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Review article

Climate change and resilience, adaptation, and sustainability of agriculture in India: A bibliometric review

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ABSTRACT

Climate change (CC) is a global issue, with effects felt across nations, including India. The influences of CC, such as rising temperatures, irregular rainfall, and extreme weather events, have a direct impact on agricultural productivity, thereby affecting food security, income, livelihoods, and overall population health. This study aims to identify trends, patterns, and common themes in research on Climate Change and Resilience, Adaptation, and Sustainability of Agriculture in India (CCRASAI). It also seeks to illuminate potential future research directions to guide subsequent research and policy initiatives. The adverse impacts of CC could push farmers into poverty and undernourishment, underscoring the imperative to focus on the resilience, adaptation, and sustainability of agriculture in India. A bibliometric review was conducted using Biblioshiny and VoSviewer software to analyze 572 articles focused on CCRASAI from the Scopus and Web of Science databases, published between 1994 and 2022. There was an evident upward trend in CCRASAI publications during this period, with steady growth appearing after 2007. Among the States and Union Territories, Delhi, Tamil Nadu, West Bengal, Andhra Pradesh, and Karnataka have the highest number of published research articles. Research on CCRASAI is most concentrated in the southern plateau, the trans-Gangetic and middle Gangetic plains, and the Himalayan regions. The frequently used terms—'climate change impacts,' 'adaptation strategies,' and 'sustainable agriculture'—in CCRASAI research emphasize the focus on analyzing the effects of CC, creating adaptation strategies, and promoting sustainable agricultural practices.

1. Introduction

Climate change (CC) has emerged as a global issue, impacting food security, human health, water availability, and overall societal progress across different countries [1,2]. As agriculture relies on rainfall, temperature, and soil conditions, CC manifests in the form of monsoon irregularities, droughts, and floods, affecting agricultural productivity and farmers' income [3]. The negative impact of CC could lead to a reduction in the productivity of various crops by 3–7 % for every one-degree rise in mean temperature [4,5], thereby

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increasing the risk of hunger and undernourishment [6]. Small and marginal farmers constitute approximately 86 percent of the total number of farmers in India [7]. The impacts of CC affect small farmers more significantly than large farmers [8]. With large farmers having a greater capacity to adapt to CC than small and marginal farmers, the latter group is more vulnerable to CC [9].

CC significantly impacts labor productivity, not only within the agricultural sector but also across various other economic sectors. Srinivasa Rao et al. [10] estimated that global warming might result in a loss of around 5.8 % of working hours, potentially leading to the loss of approximately 34 million full-time jobs, primarily in the construction and agricultural sectors. Additionally, the recent COVID-19 pandemic has caused further disruptions in the agricultural sector, exacerbating the situation created by the adverse impact of CC [11]. The impact of the COVID-19 pandemic on farmers, particularly small-scale farmers, was more pronounced in contexts characterized by less mechanization in the agricultural sector and a weak procurement system for agricultural produce [12].

The impacts of CC on agriculture vary across different regions in India [13]. Projections suggest an increase in extreme rainfall events in western and south-central areas [14]. Summer monsoon rainfall is expected to decline, while winter rainfall is anticipated to increase in northwestern regions, such as arid western Rajasthan and adjacent areas in Punjab and Haryana [15]. This could lead to higher incidences of droughts and floods, affecting both the rainy season crops (kharif), typically sown from June to July and harvested from September to October, and the winter season crops (rabi), usually planted from October to December and harvested from April to June [16]. A perception study in the Brahmaputra basin in India found that farmers believe CC contributes to recurring floods, landslides, droughts, and crop and livestock diseases [17]. The adverse impact of CC could potentially reduce agricultural yields in India 4.5–9% annually during the 2020–2039 period [18]. If translated into monetary terms, this could result in an annual GDP reduction of between 0.7 % and 1.35 % [10,19]. The impact of CC can be significantly mitigated with proper CC adaptation [20].

Recently, the need to build resilience, adaptation, and sustainability in India has been increasingly realized to ensure food security and sustainable development [21]. Few bibliometric studies have been undertaken to explore research and development and identify gaps within these themes, likely attributable to the increased focus on these areas of research only in the past decade and a half. To better understand research trends and knowledge gaps, we conducted a bibliometric review analyzing literature on Climate Change and Resilience, Adaptation, and Sustainability of Agriculture in India (CCRASAI).

The goal of this study is to identify key research themes, publication patterns, and knowledge gaps to guide future research and policy initiatives. This bibliometric review aims to answer the following research questions (RQs) related to CC and resilience, adaptation, and sustainability of agriculture in India, which were not addressed previously: (a) RQ1: What are the trends and patterns of research in relation to climate resilient and sustainable agriculture in India, based on a bibliometric analysis of scientific publications? (b) RQ2: What are the common themes across the research studies related to climate-resilient and sustainable agriculture in India? What are the major research findings across these studies within these common themes? (c) RQ3: What are potential future research directions in the field of climate resilient and sustainable agriculture in India?

2. Material and methods

Bibliometrics, a well-established research methodology, is commonly employed to evaluate scientific publications, citation patterns, and the overall impact of research in various fields [22]. The adoption of bibliometric analysis as the research methodology was

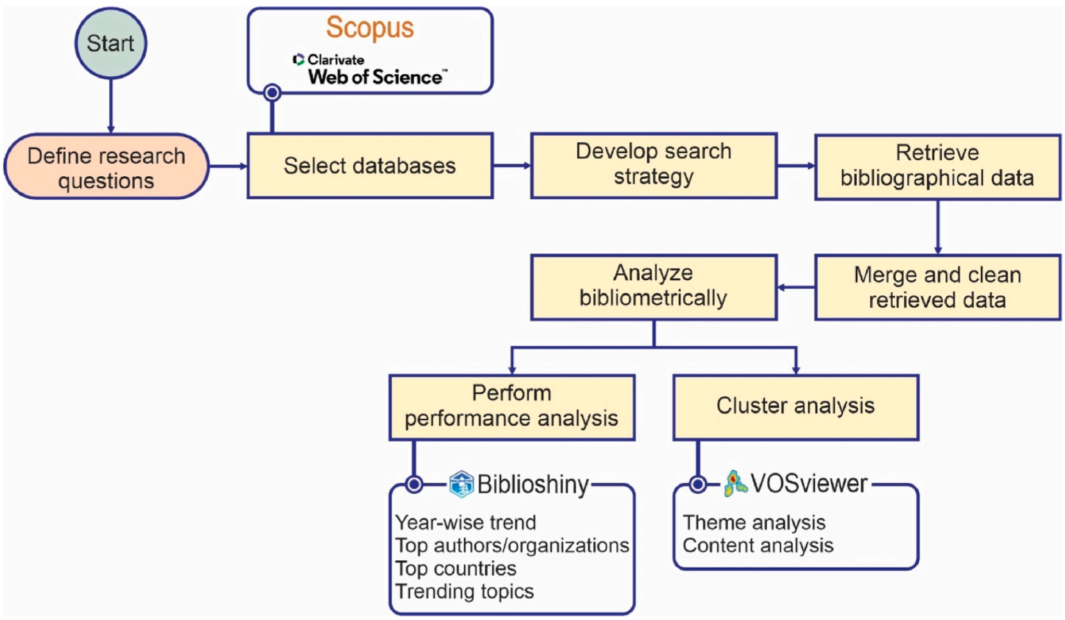

Fig. 1. Workflow of CCRASAI study.

essential in identifying key research themes, publication patterns, and knowledge gaps. It aids in recognizing current research trends in the field through both quantitative and qualitative approaches. A significant volume of bibliographic records data was analyzed to identify patterns, trends, and the most recent research topics related to the domain of interest. To conduct the bibliometric analysis, the steps proposed by Mishra et al. [23] were followed (Fig. 1). The bibliometric analysis was structured into three primary phases, as delineated in the subsequent subsections.

2.1. Selection of the database and development of the search strategy

In this paper, Scopus and the Web of Science core collection databases were chosen to collect literature related to the study area. These databases are the two most used academic databases in bibliometric analyses, covering a wide range of academic disciplines. They offer comprehensive coverage of published literature, including peer-reviewed journals, conference proceedings, and other scholarly materials, thus ensuring that no relevant articles were overlooked [24]. The search terms utilized in the study included 'adaptation strategies,' 'climate change impact,' 'climate-smart agriculture,' 'climate resilient,' 'drought management,' 'sustainable agriculture,' 'climate change adaptation,' and 'climate change risk mitigation,' among others. Details of the search strategy are presented in Fig. 2. The literature search, conducted on December 19, 2022, focused exclusively on articles and reviews in English published from 1994 to 2022, offering a comprehensive snapshot of relevant literature up to that date. A search was conducted in both databases using the outlined search strategy (Fig. 2), yielding 506 records from Scopus and 341 records from Web of Science, respectively. The bibliographical data were retrieved by extracting Scopus data in the form of '.bib' format and Web of Science data in the form of '.txt' format.

2.2. Merging and cleaning of retrieved data

Upon retrieving bibliographical data from both Scopus and Web of Science databases, records were merged into a single dataset using RStudio software [25]. To ensure data quality, any duplicate records from the merged dataset were removed, resulting in 602 records. Each record was then screened, and articles irrelevant to the study, based on pre-defined inclusion and exclusion criteria, were removed. This screening process reduced the number of records to 572. Finally, data cleaning was performed to eliminate inconsistencies, errors, or missing information from the dataset. The resulting dataset contained only high-quality records relevant to the research question, preparing it for further analysis.

