



Research article

Floods and droughts research progress and its contributions toward sustainability

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ABSTRACT

In 2015, the United Nations General Assembly launched seventeen Sustainable Development Goals (SDGs), aimed at being achieved by 2030. The SDGs 6 (clean water & sanitation) and 13 (climate actions) are two critically important goals concerning water resources that need to be addressed. This study used the Scopus database to explore climate extremes, specifically droughts and floods, in East Asia and highlight the region's efforts and contributions towards achieving SDGs 6 and 13. We found that even before the implementation of SDGs, the topics related to solving the problems of water resources, water quality, and treatment of wastewater using different conceptual models and methodologies were the main concerns in the region. The adoption of SDGs has led to a heightened focus on water and climate sustainability in East Asia, with the considerable surge in climate-related studies after 2019. Under SDG 13, all countries have contributed substantially to climate action research. Keyword analysis indicates that climate change, water management, water treatment, water quality, and adsorption remain prominent. SDGs 6 and 13 have emerged as crucial areas of focus for research and initiatives as the global community grapples with escalating water resources and climate challenges. Under specific keywords search, China has 2nd place in the search with climate and water during the SDGs period, accounting for 21 % of the entire publication from 2015 to 2023. Japan and South Korea account for of 4 % and 3 %, respectively. The research on floods and droughts has garnered significant attention, with half of the ten highly co-cited literature examining the changing pattern of drought, the influence of extreme events on crop yield, and other related topics. Despite the positive contribution of the East Asia region towards SDGs 6 and 13, there is still an urgent need for a more robust framework to improve the complex interconnections between climate actions, clean water, and sanitation for a sustainable soil-water-plant-atmosphere ecosystem.

1. Introduction

Natural calamities like flooding and droughts adversely impact the environment and human societies [1–4]. East Asian countries like China, Japan, and South Korea have been at the forefront among other developed countries of scientific research aimed at

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understanding the impacts of floods and droughts on regional economies [5–7]. Water-related risks in urbanized areas have been the source of over 90 % of catastrophic occurrences over the last century, and losses have grown fivefold since the early 1980s [8,9]. Thus, the scientific community is investigating drivers and impacts of floods and drought across regions to provide valuable insights into the hydrological extremes, which are helpful for the local and regional communities to identify the potential threats due to these extremes.

The United Nations (U.N.) established seventeen Sustainable Development Goals (SDGs) in 2015, intending to achieve a safe environment by 2030. These seventeen SDGs are critical because they are combined to improve the global social, economic, and environmental elements. SDGs 6 and 13 are the two most important goals related to the water and climate. The studies related to floods and droughts are therefore critical for accomplishing two primary U.N. SDGs 6 and 13. Combining flood and drought issues to explain and quantify them is a complicated research topic that involves numerous techniques and metrics. The researchers usually employed remote sensing, hydrological modeling, and field surveys to assess the complex interactions of the human system, climate, and hydrology to identify vulnerable areas and contribute to sustainable water resources management [10–12].

East Asia is vulnerable to floods and droughts and a great amount of population may be threatened by high risks of both hydrological extremes (floods and droughts). The capability in defending floods and droughts here is very weak and researchers and scientists are working hard to create novel technology to alleviate the effects of these hydrological extremes in East Asia. To enhance accuracy and lead time, flood forecasting and early warning systems, for example, rely on advanced modeling approaches, real-time monitoring networks, and data assimilation methodologies [13–16]. Such initiatives are critical in decreasing the loss of life and property, thus improving communities' resilience in flood-prone areas. Likewise, drought-related research has concentrated on improving water resource management and adaptation measures [17,18]. This research area includes developing drought indicators, forecasting models, and decision support systems to aid policymakers in drought preparation, water distribution, and response planning [19–21]. Integrating scientific information with socioeconomic considerations allows for developing effective policies and actions to reduce the impacts of droughts on agriculture, water supplies, and ecosystems [22,23].

In recent decades, most East Asian countries have experienced floods or droughts, resulting in significant depreciation to the country's economy [24–28]. Previous studies indicated massive casualties and colossal economic losses (780 billion US Dollars) due to floods and drought on a global scale [29]. In particular, China is also very susceptible to floods and drought. Extreme drought occurrences have become more frequent, and the afflicted region has kept growing [30–33]. In South Korea, substantial losses are due to mega-drought events have been extensively reported [34]. Different typhoons in Japan that bring a large amount of rainfall caused flooding in various areas, forcing almost seven million people to evacuate. For example, the Japan Cabinet Office reports severe damage to property and human loss [35].

