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Exploring the complex nexus of climate change, food security, and public health: A scientific perspective through bibliometric analysis

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ABSTRACT

Climate change poses a significant threat to food security and public health, with potential impacts on nutrition, food safety, and the spread of diseases. Through a comprehensive bibliometric analysis using VOSviewer software and Scopus database algorithms spanning the years 2007–2023, this study aims to explore the complex interactions among public health, food security, and climate change. Key disciplinary intersections were identified in Environmental Science, Agricultural and Biological Sciences, Medicine, and Social Sciences. Scarborough, P., stood out as a notable contributor. The research landscape on this multifaceted nexus was explored through co-occurrence network mapping and keyword cluster classification. As a result, six primary research clusters were delineated, including climate change vulnerability and health adaptation, climate-resilient agriculture for sustainable food security, balancing nutrition and environmental footprint; epidemiological insights based on climate, dietary, and gender changes, aquaculture's role in global food systems and public health, and food insecurity-public health challenges. This thorough analysis reveals the current research trends, ranging from general viewpoints on food security and climate change to more focused domains like agriculture, the environment, human health, and nutrition, frequently mediated by adaption techniques. Furthermore, the results underscore the need for interdisciplinary cooperation and stakeholder involvement in the execution of successful sustainability initiatives.

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1. Introduction

Earth's changing climate patterns have direct and indirect effects on agricultural systems, subsequently influencing food production, availability, and accessibility (Farooq et al., 2022). Adverse weather conditions, including prolonged droughts, extreme heatwaves, and more frequent natural hazards, pose challenges for farmers, compromising crop yields and quality (Motha, 2011). Consequently, the nutritional composition of crops is likely to be altered, affecting the overall health outcomes of populations that rely on these staple foods (Samuel S Myers et al., 2017). Moreover, climate change brings about temperature increases, precipitation changes, sea level rise, and extreme weather occurrences (Levy et al., 2017), leading to various public health issues such as heat-related diseases, respiratory and allergy problems, infectious diseases, malnutrition due to lack of food security, and mental health disorders.

Climate change's complex interactions with food systems exacerbate food insecurity through impacts on food availability, access, utilisation and stability (Gregory et al., 2005). These disruptions have the potential to worsen existing nutritional challenges, particularly in vulnerable populations with limited resources and inadequate access to diverse food sources. Furthermore, climate change impacts extend to the availability and quality of freshwater resources, which are crucial for sustainable agriculture and maintaining food security. Changes in precipitation patterns, melting glaciers, and rising sea levels contribute to water scarcity and contamination, directly influencing food production, processing, and sanitation practices (Handisyde et al., 2006). Consequently, compromised water quality poses a significant risk to public health, increasing the likelihood of waterborne diseases and malnutrition.

Climate change is primarily driven by anthropogenic greenhouse gas (GHG) emissions that have increased since pre-industrial era, largely due to economic and population growth. This has led to rising concentrations of carbon dioxide (CO2), methane CH4, and nitrous oxide N2O in the atmosphere, mainly from activities such as industrialization, urbanization, vehicle use, and agriculture, resulting in increased CO2 emissions and temperature from fossil fuel combustion (Marescaux et al., 2018; Nayak et al., 2020). Cumulatively, anthropogenic CO2 emissions to the atmosphere reached be 59 ± 6.6 GtCO2-eq9 in 2019, about 12 % (6.5 GtCO2-eq) higher than in 1990 with the largest share and growth in gross GHG emission (IPCC, 2023).

The consequences of climate change include extreme weather events such as droughts, floods, heavy precipitation, storms, and sea-level rise, which directly impact food security, particularly for staple crops like rice, wheat, and corn (Shahen, 2020; Sirba and Chimdessa, 2021). According to the Intergovernmental Panel on Climate Change (IPCC), a global temperature increases of 4°C or higher could significantly challenge food supply, particularly for weather-dependent crops like rice (IPCC, 2022). According to the Intergovernmental Panel on Climate Change (IPCC), a global temperature increases of 4°C or higher could significantly challenge food supply, particularly for weather-dependent crops like rice (IPCC, 2014). Molotoks et al., (2021), found that each degree Celsius increase in average global temperature could lead to a 3.1–7.4 % drop in crop productivity. The repercussions extend to food systems, potentially exacerbating competition for resources and leading to negative impacts on public health, especially in countries where rice is a staple food.

Food security, defined as the consistent access to sufficient, safe, and nutritious food, is essential for population health. Malnutrition in all its forms, including undernutrition, hunger, and micronutrient deficiencies, is closely linked to food insecurity. Recognizing the urgency of addressing malnutrition globally, the United Nations declared 2016–2025 as the Nutrition Decade of Action (also known as the Nutrition Decade), with nutrition integrated into Sustainable Development Goal 2 (Target 2.2: Ending all kinds of malnutrition by 2030). These surpass the six worldwide objectives, also called "global targets," that the World Health Assembly established for diet-related non-communicable diseases (NCDs) and the nourishment of expecting mothers, infants, and newborns to achieve the third Sustainable Development Goal (SDG no. 3) of good health and well-being by 2030 (Mohamad et al., 2023).

Given the complex interplay between climate change, food nutrition, and public health, there is a need for interdisciplinary research to understand the underlying mechanisms and implications. Recent studies have increasingly focused on this nexus (Cauchi et al., 2019; Janes, 2010; Lake et al., 2012; Schnitter and Berry, 2019; Zewdie, 2014), highlighting the importance of collaborative efforts among experts from climate science, nutrition, public health, agriculture, policymaking. To contribute to this understanding, we aim to explore emerging research trends through bibliometric analysis, examining the complexities and implications of the climate change-food nutrition-public health. By conducting a comprehensive review of peer-reviewed English articles from the SCOPUS database, we will analyse existing literature to elucidate the intricate relationships between these domains and propose evidence-based strategies to mitigate adverse impacts.

2. Methodology

2.1. Search strategy and quantitative bibliographic output

In fulfilling the objective of conducting bibliometric analysis based on published studies, it is essential assess research results and influence through citations (Khalil and Gotway Crawford, 2015). While databases like PubMed (https://pubmed.ncbi.nlm.nih.gov/), Google Scholar (https://scholar.google.com/), and Web of Science (https://www.webofscience.com/wos) are widely used, Scopus (https://www.scopus.com), is considered the most important due to its extensive coverage across disciplines (David et al., 2022). For this reason, the Scopus was utilized to identify relevant papers, focusing exclusively on journal research articles. To ensure the thoroughness of the search, only journal articles were included for analysis. A deliberate search strategy was employed, scanning titles, abstracts, and keywords within the code field, using focused phrases related to climate change, food security, and public health.

To identify relevant documents, the Scopus database was queried using a specific search algorithms: TITLE-ABS-KEY(("Climat* chang*" OR "global warming" OR "climat* variabilit*" OR "climate disaster*" OR "climat* risk*" OR "climat* extrem*" OR "greenhouse effect*" OR "climat* uncertaint*") AND ("food system" OR "food security" OR "nutrition*" OR " food availabl*" OR "food vulnerability*" OR "food access*" OR "food limitation" OR "food suppl*") AND ("human health" OR "health*" OR "public health" OR "healthcare" OR "health condition*" OR "health outcome*" OR "health stabilit*" OR "health communit*")). To prevent bias and to ensure consistency, as bibliometric databases are continuously updated, the search was fixed on January 14, 2024. The total number of documents found in the SCOPUS database were 4328.

All documents were reviewed sequentially. The initial screening process comprised selecting only the type of documents that were expressly chosen for the article type (n = 2263). The subsequent screening centred on the articles' language. 15 different languages were represented, with English being the most utilized language with around 96.5 percent of published works being in that language. This study was therefore restricted to the English language. Then, as for source type screening, we limited only from journal types (2132 documents) instead of book series (43 documents), trade journal (5 documents), and book (3 documents).

According to publication stage by Scopus database, we included both "final stage" (2102 documents) and "article in press stage" (30 documents). The section "Articles in Press" includes peer-reviewed and accepted articles that will be published in journal. The "Article in Press" edition will be taken down from this area and published in the related journal issue once the finished piece is allocated to an issue of the

publication. Next, Scopus, the data plug-in for the bibliography analysis allowed for the direct download of the quantitative output analysis data. Then, we integrated it with the usage of the Scopus and Clarivate Journal Citation Reports (JCR) database in order to determine the journal impact factor (JIF) and citescore of selected journals.