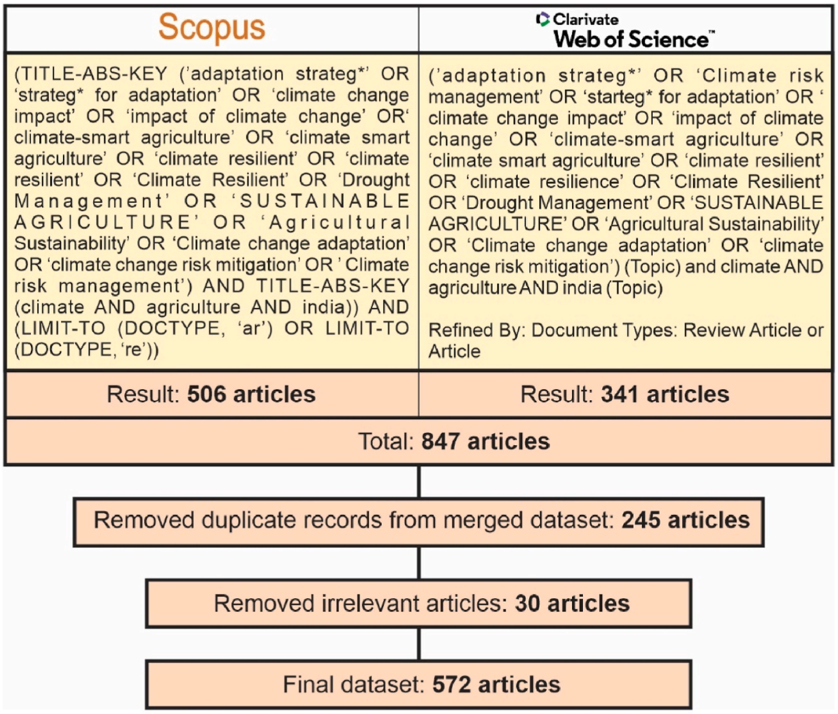

Fig. 2. Search query and strategy.

2.3. Analysis of the data

To glean insights from the dataset, a bibliometric analysis was conducted using Biblioshiny [26] and VoSviewer software [27]. Utilizing Biblioshiny enabled the analysis of the performance of the most prolific authors, institutions, journals, citation patterns, and countries in the domain. This helped answer research question RQ1. Additionally, VoSviewer software was used to perform cluster analysis and identify themes and subthemes in the domain. Each cluster was then discussed in detail, considering the major findings and suggestions of the papers within the cluster. This approach allowed for answering research question RQ2, granting a deeper understanding of the key themes and research areas in the field and providing insights for future research in the domain. The major trending topics identified are used to answer research question RQ3, supplying a comprehensive review on trending topics by identifying all cited articles on each topic. By employing this data analysis approach, a comprehensive understanding of current research trends, knowledge gaps, and future directions in the field of climate-resilient and sustainable agriculture in India can be achieved.

To address research questions RQ2 and RQ3, a co-word analysis utilizing author keywords was implemented to elucidate the knowledge structure within the CCRASAI field. This method provided insights into the predominant themes and subjects foundational to research in this domain. Following this, a network analysis of keyword co-occurrences, executed with VOSViewer software, facilitated the identification of prevalent themes (clusters) and subjects within the CCRASAI literature. Such an analytical technique is widely recognized in bibliometric studies for pinpointing the core elements that constitute the basis of research fields [28]. For the construction of the keyword network, only author keywords that appeared a minimum of five times within the dataset were considered, yielding a selection of 54 keywords. This study's analysis delineated seven distinct clusters from these keywords, with each cluster symbolizing a recurrent subject across the CCRASAI literature.

In this research, the authors also focused on studying CCRASAI at the national level, covering globally and encompassing nearly fifteen broad agro-climatic regions of India. These regions include the Western Himalayas, Eastern Himalayas, Lower Gangetic plains, Middle Gangetic plains, Upper Gangetic plains, Trans-Gangetic plains, Eastern Plateau and hills, Central Plateau and hills, Western Plateau and hills, Southern Plateau and hills, East coast, West coast, Gujarat plains and hills, and Island regions. Additionally, various bibliometric indicators, including the Hirsch index (h-index), total citations, impact factor, and the number of articles, have been utilized for ranking purposes.

3. Results and discussion

3.1. Trend in publication outputs and citations in India

A total of 572 articles pertaining to CCRASAI, published between 1994 and 2022, were retrieved from the Scopus and Web of Science databases. Table 1 presents their bibliometric characteristics. These articles, contributed by 1644 authors and encompassing 1544 keywords, predominantly originated from India. The average citation per CCRASAI article stood at 17.1. Metrics such as the number of authors per article, co-authors per article, and the collaboration index were 2.87, 4.43, and 3.11, respectively.

Fig. 3 depicts a year-by-year distribution of CCRASAI research articles. Overall, the number of publications in CCRASAI research exhibits an upward trend from 1994 (1) to 2022 (572), with a peak in 2021 & 2022. However, certain years showed fewer publications than in previous years. In 1994, there was only a single publication related to the problems and prospects of development in the Indian arid zone, and until 2007, there were only a few publications on this topic.

Moreover, the growth pattern of CCRASAI research grew steadily after 2007, which was accelerated in the past decade. This increase reflects the growing realization of the importance of research related to the impact of climate change on resilience and sustainability in the agriculture sector across different countries, including India. This might be due to the repeated occurrence of drought, flood, cyclone, unseasonal rainfall, and an increase in temperature in various parts of the world and in India. Efforts to achieve climate-resilient agriculture have been initiated both at the national and state level. For example, at the national level, the National Innovations

Table 1
Key information about the dataset.

Description	Results
Timespan	1994–2022
Sources (journals, books, etc.)	272
Documents	572
Average citations per document	17.1
Keywords Plus (ID)	2379
Author's keywords (DE)	1544
Authors	1644
Author appearances	2535
Authors of single-authored documents	53
Authors of multi-authored documents	1591
Single-authored documents	61
Documents per author	0.348
Authors per document	2.87
Co-authors per documents	4.43
Collaboration index	3.11

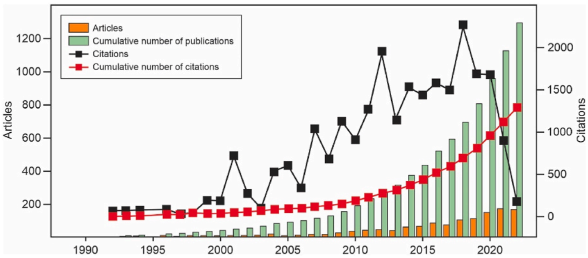

Fig. 3. Year-wise trend of CCRASAI research.

on Climate Resilient Agriculture (NICRA) in India under the Indian Council of Agricultural Research (ICAR) was established in 2011 in this direction. Various State Governments have also initiated special projects on climate-resilient agriculture, such as the Project on Climate Resilient Agriculture (PoCRA) implemented by the Government of Maharashtra and World Bank to achieve climate-resilient agriculture in the Vidharbha and Marthwada region of Maharashtra [29].

In terms of total citations (TC), the most cited articles were published in 2018 (TC = 962) and 2015 (TC = 1920), indicating that these publications significantly shaped this domain. The increase in publications in recent years might be due to heightened awareness about issues related to CCRASAI. Furthermore, the United Nations Climate Change Conferences held in Paris in 2015, Bonn in 2017, and most recently in Sharm-el-Sheikh, Egypt in 2022, likely fostered increased interest and commitment towards climate change research.

The paper titled “Mapping vulnerability to multiple stressors: Climate change and globalization in India” by O’Brien et al. [30] garnered the highest number of citations. Published in 2004, it likely garnered more citations because it provided a systematic methodology to study the regional variation of vulnerability due to climate change from multiple stressors. The vulnerability analysis is also helpful in preparing and implementing government policies and interventions, both by government and non-government agencies, to achieve climate resilience.

3.2. *Most influential authors*

The dataset was analyzed to identify the most productive authors based on their publication count. Table 2 presents the top 10 most productive authors, alongside the number of citations received and their Hirsch index (h-index) for each. The h-index is a metric that aims to measure both the productivity and citation impact of the publications of a scientist or scholar. It is based on the set of the scientist’s most cited papers and the number of citations that they have received in other publications. Mangi Lal Jat, affiliated with the Climate Change, Agriculture, and Food Security (CCAFS) in New Delhi, emerges as the most prolific author, having published 22 articles focused on climate change in agriculture (Table 2). Following this comprehensive overview of the most productive authors in the field, Table 3 elucidates the major research focuses of these top authors. This table provides insights into the specific domains within climate change and agriculture that have been the primary focus of their academic contributions.

The most productive authors were identified from the dataset based on their publication count. Table 2 displays the top 10 most productive authors, including the number of citations each has received and their Hirsch index (h-index). The h-index is determined by the number of papers (N) an author has published that have each been cited at least N times, thus reflecting both productivity and impact. Mangi Lal Jat, from the Climate Change, Agriculture and Food Security (CCAFS) in New Delhi, stands out as the most prolific author, having contributed 22 articles focused on CC in agriculture (Table 2). Following this comprehensive overview, Table 3

Table 2
Ranking of top 10 most productive authors in climate change and agriculture research.

Rank	Author	Articles	TC	h-index	Institute
1	Mangi Lal Jat	22	330	9	Climate Change, Agriculture and Food Security, New Delhi
2	Pramod K. Aggarwal	16	743	11	International Maize and Wheat Improvement Center, New Delhi
3	Hanuman Sahay Jat	12	83	5	Central Soil Salinity Research Institute, Haryana
4	Parbodh C. Sharma	12	96	5	Central Soil Salinity Research Institute, Haryana
5	Dil Bahadur Rahut	10	152	5	International Maize and Wheat Improvement Center, New Delhi
6	Tek B. Sapkota	9	231	7	International Maize and Wheat Improvement Center, New Delhi
7	P. K. Joshi	7	282	6	Jawaharlal Nehru University, New Delhi
8	Suhas Pralhad Wani	7	79	6	International Crops Research Institute for the Semi-Arid Tropics, Patancheru
9	Firoz Ahmad	7	48	4	Vindhyan Ecology and Natural History Foundation, Uttar Pradesh
10	Bhawna Anand	7	41	3	Indian Council of Agricultural Research - National Institute of Agricultural Economics and Policy Research, New Delhi

Table 3
Major research focus of top 10 authors.

Research focus		
Climate change	South Asia	Ex ante risk
Climate-smart agriculture	Rice wheat system	Climate resilient
Indo-Gangetic plains	Smart agriculture practices	Recent climate extremes
Conservation agriculture	Bihar India	Climate extremes evidence
Climate change adaptation	Agricultural sustainability	Food security
Climate-smart agriculture practices	Adaptation greenhouse gas	Past climate extremes
Cereal-based systems	Soil enzymes	Soil organic carbon
Soil enzymes activity	Greenhouse gas mitigation	Ante risk coping
Cropping systems	Impacts of climate change	Haryana India
Economic efficiency	Global warming	Turbo happy seeder

elucidates the major research focuses of these leading authors, offering insights into the specific domains within climate change and agriculture that have garnered their scholarly attention.