Furthermore, new forms of drought and flood occurrences are growing more severe, such as drought-flood abrupt alternation events [36,37]. These drought-flood phenomena significantly negatively affect agriculture, the environment, and socioeconomics [38]. For example, a considerable reduction in maize and rice yield (approximately 13 %–40 %) has been observed [39]. Thus, there is a desperate need for developing drought and flood reduction strategies. A general drought and flood reduction strategy developed by Ref. [40] emphasizes the need to consider interactions between flood and drought-related phenomena when designing disaster risk reduction measures and strategies.

There are some review studies related to drought and floods considering their impacts, retrospective and prospective evaluations, modeling challenges, improvement of attribution changes, and risk reductions [40–46]. However, a comprehensive review on the research process that uses literature analysis approaches in East Asia related to contribution to SDGs remains lacking. Therefore, here we use bibliometric analysis and visualization to concisely synthesize existing research findings on droughts and floods and the assistance of East Asian researchers to select SDGs. This study demonstrates the dynamic development laws that have guided this field of study in recent years and anticipates further growth. The number of articles on droughts and floods that have been published is expected to have grown over time, and thus, the study focus has shifted from features to causes and repercussions. This investigation of research status and the forecast of research hotspots can be used to guide future research. Moreover, this study highlights the scientific contribution by examining the available literature on flood and drought, particularly in East Asia. By synthesizing recent research publication data, this study contributes to the wider scientific discussion on sustainable development and adapting to climate change under selected SDGs.

2. Material and methods

A bibliometric tool is used to analyze the research outcomes from published literature. Various software types are available for analyzing the literature across multiple research scopes [47,48]. The bibliometric method has been applied to investigate the advances in multiple topics in hydrology and water resources, such as groundwater, evapotranspiration and climate, urban development, runoff, and precipitation [49–52]. Tools like VOSviewer (Van Eck and Waltman, 2010), CiteSpace [53], and Scopus [54,55] have been developed for literature visualization and statistical searches. These tools enable the mapping of technology fields, identification of specific science research hotspots, and the highlighting of key articles. Furthermore, these bibliometric techniques considerably enhance the accuracy of the research area distribution when compared to the standard literature review method.

In this study, the Scopus bibliographic database was retrieved from scopus.com, focusing on publications related to SDGs (6 and 13) and floods and droughts. Scopus has specific keywords for SDGs to filter data within the database. We used topic-specific keywords to search the literature, for example, floods and droughts, climate change, water resources, scarcity, resilience, precipitation, and water management. General terms, duplicates, and too-specific terms were excluded because of their irrelevancy. We adopted a straightforward search method using the title, affiliation country, and author keywords to search the data. To refine search queries and combine these terms efficiently, Boolean operators like “AND,” “OR,” and “NOT” were used. The search may have encompassed terms

such as “East Asia” in addition to “drought” and “flood”.

Furthermore, this study employs both content analysis and systematic literature review methods to identify the essential themes and derive deep insights surrounding the flood and drought. This approach leverages the strengths and mitigates the limitations of both methodologies. Systematic reviews synthesize a vast amount of information about a topic, whereas content analysis offers precise qualitative and quantitative interpretations of textual material [56,57]. From 1979 onward, all East Asian region articles were sorted to study the floods and drought contributions. SDGs 6 and 13 specific keywords are available on Scopus website [58]. The study also utilizes VOSviewer for examining the keywords co-occurrence and co-citation.

3. Results and discussion

3.1. Floods and droughts research progress

Overall, the Asian region is notably vulnerable to the impacts of climate change, with water management challenges intensifying due to shifts in the hydrological cycle [59–62]. Evidence suggested an increased atmospheric moisture demand because of rapid global warming since the late 1970s [63], resulting in climate variability and altered rainfall patterns across this region. In East Asia, long-term precipitation showed inter-annual variability [64,65]. However, many areas witnessed obviously increasing floods and drought frequency [66,67]. Drought is characterized by a scarcity of water relative to typical conditions, affecting rainfall, river streamflow, or soil moisture levels. Conversely, floods result from prolonged monsoonal rains, tropical cyclones, and storms, as well as snowmelt induced by elevated temperatures. The terms “drought” for dry conditions and “floods” for wet extremes are commonly employed in the literature to describe these hydrological phenomena. Our initial approach involved utilizing keywords related to Sustainable Development Goals (SDGs) 6 (Clean Water and Sanitation) and 13 (Climate Action) to sift through and manage the literature regarding the contributions of East Asian countries to sustainability. We excluded irrelevant keywords, concentrating on specific terms such as drought, flood, precipitation, and extreme climate change, to streamline our focus.

