggests that while important, decision-making and climate modeling need more

focused and contextual approaches in adaptation strategies. Meanwhile, emerging or declining themes like "resilience," "biodiversity," "hazard assessment," "heat wave," and "seasonal variation," located in the lower left quadrant, indicate areas that might be either emerging or declining in research focus. This points to potential new research areas or the need to reassess these themes to integrate the latest findings.

Overall, the thematic map provides a comprehensive overview of the successes and challenges in implementing climate change adaptation strategies. Successes are evident in the integration of adaptation into sustainable development and the agricultural sector, while major challenges remain in food security and vulnerability. More focused and contextual approaches are required for niche topics, and further attention should be given to emerging or declining themes to ensure effective and sustainable adaptation strategies.
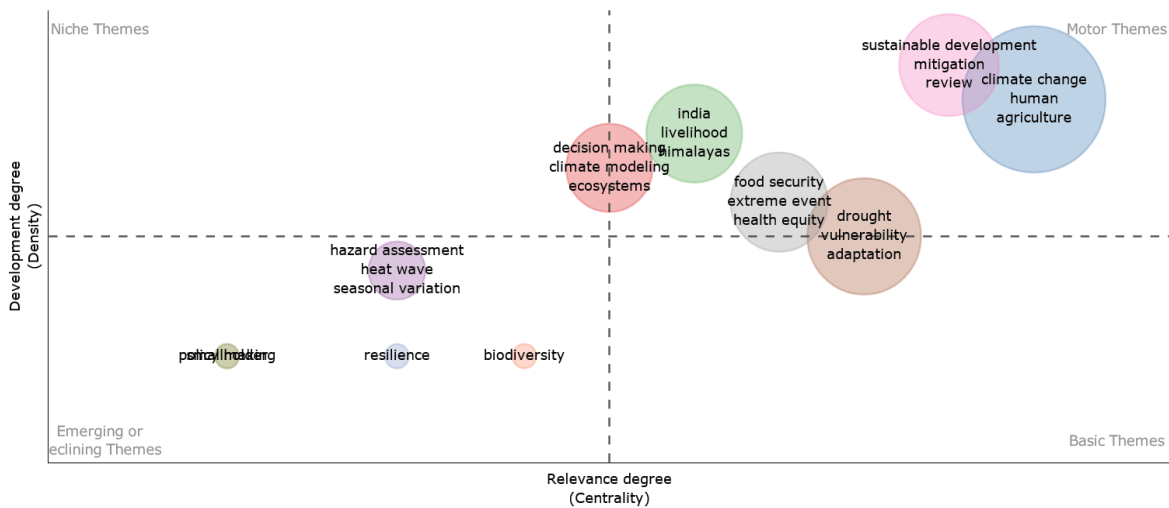


Figure 3. Thematic map visualization

Tables 4 and 5 detailed insights into the clustering and significance of various terms in climate change research, which deepens our understanding of the successes and challenges in implementing adaptation strategies. Table 4 highlights themes such as "climate change," "sustainable development," and "food security" as highly central and well-developed, indicating their crucial roles and extensive research focus. Themes like "decision making" and "India" also show significant centrality, underscoring their importance in the research landscape, though with varying levels of development.

Table 5 reveals that "climate change" dominates in terms of occurrences and centrality, reaffirming its pivotal role in the research network. Other important terms such as "agriculture," "human," "adaptive management," and "public health" are also prominent, reflecting their strong relevance and interconnections within the climate change discourse. These insights point to several successes in adaptation strategies, including the effective integration of climate adaptation into sustainable development and agricultural practices, as evidenced by their high centrality and density. The frequent occurrence of "adaptive management" further indicates the success of flexible and responsive strategies in addressing climate change impacts.