3.3. Top institution and state

Fig. 4 depicts the research activity of Indian states during the last 26 years, based on the number of articles published. This analysis was conducted with a focus on the details of the corresponding authors. The results show that New Delhi has the highest number of publications, followed by Tamil Nadu, West Bengal, Andhra Pradesh, and Karnataka. This may be due to the presence of prominent agricultural research institutions in New Delhi and in these states. Also, it may be because these institutes have received more funding from the central Government and international donors to conduct research on climate resilient and sustainable agriculture.

During the study period, the states with the highest publication output were New Delhi, West Bengal, Karnataka, and Telangana. Interestingly, despite the relatively late start of CCRASAI research in West Bengal, the significant number of published papers ranks it third, indicating the considerable attention CCRASAI research has garnered in the region.

Fig. 5 presents the top ten institutes involved in CCRASAI research. The International Maize and Wheat Improvement Center in New Delhi, with 41 publications, is the most productive institution. This is followed by the Indian Agricultural Research Institute in New Delhi and the Indian Council of Agricultural Research in West Bengal, each with 31 publications. Notably, the list includes nine Indian institutions and one from the United States, underscoring their significant contribution to CCRASAI research.

While a major share of research on CCRASAI comes from central Government or international donor-funded research institutes such as the International Maize and Wheat Improvement Center in New Delhi, the Indian Agricultural Research Institute in New Delhi, the Indian Council of Agricultural Research in West Bengal, and the Indian Council for Agricultural Research, the share of research conducted by other universities, primarily at the state level, is relatively less. This suggests that these universities, which currently have fewer publications, should receive more funding and better infrastructure for research, and should also focus more on research on CCRASAI.

3.4. Topmost multiterm used in climate resilience research

In India, the terms most frequently used in research on CCRASAI are "climate change impacts," appearing 198 times, followed by "adaptation strategies," used 123 times, and "sustainable agriculture," mentioned 93 times (Table 4). These terms indicate that Indian researchers place great emphasis on analyzing the effects of climate change, devising adaptation strategies, and promoting sustainable agricultural practices. These aspects are viewed as crucial for societal development compared to other research areas.

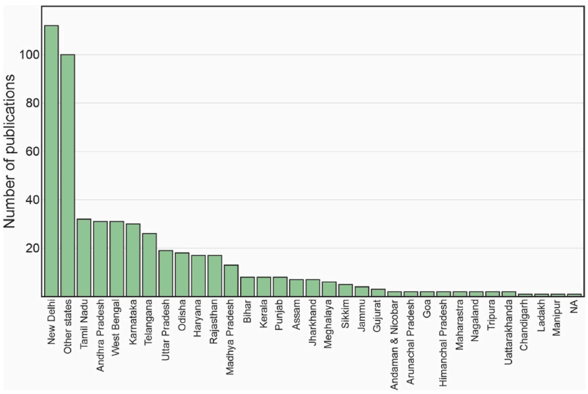

Fig. 4. State-wise research on CCRASAI (1994–2020).

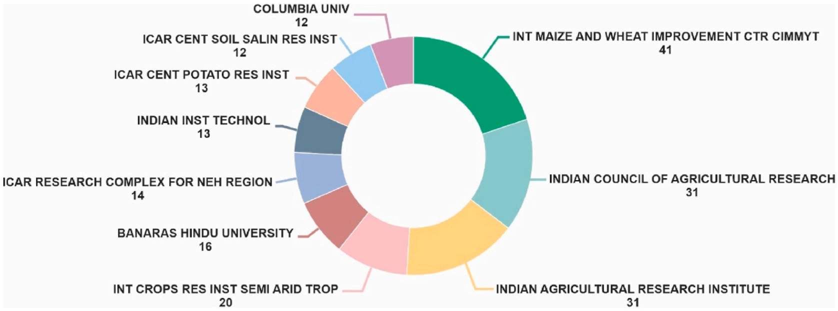

Fig. 5. Top ten institutions in the field of CCRASAI in India.

Table 4
Most frequently used multiterm in CCRASAI research.

Multiterm	Occurrences	Multiterm	Occurrences
Climate change impacts	198	Climate models	32
Adaptation strategies	123	Study area	30
Sustainable agriculture	93	Resilient agriculture	30
Water resources	57	Climate change on agriculture	30
Climate resilient	48	Climate smart agriculture	29
Future climate	48	Greenhouse gas	29
Adaptive capacity	45	Cropping system	28
Climate risk	40	Minimum temperature	26
Climate-smart agriculture	37	Farm households	25
River basin	36	Climate scenarios	25
Production system	36	Indo-gangetic plains	23
Management practices	35	Conservation agriculture	22

3.5. *Top influential journals*

A total of 572 articles related to CCRASAI were published across 272 different journals. Table 5 ranks the journals based on the number of their publications related to CCRASAI. This ranking includes the publication count for each journal, the total citations received for the published articles, and the journal's impact factor in 2023. The journal Climatic Change is identified as the most relevant for CCRASAI research, featuring 20 publications and receiving a total citation count of 625. Following closely behind are The Science of the Total Environment and Current Science, with 19 and 13 publications and citation counts of 519 and 532, respectively.

3.6. *Geographical area of focus*

Upon analyzing the geography of agro-climatic zones within India, it is observed that 572 articles related to CCRASAI analyzed, 177 were conducted at the national level, covering nearly all agro-climatic regions, and 36 were conducted globally, encompassing studies in India as well as other countries. The remaining 359 articles focused on one or several agro-climatic zones within India.

Table 5
Leading journals in climate change resilience, adaptation, and sustainability in agriculture in India (CCRASAI) research.

Journal	NP	TC	h-index	Impact Factor
Climatic Change	20	625	11	4.8
Science of the Total Environment	19	519	14	9.8
Current Science	13	532	7	1.169
Climate and Development	11	138	7	4.3
Environmental Monitoring and Assessment	11	157	8	3.0
International Journal of Climate Change Strategies and Management	11	147	6	3.6
Theoretical and Applied Climatology	10	138	6	3.4
Irrigation and Drainage	8	44	3	2.9
Journal of Agrometeorology	8	51	4	0.484
Agricultural Systems	7	255	7	6.6
Ecological Indicators	7	221	7	6.9
Sustainability	7	28	3	3.9
International Journal of Climatology	6	92	3	3.9
Journal of Water and Climate Change	6	34	4	2.8
Mausam	6	32	4	0.906

Among these 359 articles, the highest number of publications (56 articles) were conducted in Zone 10, the Southern Plateau and Hills region, which includes parts of Karnataka, Tamil Nadu, and Telangana states. As depicted in Fig. 6, this region emerged as the primary geographical area of focus. It was followed by Zone 6, encompassing the Trans-Gangetic plains covering New Delhi, Punjab, and Haryana states, with 48 articles. Zone 4, the Middle-Gangetic Plains, covering most parts of Uttar Pradesh, had 46 articles, and Zone 2, the Eastern Himalayan region, had 40 articles. In contrast, the number of CCRASAI publications is relatively low in Zone 15 (the Islands region), Zone 13 (the Gujarat plains and hills), and Zone 14 (the Western Dry region), with only 23 articles combined.

The reason for more research in the Trans-Gangetic and Middle-Gangetic plains might be due to the increased attention these regions have received as a result of higher crop production after the Green Revolution. It could also be attributable to the presence of numerous research institutes and government offices in these regions, particularly in New Delhi and its surrounding areas. Similarly, the higher number of research studies in the Southern Plateau and Hills region, which covers parts of Karnataka, Tamil Nadu, and Telangana, might be due to an increased focus on dry land agriculture and drought, and the presence of agricultural academic and research institutes in these areas. The regions where there has been less research on CCRASAI are also vulnerable to CC, suggesting a need for more research in these agro-climatic regions and states in India.

3.7. Knowledge structure of climate resilience research: Co-word analysis

The keyword network is represented in Fig. 7, where the size and color of each circle indicate the frequency and type of the cluster, respectively. Details of each cluster are discussed below. The proximity of the circles indicates the frequency of co-occurrence, while the thickness of the connecting lines (links) represents the strength of co-occurrence between the two circles. VOSViewer software was utilized to assign different colors to the clusters based on their weight or significance. The colors range from yellow (very low score) through blue (low score), green (average score), to red (high score) [27].

3.8. Sustainable agriculture (cluster 1)

The sustainable agriculture cluster is a critical research area that aims to develop agricultural practices that are environmentally sustainable, socially responsible, and economically viable. One of the clusters identified in the analysis is “sustainable agriculture,” represented by the red color in Fig. 7. This cluster comprises nine sub-topics: food security, irrigation, sustainability, water resources, biodiversity, climate resilience, dryland agriculture, the green revolution, and water scarcity. The sub-topics within this cluster address various aspects of sustainable agriculture, such as enhancing food security, managing water resources, preserving biodiversity, and adapting to CC.

The statistical information about this cluster is presented in Table 6. Most articles in this cluster underscore the importance of sustainable agriculture practices in mitigating the impacts of CC [31,32] and promoting food security. Some of the initial articles focus on the importance of climate-smart agriculture and its potential to provide farmers with advanced weather information, knowledge about resilient technology and practices, and the means to use these technologies. These articles emphasize the need for effective resource management to ensure sustainable agriculture [33,34]. They also explore the potential of solar and wind energy sources in reducing carbon emissions and increasing resilience in the agricultural sector [35].

