Journal of Air Pollution and Health (Spring 2025); 10(2): 291-310

Review Article

Available online at http://japh.tums.ac.ir

Mapping and visualization the research of climate change adaptation using artificial intelligence in Indonesia: A bibliometric analysis

Khaidar Ali[1], Serius Miliyani Dwi Putri[2], Muhammad Addin Rizaldi[1,*], Agnes Fitria Widiyanto[1], Suratman Suratman[1], R Azizah[3]

[1] Department of Public Health, Faculty of Health Sciences, University of Jenderal Soedirman, Banyumas, Indonesia
[2] NIHR Global Health Research Centre for Non-Communicable Diseases and Environmental Change, University of Brawijaya, Malang, Indonesia
[3] Department of Environmental Health, Faculty of Public Health, University of Airlangga, Surabaya, Indonesia

ARTICLE INFORMATION

Article Chronology:
Received 26 October 2024
Revised 12 March 2025
Accepted 18 May 2025
Published 29 June 2025

Keywords:
Climate change; Adaptation; Artificial intelligence; Technology; Bibliometric

CORRESPONDING AUTHOR:
muhammad.rizaldi@unsoed.ac.id
Tel: (+62 81) 331917668
Fax: (+62 81) 6572772

ABSTRACT

Climate change is not only contributing to the proliferation of infectious and vector-borne communicable diseases is a major concern, but also escalating the risk of extreme weather among community, in which research on climate change adaptation using advanced technology is necessary. This study aimed to investigate research trend on climate change adaptation in Indonesia concerning on the utilization of novel technology and artificial intelligence.

This study employed bibliographic analysis using Scopus article database during 2000-2023. The total sampling technique was used, in which every relevant document within inclusion criteria were included in the study. The analysis was conducted in R Studio, in which network analysis was measured by VOSviewer.

A total of 1,858 articles is identified. The annual of publication growth rate is 17.77%, with the average citation per document is 29. The university situated in Java Island-Indonesia was leading institution for publication. Sustainability and Biodiversitas are the most prominent journals. The scholars with high publication and citation are Yulianto (13 articles) and Murdiyarso (1,819 citation). Eight clusters have been recorded, with the most prominent term is “climate change”, "adaptation", "flood", "remote sensing", "agriculture", and "vulnerability".

This study found the research interest on climate change adaptation is elevating each year in Indonesia. The application of advanced technology, such as artificial intelligence, machine learning, and Internet of Things (IoT) remains relatively unexplored. Therefore, future research on climate change adaptation using advanced technology in Indonesia is needed to provide comprehensive knowledge, enhance predictive capabilities, and provide innovative solution to manage the effect of climate change.

Please cite this article as: Ali Kh, Dwi Putri SM, Rizaldi MA, Widiyanto AF, Suratman S, Azizah R. Mapping and visualization the research of climate change adaptation using artificial intelligence in Indonesia: A bibliometric analysis. Journal of Air Pollution and Health. 2025;10(2): 291-310. https://doi.org/10.18502/japh.v10i2.19082

Review

One of the most important global concerns is climate cange, which is already affecting the entire planet. Communities, corporations, and governments must act now to prepare for the repercussions of climate change and take proactive measures to protect themselves against it when it gets worse. Climate-change contributes to the proliferation of infectious and vector-borne communicable diseases, like dengue, malaria, hantavirus, and cholera by raising temperatures and increasing the frequency of flooding occurrences. The incidence of heart and lung diseases linked to poor air quality, as well as heat-related death rates, are predicted to rise with climate change [1]. Artificial Intelligence (AI) is a powerful technique that can be employed for this issue [2, 3].

The field of Artificial Intelligence (AI) can be defined as a branch of computer science that focuses on the development of computer systems capable of performing tasks that typically require human intelligence. The intelligence systems created are comparable to the behavioral intelligence carried out by humans. AI can be developed to create voice recognition, facial recognition, speech recognition, decision-making, audio analyzers, automatic translation programs, problem-solving theorems, and natural language processing [4–6].

In the past ten years, artificial-intelligence technology had a significant impact to human life. It can be used in a wide range of industries, including manufacturing, health-care, engineering, and communication. Better computing capabilities and data generation drive AI. Numerous high-tech companies have achieved proficiency in tasks that approach or even surpass human performance by integrating advanced algorithms that facilitate deep neural network training. Speech recognition, chess playing, picture processing, and driving cars by self are a few examples [7–10].

The resilience of communities, the state of infrastructure, and the existence of companies are of particular concern because they can be affected by climate change, including severe weather, rising sea levels, and drought. Artificial intelligence in recent years has become an instrument that can be used to overcome various climate change challenges in a region, by utilizing AI to develop an innovative strategy for climate change adaptation and mitigation. Climate change represents a multifaceted challenge that necessitates the development of innovative and effective strategies to address it. The utilization of Artificial Intelligence (AI) is imperative in the development of innovative solutions for climate change adaptation, thereby enhancing resilience through data-driven strategies. The potential of Artificial Intelligence (AI) in addressing climate-related challenges is manifold. It can assist in identifying regions that are particularly vulnerable to these dangers. Moreover, it can facilitate in developing adaptation strategies in business and in society. Additionally, AI can play a crucial role in forecasting natural disasters such as floods and wildfires. Finally, it can help in identifying areas prone to landslides, contributing to the development of effective mitigation strategies [11].

Climate change science is benefiting greatly from the application of AI. Even though AI applications are still in their infancy, current advancements point to significant opportunities for improved understanding of how the Earth's climate is likely to change, improved monitoring of the impacts of human activity on the climate, and improved climate impact forecasts [11].

Bibliometrics is a method of analyzing knowledge structure in a certain sector to provide precise and measurable information about emerging trends [12]. Bibliometric analysis is a method that provides researchers and stakeholders with a comprehensive understanding of the subject matter and facilitates the enhancement of the multidisciplinary approach [13]. This study aimed to investigate-, map- and visualize- the

research trend on climate change adaptation in Indonesia, specifically concerning the utilization of artificial intelligence and advanced technology. Specifically, the research with bibliometric method try to answer the following research questions:

1. How have research on artificial intelligence and climate change develop in Indonesia?

2. What is the geographical distribution of authors' affiliation in research on artificial intelligence and climate change?