2.2. Bibliometric analysis and mapping using VOSviewer

Bibliometric analysis is the use of statistically based techniques to quantify and examine the existing publications in order to identify the trends and patterns in academic research of the topic (Chen et al., 2019). Thus, in this study, we explored the intricate relationship between food security, public health, and climate change through the VOSviewer program (version 1.6.18). This software utilizes bibliographic data sets to conduct statistical analysis and generate visual maps, offering insights into keyworks, notable researchers, research trends, and connections across various fields of study. Through the VOSviewer program, we also conducted co-occurrence analysis to identify the most frequently occurring terms in the literature related to public health, food security, and climate change. Additionally, we employed cluster analysis to classify publications into groups based on their citation patterns, thereby gaining insights into the multidisciplinary and interdisciplinary nature of these three keywords. Our methodology, outlined in Fig. 1, provides a detailed description of our approach.

3. Results and discussion

3.1. Pattern in the yearly development of publications

The final assessment of the Scopus database yielded 2132 articles addressing the intricate relationship between climate change, food security, and public health. Despite searching for publications spanning every year, the results of the keyword search reveal a single publication dating back to 1969. The trend depicted in Fig. 2 indicates that publications remained relatively consistent until 2007 when there was a notable increase, with over 10 papers (13 articles) published in that year alone. Subsequently, the number of publications gradually increased, demonstrating a steady rise in interest in the topic from 2007–2023.

3.2. Heterogeneity subject area based on Scopus categories

A treemap of the first 25 subject area variability categories in the Scopus database analysis was shown in Fig. 3. The most prominent categories include Environmental Science (780 documents), Agricultural and Biological Sciences (637 documents), Medicine (503 documents), Social Sciences (426 documents). Further categories include Nursing (155 documents), Energy (154 documents), Biochemistry, Genetics and Molecular Biology (149 documents), Earth and Planetary Sciences (145 documents), Engineering (121 documents), Economics, Econometrics and Finance (79 documents), Multidisciplinary studies (78 documents).

Other notable categories represented in the treemap are Business, Management and Accounting (70 documents), Immunology and Microbiology (56 documents), Computer Science (47 documents), Veterinary (43 documents), Arts and Humanities (39 documents). Further down the list, we found Chemistry (33 documents), Pharmacology, Toxicology and Pharmaceutics (29 documents), Health Professions (24 documents), Psychology (22 documents), Decision Sciences (20 documents), Chemical Engineering (18 documents), Physics and Astronomy (11 documents), Mathematics (10 documents), Neuroscience (10 documents), Materials Science (8 documents), and Dentistry (3 documents). While the treemap visualizes the distribution across various subject areas, it is evident that Environmental Science, Agricultural and Biological Sciences, Medicine, and Social Sciences emerge as the most significant categories.

3.3. Authorship-most active authors

Over the course of the 55-year study period, 2111 authors in all conducted research on climate change, food security, and public health; 15 of them published at least seven research articles. Table 1 displays the top fifteen authors who are incredibly productive. Regarding the countries of origin of these top 15 writers, there are four from the United States, six from the United Kingdom, two from Australia, one each from Germany, Canada, and France. The most prolific author on the subject of the research is Fanzo, J., with 14 papers. The next most productive authors are Friel, S. (13 articles, H-index: 57), Springmann, M. (12

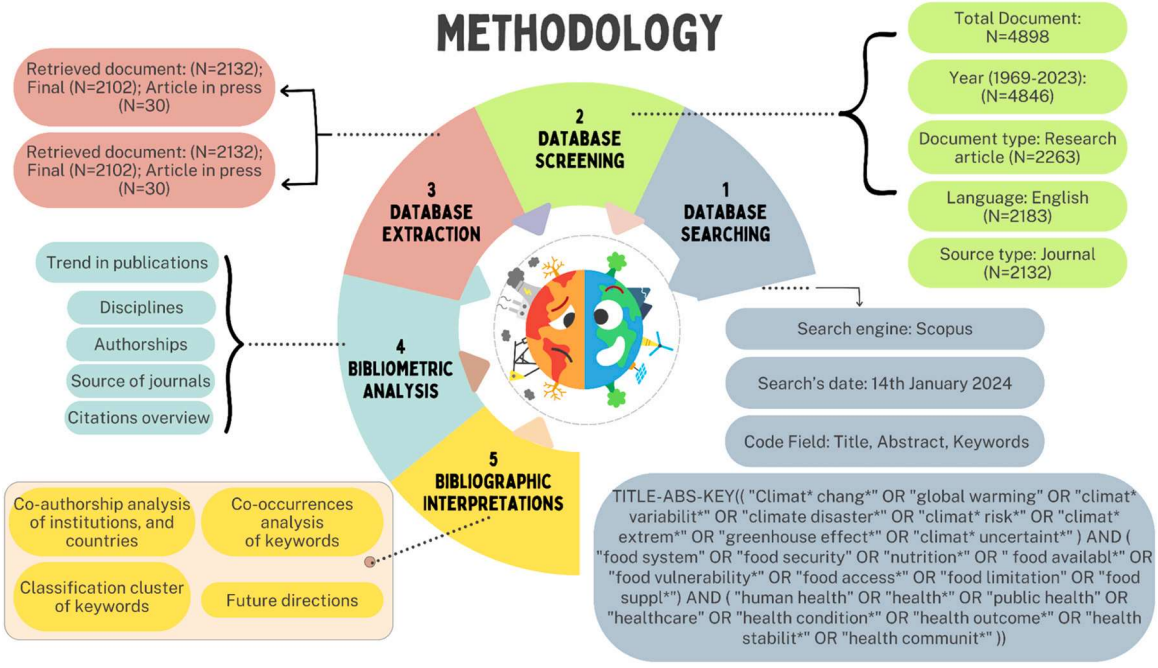


Fig. 1. Schematic design in exploring the complex nexus of climate change, food security, and public health.Schematic design illustrating the interplay between climate change, food security, and public health, highlighting the complex nexus among these interconnected factors.

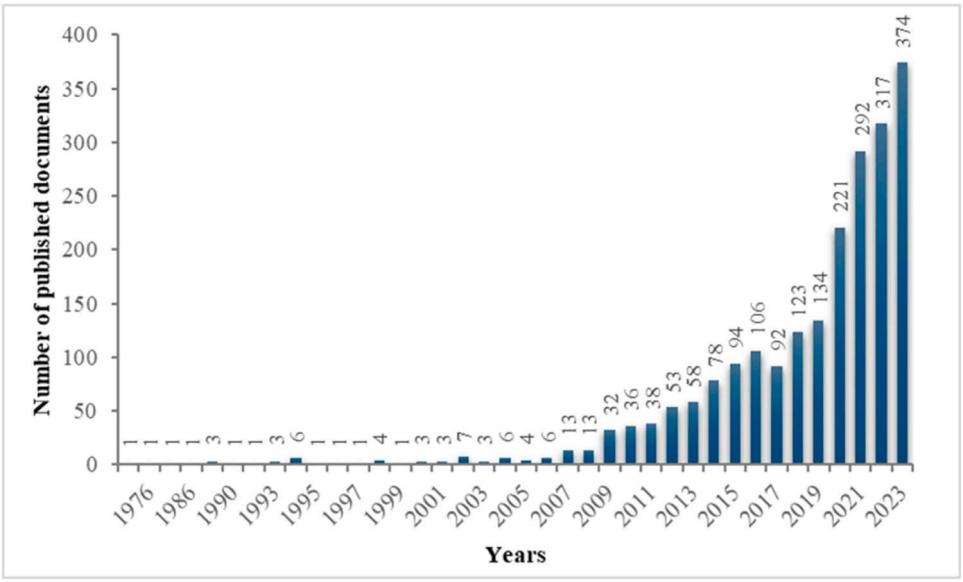


Fig. 2. Annual number of publications related to climate change, food security, and public health based on years (1969–2023). Graph depicting the annual number of publications concerning climate change, food security, and public health from 1969 to 2023, providing insight into the trends and evolution of research in these interconnected fields over time.