Other articles in the collection examine specific issues related to sustainable agriculture, such as the challenges faced by marginalized farmers [36] and the use of technology to control agronomic variables in crop production [37]. They also highlight the importance of collaboration and the use of innovative technologies, such as nanotechnology [38] and ICTs [39], in building resilience and promoting sustainable agriculture practices. Some articles even underline the need to diversify crop production to include CC

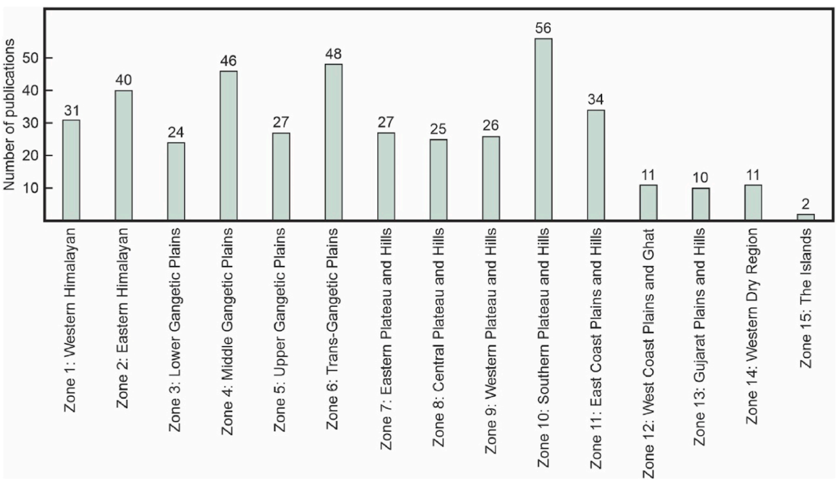

Fig. 6. Distribution of CCRASAI research by zone.

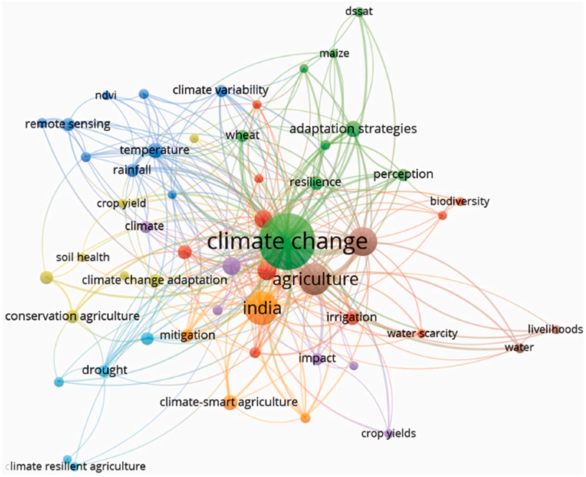

Fig. 7. Keywords used in articles in the domain of CCRASI.

Table 6
The statistical information about the cluster "Sustainable Agriculture".

Cluster	Keywords	Links	Occurrences
1	Sustainable agriculture	14	23
1	Food security	23	20
1	Irrigation	13	13
1	Sustainability	8	13
1	Water resources	10	8
1	Biodiversity	5	5
1	Climate resilience	7	5
1	Dryland agriculture	9	5
1	Green revolution	6	5
1	Water scarcity	6	5

resilient crops like millets and sorghum. Lastly, the articles address the impact of agriculture-emitted black carbon on CC and the need for policies that consider nutrition, climate, and the environment in addition to maximizing production [40].

3.8.1. *Food security*

The loss of agricultural production due to CC is a serious concern due to the need for increased food quantity to feed the growing population. A study predicts a potential food shortage in India by 2030 due to the negative impact of CC [37,41]. Sustainability and resilience in production, processing, and trading of agricultural items are crucial to minimize greenhouse gas emissions [42].

The rise of greenhouse gas in the atmosphere might reduce the nutritional value of crops, which could detrimentally affect the nutritional status of human beings [43]. Therefore, adverse impacts of CC can lead to temporary food shortages among farming households [17,44]. The CC-induced crop loss or intensification of crop and livestock can influence food availability [45]. Conservation agriculture is a good option as it helps achieve better yields, crop diversification, and improved soil quality [46]. For sustainable and climate-resilient agriculture, a mix of modern climate-resilient technologies and traditional practices might be beneficial [47]. To achieve food security, adapting to and mitigating the impact of climate change, along with the adoption of climate-smart agriculture, is vital [48].

3.8.2. *Water resources, water scarcity, and irrigation*

Recent research has demonstrated that the sustainable use of irrigation water can reduce up to one-tenth of the adverse impact of climate change [49]. The role of groundwater in building resilience is significant. If groundwater is depleted, the impact of increased variability could escalate [34]. Climate change could affect water resources by reducing their availability and reliability, leading to water scarcity in some parts of India. Implementing adaptation strategies could help mitigate groundwater depletion in India [50]. The Indian Council of Agricultural Research is endorsing various practices to manage land and water in many agriculturally vulnerable districts [33]. Agriculture in dry and semi-arid areas, heavily dependent on irrigation, makes them more susceptible to climate change [51].

Smart water management solutions aid in the sustainable use of water and contribute to achieving resilience [52]. Overexploitation of water resources and drastic land-use changes impact the hydrological cycle in many parts of India [53]. Therefore, a policy framework for implementing strategies for farmers' adaptation to climate change is crucial to mitigate its adverse impacts [54].

Confidence-building through locally adaptable solutions and the holistic efforts of stakeholders is crucial to mitigate the impact of climate change on water resources [55].

3.8.3. Sustainability and climate resilience

Sustainable agricultural practices blend traditional and modern methodologies to conserve resources, thereby achieving climate resilient agriculture [56]. Improved management and biodiversity conservation can create sustainable and productive systems while decreasing environmental pollution [57]. Gender inclusion is essential in decision-making processes to assist women in managing the impacts of climate change [58].

To devise an action-oriented model for sustainable agriculture in India, sustainability indicators specific to different agro-climatic regions are utilized [59]. Training representatives of both men and women in every local self-governing body can enhance the coping capacity of farm families [60].

Intercropping has significant potential to improve vegetable production sustainably, while a comprehensive approach to creating systems perspectives is urgently needed to mitigate the negative effects of edaphic factors [61]. Different regions of India face varying climatic challenges and necessitate distinct approaches for achieving resilience and sustainability [62]. In areas with a high and very high risk to crops due to water shortage, increasing temperatures, and precipitation variation, climate-smart agriculture practices should be adopted [63].

Cultivation of crops resilient to climate change is another method for achieving resilience and sustainability. For instance, finger millet can aid farmers in achieving adaptation and resilience [63]. Integrating disaster management and agricultural risk is vital to enhancing climate resilience among farming communities in flood plains [64]. Policymakers should encourage training for livelihood diversification, increased use of digital technologies, and the practice of conservation agriculture to reduce climate risk [65].

The promotion of local insects and bees by growing hedges, flowering plants, and cooling ponds can help maintain biodiversity [66]. Combined soil-water-vegetation efforts can fortify water resilience in the agricultural sector [67]. Donors should support sustainable seed innovation, and the Farmers' Rights Act should encourage the protection of plant and sustainable innovations through incentives to farmers [68].

3.9. Climate change (cluster 2)

The second cluster, referred to as CC (Fig. 5), is denoted by green-colored nodes, and the articles in this cluster mainly focus on the impact of climate change on agriculture and food systems in India, as well as perceptions and mitigation strategies related to CC. This cluster consists of eight sub-topics, namely adaptation strategies, resilience, wheat, perception, Decision Support System for Agrotechnology Transfer, rainfed agriculture, maize, and impacts. A summary of the statistical information related to this cluster is presented in Table 7.

3.9.1. Perception of CC and adaptation strategies

The reviewed studies suggest that farmers recognize the impact of CC on their livelihoods and endeavor to adapt to the evolving conditions [69]. Farmers perceive alterations in climatic patterns, such as rising temperatures and prolonged dry spells, and have noticed changes in crop phenology and livestock productivity [70].

Factors like crop diversification, adoption of heat-resistant crops, adjusting planting dates, agroforestry, and modification of water management strategies have been employed by farmers to minimize the risks linked to climate change [69]. However, barriers to adaptation exist, such as high input costs and limited awareness of effective adaptation technologies [31]. Farmers' perceptions of risk and their decisions to adopt specific adaptation strategies are influenced by various factors, including economic status, age, education, and farm landholding size [71,72]. Capturing ground-level evidence is essential for preparing adaptation strategies and identifying the shortcomings in achieving resilient and sustainable agriculture [73]. While promoting adaptive behavior, the perceptions of farmers to identify risks in varying socio-economic conditions should be considered. Moreover, the adoption of water management strategies is crucial in areas with water scarcity, high climate sensitivity, and constant socio-economic dynamic changes [74]. Using systematic tools to collect local knowledge can aid scientists in testing various hypotheses, which in turn helps policymakers prepare climate adaptation strategies [75].

Table 7
The statistical information about the cluster "Climate change".

Cluster	Keywords	Links	Occurrences
2	Climate change	49	205
2	Adaptation strategies	13	16
2	Resilience	13	13
2	Wheat	11	10
2	Perception	11	9
2	DSSAT	5	7
2	Rainfed agriculture	9	7
2	Maize	9	6
2	Impacts	8	5

3.9.2. Climate change impacts

The impacts of CC vary depending on the region and specific crop but are anticipated to significantly affect agriculture worldwide [76]. CC influences agriculture in multiple ways, including an increased occurrence of floods, sea-level rise, salt intrusion, and changes in rainfall patterns [77]. A study in the Ganges Basin, a major contributor to India's food supply, showed that CC has affected yields in the region [78]. These impacts threaten farmers' food security and may result in heightened food scarcity [60]. CC also affects the physiological mechanisms that regulate plant and animal productivity, which could lead to reductions in crop yield and groundwater depletion [79]. However, certain adaptation measures and enhanced agricultural practices, like early planting, nutrient management, and heat-tolerant varieties, can help mitigate some of these negative impacts [80].

3.10. Temperature and rainfall (cluster 3)

The third cluster, denoted by blue-colored nodes (see Fig. 5), is titled "temperature and rainfall." It encompasses nine sub-topics: temperature, rainfall, remote sensing, climate variability, agroforestry, Geographical Information Systems (GIS), trend analysis, global warming, and Normalized Difference Vegetation Index (NDVI). The statistical information about this cluster is presented in Table 8. In the subsequent sections, we discuss key findings and suggestions from articles related to this cluster.

High rainfall variability adversely influences agricultural specialization and household occupational choices. Better access to credit, irrigation facilities, education, roads, and communication is associated with greater emphasis on agriculture-related employment and lesser adoption of other types of employment within a household [81]. Concurrently, increases in warm extremes, specifically the daily minimum temperature, lead to reductions in cold extreme events in major areas of India [82]. A study found that a 1 °C increase in temperature results in a 3 % reduction in wheat yield. This finding does not consider potential increases in physical inputs and short-term adaptation strategies that farmers might employ to mitigate the impacts of climate change [83].