3. What are the main productive and influential scholars in artificial intelligence and climate change in Indonesia?

4. How is the distribution of publications by affiliation and journal in artificial intelligence and climate change?

5. What are the current trends of artificial intelligence and climate change field?

This research consists of several stages. Section 2 is a method, presents the description regarding research methodology in which this study using bibliometric method. And section 3 results, that are provides the result of the analysis. And section 4, is discussion, the section is discussed about the findings of the study, the research implication and the last section is conclusion, the last section concludes the paper and limitations of the study.

The role of artificial intelligence (AI) in climate change

Artificial Intelligence (AI) has recently seen significant development and is now used in various activities, including predicting the impact of climate change and mitigating its effects. AI refers to technology that enables computers and machines to simulate human abilities such as learning, understanding, problem solving, decision-making, creativity and autonomy [14]. Artificial-intelligence can be defined as creating process that allow computers to act in a way that an ordinary person would consider intelligent. According to oxford's computer science definition, AI is a branch of information technology that focuses on creating programs capable of solving problem [15]. AI has significant potential in addressing climate change. The literature review indicates that AI can play a crucial role in supporting global effort to understand the complex challenges associated with climate change [16]. According to Cowls et al. (2023), AI presents two key opportunities in combating global climate change: First, the potential applications of artificial intelligence in enhancing comprehension of climate change warrant investigation. The use of AI in climate change research holds promise, offering a means to improve and expand understanding of this critical global issue. Second, it can effectively help address the climate crisis [17].

The artificial intelligence systems can contribute to reducing deforestation and emissions by enabling the mapping of deforestation and emissions, which supports decision-making and policy development on climate change. According to the research, dataset can generate reasonable deforestation risk maps using techniques, such as Gaussian processes model. The Gaussian process model is a alternative or non-parametric machine learning approach that predicts spatial patterns based on observed data, in which it helps estimate risk level by analyzing environmental variable [18] Nevertheless, the model are limited in that they cannot predict the total amount or extent of deforestation, or its risk factor; they can only determine whether deforestation risk exist [18, 19]. Therefore, this issue can be addressed by using hybrid model. Beyond natural resources management, AI also plays a critical role in agriculture, and industrial processes. Deforestation monitoring and visual navigation assessment can be enhanced using a weightless neural network architecture, a pattern-based artificial intelligence model that efficiently detects changes in forest cover from satellite imagery. This system can be implemented through a Field-Programmable Gate Array (FPGA), a reconfigurable computing device, and integrated with an Unmanned Aerial Vehicle

(UAV) [18, 20]. Furthermore, machine learning can be employed to identify environmental components within existing biodefence zones, facilitating the prediction of green resources. The utilization of Artificial-Intelligence (AI) and machine-learning algorithms has emerged as a promising avenue for addressing challenges related to land pollution. These algorithms have been demonstrated to facilitate predictive analytics, facilitate data-centric analysis, and enable the evaluation of soil quality [18, 21- 23]. Therefore, as indicated by the preponderance of research, Artificial Intelligence (AI) can be used for natural resource management, including forest, ecosystem, water, and land use planning management [18].

The utilization of AI has the potential to enhance the accuracy of weather prediction, thereby facilitating more precise weather forecasting and modeling. This, in turn, can assist in the effective preparation for and response to extreme weather events through the implementation of early warning systems. Additionally, AI facilitates a more profound comprehension of natural elements, including climate and geography. The utilization of AI facilitates the prediction of renewable energy production, the adjustment of grid output, and the assurance of uninterrupted electricity supply [18]. The study by Muniandi, reported that AI-driven energy management systems for smart building can optimize the consumption of energy, to immprove operational efficiency, and support sustainability goals [24]. Furthermore, the integration of AI is imperative in reducing the environmental impact of agrochemical use. This technology assists those responsible for decision-making in the field of industry, facilitating the optimization of industrial processes. It accomplishes this by means of data analysis, the development of models, and the supplementation of missing information from hardware sensors. The technology's primary function is to conserve energy and reduce emissions.. AI is crucial for assisting decision-maker in creating more effective policies for climate change adaptation and mitigation.

Methods

The study using a bibliometric analysis to explore the existing knowledge base of artificial-intelligence and advanced technologies in climate change adaptation-mitigation in Indonesia. This approach is widely used in meta-analytical research and serves as a statistical method to identify changes in both qualitative-quantitative aspects of research topics. It yielded a comprehensive examination of the research landscape, serving as a systematic methodology to identify the most influential researchers, their institutional affiliations, the key terms they employ, and the interrelationships among scholarly publications [25, 26]. Bibliometric analysis is a widely recognized meta-analytical method and a statistical method used to identify the qualitative-quantitative change in a particular topic of research [27]. Bibliometric analysis commonly used in previous studies to investigate various topics, such as artificial intelligence in healthcare [4] green spaces and senior mental health [28], and health information systems in Indonesia [29]. These studies provided information regarding the utilizing of bibliometric technique in particular topic, such as the trend of annual publication, the geographical distribution, top contribution, including the co-occurrence analysis. Consequently, this study utilizes bibliometric analysis as an optimal method to explore the existing knowledge base underpinning the use of artificial intelligence and advanced technologies in climate change adaptation and mitigation in Indonesia.

Analysis and collecting data

The data were extracted from the Scopus database between 2000-2023. Scopus database was selected in accordance with the following rational, namely: a) comprehensive coverage, b) high-quality data, c) advanced search and retrieval, d) citation and metrics data, and e) global reach. In addition, Scopus includes a vast number of publications, encompassing journals

from major international publishers such as Elsevier, Springer, Taylor and Francis, Emerald Insight, and IEEE [30, 31]. The search query terms associated to climate change adaptation and artificial intelligence, or advanced technology were presented in Table 1, as follow:

Table 1. Search query terms

Construct	Search key terms
Climate change– related terms	("extreme weather") OR ("climate change") OR ("flood*") OR ("droughts") OR ("storms") OR ("heatwaves") OR ("cyclones") OR ("hurricanes") OR ("typhoons") OR ("wildfires") OR ("sea level rises")
Technology and artificial intelligence in accordance to Adaptation- related terms	("early warning") OR ("adaptation") OR ("response") OR ("recovery") OR ("policy") OR ("regulation") OR ("remote sensing") OR ("satellite technology") OR ("artificial intelligence") OR ("machine learning") OR ("Internet of Thing*") OR ("GIS") OR ("drone*") OR ("big data") OR ("cloud computing") OR ("renewable energy") OR ("modelling") OR ("simulation") OR ("mobile app*") OR (social media)
Settings	(“Indonesia”)
Document type	Articles
Language	English
Period	2000-2023

The data extraction was performed by two independent authors (KA and MAR), in which the extracted data will be cleaned to eliminate duplicate records and irrelevant publication based on inclusion and exclusion criteria. This action was implemented to robust the accuracy of study. The total sampling technique was used, in which every relevant document within inclusion criteria were included in the study. The inclusion criteria were as follows: (a) the document must be a peer-reviewed original research article, (b) the article must have been published between 2000 and 2023, and (c) the article must be written in English. Conversely, we excluded review articles, conference papers, book chapters, and short communications, as they do not represent original research. Additionally, articles written in languages other than English were excluded from this study.