Table 4. *Thematic_Map_Clusters*

| Cluster | CallonCentrality | CallonDensity | RankCentrality | RankDensity | ClusterFrequency |
|---|---|---|---|---|---|
| Decision making | 3.472222222 | 112.3015873 | 6 | 8 | 16 |
| Climate change | 34.6878744 | 141.678601 | 11 | 10 | 107 |
| India | 6.673611111 | 122.8395062 | 7 | 9 | 22 |
| Hazard assessment | 0.75 | 83.33333333 | 3.5 | 5 | 6 |
| Policy making | 0 | 50 | 1.5 | 2.5 | 2 |
| Drought | 12.57222222 | 83.94907407 | 9 | 6 | 40 |
| Sustainable development | 13.37222222 | 161.3636364 | 10 | 11 | 25 |
| Food security | 9.060555556 | 108.2291667 | 8 | 7 | 23 |
| Smallholder | 0 | 50 | 1.5 | 2.5 | 2 |
| Biodiversity | 2.375 | 50 | 5 | 2.5 | 2 |
| Resilience | 0.75 | 50 | 3.5 | 2.5 | 2 |

Table 5. *Thematic_Map_Terms*

| Occurrences | Words | Cluster | *Cluster_Label* | *btw_centrality* | *clos_centrality* | *pagerank_centrality* |
|---|---|---|---|---|---|---|
| 23 | Climate change | 2 | climate change | 7940.81325 | 0.00304878 | 0.039669463 |
| 9 | Agriculture | 2 | climate change | 2032.161363 | 0.002645503 | 0.020418454 |
| 10 | Human | 2 | climate change | 2212.399376 | 0.002710027 | 0.022738247 |
| 9 | Adaptive management | 2 | climate change | 1556.774771 | 0.002506266 | 0.018147688 |
| 5 | Public health | 2 | climate change | 752.3687364 | 0.002217295 | 0.010337541 |
| 8 | Humans | 2 | climate change | 1349.835841 | 0.002457002 | 0.017648718 |
| 4 | Agricultural worker | 2 | climate change | 383.1690728 | 0.002267574 | 0.009120131 |
| 4 | Article | 2 | climate change | 385.4847483 | 0.002262443 | 0.010671177 |
| 2 | Ecosystem | 2 | climate change | 105.37032 | 0.001897533 | 0.004774153 |
| 3 | Adult | 2 | climate change | 228.0670899 | 0.002217295 | 0.008416216 |
| 2 | Air temperature | 2 | climate change | 141.6164357 | 0.002083333 | 0.004119337 |
| 3 | Female | 2 | climate change | 228.0670899 | 0.002217295 | 0.008416216 |
| 3 | Human experiment | 2 | climate change | 174.8304248 | 0.00203666 | 0.007141014 |
| 3 | Infrastructure | 2 | climate change | 63.69149764 | 0.002004008 | 0.005434113 |
| 3 | Male | 2 | climate change | 228.0670899 | 0.002217295 | 0.008416216 |
| 2 | Agricultural land | 2 | climate change | 37.49431568 | 0.001886792 | 0.00386828 |
| 2 | Built environment | 2 | climate change | 38.2719232 | 0.001964637 | 0.005134179 |
| 2 | Canada | 2 | climate change | 39.85636267 | 0.001934236 | 0.003662714 |
| 2 | Environmental health | 2 | climate change | 93.65801901 | 0.002096436 | 0.005908191 |
| 2 | Ontario [Canada] | 2 | climate change | 39.85636267 | 0.001934236 | 0.003662714 |
| 2 | Strategic approach | 2 | climate change | 10.60106637 | 0.001908397 | 0.002198944 |
| 2 | Temperature effect | 2 | climate change | 116.0393413 | 0.001915709 | 0.004517406 |
| 2 | Transportation | 2 | climate change | 72.36591085 | 0.002079002 | 0.003878708 |

However, the data also highlights ongoing challenges, particularly in ensuring food security and health equity amid climate impacts. Despite their relevance, these themes show varied levels of development, suggesting the need for continued focus to overcome barriers and enhance adaptive capacities. The significant centrality but lower density for "decision making" and "policy making" points to the critical yet underdeveloped nature of these areas, emphasizing the necessity for more comprehensive approaches. The importance of regional focus, illustrated by the centrality of "India," underscores the need for tailored, context-specific strategies to address local challenges and conditions. Overall, the analysis provides a comprehensive overview of climate change research, highlighting both the progress made and the obstacles that remain in adaptation strategies. These insights align well and offering a detailed understanding of the advancements and persistent issues in the field.