Adaptation to extreme heat is challenging for crops, as found in a case study in the Janjigir-Champa district of Chhattisgarh. Here, erratic rainfall patterns and delayed monsoons have affected food security and livelihoods, leading to migration as the most common coping strategy [84]. In southern peninsular India, a study discovered that the minimum, maximum, and mean monthly temperatures over different annual periods have decreased while rainfall has increased in the past 20 years [85]. Understanding long-term rainfall and temperature trends at regional scales is crucial for planning adaptation strategies. Mapping observed rainfall trends and their association with large-scale modes of circulation can assist policymakers in prioritizing mitigation and adaptation strategies [86].

3.11. Climate change adaptation and carbon sequestration (cluster 4)

The fourth cluster, represented by yellow-colored nodes (see Fig. 5), is known as CC adaptation and carbon sequestration. This cluster encompasses seven sub-topics: carbon sequestration, climate change adaptation, conservation agriculture, crop diversification, crop yield, Himalayas, and soil health. The statistical information about this cluster is presented in Table 9, and we review some of the key articles related to this cluster in the following sections.

Soil organic carbon (SOC) levels in various agro-ecological regions in India have drastically decreased due to extractive farming practices, uncontrolled grazing, shifting cultivation, and other factors [87]. Carbon sequestration projects can potentially reduce greenhouse gas emissions and aid in climate change adaptation, but trust-building measures are required to promote the adoption of these projects [88]. The introduction of drought-resistant crop varieties can help farmers adapt to climate change and boost food production [89], but resource conservation methods like non-tillage-based systems and conservation agriculture play a significant role in SOC sequestration and in mitigating negative environmental and social effects [90]. Mangrove-rice systems offer potential ecosystem services for carbon sequestration but face specific challenges such as sea-level rise, cyclones, floods, and poor management practices that impede productivity [91].

3.12. Vulnerability assessment (cluster 5)

The fifth cluster, depicted by purple-colored nodes (see Fig. 5), represents the topic of vulnerability assessment. This cluster consists of six sub-topics: climate, crop yields, impact, Indian agriculture, sensitivity, and vulnerability. Table 10 provides statistical information about this cluster. In the following sections, key findings and recommendations on agricultural vulnerability in India to climate

Table 8
The statistical information about the cluster "Temperature and Rainfall".

Cluster	Keywords	Links	Occurrences
3	Temperature	18	15
3	Rainfall	13	11
3	Remote sensing	10	11
3	Climate variability	13	10
3	Agroforestry	10	7
3	Geographical Information Systems (GIS)	4	7
3	Trend analysis	7	7
3	Global warming	9	6
3	Normalized Difference Vegetation Index (NDVI)	6	5

Table 9
The statistical information about the cluster "Climate change adaptation and carbon sequestration".

Cluster	Keywords	Links	Occurrences
4	Carbon sequestration	5	11
4	Climate change adaptation	10	12
4	Conservation agriculture	7	12
4	Crop diversification	5	6
4	Crop yield	10	6
4	Himalaya	5	6
4	Soil health	4	5

change, as discovered in the articles, will be discussed.

Studies on the vulnerability of the agricultural sector show significant spatial, temporal, and thematic differences in India [92]. Most studies emphasize climate-induced external stressors over internal ones, often neglecting the socio-cultural-politico-economic and physical dynamics of agriculture that generate agricultural risks and vulnerabilities. Vulnerability assessments conducted at macro spatial scales cannot adequately evaluate vulnerability at micro-levels, where small and marginal farmers dominate, thereby impeding the implementation of efficient mitigation strategies at the grassroots level [93].

The impacts of CC cause crop losses and affect crop intensification and livestock production, which in turn influence the food supply. However, these impacts vary at the household level depending on the household's livelihood strategies and the degree of farming diversification [45]. To mitigate the effects of climate-induced droughts, the government needs to adopt a more proactive approach to developing micro-level adaptation strategies to safeguard livelihoods in the agricultural and dairy sectors [94]. Integrating climate change into development planning is crucial to minimize the risk of maladaptation [95]. Moreover, it is vital to address farmers' distress by developing a multidimensional Farmers' Distress Index (FDI) at the farmer, district, and sub-district levels. This index could serve as a planning tool to devise strategies to address the causes of farmers' distress [96]. Finally, adopting a participatory approach to collect local knowledge, integrating this knowledge into vulnerability assessments, and then using these findings in policy recommendations can help achieve climate resilience [75].

3.13. Climate smart agriculture and drought (cluster 6)

The sixth cluster, indicated by nodes colored light blue in Fig. 5, represents the topic of climate smart agriculture and drought. This cluster includes six sub-topics, namely resilient agriculture, climate smart agriculture, drought, livestock, and rainwater harvesting. Table 11 provides statistical information on this cluster. Selected key findings and recommendations regarding climate-smart agriculture and drought, as found in the associated articles, are discussed in the following sections.

The articles discuss various technologies to manage drought, particularly in dryland regions. Measures such as rainwater harvesting, moisture conservation and recycling, adoption of climate resilient crops and practices, and mixed farming systems are recommended [20]. Small and marginal farmers, who constitute the overwhelming majority in India, are significantly impacted by climate change [9]. To address this issue, it is suggested that the government focus on developing micro-level adaptation strategies [94]. There is also a call for the development of institutions that assist farmers in managing risks, promoting better access to credit, building capacity, and preparing communities to mitigate climate change [97]. A few articles emphasize the importance of practicing climate-smart agricultural approaches [98], and laser land leveling [99] to improve soil productivity, water use efficiency, and reduce risks due to weather variability. However, it is also noted that the implementation of these strategies requires robust institutional support, government policies, and convergence among various institutions [100].

3.14. Climate change adaptation in agriculture (cluster 7)

The seventh cluster, represented by grey-colored nodes in Fig. 5, is titled "Climate Change Adaptation in Agriculture." This cluster comprises four sub-topics: adaptation, agriculture, livelihoods, and water. Statistical information about this cluster can be found in Table 12. Key findings and suggestions from some significant articles related to this cluster will be discussed in this section.

Approximately half of India's agricultural land depends on rainfall, and climate change affects crop yield and the status and dynamics of soil, water, and pests [101]. Farmers adopt various climate adaptation methods to mitigate the impacts of climate change, which can vary in different geographical areas and over time [102]. Major risks include unseasonal rainfall, drought, and other factors such as crop diseases and pests [103]. Both central and state governments should emphasize planned adaptation and mitigation measures to achieve long-term sustainability [5].

The traditional method of rice-wheat rotation cultivation in the Indo-Gangetic Plains involves tillage and extensive use of water and energy, which are capital intensive [104]. This conventional agricultural method impacts climate change through increased greenhouse gas emissions, and agriculture in these regions is also affected by climate change and the degradation of soil conditions. Mangrove forests and their agricultural ecosystems are also under threat due to extreme events such as cyclones and floods, and human interference [91]. Climate impacts continue to reduce crop yields, threatening the food security of farmers [77].

The promotion of suitable conservation agriculture (CA) practices is a viable strategy for mitigating the impact of climate change on agriculture [105]. CA offers many benefits, including an increase in yield and production and improved ecology, to achieve sustainable agriculture and enhance the household income of farmers [46].

Table 10
The statistical information about the cluster "Vulnerability assessment".

Cluster	Keywords	Links	Occurrences
5	Climate	10	10
5	Crop yields	4	5
5	Impact	10	10
5	Indian agriculture	4	5
5	Sensitivity	6	7
5	Vulnerability	20	20

Table 11
The statistical information about the cluster "Climate smart agriculture and drought."

Cluster	Keywords	Links	Occurrences
6	Climate resilient agriculture	4	5
6	Climate smart agriculture	10	11
6	Drought	14	10
6	Livestock	5	7
6	Rainwater harvesting	2	5

Table 12
The statistical information about the cluster "Climate change adaptation in agriculture."

Cluster	Keywords	Links	Occurrences
7	adaptation	32	54
7	agriculture	31	67
7	livelihoods	5	5
7	water	6	7

4. Conclusions

This study has conducted an extensive bibliometric analysis of research publications in the field of CCRASAI spanning from 1994 to 2022. It has delineated seven primary themes: sustainable agriculture, climate change, temperature and rainfall, climate change adaptation and carbon sequestration, vulnerability assessment, climate-smart agriculture and drought, and climate change adaptation in agriculture. Notably, the research is concentrated in specific agro-climatic regions, underscoring the urgency for intensified research efforts in more vulnerable areas. This necessitates enhanced support from State Governments and the Government of India in terms of funding and infrastructure to foster research in these critically undercovered regions.

The findings underscore the critical need to comprehend the impacts of climate change, formulate effective adaptation strategies, and promote sustainable agricultural practices, particularly for small and marginal farmers. The study advocates for the development of a framework focused on multi-stressor vulnerability research, risk assessment, and the transformation of research findings into actionable solutions. This is aimed at bolstering awareness and facilitating the adoption of climate-resilient practices. Additionally, it recognizes the contributions of various initiatives, highlighting the imperative to leverage research outcomes to diminish the impacts of climate change and enhance climate resilience and sustainability in the agricultural sector of India.

4.1. Limitations of the research work

While the bibliometric analysis undertaken in this study covered a vast array of research conducted in the area of CCRASAI, it does present some limitations. The keywords selected for the bibliometric analysis are based on a scientific literature review and are used to retrieve data on research in these areas. Relying on these keywords for data retrieval may introduce some bias. Furthermore, the keyword search was only performed within the Scopus and Web of Science databases and only included works published from 1994 to 2022. Although these two search engines cover a wide scope of scientific publications, the study's reliance on these databases within a specific timeframe might have resulted in the exclusion of some publications.

The bibliometric analysis primarily focuses on scientific publications; however, it may not have included other types of literature, such as governmental and regulatory documents. Therefore, while this study provides valuable insights into the trends and gaps in CCRASAI research, it might not capture the full breadth of knowledge and developments in this domain.

4.2. Future directions for CCRASAI research

Despite these limitations, this study points to several promising directions for future research on CCRASAI. One of the significant directions can be exploring the practical application of advanced digital technologies to achieve climate resilience and sustainability in agriculture. Research should also focus on agro-climatic regions which are under-studied and are likely to be more impacted by climate change.