The bibliographic variables consist of tittle of articles, author, abstract, keyword, publication year, publisher journal, type of publication and affiliation. The study of Jimma (2023) and Wu et al (2023) was used as methodological references [4, 28].

A meticulous search of scholarly journals was conducted by the author, utilizing a predetermined search query. The present study excluded literature of conference proceedings, books, and book chapters, as well as gray literature. Additionally, articles published in languages other than English were excluded from the analysis. The bibliography data, retrieved from Scopus databased by using search query term (Table 1), was downloaded in CSV format (comma-separated value). Thus, the data was imported to R and VOSViewer for data analysis, which are free- and open- data analysis and visualization's tool. Data preprocessing has been conducted by using OpenRefine. OpenRefine is free-open-source tool, which is used for data cleaning as reported by Ahmi (2023) [32], his tool is used to handle issue related to inconsistencies of data, variation of similar term, misspellings, and incomplete information. In addition, the cleaned data was analyzed using R and VOSViewer (version 1.6.20).

The bibliometrics analysis in R was conducted to measure: a) the growth of publication, international co-authorship, and publication distribution by country, and b) the scholar, affiliation and journals' production over time trend. The r command is as follow:

Install.packages ("bibliometrix"): Installs the required package

Library(bibliometrix): Loads it into the R environment

Biblioshiny( ): launches the graphical interface for bibliometric analysis

VOSviewer was used to identify topic trends and visualize the keyword co-occurrence network and keyword co-occurrence network.

Results

The descriptive statistics

A total of 1,858 articles were published between 2000-2023. The overall publicatioon growth rate (%) is 4,200%, with an annual growth rate of approximately 17.77%. it indicates that, on average, the number of published articles increase by approximately 17-18% each year. Compared to general bibliometric trends in rapidly evolving fields like artificial intelligence and climate change. This growth rate reflects a significant and sustained rise in research interest.

Fig. 1 illustrates the rising trend in publications and the average citation rate per year. This figure is demonstrating increasing academic interest in climate change adaptation in Indonesia. The graph addresses research question 1. Based on the graph confirms the increase interest in research on climate change adaptation in Indonesia, in which the highest total publication was recorded om 2023 with 301 publications. Moreover, the international co-authorship was reported 43.27%, indicating strong international collaboration in this research field. The average citations rate was 29 citations per documents, indicating a high level of interest in climate change research.