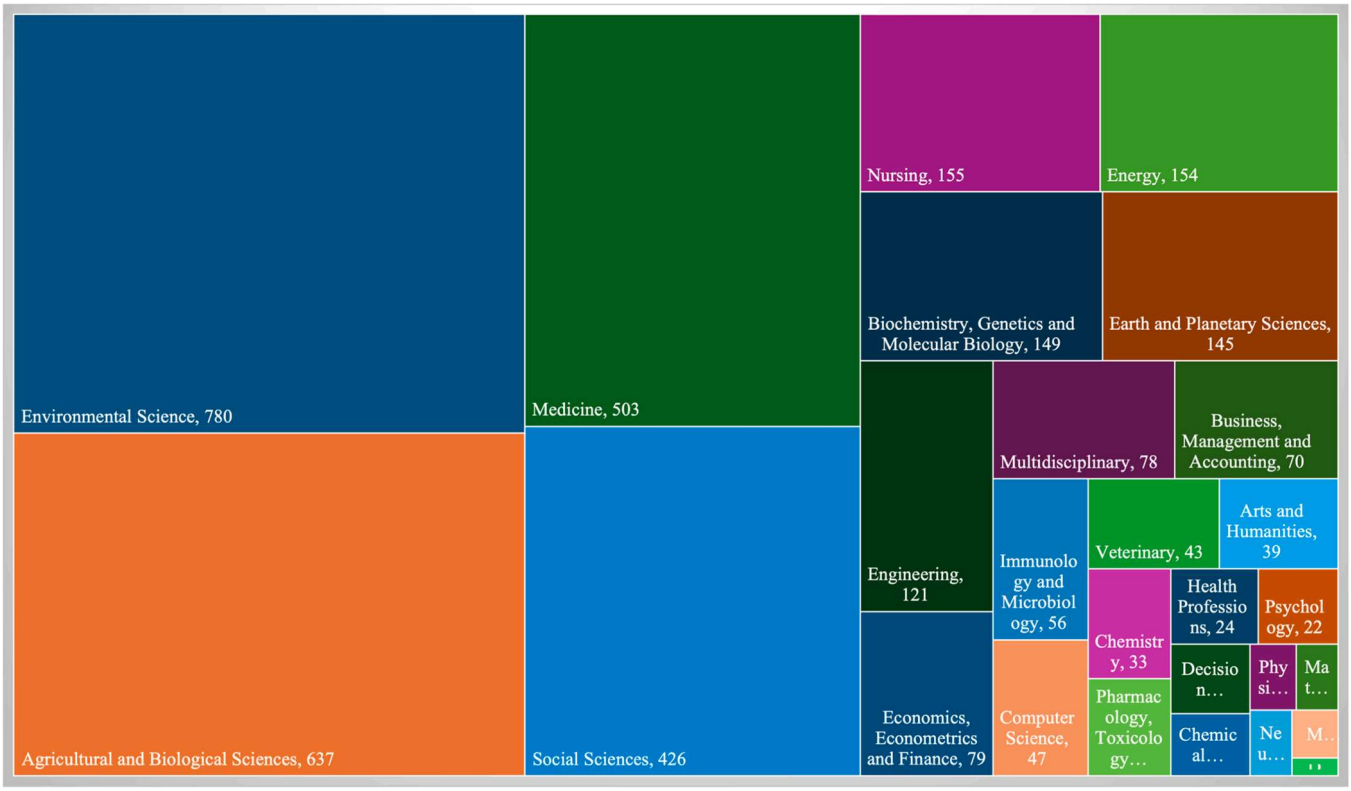


Fig. 3. Tree map of the first 25 subject areas based on SCOPUS categories. Related to climate change, food security, and public health from 1969 to 2023. Treemap visualizing the distribution of the first 25 subject areas based on SCOPUS categories related to climate change, food security, and public health research from 1969 to 2023, offering a comprehensive overview of the primary research focus areas within these interconnected fields over the specified timeframe.

articles, H-index: 26), Sauerborn, R. (11 articles, H-index: 48), and Scarborough, P. (11 articles, H-index: 58).

Nevertheless, different results were found based on the authors' publication ratios. The publishing ratios provide a percentage-based representation of the authors' respective contributions to papers published on the topic in relation to their publications on other subjects. Table 3 shows that Grace, K., Harper, S.L., and Springmann had the highest publishing ratios among the top three authors, with scores of 66.67 %, 36.36 %, and 22.22 %, respectively. Furthermore, it is evident that although Fanzo, J. (H-index 48) authored the greatest number of articles about the climate change, food security, and public health, the proportion of his publications on the topic is rather small—roughly

Table 1
The fifteen most active authors on the study's topic in relation to the total number of papers published.

Authors	Articles on the topic	Total articles	Ratio of article (%)	Total citations of the author	H-index	Affiliation
Fanzo, J.	14	190	7.37	26,571	48	Columbia University, New York, United
Friel, S.	13	253	5.14	16,168	57	The Australian National University, Canberra, Australia
Springmann, M.	12	54	22.22	15,219	26	London School of Hygiene & Tropical Medicine, London, United Kingdom
Sauerborn, R.	11	226	4.87	7870	48	Universitätsklinikum Heidelberg, Heidelberg, Germany
Scarborough, P.	11	177	6.21	28,140	58	NIHR Oxford Biomedical Research Centre, Oxford, United Kingdom
Haines, A.	9	91	9.89	509	7	London School of Hygiene & Tropical Medicine, London, United Kingdom
Berrang-Ford, L.	8	134	5.97	6197	44	University of Leeds, Leeds, United Kingdom
Dangour, A.D.	8	167	4.79	8289	45	London School of Hygiene & Tropical Medicine, London, United Kingdom
Golden, C.D.	8	107	7.48	6099	38	Harvard T.H. Chan School of Public Health, Boston, United States
Grace, K.	8	12	66.67	153	6	DB Environmental, Inc., Rockledge, United States
Harper, S.L.	8	22	36.36	34	3	University of Alberta, Edmonton, Canada
McMichael, A. J.	8	190	4.21	4230	33	Wake Forest, Salem, United States
Benkendorff, K.	7	148	4.73	3546	35	Southern Cross University, Lismore, Australia
Darmon, N.	7	169	4.14	9703	45	Université de Montpellier, Montpellier, France
Ford, J.D.	7	254	2.76	12,916	63	University of Leeds, Leeds, United Kingdom

List of the fifteen most active authors on the study's topic, ranked in relation to the total number of papers published, providing insight into the key contributors and their impact within the research domain.

7.37 % of his entire output. Table 1 also showed that Scarborough, P. had the highest total number of citations (28,140), which resulted in the highest H-index value (58).

3.4. Top five of sources of journals on the relationship climate change, food security, and public health

The top five active journals from 1969 to 2023 are visualized in Fig. 4, along with the number of articles they published on climate change, food security, and public health. Additionally, we examined each journal's CiteScore and citation count during a ten-year period, from 2013 to 2022. As we can see, there has been a notable increase in citations across all journals over time. However, differences in CiteScore values between journals were observed. This variation can be attributed to the algorithms used to calculate CiteScore, which also consider the quantity of documents published in a given year. As shown in Fig. 4, three journals–Sustainability Switzerland, Science of the Total Environment, and Journal of Cleaner Production–exhibited nearly identical trends in CiteScore and citation counts. This suggests that the value of CiteScore increased with the increase in citation counts over the years.

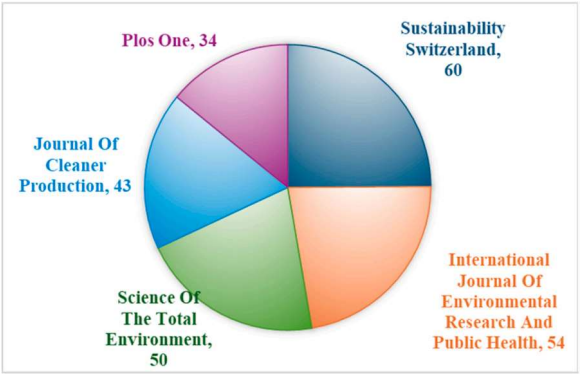


Fig. 4. The top five active journals related to climate change, food security, and public health from 1969 to 2023 together with the total number of citations, CiteScore, and articles published over a ten-year period. Visualization showcasing the top five active journals related to climate change, food security, and public health from 1969 to 2023, accompanied by data on total citations, CiteScore, and the number of articles published over a ten-year period, offering valuable insights into the prominence and impact of these journals within the interdisciplinary research landscape.