Furthermore, there is a need to foster research that prioritizes the needs of small and marginal farmers, who constitute the majority of India's farming population. Along with this, the conversion of research into actionable products for creating awareness and providing last-mile connectivity to farmers is of paramount importance. Lastly, a more significant emphasis should be placed on how research findings can be practically utilized by the Government and end-users to mitigate climate change impacts. Such efforts can pave the way for achieving better climate resilience and sustainability in the agriculture sector in India.

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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.

References

[1] F. Liu, Y. Masago, An analysis of the spatial heterogeneity of future climate change impacts in support of cross-sectoral adaptation strategies in Japan, Climate Risk Management 41 (2023) 100528, https://doi.org/10.1016/j.crm.2023.100528.

[2] A. Crespi, K. Renner, M. Zebisch, I. Schauser, N. Leps, A. Walter, Analysing spatial patterns of climate change: climate clusters, hotspots and analogues to support climate risk assessment and communication in Germany, Climate Services 30 (2023) 100373, https://doi.org/10.1016/j.cliser.2023.100373.

[3] IPCC, 2022: *Climate Change 2022: Impacts, Adaptation, and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi: 10.1017/9781009325844. (Accessed 17 June 2023).

[4] P.K. Aggarwal, Global climate change and Indian agriculture: impacts, adaptation and mitigation, Indian J. Agric. Sci. 78 (11) (2008) 911.

[5] P. Dhanya, R. Ramachandran, Farmers' perceptions of climate change and the proposed agriculture adaptation strategies in a semi-arid region of south India, J. Integr. Environ. Sci. 13 (1) (2016) 1–18, https://doi.org/10.1080/1943815X.2015.1062031.

[6] S.A.R. Khan, A. Razzaq, Z. Yu, A. Shah, A. Sharif, L. Janjua, Disruption in food supply chain and undernourishment challenges: an empirical study in the context of Asian countries, Soc. Econ. Plann. Sci. 82 (Part A) (2022) 101033, https://doi.org/10.1016/j.seps.2021.101033.

[7] Government of India, All India report on agriculture census 2015-16, Available at: https://agcensus.nic.in/document/agcen1516/ac_1516_report_final-220221.pdf, 2022. (Accessed 18 December 2023).

[8] S. Singh, Assessing livelihood vulnerability of farmers' in backward regions of India, Indian J. Agric. Res. 55 (2) (2020) 222–226, https://doi.org/10.18805/IJARe.A-5413.

[9] P. Udmale, Y. Ichikawa, S. Manandhar, H. Ishidaira, A.S. Kiem, Farmers′ perception of drought impacts, local adaptation and administrative mitigation measures in Maharashtra State, India, Int. J. Disaster Risk Reduc. 10 (2014) 250–269, https://doi.org/10.1016/j.ijdrr.2014.09.011.

[10] C. Srinivasa Rao, K.A. Gopinath, J.V.N.S. Prasad, Prasannakumar, A.K. Singh, Climate resilient villages for sustainable food security in tropical India: concept, process, technologies, institutions, and impacts, Adv. Agron. 140 (2016) 101–214, https://doi.org/10.1016/bs.agron.2016.06.003.

[11] G. Rasul, A framework for addressing the twin challenges of COVID-19 and climate change for sustainable agriculture and food security in South Asia, Front. Sustain. Food Syst. 5 (2021) 679037, https://doi.org/10.3389/fsufs.2021.679037.

[12] F. Ceballos, S. Kannan, B. Kramer, Impacts of a national lockdown on smallholder farmers' income and food security: empirical evidence from two states in India, World Dev. 136 (2020) 105069, https://doi.org/10.1016/j.worlddev.2020.105069.

[13] C.A.R. Rao, B.M.K. Raju, A.V.M.S. Rao, K.V. Rao, V.U.M. Rao, K. Ramachandran, B. Venkateswarlu, A.K. Sikka, M.S. Rao, M. Maheswari, Ch S. Rao, A district level assessment of vulnerability of Indian agriculture to climate change, Curr. Sci. 110 (10) (2016) 1939–1946. http://www.jstor.org/stable/24908182.

[14] A.V. Sreenath, S. Abhilash, P.P. Ajilesh, Changes in the dynamical, thermodynamical and hydrometeor characteristics prior to extreme rainfall events along the southwest coast of India in recent decades, Atmos. Res. 289 (2023) 106752, https://doi.org/10.1016/j.atmosres.2023.106752.

[15] N. Subash, D. Dutta, P.C. Ghasal, P. Punia, V.P. Mandal, Brahmadut, V.P. Chaudhary, Relevance of climatological information on spatial and temporal variability of Indian Summer monsoon rainfall (ISMR) in recent El Niño years and its impact on four important kharif crops over India, Climate Services 30 (2023) 100370, https://doi.org/10.1016/j.cliser.2023.100370.

[16] N.L. Joshi, A. Kar, Contingency crop planning for dryland areas in relation to climate change, Indian J. Agron. 54 (2) (2009) 237–243.

[17] A. Hussain, G. Rasul, B. Mahapatra, S. Tuladhar, Household food security in the face of climate change in the Hindu-Kush Himalayan region, Food Secur. 8 (5) (2016) 921–937, https://doi.org/10.1007/s12571-016-0607-5.