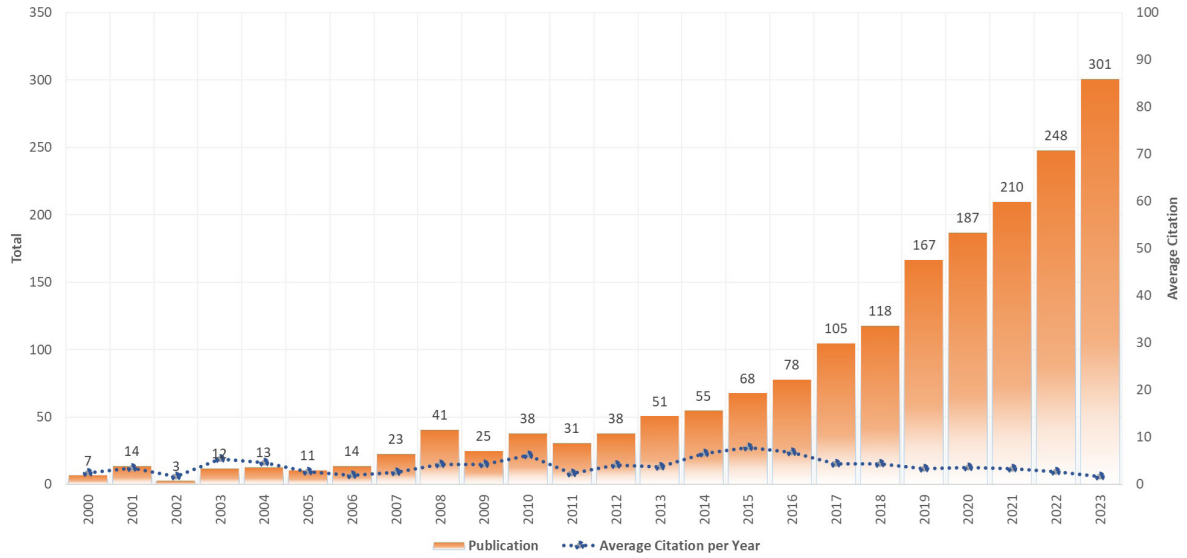


Fig. 1. The trend of publication and average citation per year

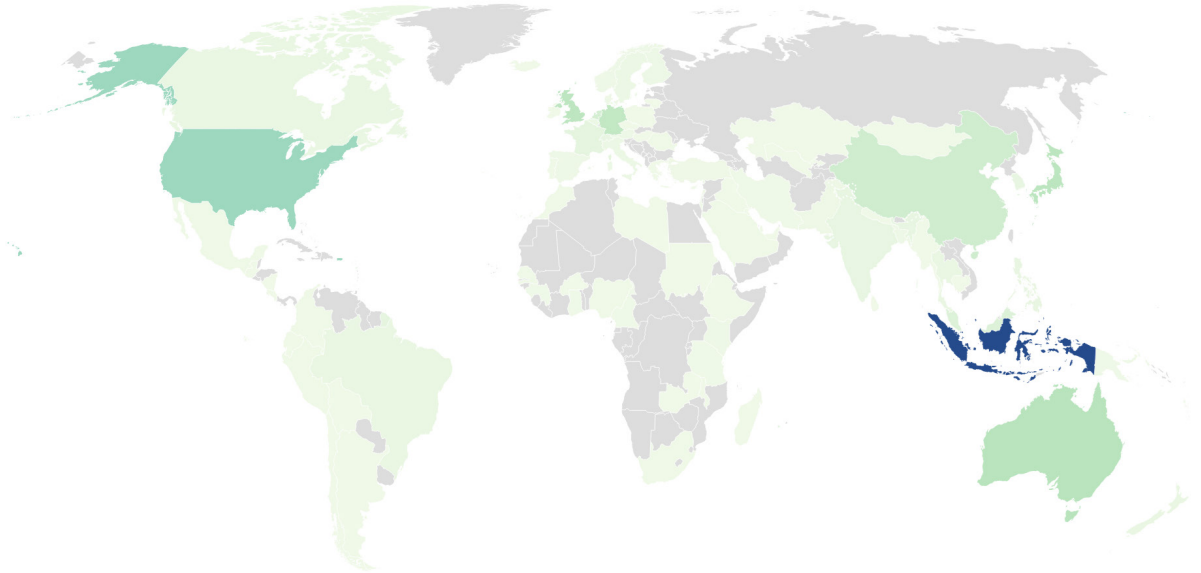


Fig. 2. The global distribution of scientific publication by country

Fig. 2 highlights a global disparity in scientific publications. The geographical distribution of author affiliation is significantly concentrated in Indonesia (3632 articles). Nevertheless, certain countries, notably United States of America (858 articles), Australia (576 articles), and Japan (537 articles) show significant number.

The statistics of the influential scholar, institution, and journal

As presented by Fig. 3, Yulianto emerged as the most productive author with 13 articles, while Farid M and Marfai MA closely followed with 12 articles each. Murdiyarso's article is the most cited, amassing 1,819 total citations.

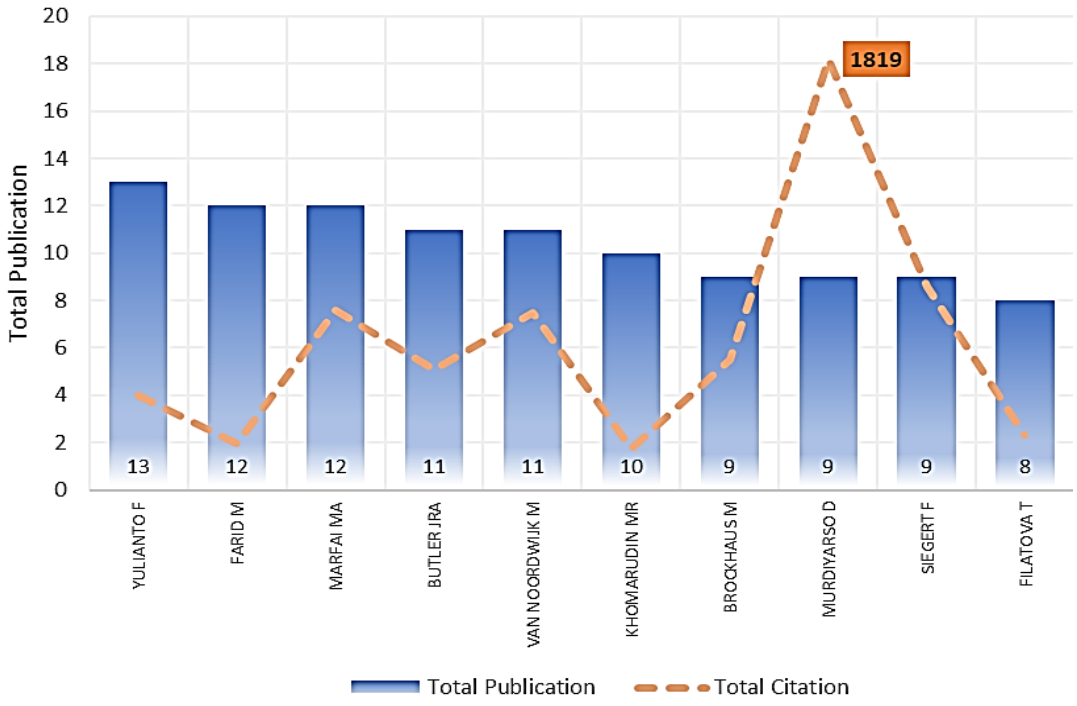
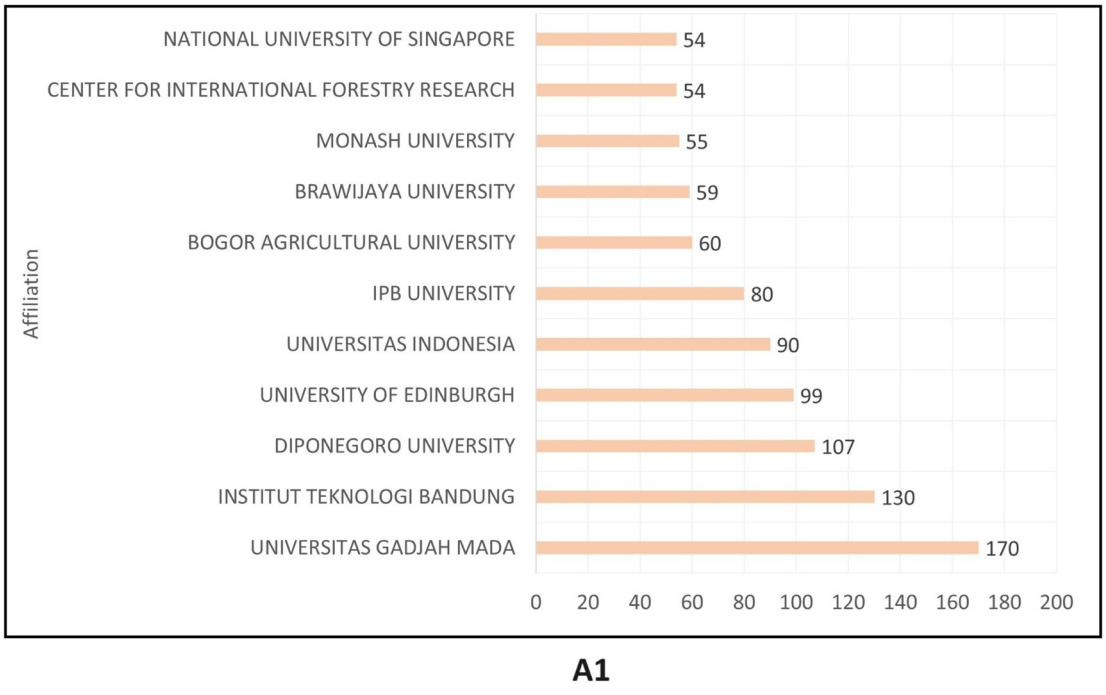
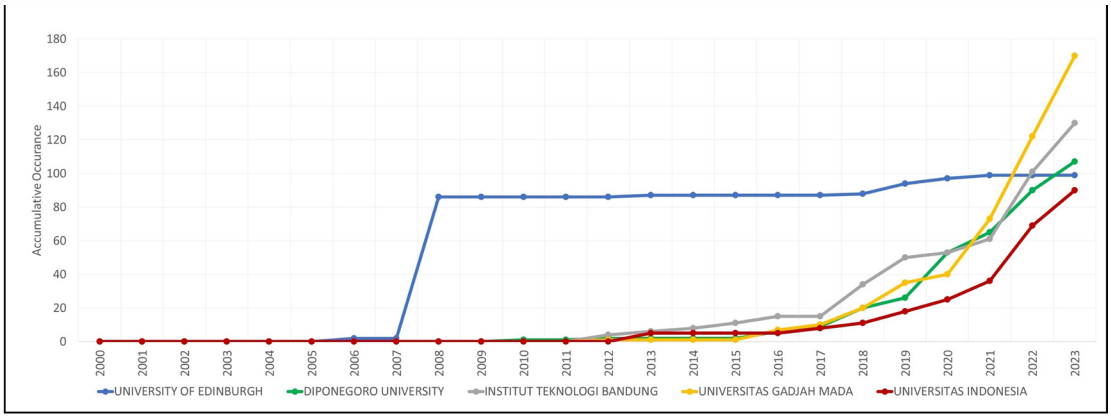
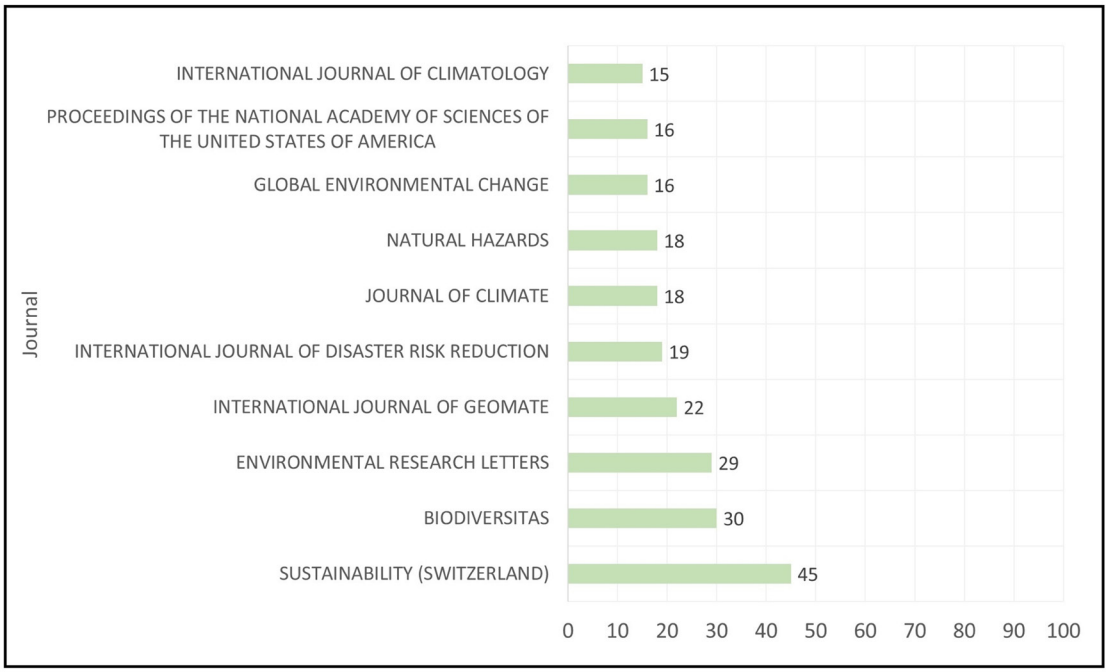