Sustainability Switzerland (MDPI) emerged as the leading journal in terms of research articles (article's count: 60, JIF: 3.9, and rank Q2 in year 2022), with an emphasis on Environmental Sciences. Following closely is the International Journal of Environmental Research and Public Health (MDPI), which published 54 articles and had an IF of 4.614 in the major category of Public, Environmental & Occupational Health. The third-highest publishing category, Science of The Total Environment (Elsevier) had 50 papers with 9.8 IF. Subsequently, articles related to the keyword's search were also published in the Journal of Cleaner Production (Elsevier) (article's count: 43, JIF: 11.1, category: Environmental Science, and rank Q1 in year 2022), and PLoS One (PLOS) (article's count: 34, JIF: 3.7, category: Multidisciplinary Science, and rank Q2 in year 2022).

Among these top five journals, the highest IF journal related to climate change, food security, and public health was Journal of Cleaner Production, followed by Science of The Total Environment. It is noteworthy that both journals operate on a subscription-based model.

3.5. Citation overviews

The selection of the top ten papers in this study was based on citation analysis, a widely used bibliometric method to gauge the influence and relevance of published literature. Specifically, we identified the top ten most cited articles within the dataset retrieved from the Scopus database, as shown in Table 2. These articles were ranked solely by their total citation count at the time of data extraction. This table also provides each article's years, specialized journals, CiteScore, and rank/JIF for each article. It was discovered that the article " Options for keeping the food system within environmental limits " published in the journal " Nature " with highest CiteScore value; 83.4, and JIF; Q1/ 64.8 received the most citations (1524 citations). The following two articles, "Natural climate solutions" and "The global burden of pathogens and pests on major food crops", both had almost similar citation counts published in 2017 and 2019, respectively.

The next one was "The significance of soils and soil science towards realization of the United Nations sustainable development goals" article

Table 2
The top ten articles along with article's citation counts, years, specialized journals, CiteScore, and rank/JIF.

No	Total Citation	Document Title	Year	Source	CiteScore	Rank / JIF
1.	1524	Options for keeping the food system within environmental limits	2018	Nature	83.4	Q1/ 64.8
2.	1453	Natural climate solutions	2017	Proceedings of the National Academy of Sciences of the United States of America	19.2	Q1/ 11.1
3.	1426	The global burden of pathogens and pests on major food crops	2019	Nature Ecology and Evolution	24.9	Q1/ 16.8
4.	1017	The significance of soils and soil science towards realization of the United Nations sustainable development goals	2016	Soil	9.5	Q1/6.8
5.	937	Simultaneously mitigating near-term climate change and improving human health and food security	2012	Science	59.0	Q1/ 56.9
6.	888	The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change-A case study in Mozambique	2009	Global Environmental Change	16.5	Q1/8.9
7.	825	Food-borne diseases - The challenges of 20years ago still persist while new ones continue to emerge	2010	International Journal of Food Microbiology	10.3	Q1/ 5.4
8.	680	Analysis and valuation of the health and climate change cobenefits of dietary change	2016	Proceedings of the National Academy of Sciences of the United States of America	19.2	Q1/ 11.1
9.	679	Food security and sustainable intensification	2014	Philosophical Transactions of the Royal Society B: Biological Sciences	12.0	Q1/6.3
10.	628	Consequences of human modification of the global nitrogen cycle	2013	Philosophical Transactions of the Royal Society B: Biological Sciences	12.0	Q1/6.3

Compilation of the top ten articles, including their citation counts, publication years, specialized journals, CiteScore, and rank/JIF (Journal Impact Factor), providing a comprehensive overview of the most influential and impactful contributions within the field of climate change, food security, and public health research.

that published in the "Soil" with CiteScore; 9.5 and impact factor; Q1/ 6.8. The fifth-ranked most-cited publication, "Simultaneously mitigating near-term climate change and improving human health and food security", shown exceptional performance considering that it was published in high impact factor journal (JIF: Q1/56.9). As can be seen in Table 2, the top ten most cited publications were high impact studies because all the articles were published in Q1 or Q2 journal's rank only. Additionally, a preliminary understanding of some relevant issues related to food security, public health, and climate change that have drawn attention from researchers was gained from reading the most cited publications. The bibliometric network analysis of the most frequently used author's keywords will be followed by further discussion of the most important research themes.

All ten articles cover a variety of scientific topics related to environmental health and sustainable food systems. The study encompasses topics such as how to keep the food chain within environmental bounds, how to emphasize natural climate solutions, and how pests and diseases affect important food crops globally. Some articles focus on the combined objectives of mitigating climate change and enhancing human health and food security, while others stress the role of soil science in meeting the Sustainable Development Goals of the United Nations. Furthermore, a pragmatic approach to evaluating the hazards associated with climatic variability is emphasized, as exemplified by a case study conducted in Mozambique. Also covered are the enduring nature of food-borne illnesses, the joint advantages of dietary modifications for the environment and human health, and the incorporation of sustainable intensification into food security measures. Lastly, a review of the effects of human alteration of the global nitrogen cycle highlights the intricate relationships among climate change, human activity, and the environment.

3.6. Co-authorship analysis of institutions

A co-authorship analysis with counting method of organizations was conducted using VOSViewer, and clusters were created using the association strength approach. Out of 7105 organizations, six institutions in total were found by excluding documents with fewer than two documents. Table 3 displays the quantity of publications, countries, citing articles, and total link strengths for all six institutions from 1969 to 2023 (a 55-year span). The dataset sheds light on the different levels of collaboration and research effect that these institutions have, giving rise to some interesting conclusions about their relative advantages and future growth prospects within the international academic community.

Table 3
The most active organizations produced articles related to climate change, food security, and public health from 1969 to 2023.

Organizations	Countries	Documents	Citations	Total link strength
Tufts University	USA	9	511	6
Stockholm University	Sweden	8	1703	19
McGill University	Canada	5	479	6
Harvard University	USA	5	188	7
Chinese Academy of Sciences	China	5	83	0
British Nutrition Foundation	United Kingdom	5	80	0
Lancaster University	United Kingdom	4	644	1
International Institute for Applied Systems Analysis	United Kingdom	4	470	8
International Livestock Research Institute	Kenya	4	350	4
University of Guelph	Canada	4	349	5

Overview of the most active organizations that have produced articles related to climate change, food security, and public health from 1969 to 2023, highlighting their contributions and involvement in research within these interconnected fields over the specified timeframe.

With 1703 citations, Stockholm University (Sweden) is clearly in the lead in terms of citations, despite having just 8 publications published. This indicates that the university has a considerable influence on the academic community. The highest total link strength of 19 and the high citation count indicate broad international collaboration, which is crucial for tackling the intricate and transnational aspects of public health, food security, and climate change. Both Tufts University (USA) and McGill University (Canada) have comparable metrics for the number of documents published (9 and 5, respectively) and total link strength (both 6). However, Tufts University has a marginally higher research impact due to its slightly higher citation count of 511 compared to McGill's 479.

Organizations like the International Institute for Applied Systems Analysis (UK) and the International Livestock Research Institute (Kenya) have moderate numbers of citations (470 and 350, respectively), but

their total link strengths (8 and 4, respectively) indicate different levels of collaboration. With 349 citations and a total link strength of 5, the University of Guelph (Canada) likewise exhibits a balanced profile that suggests a moderate impact and cooperative efforts. The dataset emphasizes how important it is to collaborate internationally and transdisciplinary in order to address the intricate relationship between public health, food security, and climate change. While other universities exhibit a variety of features with regard to research output, impact, and collaborative efforts, Stockholm University stands out for its high citation count and wide-ranging collaboration network. These measurements offer insightful information about the importance and interconnectedness of every organization in the international academic community.

3.7. Co-authorship analysis of countries

The top ten nations at the intersection of public health, food security, and climate change from 1978 to 2022 are shown in Fig. 5. The United States (US) emerges as the most productive country in this area, with a total of 638 articles, followed by the United Kingdom (UK) with 350 articles, Australia (243 articles), Canada (167 articles), Germany (165 articles), China (157 articles), India (152 articles), Italy (133 article), Netherlands (109 articles) and Spain (106 articles). The multidisciplinary nature of research on climate change, food security and public health fosters collaboration among scholars from around the world, leading to diverse at mitigating the consequences of climate change on public health. European countries such as the UK, Australia, Canada, Germany, Italy, Netherlands and Spain, actively contribute to research in this field, driven by concerns about sustainable agriculture and the disruption of food chains due to climate change, which has become an international agenda to ensure global food security and population well-being.

Meanwhile, significant research contributions from China and India are attributed to their rapidly growing populations and their status as the world's largest contributors to rice production. Researchers from these countries are particularly concerned about the impact of climate change on food security and public health, given that rice is a staple food in their populations. According to Mbow et al., (2019), shortages in rice production can have global public health implications, leading to malnourishment and malnutrition, characterized by imbalances in energy or nutrient intake (Mbow et al., 2019).