[18] P.J. Kamdi, D.K. Swain, S.P. Wani, Developing climate change agro-adaptation strategies through field experiments and simulation analyses for sustainable sorghum production in semi-arid tropics of India, Agric. Water Manag. 286 (2023) 108399, https://doi.org/10.1016/j.agwat.2023.108399.
[19] T. Singh, Economic growth and the state of poverty in India: sectoral and provincial perspectives, Econ. Change Restruct. 55 (2022) 1251–1302, https://doi.org/10.1007/s10644-021-09345-5.
[20] C. Srinivasa Rao, K.A. Gophinath, Resilient rainfed technologies for drought mitigation and sustainable food security, Mausam 67 (1) (2016) 169–182, https://doi.org/10.54302/mausam.v67i1.1174.
[21] G. Ziervogel, P.J. Ericksen, Adapting to climate change to sustain food security, Wiley Interdisciplinary Reviews: Clim. Change 1 (4) (2010) 525–540, https://doi.org/10.1002/wcc.56.
[22] M. Mishra, S. Desul, C.A.G. Santos, S.K. Mishra, A.H.M. Kamal, S. Goswami, A.M. Kalumba, R. Biswal, R.M. da Silva, C.A.C. dos Santos, K. Baral, A bibliometric analysis of sustainable development goals (SDGs): a review of progress, challenges, and opportunities, Environ. Dev. Sustain. (2023), https://doi.org/10.1007/s10668-023-03225-w.
[23] M. Mishra, M.K. Dash, D. Sudarsan, C.A.G. Santos, S.K. Mishra, D. Kar, I.A. Bhat, B.K. Panda, M. Sethy, R.M. Silva, Assessment of trend and current pattern of open educational resources: a bibliometric analysis, J. Acad. Librarian 48 (3) (2022) 102520, https://doi.org/10.1016/j.acalib.2022.102520.
[24] R.K. Patra, N. Pandey, D. Sudarsan, Bibliometric analysis of fake news indexed in Web of Science and Scopus (2001-2020), Global Knowledge, Memory and Communication (2022), https://doi.org/10.1108/GKMC-11-2021-0177.
[25] M. Mishra, D. Sudarsan, D. Kar, A.K. Naik, P.P. Das, C.A.G. Santos, R.M. Silva, The development and research trend of using DSAS tool for shoreline change analysis: a scientometric analysis, J. Urban Environ. Eng. 14 (1) (2020) 69–77, https://doi.org/10.4090/juee.2020.v14n1.069077.
[26] M. Aria, C. Cuccurullo, Bibliometrix : an R-tool for comprehensive science mapping analysis, Journal of Informetrics 11 (4) (2017) 959–975, https://doi.org/10.1016/j.joi.2017.08.007.
[27] N.J. Van Eck, L. Waltman, Software survey: VOSviewer, a computer program for bibliometric mapping, Scientometrics 84 (2) (2010) 523–538, https://doi.org/10.1007/s11192-009-0146-3.
[28] N. Donthu, S. Kumar, D. Mukherjee, N. Pandey, W.M. Lim, How to conduct a bibliometric analysis: an overview and guidelines, J. Bus. Res. 133 (2021) 285–296, https://doi.org/10.1016/j.jbusres.2021.04.070.
[29] PoCRA – Project on Climate Resilient Agriculture, DBT Maharashtra, Nanaji Deshmukh Krushi Sanjivani Prakalp. Available at: https://dbt.mahapocra.gov.in. (Accessed 17 June 2023).
[30] K. O'Brien, R. Leichenko, U. Kelkar, H. Venema, G. Aandahl, H. Tompkins, A. Javed, S. Bhadwal, S. Barg, L. Nygaard, J. West, Mapping vulnerability to multiple stressors: climate change and globalization in India, Global Environ. Change 14 (4) (2004) 303–313, https://doi.org/10.1016/j.gloenvcha.2004.01.001.
[31] A.K. Bhalerao, L. Rasche, J. Scheffran, U.A. Schneider, Sustainable agriculture in Northeastern India: how do tribal farmers perceive and respond to climate change? International, Journal of Sustainable Development and World Ecology 29 (4) (2022) 291–302, https://doi.org/10.1080/13504509.2021.1986750.
[32] U. Das, M.A. Ansari, The nexus of climate change, sustainable agriculture and farm livelihood: contextualizing climate smart agriculture, Clim. Res. 84 (2021) 23–40, https://doi.org/10.3354/cr01648.
[33] A.K. Sikka, A. Islam, K.V. Rao, Climate-smart land and water management for sustainable agriculture, Irrigat. Drain. 67 (1) (2018) 72–81, https://doi.org/10.1002/ird.2162.
[34] A.K. Sikka, M.F. Alam, P. Pavelic, Managing groundwater for building resilience for sustainable agriculture in South Asia, Irrigat. Drain. 70 (3) (2021) 560–573, https://doi.org/10.1002/ird.2558.
[35] A. Chel, G. Kaushik, Renewable energy for sustainable agriculture, Agron. Sustain. Dev. 31 (1) (2011) 91–118, https://doi.org/10.1051/agro/2010029.
[36] U.K. Behera, Integrated farming systems for prosperity of marginal farmers and sustainable agriculture: a roadmap for India, Indian J. Agric. Sci. 89 (11) (2019) 1764–1772.
[37] K. Kour, D. Gupta, K. Gupta, S. Juneja, M. Kaur, A.H. Alharbi, H.-N. Lee, Controlling agronomic variables of Saffron crop using IoT for sustainable agriculture, Sustainability 14 (9) (2022) 5607, https://doi.org/10.3390/su14095607.
[38] G. Pandey, Challenges and future prospects of agri-nanotechnology for sustainable agriculture in India, Environ. Technol. Innov. 11 (2018) 299–307, https://doi.org/10.1016/j.eti.2018.06.012.
[39] B. Chaudhuri, L. Kendall, Collaboration without consensus: building resilience in sustainable agriculture through ICTs, Inf. Soc. 37 (1) (2021) 1–19, https://doi.org/10.1080/01972243.2020.1844828.
[40] K.F. Davis, A. Chhatre, N.D. Rao, D. Singh, S. Ghosh-Jerath, A. Mridul, M. Poblete-Cazenave, N. Pradhan, R. DeFries, Assessing the sustainability of post-Green Revolution cereals in India, Proc. Natl. Acad. Sci. USA 116 (50) (2019) 25034–25041, https://doi.org/10.1073/pnas.1910935116.
[41] J.S. Bandara, Y. Cai, The impact of climate change on food crop productivity, food prices and food security in South Asia, Econ. Anal. Pol. 44 (4) (2014) 451–465, https://doi.org/10.1016/j.eap.2014.09.005.
[42] J. Pretty, T.G. Benton, Z.P. Bharucha, L.V. Dicks, C.B. Flora, H.C.J. Godfray, D. Goulson, S. Hartley, N. Lampkin, C. Morris, G. Pierzynski, P.V.V. Prasad, J. Reganold, J. Rockström, P. Smith, P. Thorne, S. Wratten, Global assessment of agricultural system redesign for sustainable intensification, Nat. Sustain. 1 (8) (2018) 441–446, https://doi.org/10.1038/s41893-018-0114-0.
[43] S.S. Myers, K.R. Wessells, I. Kloog, A. Zanobetti, J. Schwartz, Effect of increased concentrations of atmospheric carbon dioxide on the global threat of zinc deficiency: a modelling study, Lancet Global Health 3 (10) (2015) e639–e645, https://doi.org/10.1016/S2214-109X(15)00093-5.
[44] J. Fanzo, R. McLaren, C. Davis, J. Choufani, Climate change and variability: what are the risks for nutrition, diets, and food systems? IFPRI Discussion Paper (2017) 1645. Available at: https://ssrn.com/abstract=3029325. (Accessed 18 December 2023).
[45] S. Lopez-Ridaura, R. Frelat, M.T. van Wijk, D. Valbuena, T.J. Krupnik, M.L. Jat, Climate smart agriculture, farm household typologies and food security, Agric. Syst. 159 (2018) 57–68, https://doi.org/10.1016/j.agsy.2017.09.007.
[46] A. Pradhan, C. Chan, P.K. Roul, J. Halbrendt, B. Sipes, Potential of conservation agriculture (CA) for climate change adaptation and food security under rainfed uplands of India: a transdisciplinary approach, Agric. Syst. 163 (2018) 27–35, https://doi.org/10.1016/j.agsy.2017.01.002.
[47] M.S. Swaminathan, Achieving food security in times of crisis, N. Biotech. 27 (5) (2010) 453–460, https://doi.org/10.1016/j.nbt.2010.08.002.
[48] J.P. Aryal, T.B. Sapkota, D.B. Rahut, M.L. Jat, Agricultural sustainability under emerging climatic variability: the role of climate-smart agriculture and relevant policies in India, Int. J. Innovat. Sustain. Dev. 14 (2) (2020) 219, https://doi.org/10.1504/IJISD.2020.106243.
[49] R. Fishman, Groundwater depletion limits the scope for adaptation to increased rainfall variability in India, Climatic Change 147 (1–2) (2018) 195–209, https://doi.org/10.1007/s10584-018-2146-x.
[50] H. Biemans, L.H. Speelman, F. Ludwig, E.J. Moors, A.J. Wiltshire, P. Kumar, D. Gerten, P. Kabat, Future water resources for food production in five South Asian river basins and potential for adaptation — a modeling study, Sci. Total Environ. 468–469 (2013) S117–S131, https://doi.org/10.1016/j.scitotenv.2013.05.092.
[51] M. Robert, J.-E. Bergez, A. Thomas, A stochastic dynamic programming approach to analyze adaptation to climate change – application to groundwater irrigation in India. European, Journal of Operational Research 265 (3) (2018) 1033–1045, https://doi.org/10.1016/j.ejor.2017.08.029.
[52] A.K. Sikka, M.F. Alam, V. Mandave, Agricultural water management practices to improve the climate resilience of irrigated agriculture in India, Irrigat. Drain. 71 (S1) (2022) 7–26, https://doi.org/10.1002/ird.2696.
[53] A.K. Misra, Climate change impact, mitigation and adaptation strategies for agricultural and water resources, in Ganga Plain (India), Mitig. Adapt. Strategies Glob. Change 18 (5) (2013) 673–689, https://doi.org/10.1007/s11027-012-9381-7.
[54] M.K. Goyal, R.Y. Surampalli, Impact of climate change on water resources in India, J. Environ. Eng. 144 (7) (2018), https://doi.org/10.1061/(ASCE)EE.1943-7870.0001394.
[55] S. Sharma, S. Tamchos, R. Kumar, P. Sah, Low-cost mitigation strategies for community resilience in the Trans-Himalaya to address food and water scarcity in changing environment, Environ. Monit. Assess. 194 (12) (2022) 879, https://doi.org/10.1007/s10661-022-10546-2.