Fig. 3. The most productive and influential scholar

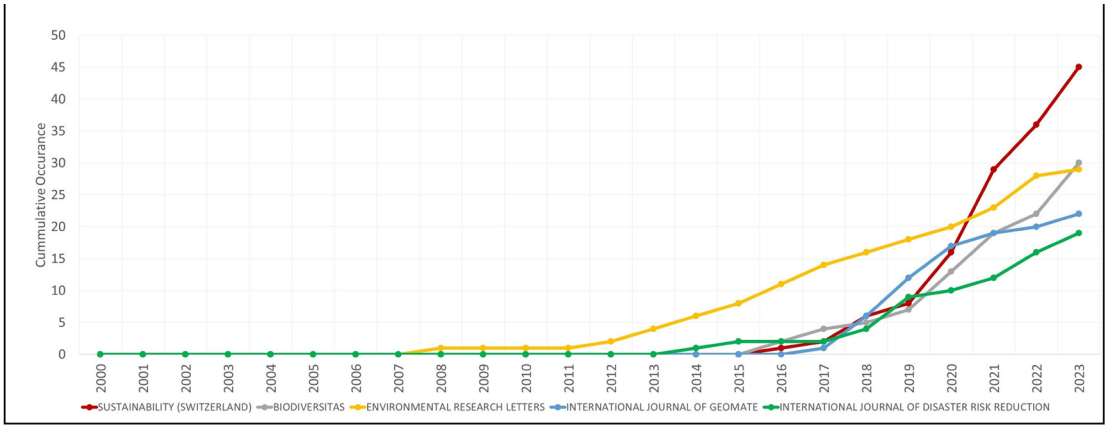




A2



B1



B2

Fig. 4. The distribution and pattern of publication by Affiliation and Journal (A1: top 10 affiliation; A2: top 5 affiliation overtime; B1: top 10 journal; B2: top 5 journal overtime)

The distribution and pattern of publication by affiliation and journal exist in Figure 4. Based on Fig. 4A1, the highest number of publications was recorded from Universitas Gadjah Mada (170 articles), followed by Institute Teknologi Bandung (130 articles) and Diponegoro University (107 articles). Fig. 4A2 indicates that Universitas Indonesia showed early research activity in climate change adaptation, achieving stability post-2007, while institutions like Universitas Gadjah Mada and Institut Teknologi Bandung experienced a research surge post-2015, possibly due to increased funding or strategic initiatives

Fig. 4B1, the highest number of publications was distributed in Sustainability (Switzerland) (45 articles), followed by Biodiversitas (30 articles) and Environmental Research Letter (29 articles). Fig. 4B2 visualized the cumulative occurrence of publication in top five journal during 2000-2023. This figure indicates that Sustainability (Switzerland) leading the pack with a significant increase starting around 2015, followed by Environmental Research Letters and Biodiversitas. The prominence of Sustainability (Switzerland) may be attributed to its broad interdisciplinary scope, open-access policy and high visibility in environmental and sustainability research.