The broadening of research on the complex nexus of climate change, food security, and public health based on co-occurrence network mapping and classification cluster of keywords.

Analysing the co-occurrence of notable keywords is crucial for identifying the problems that will be addressed in future studies and for developing impactful publications. Additionally, understanding trends and direction through keyword analysis aids in identifying research gaps and hotspots. In this study, co-keyword links were evaluated based on the "author's keywords" from the selected publications published between 1969 and 2023. A total of 2132 articles yielded 5561 recognized keywords, with 131 terms meeting the criterion of appearing at least eight in the investigation. The VOSviewer program's bibliometric mapping algorithm was then used to categorize and systematically link the terms. (Fig. 6a). Each in the network visualization is represented by a different colour. Based on cluster analysis, the author's keywords for climate change, food security, and public health were classified into six clusters:

Cluster 1: Climate change vulnerability towards health and its adaptation (green)

Cluster 2: Climate-resilient agriculture for sustainable food security (light blue);

Cluster 3: Balancing nutrition and environmental footprint (red);

Cluster 4: Epidemiological insights based on changes in climate, diets, and gender (blue)

Cluster 5: Aquaculture's role in global food systems and public health (purple)

Cluster 6: Food insecurity-public health challenges (yellow).

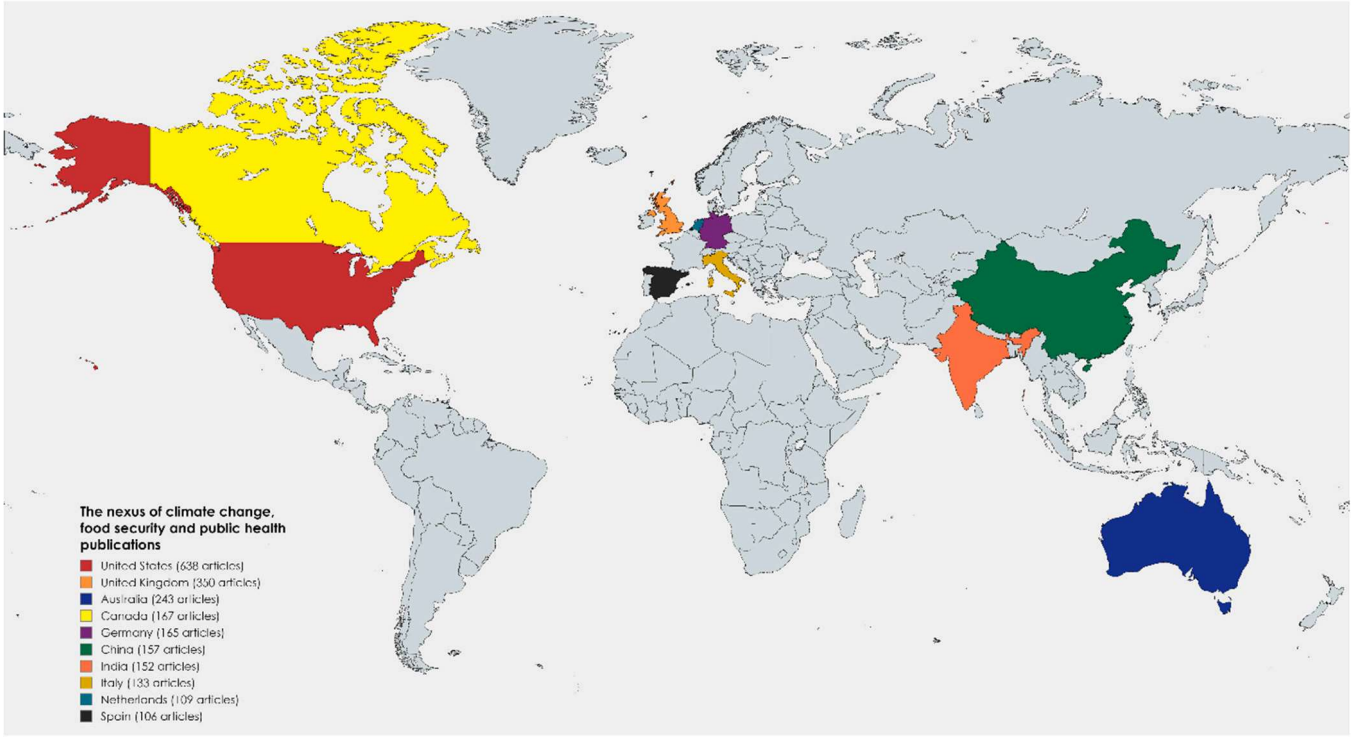


Fig. 5. Map illustrating the top ten countries in terms of efficiency among all the selected articles. Map displaying the geographical distribution of the top ten countries in terms of efficiency among all the selected articles, providing a visual representation of the global impact and contributions of various nations to research on climate change, food security, and public health.

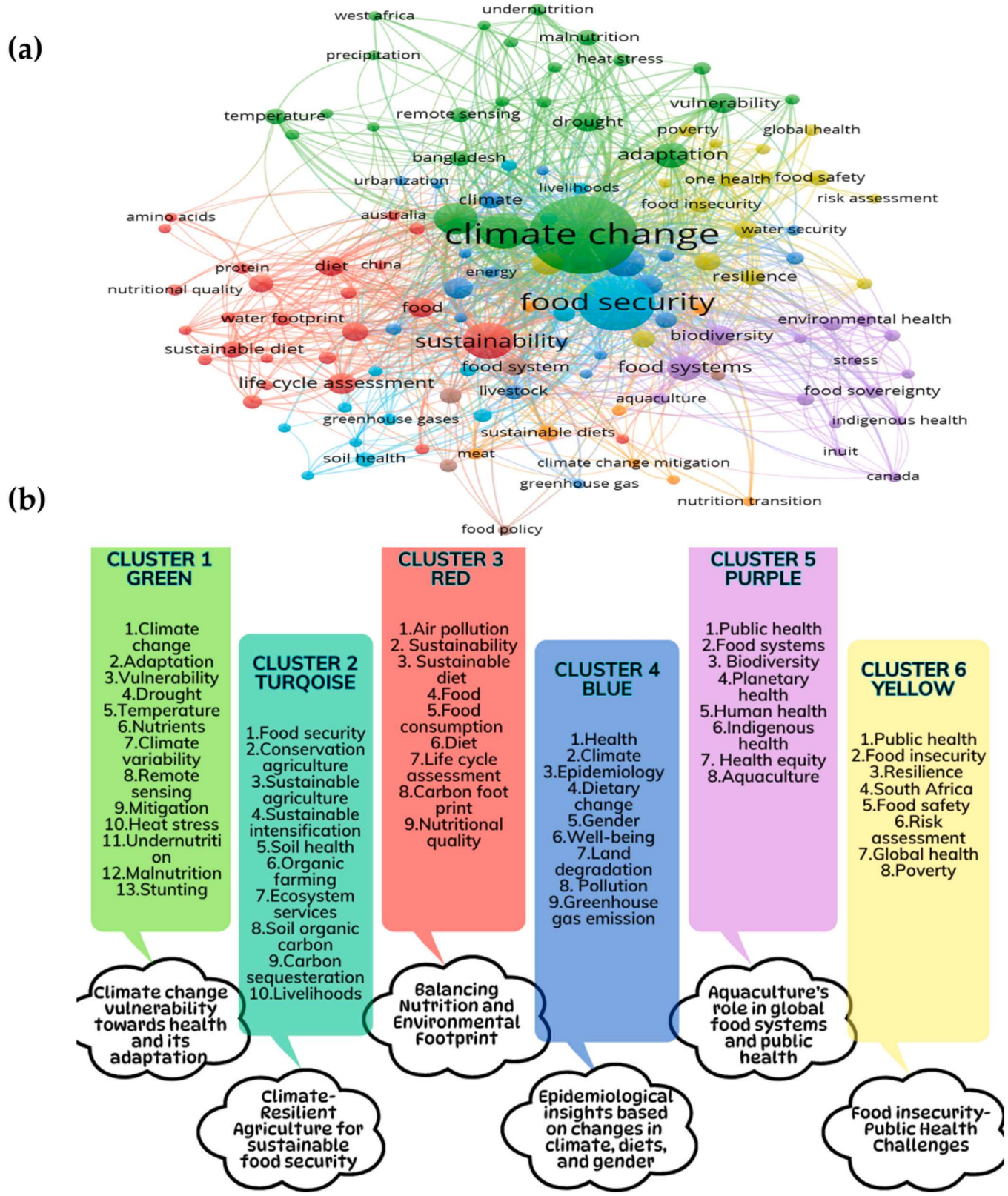


Fig. 6. Co-occurring author keywords related to the complex nexus of climate change, food security, and public health mapped out using a network diagram. Network diagram illustrating co-occurring author keywords related to the complex nexus of climate change, food security, and public health, offering insights into the interconnected themes and concepts prevalent in scholarly literature within these interdisciplinary fields.