[56] R. Singh, H. Singh, A.S. Raghubanshi, Challenges and opportunities for agricultural sustainability in changing climate scenarios: a perspective on Indian agriculture, Trop. Ecol. 60 (2) (2019) 167–185, https://doi.org/10.1007/s42965-019-00029-w.
[57] L.W. Bell, A.D. Moore, J.A. Kirkegaard, Evolution in crop–livestock integration systems that improve farm productivity and environmental performance in Australia, Eur. J. Agron. 57 (2014) 10–20, https://doi.org/10.1016/j.eja.2013.04.007.
[58] FAO – Food and Agriculture Organization of the United Nations, Good practices for integrating gender equality and women's empowerment in climate-smart agriculture programmes Available at: https://www.fao.org/3/ca3883en/ca3883en.pdf. (Accessed 17 June 2023).
[59] C. Srinivasa Rao, K. Kareemulla, P. Krishnan, G.R.K. Murthy, P. Ramesh, P.S. Ananthan, P.K. Joshi, Agro-ecosystem based sustainability indicators for climate resilient agriculture in India: a conceptual framework, Ecol. Indicat. 105 (2019) 621–633, https://doi.org/10.1016/j.ecolind.2018.06.038.
[60] M.S. Swaminathan, P.C. Kesavan, Agricultural research in an era of climate change, Agric. Res. 1 (1) (2012) 3–11, https://doi.org/10.1007/s40003-011-0009-z.
[61] L. Varghese, Indicators of production sustainability in intercropped vegetable farming on montmorillonitic soils in India, J. Sustain. Agric. 16 (4) (2000) 5–17, https://doi.org/10.1300/J064v16n04_03.
[62] L. Goparaju, F. Ahmad, Analyzing the risk related to climate change attributes and their impact, a step towards climate-smart village (CSV): a geospatial approach to bring geoponics sustainability in India, Spatial Information Research 27 (6) (2019) 613–625, https://doi.org/10.1007/s41324-019-00258-0.
[63] C. Grovermann, K. Umesh, S. Quiédeville, B.S.S. Kumar, S. Moakes, The economic reality of underutilised crops for climate resilience, food security and nutrition: assessing Finger Millet Productivity in India, Agriculture 8 (9) (2018) 131, https://doi.org/10.3390/agriculture8090131.
[64] L. Borah, B. Kalita, P. Boro, A.S. Kulnu, N. Hazarika, Climate change impacts on socio-hydrological spaces of the Brahmaputra floodplain in Assam, Northeast India: a review, Frontiers in Water 4 (2022), https://doi.org/10.3389/frwa.2022.913840.
[65] T.E. Venus, S. Bilgram, J. Sauer, A. Khatri-Chettri, Livelihood vulnerability and climate change: a comparative analysis of smallholders in the Indo-Gangetic plains, Environ. Dev. Sustain. 24 (2) (2022) 1981–2009, https://doi.org/10.1007/s10668-021-01516-8.
[66] C.T. Jacob, A. Parida, N.K. Krishna Kumar, Conservation of India's agrobiodiversity towards increasing food, nutritional and livelihood security, Curr. Sci. 119 (4) (2020) 607, https://doi.org/10.18520/cs/v119/i4/607-612.
[67] K.K. Garg, R. Singh, K.H. Anantha, A.K. Singh, V.R. Akuraju, J. Barron, I. Dev, R.K. Tewari, S.P. Wani, S.K. Dhyani, S. Dixit, Building climate resilience in degraded agricultural landscapes through water management: a case study of Bundelkhand region, Central India, J. Hydrol. 591 (2020) 125592, https://doi.org/10.1016/j.jhydrol.2020.125592.
[68] N. Kopytko, Supporting sustainable innovations: an examination of India farmer agrobiodiversity conservation, J. Environ. Dev. 28 (4) (2019) 386–411, https://doi.org/10.1177/1070496519870299.
[69] P. Datta, B. Behera, Factors influencing the feasibility, effectiveness, and sustainability of farmers' adaptation strategies to climate change in the Indian eastern Himalayan Foothills, Environ. Manag. 70 (6) (2022) 911–925, https://doi.org/10.1007/s00267-022-01724-6.
[70] P. Dhanya, A. Ramachandran, K. Palanivelu, Understanding the local perception, adaptation to climate change and resilience planning among the farmers of semi-arid tracks of south India, Agric. Res. 11 (2) (2022) 291–308, https://doi.org/10.1007/s40003-021-00560-0.
[71] C. Funk, A. Raghavan Sathyan, P. Winker, L. Breuer, Changing climate - changing livelihood: smallholder's perceptions and adaption strategies, J. Environ. Manag. 259 (2020) 109702, https://doi.org/10.1016/j.jenvman.2019.109702.
[72] F.A. Lone, M. Maheen, M. ul Shafiq, M.S. Bhat, J.A. Rather, Farmer's perception and adaptation strategies to changing climate in Kashmir Himalayas, India, Geojournal 87 (3) (2022) 1743–1757, https://doi.org/10.1007/s10708-020-10330-0.
[73] N.P. Singh, B. Anand, S.K. Srivastava, N.R. Kumar, S. Sharma, S.K. Bal, K.V. Rao, M. Prabhakar, Risk, perception and adaptation to climate change: evidence from arid region, India, Nat. Hazards 112 (2) (2022) 1015–1037, https://doi.org/10.1007/s11069-022-05216-y.
[74] P.D. Wagner, T.G. Reichenau, S. Kumar, K. Schneider, Development of a new downscaling method for hydrologic assessment of climate change impacts in data scarce regions and its application in the Western Ghats, India, Reg. Environ. Change 15 (3) (2015) 435–447, https://doi.org/10.1007/s10113-013-0481-z.
[75] N.P. Kettle, K. Dow, S. Tuler, T. Webler, J. Whitehead, K.M. Miller, Integrating scientific and local knowledge to inform risk-based management approaches for climate adaptation, Climate Risk Management 4–5 (2014) 17–31, https://doi.org/10.1016/j.crm.2014.07.001.
[76] P. Dasgupta, D. Bhattacharjee, A. Kumari, Socio-economic analysis of climate change impacts on foodgrain production in Indian states, Environmental Development 8 (2013) 5–21, https://doi.org/10.1016/j.envdev.2013.06.002.
[77] S.W. Wang, W.-K. Lee, Y. Son, An assessment of climate change impacts and adaptation in South Asian agriculture, International Journal of Climate Change Strategies and Management 9 (4) (2017) 517–534, https://doi.org/10.1108/IJCCSM-05-2016-0069.
[78] D. Mohan, S. Sinha, Assessing vulnerability to climate change in the Ganges Basin using a combined macro-and micro-level approach, Clim. Dev. 8 (4) (2016) 312–323.
[79] N.P. Singh, B. Anand, M.A. Khan, Micro-level perception to climate change and adaptation issues: a prelude to mainstreaming climate adaptation into developmental landscape in India, Nat. Hazards 92 (3) (2018) 1287–1304, https://doi.org/10.1007/s11069-018-3250-y.
[80] P. Deb, S. Shrestha, M.S. Babel, Forecasting climate change impacts and evaluation of adaptation options for maize cropping in the hilly terrain of Himalayas: Sikkim, India, Theor. Appl. Climatol. 121 (3–4) (2015) 649–667, https://doi.org/10.1007/s00704-014-1262-4.
[81] E. Skoufias, S. Bandyopadhyay, S. Olivieri, Occupational diversification as an adaptation to rainfall variability in rural India, Agric. Econ. 48 (1) (2017) 77–89, https://doi.org/10.1111/agec.12296.
[82] D.K. Panda, A. Mishra, A. Kumar, K.G. Mandal, A.K. Thakur, R.C. Srivastava, Spatiotemporal patterns in the mean and extreme temperature indices of India, 1971-2005, Int. J. Climatol. 34 (13) (2014) 3585–3603, https://doi.org/10.1002/joc.3931.
[83] K. Philip, S.S.A. Devi, G.K. Jha, B.M.K. Raju, B. Sen, A. Ali, J. Kumari, Sensitivity of wheat yields to rise in growing season temperature: evidences from panel data analysis, Journal of Agrometeorology 22 (2) (2020) 191–197.
[84] J. Murali, T. Afifi, Rainfall variability, food security and human mobility in the Janjgir-Champa district of Chhattisgarh state, India, Clim. Dev. 6 (1) (2014) 28–37, https://doi.org/10.1080/17565529.2013.867248.
[85] L.R. Thotli, B. Gugamsetty, R.O.R. Kalluri, C.R. Tandule, R.G. Kotalo, B. Akkiraju, S.S.R. Lingala, Long-term (2001–2020) trend analysis of temperature and rainfall and drought characteristics by in situ measurements at a tropical semi-arid station from southern peninsular India, Int. J. Climatol. (2022), https://doi.org/10.1002/joc.7783.
[86] D.K. Panda, A. Kumar, The changing characteristics of monsoon rainfall in India during 1971-2005 and links with large scale circulation, Int. J. Climatol. 34 (15) (2014) 3881–3899, https://doi.org/10.1002/joc.3948.
[87] R. Lal, Soil carbon sequestration in agroecosystems of India, J. Indian Soc. Soil Sci. 63 (2) (2015) 125, https://doi.org/10.5958/0974-0228.2015.00018.3.
[88] R. Sharma, S.K. Chauhan, A.M. Tripathi, Carbon sequestration potential in agroforestry system in India: an analysis for carbon project, Agrofor. Syst. 90 (4) (2016) 631–644, https://doi.org/10.1007/s10457-015-9840-8.
[89] W. Pradel, M. Gatto, G. Hareau, S.K. Pandey, V. Bhardway, Adoption of potato varieties and their role for climate change adaptation in India, Climate Risk Management 23 (2019) 114–123, https://doi.org/10.1016/j.crm.2019.01.001.
[90] M. Baccar, J.-E. Bergez, S. Couture, M. Sekhar, L. Ruiz, D. Leenhardt, Building climate change adaptation scenarios with stakeholders for water management: a hybrid approach adapted to the south indian water crisis, Sustainability 13 (15) (2021), https://doi.org/10.3390/su13158459.
[91] S.R. Padhy, P.K. Dash, P. Bhattacharyya, Challenges, opportunities, and climate change adaptation strategies of mangrove-agriculture ecosystem in the Sundarbans, India: a review, Wetl. Ecol. Manag. 30 (1) (2022) 191–206, https://doi.org/10.1007/s11273-021-09844-2.
[92] S. Das, K. Goswami, Progress in agricultural vulnerability and risk research in India: a systematic review, Reg. Environ. Change 21 (1) (2021), https://doi.org/10.1007/s10113-021-01749-3.
[93] A. Singhal, S.K. Jha, Can the approach of vulnerability assessment facilitate identification of suitable adaptation models for risk reduction? Int. J. Disaster Risk Reduc. 63 (2021) https://doi.org/10.1016/j.ijdrr.2021.102469.
[94] G. Balaganesh, R. Malhotra, R. Sendhil, S. Sirohi, S. Maiti, K. Ponnusamy, A.K. Sharma, Development of composite vulnerability index and district level mapping of climate change induced drought in Tamil Nadu, India, Ecol. Indicat. 113 (2020) 106197, https://doi.org/10.1016/j.ecolind.2020.106197.

[95] U. Patnaik, P.K. Das, C.S. Bahinipati, Development interventions, adaptation decisions and farmers' well-being: evidence from drought-prone households in rural India, Clim. Dev. 11 (4) (2019) 302–318, https://doi.org/10.1080/17565529.2017.1410084.
[96] A.A. Reddy, A. Bhattacharya, S.V. Reddy, S. Ricart, Farmers' distress index: an approach for an action plan to reduce vulnerability in the drylands of India, Land 10 (11) (2021) 1236, https://doi.org/10.3390/land10111236.
[97] J. Samuel, C.A.R. Rao, B.M.K. Raju, A. A.Pushpanjali Reddy, A.G.K. Reddy, R.N. Kumar, M. Osman, V.K. Singh, J.V.N.S. Prasad, Assessing the impact of climate resilient technologies in minimizing drought impacts on farm incomes in drylands, Sustainability 14 (1) (2022), https://doi.org/10.3390/su14010382.
[98] H.S. Jat, A. Datta, M. Choudhary, P.C. Sharma, A.K. Yadav, V. Choudhary, M.K. Gathala, M.L. Jat, A. McDonald, Climate Smart Agriculture practices improve soil organic carbon pools, biological properties and crop productivity in cereal-based systems of North-West India, Catena 181 (2019) 104059, https://doi.org/10.1016/j.catena.2019.05.005.
[99] B.D. Pal, S. Kapoor, S. Saroj, M.L. Jat, Y. Kumar, K.H. Anantha, Adoption of climate-smart agriculture technology in drought-prone area of India – implications on farmers' livelihoods, J. Agribus. Dev. Emerg. Econ. 12 (5) (2022) 824–848, https://doi.org/10.1108/JADEE-01-2021-0033.
[100] H.W. Fischer, N.L.N. Reddy, M.L.S. Rao, Can more drought resistant crops promote more climate secure agriculture? Prospects and challenges of millet cultivation in Ananthapur, Andhra Pradesh, World Development Perspectives 2 (2016) 5–10, https://doi.org/10.1016/j.wdp.2016.06.005.
[101] H. Pathak, Impact, adaptation, and mitigation of climate change in Indian agriculture, Environ. Monit. Assess. 195 (1) (2023) 52, https://doi.org/10.1007/s10661-022-10537-3.
[102] A.A. Nambi, C.S. Bahinipati, R. Raghunath, R. Nagendran, Farm household level adaptation metrics for agriculture and water sectors, International Journal of Climate Change Strategies and Management 7 (1) (2015) 27–40, https://doi.org/10.1108/IJCCSM-04-2013-0048.
[103] K.J. Raghavendra, A. Suresh, Risk management in rainfed agriculture: an analysis of strategies and adaptations followed by farmers in Madhya Pradesh, Indian J. Agric. Sci. 88 (6) (2018), https://doi.org/10.56093/ijas.v88i6.80638.
[104] S.K. Kakraliya, H.S. Jat, T.B. Sapkota, I. Singh, M. Kakraliya, M.K. Gora, P.C. Sharma, M.L. Jat, Effect of climate-smart agriculture practices on climate change adaptation, greenhouse gas mitigation and economic efficiency of rice-wheat system in India, Agriculture 11 (12) (2021), https://doi.org/10.3390/agriculture11121269.
[105] T.B. Sapkota, M.L. Jat, J.P. Aryal, R.K. Jat, A. Khatri-Chhetri, Climate change adaptation, greenhouse gas mitigation and economic profitability of conservation agriculture: some examples from cereal systems of Indo-Gangetic Plains, J. Integr. Agric. 14 (8) (2015) 1524–1533, https://doi.org/10.1016/S2095-3119(15)61093-0.