The keyword co-occurrence network analysis

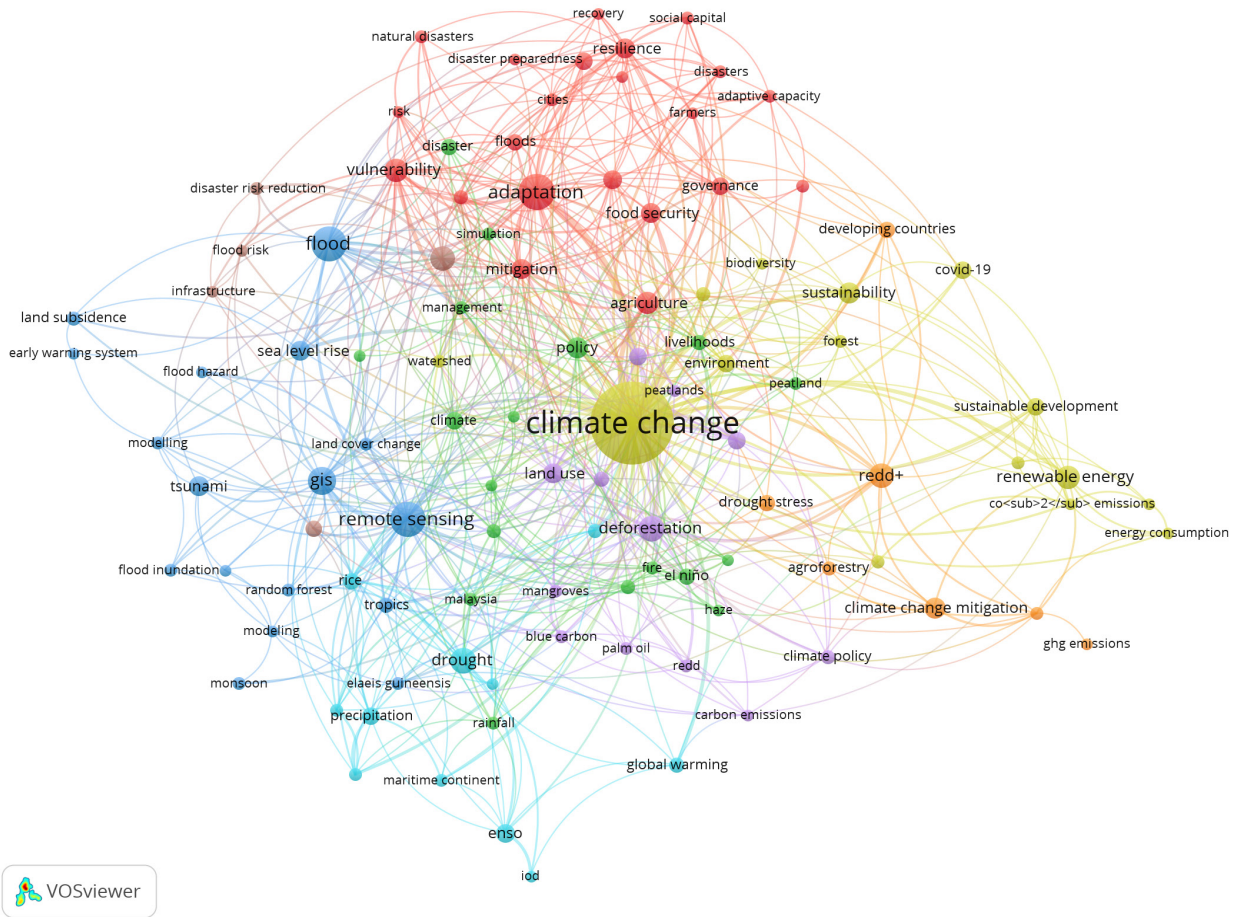


Fig. 5. Co-occurrence of Author's keyword

Fig. 5 captures the co-occurrence of author's keyword using full count method. A comprehensive analysis of the data revealed that out of a total of 5,277 keywords, those selected through the network visualization technique appeared a minimum of seven times. This calculation excludes terms pertaining to regions such as "Indonesia," "Sumatera," "Palembang," "Java," etc., consequently resulting in 107 keywords grouped into eight clusters, as displayed in the network diagram. As illustrated in Fig. 5, the array of circles is composed of multiple colors and varying sizes, with each circle linked to adjacent circles at varying distances. The color serves to denote the specific element or category within a given cluster or group. This cluster mapping identifies topics that have highly interrelated aspects. The size of each circle indicates the frequency of term usage. The strong association between keyword was noted by shorter distances, in which the connection of items in terms is symbolized by lines.

As illustrated in the figure, 8 clusters are identified. Cluster 1 focuses on climate change mitigation and renewable energy. Cluster 2 covers adaptation, vulnerability, and food security. Cluster 3 examines floods, tsunamis, and early warning systems. Cluster 4 delves into deforestation and land use change. Cluster 5 relates to sustainability and socio-ecological systems. Cluster 6 highlights remote sensing and GIS for climate studies. Cluster 7 explores ENSO, drought, and climate variability. Lastly, Cluster 8 centers on disaster risk reduction and management. For instance, "climate change" is closely linked with "adaptation," and "vulnerability" suggesting a strong research focus on adaptive strategies in response to climate impacts. In addition, some terms are more interconnected due to the interdisciplinary nature of climate change research and the emergence of new focus areas. Keywords related to innovative technology and AI, including "machine learning" and "GIS" are present in Fig. 5. The presence of keywords related to technology suggests an increasing integration of AI and machine learning in climate studies, pointing to potential future research opportunities in data-driven environmental management.