According to the Scopus database, 40180, 118345, and 8659 papers were published under SDG 6, SDG 13, and specific keywords from 1980 to 2023 (Fig. 1) (The presented data was fetched from Scopus in July 2023). Most published articles were research papers. There is an obvious increasing trend of research articles after 2000, suggesting these regions started focusing on water and climate sustainability. There has been a dramatic increase in climate-related studies after 2019, during which more than 10,000 articles were published. Although the volume of water-related publications is lower, there is an upward trend, driven by critical issues such as water pollution and groundwater depletion. The surge in climate-related research is primarily fueled by environmental problems (due to urbanization and rapid development) and climate extremes (floods and droughts). The flood and drought processes have been better understood due to these new technologies, particularly hydrological models, machine learning approaches, and the supplementation of high-resolution spatial and temporal data. Research into floods and droughts spans a diverse array of methodologies and intersects with multiple disciplines, including geology, remote sensing and GIS, hydrology, meteorology, and environmental sciences. Factors influencing floods and droughts encompass natural phenomena, topography, climate variability, soil conditions, catchment characteristics, land use changes, climate change, urbanization, and more. The involvement of such a wide range of disciplines introduces complex challenges but also opens up significant opportunities for the study of floods and droughts.

Using SDG 6 keywords, it was observed that climate change, water quality, and wastewater-related topics were the focus during the retrieval period (Fig. 2). It is found that even before the implementation of SDGs, climate change and water reuse were the main concerns in the region. These topics concentrated on solving the problems of water resources, water quality, and wastewater treatment using different conceptual models and methodologies. Likewise, climate change, carbon neutrality, precipitation, and drought occurrences were found under SDG 13 (Fig. 3). The researchers commonly used machine learning and remote sensing techniques to address such problems due to climate change. It was found that the keyword-“climate change”-had the highest occurrences (3259),

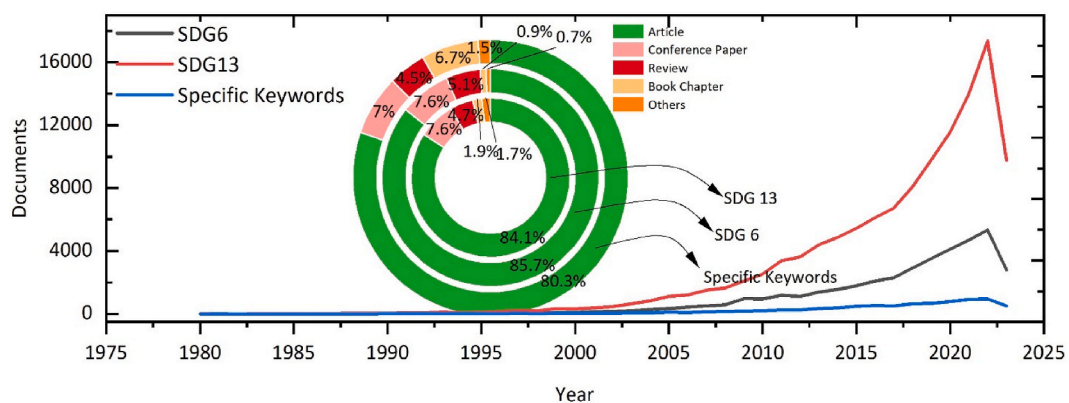


Fig. 1. Documents published related to SDGs (6 and 13). The doughnut plot represents the percentage of the document category; specific keywords are presented in the method section; in the doughnut plot, others indicate editorials, notes, erratum, etc.