## 3.2. Policy recommendations and best practices
### 3.2.1. Most global cited documents

Table 6 highlights influential research papers in the field of climate change, offering valuable insights for formulating policy recommendations and identifying best practices. The table lists key papers along with their total citations, citations per year, and normalized citation counts, which reflect the impact and relevance of these studies.

Table 6. Most global cited documents

| Paper | Author | Total citations | TC per year | Normalized TC |
|---|---|---|---|---|
| Development of future heatwaves for different hazard thresholds | Vogel *et al.* [16] | 51 | 10.20 | 2.55 |
| Drivers and impacts of Eastern African rainfall variability | Palmet *et al.* [17] | 50 | 25.00 | 6.16 |
| Positive externalities of climate change mitigation and adaptation for human health: a review and conceptual framework for public health research | Bikomeye *et al.* [18] | 32 | 8.00 | 2.95 |
| Compound events and associated impacts in China | Hao [19] | 27 | 9.00 | 2.36 |
| Farmers' perceptions of climate change and adaptation behavior in Wushen Banner, China | Zhang [20] | 24 | 4.80 | 1.20 |
| Low impact development practices in the context of United Nations sustainable development goals: a new concept, lessons learned and challenges | Macedo *et al.* [21] | 23 | 7.67 | 2.01 |
| The synergistic relationship between climate change and the HIV/AIDS epidemic: a conceptual framework | Lieber *et al.* [22] | 22 | 5.50 | 2.03 |
| Livelihood vulnerability and climate change: a comparative analysis of smallholders in the Indo-Gangetic plains | Venus *et al.* [23] | 22 | 7.33 | 1.93 |
| Climate change policies in 16 West African Countries: a systematic review of adaptation with a focus on agriculture, food security, and nutrition | Sorgho *et al.* [24] | 20 | 4.00 | 1.00 |
| Knowledge for a warmer world: a patent analysis of climate change adaptation technologies | Hötte and Jee [25] | 18 | 6.00 | 1.58 |

For Vogel *et al.* [15] on "Development of future heatwaves for different hazard thresholds" and Palmer *et al.* [16] on "Drivers and impacts of Eastern African rainfall variability" are among the most cited, indicating significant contributions to understanding climatic extremes and variability. These studies emphasize the importance of preparing for and mitigating the impacts of extreme weather events, suggesting that policies should focus on enhancing resilience and adaptive capacity in vulnerable regions. Similarly, Bikomeye *et al.* [17] highlight the "Positive externalities of climate change mitigation and adaptation for human health," underscoring the interconnectedness of climate actions and public health benefits. This suggests a holistic approach to policy-making, integrating health and environmental strategies to maximize co-benefits. Research by Zhang *et al.* [19] on "Farmers' perceptions of climate change and adaptation behavior in Wushen Banner, China" and de Macedo *et al.* [20] on "Low impact development practices" provide insights into local adaptation practices and sustainable development goals. These studies emphasize the need for policies that support sustainable agricultural practices and low-impact development, fostering local-level adaptations that are context-specific and community-driven. Hao [18] on "Compound events and associated impacts in China" and Venus *et al.* [22] on "Livelihood vulnerability and climate change" further illustrate the complex interactions between climate phenomena and socio-economic vulnerabilities. Policies should therefore focus on integrated risk management approaches that consider multiple stressors and their compounded effects on livelihoods.