Discussion

The total publication was recorded 1,858 articles published between 2000-2023. Building on these publication trends, the overall growth rate of publications on climate change is 4,200%, with an annual growth rate of 17.77%, indicating a consistent annual increase of 17-18% in published articles which is indicating the number of published articles increase by 17-18% per year. Based on Fig. 1, an increase in interest in research on climate change adaptation in Indonesia is notified, and there are approximately 43.27% of the research involves international co-authorship, highlighting the global collaboration in addressing climate change challenges in Indonesia. Enhanced collaboration in research is essential for achieving climate change adaptation objectives in Indonesia. To effectively address the consequences and repercussions of climate change., particularly on agriculture and marginalized farmers, it is crucial to foster international partnerships. Emphasizing research on the utilization of renewable energy can play a pivotal role in minimizing these impacts, thereby facilitating more robust and sustainable adaptation strategies [33, 34]. Recent research shows that applying a circular economy approach to solid waste management in Hainan can achieve up to a 90% reduction in waste through digital recycling technologies. This approach is also relevant for Lombok Island, where adopting similar strategies could significantly improve waste management outcomes [35]. Therefore, collaborative research in Indonesia, especially on climate adaptation and technology, is key to driving impactful solutions like improved waste recycling and management. Strong stakeholder support—government, private sectors, and communities—is essential to ensure these innovations are implemented effectively and sustainably.

Fig. 2 presents the countries' scientific production. It means the total number of publications

produced by researchers from each country. As visualized by Fig. 2, a significant concentration of scientific publication was spotted in Indonesia, followed by China, Japan, USA, and Australia. This finding indicates research on climate change is concentrated in Indonesia reflecting growing national efforts to address these challenges. Nevertheless, a small portion of other nations indicates that research in climate change is a global priority.

The most productive and influential scholar visualized by Fig. 2. Based on Fig. 2, There is not always a direct correlation between the number of publications and the number of citations. For instance, although Yulianto F has the highest number of publications (13 articles), their citation count is significantly lower compared to Murdiyarso D (401 citations vs 1,819 citations). This indicates that the quality or impact of each publication is more crucial than merely the quantity when it comes to receiving citations. Murdiyarso D stands out as the author with the highest impact in this field, despite having a relatively modest number of publications. There is a significant variation in the number of citations among the authors, which may reflect differences in research topics, the quality of work, or influence within the academic community.

As presented Fig. 4, the distribution and pattern of publication by Affiliation and Journal. As presented Fig. 4, The university situated in Java Island-Indonesia was leading institution for publication on climate change in Indonesia. The Universitas Gadjah Mada is the primary source of publications, with Institut Teknologi Bandung and Universitas Diponegoro following closely behind. These universities are leaders in the scientific contributions in Indonesia due to their strong academic infrastructure, experience, and cooperative efforts, which contribute significantly to the advancement of climate change research. The majority of publications on climate change adaptation are found in the Journal of Sustainability (Switzerland), Biodiversitas, and Environmental Research Letters. These journals have become key outlets for research on climate change and sustainable development, which are critical areas of study that have gained significant attention in recent years due to their global relevance and urgency.

Climate change adaptation strategies are closely tied to disaster risk management and urban/rural development plans, as they help assess the impacts of climate change [36, 37]. In Indonesia, one approach to climate adaptation is through leveraging social capital. A study in Yogyakarta revealed that 70% of farmers are willing to contribute financially to support climate change adaptation, particularly those with greater economic resources [38]. To broaden the applicability of these findings beyond Yogyakarta, a framework for scaling social capital-driven adaptation strategies should be developed. The Climate Village Program, a program in Indonesia, is focused on the adaptation and mitigation of climate change. The extant research demonstrates a clear correlation between the implementation of waste management strategies within the context of the Climate Village program and a concomitant reduction in the prevalence of climate-related diseases [39]. The management of waste is an integral component of adaptation and mitigation strategies in response to climate change. It has been demonstrated that the implementation of effective waste management practices is paramount in reducing the risk of diseases that are exacerbated by climate change.

As presented Fig. 5, eight clusters have been identified. The term “climate change” is the most prominent term. Surrounding it, terms such as "adaptation," "flood," "remote sensing," "agriculture," and "vulnerability" also appear frequently, albeit with less intensity. The VOS viewer automatically groups of term into clusters based on co-occurrence [40], highlighting AI applications in climate adaptation, disaster management, and environmental monitoring. These clusters reflect interdisciplinary research trends and reveal emerging direction in AI-driven climate studies.

In the VOS Viewer image, the colors represent different keyword clusters, while the curved lines indicate the strength of the relationships between these clusters. The color variations in the bibliometric image reflect distinct keyword clusters based on their connections or occurrences within the dataset. This visual representation helps in understanding the interrelationships between key concepts and the thematic organization of the research. [41, 42]. The yellow cluster comprises 9 keywords such as renewable energy, climate change mitigation, dan sustainability presents the various keyword to understanding the impact of climate change.

Climate change emerges as the most prominent term among various related concepts. It represents a critical issue faced by societies and countries worldwide, as it is the most significant environmental threat today. Climate change can lead to rising temperatures, increasing sea levels, and the melting of glaciers, which collectively pose severe risks to ecosystems, communities, and global stability [43, 44]. As visualized Figure 4, the most prominent yellow cluster represents Climate Change, which is interconnected with various related terms. The most notable among these connections is the focus on renewable energy and sustainability. This indicates that research on climate change predominantly emphasizes sustainability the adaptation and mitigation strategies and the use of renewable energy. This focus reflects the urgent need to address climate change impacts through effective adaptation and mitigation efforts and the adoption of new renewable energy solutions.

Increasing the use of renewable energy across countries can significantly reduce carbon emissions, thereby minimizing the impacts of climate change. Renewable energy can be used to replace fossil fuels, with renewable energy can decrease reliance on carbon-intensive practices. This shift is a crucial strategy for both mitigating and adapting to climate change, as it helps to address the root causes of global warming while supporting sustainable development. [45, 46]. Additionally, the term Climate Change is connected to the red cluster, where adaptation and vulnerability are the most prominent terms. This connection highlights the importance of climate change adaptation interventions in enhancing food security and the need for assessing local community vulnerabilities. Understanding these vulnerabilities is crucial for increasing community resilience to climate change and is essential for effectively implementing adaptation plans and actions [47, 48]. To achieve success in climate change adaptation, socio-ecological transformation is essential. Policymakers can use this transformation to prioritize adaptation strategies, such as implementing heat control measures. One effective approach involves enhancing evaporation and improving water landscape retention, which can help mitigate the impacts of heat and support overall climate resilience. [49, 50]. In Indonesia, the initiative of National Energy Policy (KEN) was established to elevate the share of renewable energy in the national energy mix. Therefore, extensive research on climate change adaptation and mitigation in Indonesia is crucial. Such studies will provide valuable insights and data, helping policymakers make informed decisions and develop effective strategies for climate change adaptation and mitigation.