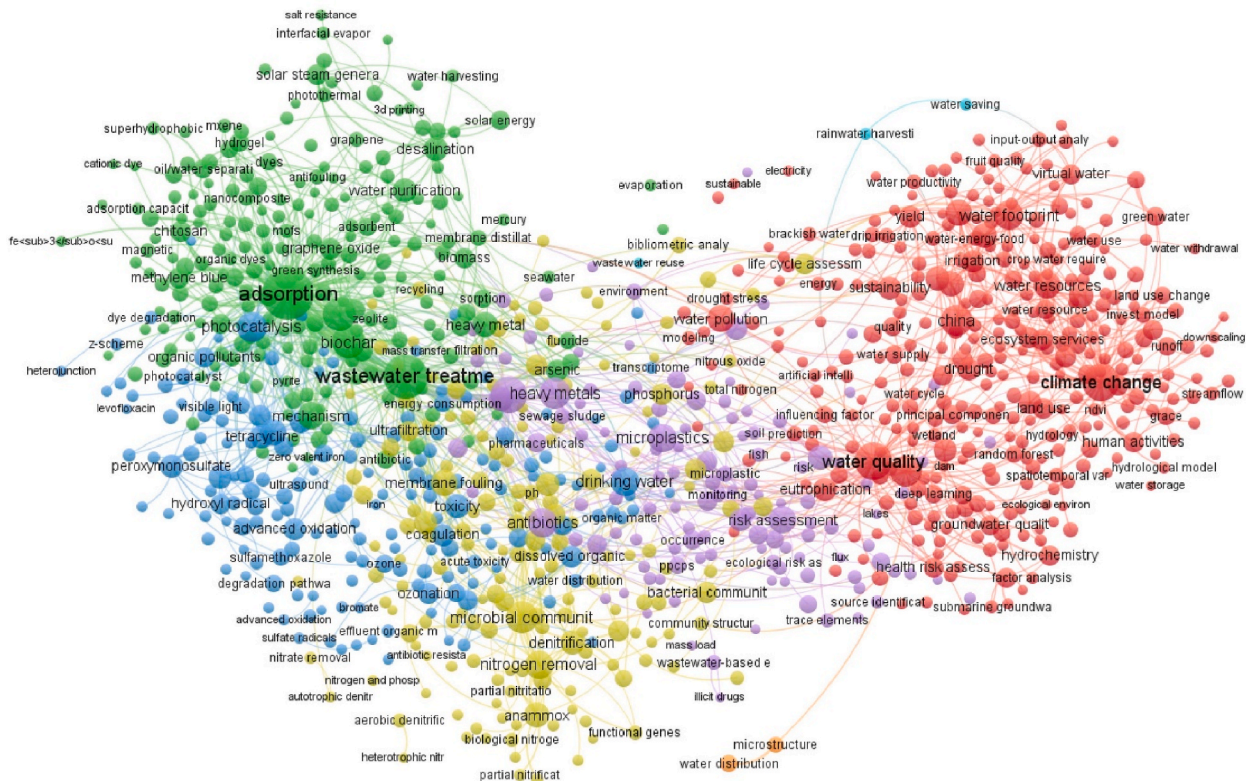


Fig. 2. SGD 6 keywords search from 1980 to 2023 in Scopus database. The text, circles, and circle sizes correspond to the articles published in the SDG 6 domain. Colors represent the cluster, and terms that share the same color often appear in publications. This figure is generated with VOSviewer. 1st 20,000 documents were used to create the figure.

which linked with precipitation (299 links), drought (242 links), renewable energy (106 links), carbon neutrality (144 links), and warming (102 links). Those used to study these links like machine learning (215 links) and remote sensing (249 links) methods were also found. Using specific keywords, the researchers focused on climate change problems. They were primarily concerned with precipitation and drought (Fig. 4). It was observed that the cumulative occurrence of climate change and drought was highest in keywords used. In 2023, 5579 (climate change) and 4579 (drought) times keywords were used for research purposes.

Based on keywords, we explore detailed research topics and research focus. Climate change is a top priority subject among East Asian countries. Of the top ten countries around the globe, China secures the top position in publishing climate-related issues. There are 306,779 documents published in China, while Japan and South Korea are at number three and fourth with 55,484 and 32,935 number documents (Table 1).

There are various factors for the growth in the number of publications. The 4th IPCC report, published in 2007, urged all governments to pursue climate-change adaptation measures [68]. This corresponds to a significant increase in the number of articles. Several warning signs about the dangerous influence of climate change on livelihood surfaced in the 1980s and 1990s. The Climate Change Convention, signed in 1992, pledges to limit emissions from developed nations to halt global warming [69]. The Kyoto Protocol, signed in 1997, demands developed nations to reduce their emissions [70]. However, due to economic factors in developed countries, the protocol did not enter into force till 2005. All these warnings were converted into policies established under the SDGs. The rapid increase in publications highlights that national and international policymakers are fully aware of the issues and are taking action to address problems like food security and climate change by funding research in not only academic but also non-academic centers. According to the present study, the documents retrieved under SDGs and specific keywords covered various topics, primarily environmental and water-related issues. The literature review reveals the significant contributions of multiple subject areas, emphasizing the intricate nature of the subject and the essential role played by various sectors in addressing the effects of climate change, especially those linked to extreme events.