Lieber *et al.* [21] and Sorgho *et al.* [23] highlight the importance of addressing the synergistic relationships between climate change and other social issues, such as public health crises and food security. These papers call for comprehensive policy frameworks that address the multifaceted nature of climate impacts, promoting resilience through diversified and inclusive strategies. Finally, Hötte and Ziet [24] emphasize the importance of advancing climate adaptation technologies, suggesting that innovation and technology transfer should be key components of policy frameworks to enhance adaptive capacities globally. The analysis of the most cited documents reveals key themes and areas of overlap in climate change research, such as the importance of resilience, health co-benefits, sustainable agricultural practices, and integrated risk management. These insights can inform policy recommendations, emphasizing the need for holistic, context-specific, and innovative approaches to effectively address the multifaceted challenges of climate change [26].

Table 7 reinforces the findings from the previous tables and provides deeper context for policy recommendations related to climate change. Terms such as "climate change" (43 occurrences), "agriculture" (14 occurrences), and "human" (10 occurrences) frequently appear, emphasizing that climate change, the agricultural sector, and its impact on humans are major focuses in research. This aligns with the "Most global cited documents" table, which shows these topics receive significant attention in academic literature. The terms "adaptive management" (9 occurrences) and "public health" (9 occurrences) also appear frequently, highlighting the importance of adaptive management and public health in the context of climate change. This reflects the need for policies that incorporate flexible and responsive adaptation while considering the health impacts of climate change, as discussed in Bikomeye *et al.* [17]. Words such as "food security" (8 occurrences) and "drought" (6 occurrences) underscore key challenges faced in climate change adaptation. Food security and drought are critical issues that require special attention in adaptation policies, consistent with the studies by Zhang *et al.* [19] and Venus *et al.* [22], which address livelihood vulnerabilities and farmer adaptation.

The term "sustainable development" (6 occurrences) indicates that sustainable development remains a significant theme in climate change discourse. This supports the findings from de Macedo *et al.* [20], which emphasize low-impact development practices as part of sustainable development goals. The high frequency of these words in the research literature reinforces the importance of these topics and highlights the main areas of focus that should be prioritized in policy-making. This supports policy recommendations that emphasize holistic, context-specific, and innovative approaches to address the multifaceted challenges of climate change and ensure the success of adaptation strategies.

Table 7. Most frequent words

| Words | Occurrences |
|---|---|
| Climate change | 43 |
| Agriculture | 14 |
| Human | 10 |
| Adaptive management | 9 |
| Public health | 9 |
| Food security | 8 |
| Humans | 8 |
| Africa | 6 |
| Drought | 6 |
| Sustainable development | 6 |

### 3.2.2. WordCloud

The WordCloud in Figure 4, generated from different fields such as "keywords plus", "author's keywords", and "abstracts", visually reinforce the findings from the "most frequent words" table and other analyses. In all three-word clouds, "climate change" and "adaptation" stand out prominently, highlighting their central role in the research discourse. In Figure 4(a), terms like "agriculture," "adaptive management," "public health," "food security," and "sustainable development" are highly visible, corroborating the frequent occurrence of these terms identified in the "Most frequent words" table. This indicates that these topics are not only central but also widely recognized in various research contexts, aligning with the importance of integrating adaptation strategies into agricultural practices and public health initiatives. The author's keywords WordCloud in Figure 4(b) similarly emphasizes "climate change" and "adaptation," along with related terms such as "resilience," "agriculture," "public health," and "food security." This visualization underscores the key challenges and focus areas in adaptation strategies, reaffirming the need for policies that address resilience building, health impacts, and food security in the face of climate change. The abstracts WordCloud in Figure 4(c) provides a broader context, with "climate change adaptation," "climate change policy," and "sustainable development goals" appearing prominently. This highlights the interconnectedness of policy frameworks and adaptation efforts, suggesting that successful implementation of adaptation strategies requires comprehensive policies that align with sustainable development goals and mitigation efforts.