Artificial intelligence and advanced technology on climate change adaptation in Indonesia

The minimum occurrence of terms such as “machine learning”, “internet of things”, “big data”, “cloud computing”, “mobile app”, and “social media” in social network analysis suggests a significant scarcity of research on climate change adaptation that utilized Artificial Intelligence (AI) and/or advanced technology (IoT, cloud computing, machine learning) in Indonesia. This indicates a notable gap in the literature, highlighting the need for more studies that explore the utilization of AI and/or advanced technology in Indonesia. Additionally, the limited funding, lack of technological infrastructure,

and insufficient expertise also emerge as the significant gap within research on AI in Indonesia.

Several countries have effectively used AI and advance technologies into climate change adaptation strategies, including Nepal and China [51, 52]. In Nepal, the use of AI, big data analytics, autonomous vehicle and advance robotic minimize the impact of future disaster [52]. Additionally, Wang et al. highlighted that advanced machine learning techniques can enhance the accuracy of rainfall prediction and that the application of digital twin systems can enable real-time management of urban sewer systems [51]. The utilizing of advance technologies could improve climate adaptation in Indonesia. IoT devices can enable real-time monitoring of environmental changes, while mobile applications can facilitate community-based reporting and enhance response mechanisms during climate-related disasters, thereby improving disaster preparedness and adaptive capacity.

A substantial body of research has demonstrated that the implementation of AI and other advanced technologies in climate change adaptation and mitigation strategies has been shown to have a considerable impact in mitigating the adverse effects on communities. Artificial Intelligence (AI) has the potential to serve as a powerful tool for various applications, including the prediction of food security, the detection of intricate patterns within climate data, and the assessment of the impact of climate change on groundwater resources [53, 54]. Additionally, AI is capable of executing sophisticated models in order to ascertain the correlation between multiple climate-related and environmental concerns [55], as well as the investigation of the effect of climate change on groundwater resources [56, 57]. The study of Janizadeh et al., (2024) also reported that the AI can also predict the flood susceptibility by using three AI algorithms (the K Nearest Neighbor (KKN), Conditional Inference Random Forest (CIRF), and Regularized Random Forest (RRF)). The prediction was generated by using historical flood events data, in which the model can demonstrated the influence of climate change on susceptibility classifications and signaling a dynamic landscape of flood-prone areas over time. This approach can be adapted to the Indonesian context by incorporating local hydrometeorological data, topographic characteristics, and land-use dynamics into AI models. Given Indonesia's high susceptibility to extreme weather events and climate change, these models have the potential to improve early warning systems by generating dynamic flood susceptibility maps, thereby supporting risk assessment and disaster preparedness efforts.

Given the scarcity of studies integrating AI with climate change adaptation strategies in Indonesia, our study underscores the necessity for future research to explore this promising area. This underrepresentation of cutting-edge technologies noted a missed opportunity to leverage AI and/or advanced technology to climate change adaptation strategies and response. Furthermore, this finding encourages the scope of the research is not confined solely to examining the effects of climate change on extreme weather condition. The research also involves an investigation into how climate change impacts health among communities, by leveraging AI and/or advanced technology. Finally, future research should focus on integrating AI with local climate data, developing predictive models for climate-related health impacts, and creating technology-driven adaptation strategies tailored to Indonesian ecosystems and communities.

We recommend that future research and international collaborations focus on establishing AI-climate research hubs that bring together AI experts, climate scientists, public health researchers, and policymakers. These hubs should facilitate interdisciplinary research, foster innovation, and enhance data-driven decision-making for climate resilience. Furthermore, fostering partnerships between developed and developing nations is essential to ensuring equitable access to AI technologies.

Conclusion

Summary of findings

This study recorded significant research growth in climate change, with leading contribution from institutions located in Java Island, Indonesia. The most prolific scholars were Yulianto (13 articles) and Murdiyarso (1,819 citation). However, research on climate change utilizing advanced technologies such as AI, machine learning, and Internet of Things (IoT) remains notably limited, indicating a critical knowledge gap.

Research implications

For researchers interested in the role of AI in predicting the impacts of climate change, the core content of AI and climate change was identified using keyword frequency analysis. The findings in this study, based on bibliometric analysis, provide an in-depth examination of how AI can be used to predict the impacts of climate change and inform strategies for climate change adaptation and mitigation.

The low occurrence of terms such as "machine learning", "Internet of Things (IoT)", "big data", "cloud computing", "mobile app", and "social media" in the social network analysis indicates a significant scarcity of research utilizing artificial intelligence (AI) and advanced technologies for climate change adaptation in Indonesia.

Our research finding will be valuable to scholars and practitioners in AI and Climate change. Our research findings provide valuable insights for scholars and practitioners in AI and climate change. These insights offer a broader perspective on the current state of AI and climate change research in Indonesia. We recommend that future research prioritize expanding the use of AI to predict climate change impacts, particularly within Indonesia

Limitation the study

There are limitations in the study : 1) the study is restricted by its reliance on a single database, which may limit the comprehensiveness of the analysis and the representativeness of the findings, 2) there is a potential for relevant research on the application of AI in climate change adaptation to be overlooked, as studies published in other databases may not be captured within the scope of this research, 3) further investigation is necessary into the use of AI for climate change mitigation, particularly concerning the impacts of climate change on public health. A more in–depth exploration is required to understand how AI can be employed to address health-related challenges arising from climate change. Nevertheless, this study provides valuable insights into research trends related to climate change and the application of common technology in Indonesia.

Future studies could enhance the comprehensiveness of bibliometric analyses by incorporating multiple databases, such as Web of Science and Google Scholar, to avoid potential biases and omissions. Additionally, targeted studies on the intersection of AI and public health within the climate change context are needed to bridge current knowledge gaps.

Financial supports

The authors express their gratitude to University of Jenderal Soedirman for providing institutional support.

Competing interests

Authors declare there is no conflict of interest in this study.

Acknowledgements

The Author are grateful to University of Jenderal Soedirman for supporting this research.

Ethical considerations

"Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors."

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