These clusters are further investigated based on keywords to develop an integrated understanding of the intricate relationship between food security, public health research, and climate change.

Cluster (1): Climate change vulnerability towards health and its adaptation (green)

Malnutrition, encompassing both undernutrition and overnutrition, is a global concern affecting all nations to varying degrees (WHO, 2021a). In 2021, nearly 690 million people were undernourished globally, while over 1.9 billion adults were overweight or obese (FAO, 2022; WHO, 2021b). The epidemiology of malnutrition is multifaceted and interconnected with numerous factors, one of which is climate change. The impacts of climate change on food systems significantly influence malnutrition, particularly undernutrition, Extreme weather events, rising temperatures, and changing precipitation patterns linked to climate change can reduce agricultural yields, impacting the availability and accessibility of nutritious foods (Brown et al., 2015; Samuel S. Myers et al., 2017). Moreover, it has been projected that climate change will reduce the productivity of crops, livestock, and fisheries, particularly in regions already facing food insecurity.

According to the IPCC, without adaptation, local temperature increases of 2°C or more above pre-industrial levels are projected to negatively impact yields of major crops such as wheat, rice, and maize in tropical and temperate regions (IPCC, 2022). Concurrently, climate change may exacerbate the obesity epidemic, often referred to as overnutrition. Changes in climate patterns can discourage physical activity and promote a shift towards energy-dense, nutrient-poor foods. Extreme heat events can deter outdoor physical activity while increased economic instability due to climate-related events might make cheaper, less nutritious foods more appealing (Patz and Thomson, 2018).

Climate change not only directly impacts food security but also indirectly threatens nutrition by increasing the risk of infectious diseases. This amplifies the challenge of maintaining adequate nutritional status, particularly in vulnerable populations. For instance, the expansion of disease vectors' habitats, such as mosquitoes, due to climate change, can lead to a rise in diseases like malaria and dengue, further exacerbating malnutrition among affected communities (Caminade et al., 2014). Thus, addressing the interconnection between malnutrition and climate change necessitates a holistic approach that integrates adaptation and mitigation strategies with nutrition-sensitive policies. Such measures could encompass promoting climate-resilient and sustainable food systems, enhancing disease surveillance and response mechanisms, and implementing awareness campaigns highlighting the intricate links between climate change, dietary patterns, and overall health. A more cohesive and successful response may be possible by using resilience as a concept that bridges various domains (Rana, 2020). Adopting an all-encompassing and interrelated paradigm makes it feasible to improve public health outcomes and long-term community resilience in addition to reducing the negative effects of climate change on nutrition.

Cluster (2): Climate-resilient agriculture for sustainable food security (light blue)

Global GHG emissions happen because the massive human activities during the pre-industrial was increased by 70 percentage between 1970 and 2004. According IPCC (2007), the primary factors contributing to climate change since 1970 have been CO_2, methane (CH_4), and nitrous oxide (N_2O). The rise in global temperature by 0.74 °C to 0.85 °C will threatens the agricultural ecosystems, leading to increased hunger worldwide (Chhogyel and Kumar, 2018; Pujar et al., 2024). Meanwhile, climate change also impacts water supplies, particularly by altering precipitation and evaporation cycles. Further, increased temperatures, changing precipitation patterns, low soil fertility, extreme weather events, elevated levels of carbon dioxide (CO2), and ozone contribute to reduced agricultural production, as highlighted by Chen et al. (2017); Ali et al. (2022), increased temperatures, changed precipitation patterns, low fertilizer in soil, extreme event frequency, escalated carbon dioxide (CO_2) and ozone with reduce the agriculture production. These factors can lead to a decline in paddy production, as paddy plants are highly sensitive to temperature fluctuations and require adequate water for growth.

Furthermore, climate change poses a threat to food production in many countries worldwide, with potential vulnerabilities in staple crops such as rice, wheat, and corn. For instance, Cambodia faces challenges in food security and nutrition, with approximately 15 % of its population suffering from undernutrition, particularly children who lack access to sufficient nutritious food. Implications of climate change in Cambodia include a projected decrease in rice production by 30 kg per hectare and a loss of 1.6–2.0 % of rice yields due to increased insect and pest infestations exacerbated by higher temperatures, as discussed by Bairagi et al.(2020).

In Cluster 2, several terms related to sustainable agriculture, such as "conversation agriculture," "sustainable intensification," "sustainable agriculture," were mentioned. Sustainability is a concept that involves balancing social, cultural, environmental and economic factors. Sustainable development, on the other hand, aims to meet present needs without compromising the ability of future generations to meet their own needs (Najim et al., 2007). Sustainable agriculture encompasses farming practices such as land preparation, adherence to good agricultural practices, judicious use of fertilizers and herbicides, and management strategies aimed at protecting the environment, as highlighted by Adnan et al. (2017) and Mohamed et al. (2016). Meanwhile, sustainable agriculture practices able to produce safe and high-quality products to fulfil global demand.

To address these challenges, climate risk management strategies must be implemented among farmers to achieve the global SDGs, which aim to reduce poverty and hunger worldwide. Sustainable practices in paddy farming are particularly crucial because rice is a primary cereal and staple food in many countries. Climate change scenarios threaten paddy agriculture and may reduce rice production. Therefore, the agricultural sector must enhance climate change mitigation efforts to increase agricultural production, especially in the face of extreme weather events.

Climate resilience is essential in agricultural farming, involving the transfer of knowledge about climate change and its implications for agriculture. This includes considerations such as water resource management, soil health, resilient seed varieties, drought or flood resilience, and integrated pest management (IPM) to control plant diseases and pests. Government entities, researchers, and scientists must collaborate to develop new techniques, technologies, and technical practices for climate resilience in agricultural practices, particularly in rice cultivation, to boost rice production (Idawati et al., 2018).

Meanwhile, the findings from Jiang and co-workers on adaptive policy adjustments in southeastern China offer compelling evidence that ecosystem restoration efforts, when guided by adaptive and inclusive policies, can directly support climate-resilient agriculture and sustainable food security (Jiang et al., 2023). While initial implementation of restoration projects (e.g., converting cropland to grassland or forest) posed short-term challenges to grain production, the adaptive policy responses including improved agricultural infrastructure, farmer support, and diversification of livelihoods restored food productivity and enhanced local economic resilience. This supports the argument that climate-resilient agriculture must be dynamic and policy-driven, capable of responding to evolving environmental and socioeconomic conditions.

Cluster (3): Balancing nutrition and environmental footprint (red)

Forecasts for population growth over the next 10–50 years underscore the urgency of ensuring that our food system becomes more environmentally sustainable and of higher quality, particularly in light of the challenges posed by climate change and the growing demand for foods products (Johnston et al., 2014). The adoption of widely recognised national and international life cycle assessment (LCA) enable consumers, food policymakers, to swiftly multiple impact categories affecting various foods, including carbon emissions, land utilization,

water scarcity, emissions of air pollutants, and the release of water contaminants like nitrate (NO3) and phosphate (PO43-) (Katz-Rosene et al., 2023). This transition not only promotes environmental sustainability but also contributes to improved public health outcomes by providing essential nutrients through diverse and balanced diets.

Modifications to agricultural techniques and dietary shifts toward plant-based foods, which generally have lower GHG emissions than animal-based foods-are two strategies to minimize these emissions. The sustainable diets prioritize plant-based foods, limiting intake of meat and dairy products, and including produce that is acquired locally (Jones et al., 2016). These dietary habits offer long-term sustainability benefits, as they require less land and water and result in smaller carbon footprints. It's important to note that diverse food habits have unique carbon footprints. Recent research indicates that animal-based food production accounts for up to 57 % of worldwide greenhouse gas emissions from food production, while plant-based food production accounts for 29 %, with the remaining 14 % allocated to other uses (Xu et al., 2021).