(a)                                                                 (b)



(c)
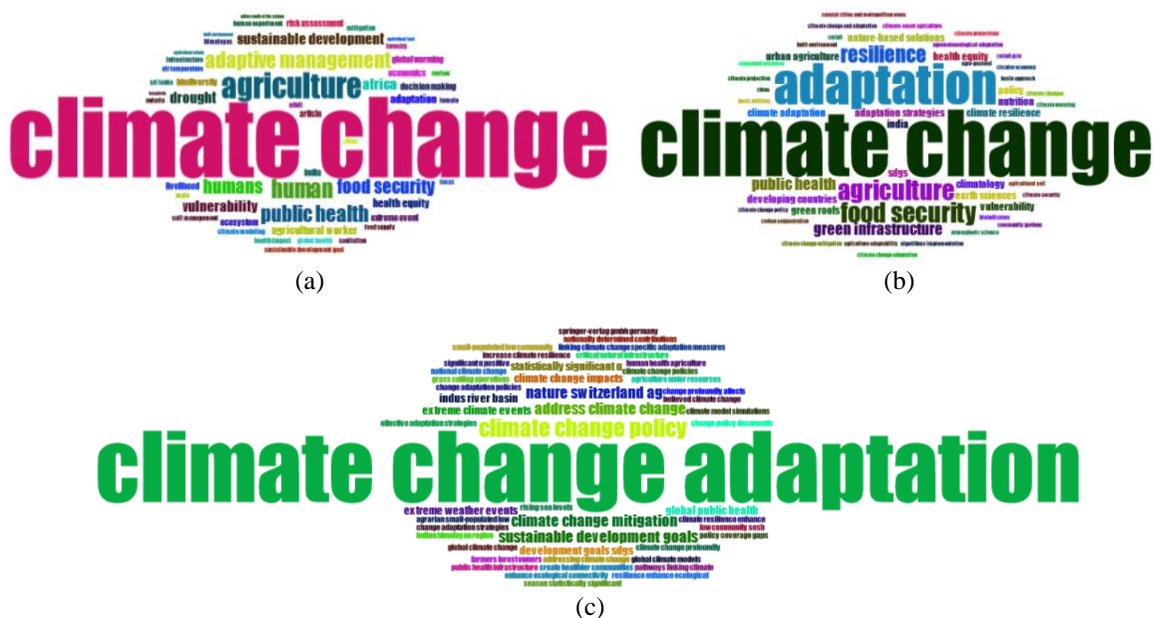
Figure 4. WordCloud uses various fields (a) field by keywords plus, (b) field by author's keywords, and (c) field by abstracts

The WordCloud reinforce the textual analysis by visually demonstrating the prominence and interconnectedness of key themes such as climate change, adaptation, agriculture, public health, food security, and sustainable development. These visualizations support the policy recommendations that emphasize holistic, context-specific, and innovative approaches to effectively address the multifaceted challenges posed by climate change and ensure the success of adaptation strategies. The following flow can be seen in Figure 5.

Figure 5 solidifies the key themes identified in the previous analyses and visually represents the frequency and importance of various topics in climate change research. "Climate change" is prominently featured, occupying 17% of the total area, highlighting its central role in the research landscape. Other significant themes include "agriculture" (6%), "public health" (4%), "human" (4%), "adaptive management" (4%), and "food security" (3%). These align closely with the dominant themes identified in the word clouds and the "Most Frequent Words" table, emphasizing the interconnectedness of these issues. The tree map in Figure 5, alongside the previous analyses, provides a comprehensive overview of the key themes in climate change research, offering clear insights into the areas that need focused attention in policy-making. This

approach ensures that best practices are grounded in the most critical and frequently discussed themes in the research landscape, effectively addressing the policy recommendations and best practices.
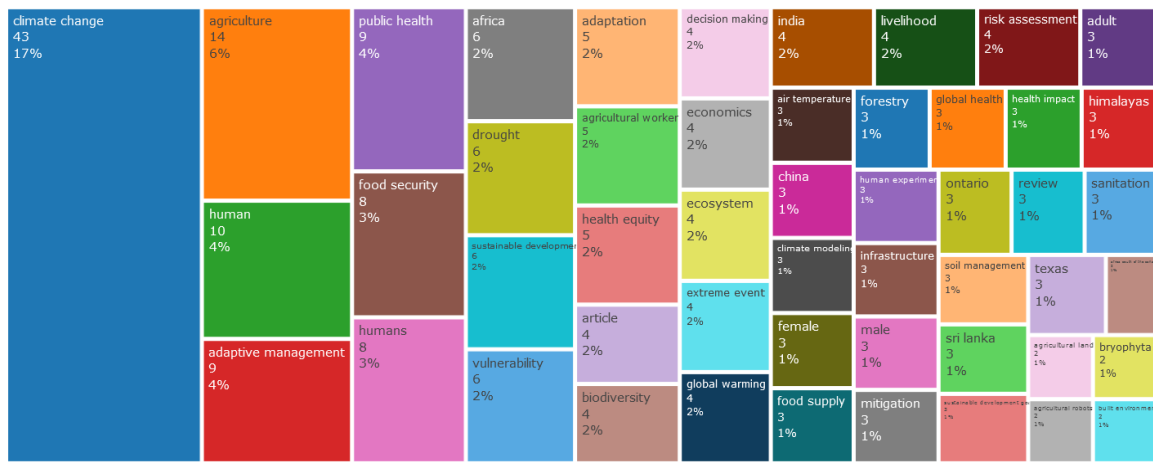


Figure 5. TreeMap

## 3.3. Identification of research gaps

The diagram in Figure 6 illustrates the flow connecting various research topics (ID) with publication journals (SO) and main themes (*TI_TM*). This diagram can be used to identify research areas that receive less attention or studies that have not been adequately integrated with other topics. The following flow can be seen in Figure 6.
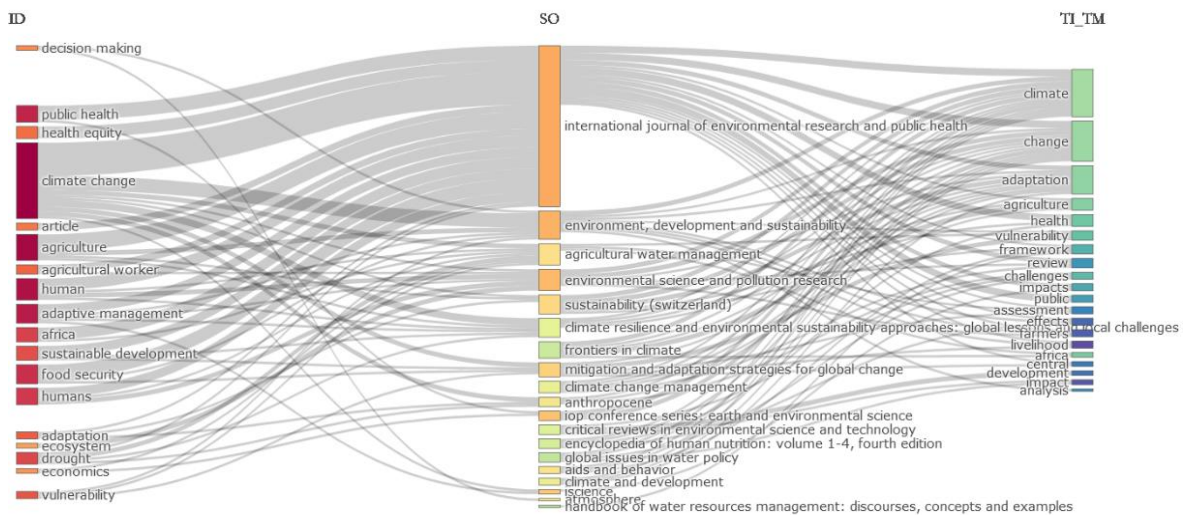