Moreover, a study conducted by Takacs and co-workers revealed that meals containing meat had an environmental impact 14 times higher than vegetarian's meals, while vegan meals had an impact three times higher. Whole-food vegan meals, composed of whole, minimally processed plant-based components, exhibited the least environmental impact among all meals (Takacs et al., 2022). Although plant-based diets are associated with reduced carbon footprints, it is crucial to ensure that these diets meet nutritional requirements. Research has demonstrated that well-designed plant-based diets can provide all the necessary nutrients required, offering benefits such as reduced risks of heart disease, hypertension, type 2 diabetes, and certain cancers (Clem and Barthel, 2021). However, it is essential to be mindful of potential deficiencies in minerals, such as vitamin B12, iron, zinc, and omega-3 fatty acids, that are frequently present in animal products.

By ensuring a balanced intake through supplements or fortified meals, individuals can minimize their environmental impact while preserving nutritional quality. Notably, the national dietary guidelines of four out of the eighty-three nations that have food-based dietary guidelines (FBDGs) have integrated sustainability considerations (Springmann et al., 2016). These guidelines advocate for the purchase and consumption of healthier, sustainably produced foods. Furthermore, dietary guidelines can be tailored to accommodate cultural preferences and the availability of sustainable food options within local community (James-Martin et al., 2022). Thus, integrating dietary recommendations with sustainability principles can yield positive synergistic effect on public health and reduce the carbon footprint of the food system.

Cluster (4): Epidemiological insights based on changes in climate, diets, and gender (blue)

The intersection of well-being and sustainable development is profoundly affected by climate change, dietary patterns, and gender dynamics. Understanding these gender-specific vulnerabilities is crucial for crafting equitable health outcomes through public health policies. Gender inequality is exacerbated by climate change, particularly in low- and middle-income countries where women heavily rely on environmental resources for their daily needs (Sorensen et al., 2018). Study by Geere et al., (2018) reveal that women are responsible for 72 % of water collection and 78 % of solid fuel gathering, highlighting the disproportionate burden borne by women in resource collection tasks (Geere et al., 2018). Similar gender disparities exist in rural areas, where 54.7–95 % of women take on such responsibilities, often due to traditional customs and sociocultural biases that discourage men from engaging in tasks deemed as "women's work" (Ho et al., 2021).

Climate change can exacerbate these inequities and add further burdens. Research, such as Bryson's findings, indicates that women in rural areas, including China, Mexico, Tanzania, and Burkina Faso, typically do not reduce their physical labor during pregnancy, which can lead to adverse outcomes such as high blood pressure, miscarriage, and premature birth (Bryson et al., 2021). Besides, a worldwide epidemic, mismanagement, policy changes, catastrophic weather and climatic events, as well as geopolitical and economic events also contribute to shocks that disrupt the food system (Cottrell et al., 2019). Climate change also increases the likelihood of multiple crop failures due to extreme weather events occurring simultaneously across various agricultural regions (Gaupp et al., 2020).

The lower and erratic yields of essential crop commodities have the potential to undermine food security, dietary diversity, and nutrition outcomes by driving up food prices. This disproportionately affects low-income households, making it harder for them to access or afford nutritious foods. The impact of these events on diets and nutritional outcomes will vary, with vulnerable populations facing heightened risks.

Cluster (5): Aquaculture's role in global food systems and public health (purple)

Aquaculture, which involves the farming of aquatic organisms such as fish, shellfish, and aquatic plants, has seen unprecedented growth in production worldwide (FAO, 2022). Aquaculture has the potential to contribute to improved food security, reduced poverty rates, and sustainable natural resources management, particularly in developing country (Martuscelli, 2022). In low-income countries with limited access to food, fish accounts for approximately 22 % of animal protein consumption (Tacon and Metian, 2017). Thus, integrating aquaculture production with fisheries is the sole solution to address the growing global demand for nutritious and healthy aquatic products (World Economic Forum, 2023). Besides, aquaculture presents an opportunity to diversify income and mitigate the impact of market fluctuations in agricultural prices. This integrated approach, which involves raising fish on agricultural land, enhances annual yield rates and improves land productivity by utilizing farm by-products as aquaculture feed and aquaculture site water for crop irrigation. Thus, commercial aquaculture is recommended as a significant contributor to food security, given its ability to generate employment and income opportunities, especially in developing countries.

Aquaculture also plays a vital role in enhancing global food security and public health. Fish and seafood are rich sources of essential nutrients such as omega-3 fatty acids, iodine, vitamin D, and high-quality protein (Bourre and Paquotte, 2009). Consumption of fish and seafood has been associated with various health benefits, including brain development, cardiovascular health, and the prevention of chronic diseases (Jayasekara et al., 2020; Tacon et al., 2024). However, for aquaculture to effectively contribute to food security and public health, it must be practice sustainably (Jennings et al., 2016). Addressing environmental issues such as pollution and overuse of antibiotics, as well as ensuring ethical practices related to animal welfare, are essential steps in realizing the potential of aquaculture to improve food security and public health globally (Naylor et al., 2023; Okocha et al., 2018).

Cluster (6): Food insecurity-public health challenges (yellow)

Food insecurity arises when individuals or households lack access to sufficient, nutritious food to maintain an active and healthy life. This issue has significant implications for public health, leading to hunger, malnutrition, and various deficiencies in essential vitamins and minerals (Beach et al., 2019). Climate change exacerbates food insecurity by disrupting food production and distribution systems. Extreme weather events such as high temperatures and erratic rainfall can destroy crop yields, leading to increased demand for food and financial insecurity. Unsustainable food production practices further compound the problem, preventing people from accessing healthy diets and increasing the risk of diet-related diseases.

Low- and middle-income countries, particularly in Africa and South Asia, are disproportionately affected by food insecurity due to climate change (Mahmood et al., 2022). In addition, United Nation (2024) reported continent of Africa has a high prevalence of malnutrition. According Fanzo and Downs., (2021), the effect on climate change will treat the nutritional quality of grains also decline with elevated atmospheric CO_2 concentration and it will increase the risk of zinc and iron

deficiency among the low-income countries such as Africa. Meanwhile, paddy production in Asian countries had decline and will affect the self-sufficiency level (SSL) in their food security (Mishra et al., 2018).

The vulnerability of the global agricultural sector to climate change is poised to diminish agricultural production, with detrimental consequences for health. Local shifts in temperature and rainfall patterns have disrupted food distribution and reduced production, leaving vulnerable populations at risk. This decline in food availability has resulted in escalating food costs, impacting consumers, especially those in low- or middle-income countries, by reducing their purchasing power (Tchonkouang et al., 2024). The rise in food prices, particularly staples like rice, contributes to stress and depression, given rice's status as a daily energy source for many worldwide. According Baars et al., (2023), around 210 million children in the world suffer from stunted growth and wasting, while 790 million people fail to meet their daily energy requirements.

Therefore, as the global population is projected to reach 9.7 billion by 2050, the demand for food is expected to surge. However, regions like Africa, already grappling with the highest number of rural inhabitants, face significant challenges due to climate change, exacerbating chronic hunger and malnutrition (Ngcamu and Chari, 2020).

3.8. Future directions and potential strategies

Primarily, efforts must be directed toward comprehending and reducing the negative effects of climate change on health (Cluster 1) by focusing on adaptation measures such enhancing healthcare systems. Climate change is considered one of the most serious risks to human health. The human health will affect when the climate change through long-term changes in rainfall and temperature, climatic extremes (such as hurricanes, drought, heatwaves and flood), sea-level rose in low-land coastal regions and air quality. According to Caminade et al. (2019), increasing temperature spreads the vector, and pathogen survival tends to encourage transmission, whereas precipitation can provide vector breeding sites, and the interaction between temperature, rainfall, and malaria is highly vector specific. Furthermore, morbidity and mortality from extreme weather, increased respiratory illness, and infectious disease will keep rising if no action is taken.

This includes building community resilience, strengthening infrastructure, and implementing early warning systems for health hazards associated with climate change. Climate change could spread new infectious disease globally. Centres for disease control and prevention (CDC) and World Health Organization (WHO), need to monitor, protect, detect, and screening or establish early warning systems for public health, especially infectious diseases. However, governments also need to play a role in controlling the impact of climate change on human health by investing sufficient funds in research for innovative solutions. Furthermore, the government optimizes disease surveillance in potential areas to avoid the spread of epidemic diseases and take precautions before outbreaks occur. The collaboration the government, meteorological department and health departments to improvise the hazard management with data sharing based on climate change and human health (such as give effective information to public about timely weather forecasting). This situation will help the population more alert or take extra preventive about the effect of extreme weather such as heat waves, haze and cold waves.

Secondly, to guarantee food security amidst climate variability, sustainable agriculture practices (Cluster 2) must be given top priority. The impacts of climate change on agriculture are complicates because the extreme weather such as drought, storms, and flood will give negative impacts on agricultural systems. This scenario will affect staple crops such as rice, maize, wheat, and corn due to cultivation is a complex natural-social system that combines long-term production changes with climate change and anthropogenic activity. According to Alam et al. (2015), the increase in temperature of 1 % had potential to reduce paddy production of between 3.44 % and 0.03 %, while an increase in rainfall intensity of 1 % will reduce 0.12 % paddy yield. The climate change not only affect the production but also disrupt the nutritional components of rice grains (such as storage protein, starch and fatty acids) (Saud et al.2022). However, the collaboration among the researcher, Non-government Organization (NGO) and the stakeholder must cooperate to achieve Sustainable Goal Development (SDG) in theme 2 (zero hunger) to promote the sustainable agriculture concept among the farmers for increase the food production.

The sustainability concepts such agroecological methods, agricultural extension services, and investments in climate-resilient crops can boost food productivity while minimizing environmental degradation. Implement agroecology method in agricultural farming is a comprehensive strategy that includes ecological, health, social and economic into agricultural and food system. For example, Integrated pest management (IPM) one of part method in agroecology is a sustainable method to pest control in agriculture. The IPM can monitoring, biological control, and using limited chemical use to maintains crop health and prevents pesticide resistance towards environmentally friendly (Vikas and Ranjan, 2024). Agroecological methods, agricultural extension services, and investments in climate-resilient crops can boost food productivity while minimizing environmental degradation. Practising sustainable agriculture system needs to be implemented to reduce the impact of climate change and achieve SDGs, while improving food production to meet the demands of the future.

Thirdly, developing sustainable eating habits (Cluster 3) helps to lessen environmental deterioration and malnutrition. It is imperative to promote plant-based diets and strengthen regional food systems. Successfully addressing disparities requires incorporating education campaigns, food labelling initiatives, and policy incentives to encourage consumers to adopt healthier and more sustainable dietary patterns. Meanwhile, to improve sustainable agriculture, social development, and the economy, and to supply high-quality, safe-to-eat food, the government must encourage farmers to implement good agricultural practices (GAP). The sustainable agriculture practices had capability to fulfil the demand of food security among the population and provide the safe and high quality of agricultural product. According to Mohd Ali et al., (2021), the industry and the governments play an essential role in the sustainable development in agricultural farming in promote the benefit of MyGAP products to human health. The promotion such as television programs, marketing products of MyGAP in hypermarket in local and international market to help the paddy farmers to market their product for increase paddy farmers' income. Meanwhile, The Food and Agriculture Organization of the United Nations (FAO) created the GAP to boost agricultural output towards sustainability while protecting the health and safety of workers.

Subsequently, epidemiological understanding (Cluster 4) ought to persist in clarifying the intricate interplay of food practices, gender differences in health outcomes, and climate change. This information can help design focused treatments to reduce the health hazards brought on by shifting dietary and climatic conditions. Gender perspectives in climate adaptation and nutrition treatments must be included into targeted public health programs in order to address gender-specific health vulnerabilities. Policy should aim to empower women by providing them with access to healthcare, economic opportunities, and education. According to Mulema et al., (2022), the stakeholder should engage stakeholder on gender and climate change policies. Implementing mechanisms for tackling the balance of power is crucial for integrating gender considerations and involving women in decision-making. Women's nutrition and food security can be improved by the implementation of gender-sensitive agricultural initiatives. Giving women access to resources and training on climate-resilient farming techniques, for instance, can enhance their standard of living and health. Public health campaigns should also encourage dietary habits that satisfy the nutritional needs of every family member, particularly women and girls, and increase awareness of the significance of fair food distribution within households.

Additionally, recognizing the role of aquaculture (Cluster 5) is essential in preserving food security and public health must be further investigated and supported. Climate change has the potential to affect aquaculture productivity, and heavy precipitation will increase production risks in lowland areas. The loss of fish from ponds damage can affect the environment sustainability of aquaculture production and will give negative impact on water quality. However, enhancing aquaculture's contribution to the world food systems can be achieved through investments in sustainable practices, aquatic food safety research, and policy frameworks for responsible aquaculture development. However, the stakeholder also should provide climate information services to aquaculture farmers can also assist them in managing the risks brought on by climate variability and extreme weather, ensuring future food production in the fisheries sector. Additionally, assisting small-scale farmers can improve nutrition and food security.

Lastly, to alleviate food insecurity (Cluster 6), comprehensive initiatives are needed to address underlying issues including poverty, inequality, and limited access to wholesome food. Climate change has posed a significant challenge to crop production and food security, particularly as extreme weather events become more frequent. This situation can give pressure on low-income countries such as South Sudan (more than 6.3 million people are food insecure, while 2.1 million experiencing acute malnutrition), Somalia had 17 percent of the population insecure, and 1.7 million children are expected to experience acute malnutrition on December 2025 (WorldBank, 2025). Food insecurity among low-income countries and middle-income countries needs to be addressed through collaboration with climate scientists, stakeholders, and policymakers to develop eco-friendly policies to reduce the climate change. Achieving food security and enhancing public health outcomes requires bolstering social safety nets, increasing smallholder farmers' agricultural output, and empowering marginalized groups.

Additionally, increasing awareness and knowledge can reduce the vulnerability of climate change in agricultural production and public health, especially among communities. According to Waseem and coworkers through their Advanced Bibliometric Analytical Framework (ABAF) findings, adaptation planning has emerged as a prominent topic in discussions on mitigating the impacts of catastrophic climatic events (Waseem et al., 2024). Therefore, increased collaboration among scholars, particularly climate scientists and researchers are essential, with a focused effort on interdisciplinary research in climate change, agriculture, and public health, especially in the areas of adaptation and strategic planning.

4. Conclusion

This study examines the complex nexus between climate change, food security, and human health through a bibliometric analysis of existing literature. The findings reveal significant research trends, spanning broad discussions on climate change and food security while also addressing more specific themes such as agriculture, environmental sustainability, human health, and nutrition. By mapping these trends, this study provides an overview of how research in this field has evolved and where current efforts are concentrated.

A key takeaway from this analysis is the need for interdisciplinary collaboration. Climate change, food security, and public health are deeply interconnected issues that require coordinated efforts from policymakers, researchers, and practitioners. Strengthening partnerships across these domains can lead to more effective policies that enhance food system resilience and mitigate health risks associated with climate change. Additionally, education and awareness play a crucial role in addressing these challenges, particularly in recognizing the often-overlooked indirect impacts. Encouraging cross-sectoral dialogue can help bridge knowledge gaps and drive the development of innovative, evidence-based solutions.

Despite its valuable insights, this study has certain limitations. The analysis is based on publications indexed in specific databases, which may exclude relevant studies from non-indexed sources, regional reports, or gray literature. Additionally, while bibliometric analysis is a powerful tool for identifying research trends, it does not capture the depth of discussion found in qualitative studies. Future research could complement this approach with systematic reviews or meta-analyses to provide a more nuanced understanding of these relationships. Expanding data sources and incorporating more regional studies would further enhance the comprehensiveness of future investigations. Besides, future bibliometric analyses should consider expanding search queries to include water-related terms, ensuring a more comprehensive representation of its role in these interconnected systems. This is due to water is undoubtedly a key factor in climate change, food security, and public health (Nuwayhid and Mohtar, 2022; Rhouma et al., 2024). Strengthening research efforts in this domain will be crucial in developing sustainable, evidence-based strategies to address global food security challenges in an increasingly volatile climate.

CRediT authorship contribution statement

Nurul Izzati Mohd Ali: Writing – review & editing, Validation, Software, Investigation, Conceptualization. **Nur Syamimi Mohamad:** Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Nurul Izzaty Hassan:** Investigation, Supervision, Visualization, Writing – review & editing. **Zein Kallas:** Writing – review & editing, Validation. **Muhammad Adzran Che Mustapa:** Writing – review & editing, Validation, Investigation. **Kuok Choy Lam:** Conceptualization, Investigation, Supervision. **Kadaruddin Aiyub:** Supervision, Validation. **Sharif Shofirun Sharif Ali:** Validation. **Najwa Imani Mohd Ali:** Visualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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