Figure 6. Three-field plot by keyword plus–sources–titles

Topics like "climate change," "public health," "adaptive management," and "food security" show strong connections with multiple journals and main themes, indicating that these areas are well-established and receive significant research attention. In contrast, topics such as "agricultural worker," "sanitation," "health equity," and "vulnerability" have fewer and weaker connections, suggesting that these areas may be under-researched and need more focus in climate change studies. The topic of "agricultural worker," while important, seems to receive less attention in research, indicating a need for further studies to understand the impact of climate change on agricultural workers and the potential adaptations. Similarly, sanitation, a crucial aspect of public health affected by climate change, is under-researched, highlighting the need for studies to explore its impact and effective adaptation strategies. Health equity, a critical issue particularly in the context

of climate change exacerbating existing inequalities, shows weak links with major journals, suggesting a need for deeper studies on how adaptation policies can be designed to reduce health inequalities. The topic of vulnerability to climate change, although frequently mentioned, appears to be less thoroughly researched, necessitating a focus on vulnerable populations and how they can be protected through effective adaptation strategies.

Figure 7 shows the distribution of various climate change research topics based on two main dimensions (Dim 1 and Dim 2). Each point represents a keyword or research theme, and its position and distance from the center indicate the frequency of occurrence and its interconnectedness with other themes. This helps identify areas that are under-researched or require more attention in studies. The following flow can be seen in Figure 7.
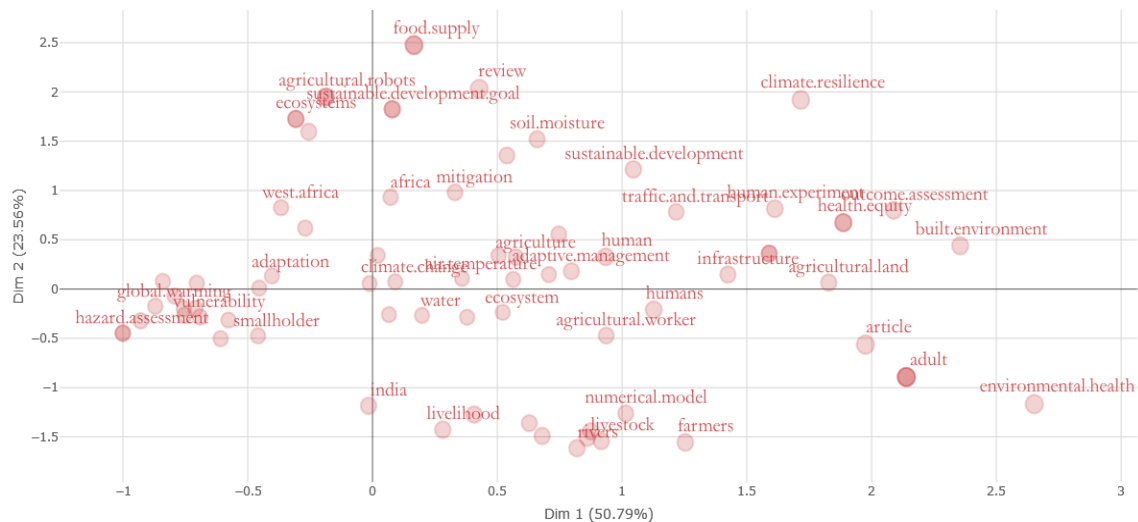


Figure 7. Factorial analysis with word map

The scatter plot as shown in Figure 7 reveals the distribution of key topics in climate change research, enabling us to identify significant research gaps. Central topics like "climate change," "sustainable development," "public health," and "adaptive management" are clustered near the center, indicating they are frequently researched and strongly interconnected with other themes. This reflects extensive attention and in-depth studies in these areas.

However, several topics are positioned on the periphery, suggesting they receive less attention in research. Topics such as "agricultural worker," "sanitation," "livelihood," and "smallholder" are distant from the center, indicating they are less frequently studied or poorly integrated with other themes. This highlights the need for more focused research to understand the impacts of climate change and develop effective adaptation strategies for these areas.

Additionally, topics like "hazard assessment" and "resilience" are also on the outskirts, suggesting the need for more comprehensive studies to develop robust risk assessment methods and effective resilience strategies. "Climate resilience," despite its importance, appears to be insufficiently integrated with other main research themes, indicating opportunities for further exploration. The following flow can be seen in Figure 8.

The dendrogram shows the hierarchical relationships among various climate change research topics, identifying clusters of frequently co-occurring themes. Key topics such as "climate change," "public health," "adaptive management," and "food security" are central and highly interconnected with other areas. Large clusters likely include frequently discussed topics like "climate change," "agriculture," and "sustainable development," indicating their prominence and interconnectedness. In contrast, less-researched topics like "agricultural worker," "sanitation," and "livelihood" appear in smaller, isolated clusters, highlighting their infrequent mention and weaker connections to main themes.

The dendrogram also helps identify research gaps, with smaller, isolated clusters indicating topics needing more attention. For example, "hazard assessment" and "resilience," found on the periphery in previous analyses, likely form isolated clusters, showing their importance but incomplete integration into mainstream research. By identifying less-connected and smaller clusters, we can focus on under-researched areas, guiding future research efforts to enhance understanding and develop effective adaptation policies.
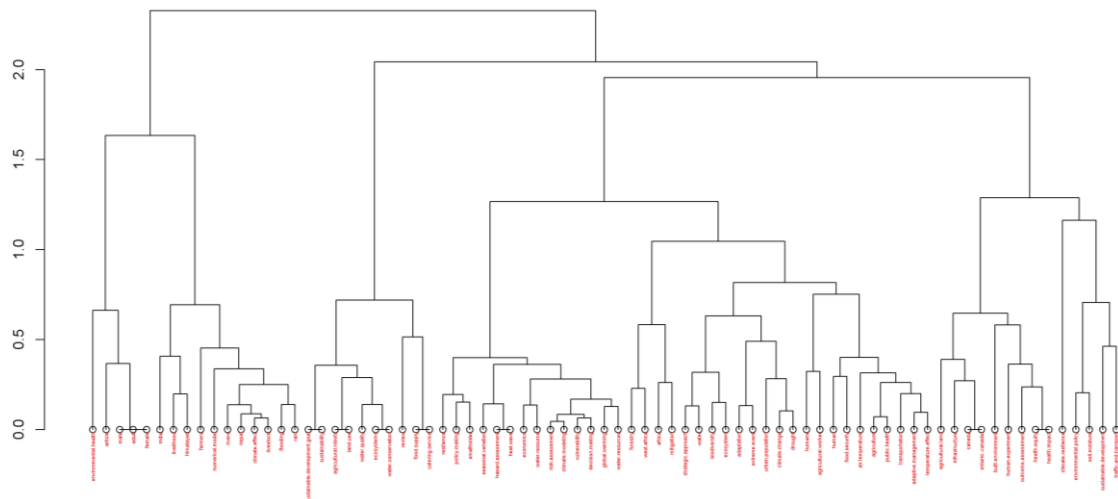
Figure 8. Factorial analysis with topic dendrogram

## 4.    CONCLUSION

The systematic literature review highlights the central themes in climate change research, such as climate change, agriculture, human impacts, adaptive management, and food security. These themes are well-developed and highly relevant, reflecting the extensive attention they receive in academic literature. The frequent occurrence of terms like adaptive management and public health indicates the importance of flexible strategies and health considerations in adaptation efforts. However, significant research gaps exist in areas like health equity, sanitation, and the impact of climate change on agricultural workers. These gaps suggest a need for more focused research and comprehensive policy frameworks that address these critical yet underexplored areas. The thematic map and network analyses reveal the interconnectedness of key research themes, with sustainable development and agriculture prominently featured as motor themes. Basic themes such as food security and health equity, while relevant, face substantial challenges in implementation. The identification of niche and emerging themes provides a roadmap for future research, highlighting areas that require more attention and integration into the broader climate change discourse. The review underscores the importance of holistic and context-specific approaches in developing climate change adaptation strategies. By addressing the identified research gaps and focusing on underexplored areas, researchers and policymakers can enhance the effectiveness of adaptation measures and ensure resilience in the face of climate change. This comprehensive overview serves as a valuable resource for guiding future research and informing policy decisions, ultimately contributing to sustainable development and improved adaptive capacities globally.

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