Moreover, these findings underscore the critical importance of addressing water-related concerns in the context of climate change adaptation and mitigation strategies. Variations in temperature, drought, heatwaves, and floods directly influence agriculture, consequently impacting the nation's economy [71].

Table 2
Literature published under SDGs 6 and 13 from 2015 to 2023.

Sr.	Country	SDG 6	SDG 13	Documents with specific keywords
1	China	25,933	73,558	3637
2	United States	2444	104,713	4233
3	Australia	1000	28,020	1212
4	United Kingdom	693	43,059	1886
5	Canada	657	24,430	849
6	Pakistan	480	4424	339
7	Hongkong	471	3092	151
8	Germany	456	35,053	1238
9	Japan	352	10,633	687
10	Netherlands	321	13,334	887
11	India	312	22,870	1424
12	Singapore	250	2427	130
13	South Korea	239	7633	440
14	Saudi Arabia	225	3268	140
15	Taiwan	217	3461	212

China's huge land area, diversified ecosystems, and water sources bring different problems and research objectives. Policy and institutional changes affect research funding, collaboration, and incentives. East Asian countries may provide different SDG 6 and 13 research outputs due to government priorities, legislation, and research and development investments. International collaboration may influence research objectives and SDG contributions. Strong research networks and international collaborations may help countries shape global climate action and water sustainability issues. These factors can affect regional climate action and water sustainability efforts. Differences in study focus may reflect awareness, capacity, and commitment to water and climate change issues. Sharing expertise and best practices among East Asian countries can improve regional efforts to achieve SDGs 6 and 13.

3.3. Core research and knowledge under SDG 6 and 13

SDG 6 aims to ensure the availability and sustainable management of water and sanitation for all. It focuses on improving access to clean water, proper sanitation, and the efficient use of water resources. In the East Asian region, several countries face water scarcity, water pollution, and inadequate sanitation facilities. The United Nations Environment Program published the State of the Environment in Asia and the Pacific 2020 and discussed the water-related challenges, including environmental issues [72]. Likewise, the Asian Development Bank studied water security in East Asia and explored water security challenges and solutions in East Asian countries, focusing on policy recommendations. Moreover, a study conducted by Ref. [73] about the Water-Energy-Food Nexus in East Asia examined the interconnections between water, energy, and food and the implications for sustainability.

Similarly, SDG 13 calls for urgent action to combat climate change and its impacts. It involves strengthening resilience and adaptive capacity to climate-related hazards and integrating climate change measures into policies and planning. The Asian Development Bank highlights the core literature about climate change in Asia and the Pacific (Anbumozhi et al. [74]). This literature provides an overview of climate change impacts and mitigation strategies. The economics of climate change and low carbon growth strategies in Northeast Asia, funded by the Korean INTERNATIONAL COOPERATION Agency and the Asian Development Bank, address the impacts of climate change and the importance of initiatives to mitigate that impact [75]. This study provides a detailed framework on the cost of mitigation, adaptation, and its linkage to the global economy. In addition to this core literature, the number of citations of published articles from different research institutes can also be used as an evaluation index. The referenced publication may not necessarily be a part of the target retrieval field. The citation frequency directly received from the Scopus database corresponds to the total number of times the paper has been cited [76]. For instance, a study of health and climate change is relevant to SDG 6 and gets citations from environmental and climate research. Thus, widely referenced material may be related to SDG 6, although it is not required to contain fundamental and recognized information. To identify the essential research of the SDG6 subject, 47101 papers were filtered by the Scopus database, which provides SDG 6-related literature information. The highly cited paper was focused on water quality and the water treatment field. Largely, research suggested that the water quality can be monitored effectively by knowing the assimilative capacity and geographical temporal variability of the surface water process. The themes of the most co-cited publications typically reflect hotspots in core research disciplines, which have great reference relevance [77].

Likewise, in SDG 13, the core literatures published are about rainfall, land use, greenhouse gases, and soil moisture conditions under a changing climate and the highly cited articles (3391 citations: Scopus database, 3715 Google scholar) focused on the aerosol contribution to particulate pollution [78]. Using specific keywords for flood and drought research from the same period (2015–2023), the highly cited article (415 citations) in East Asia discussed the increase in extreme frequency of La Nina events [79]. During citation analysis, it was found that most influential papers are research articles focused on new methods and challenges to the water and climate field. As the world faces increasing water resources and climate change challenges, SDGs 6 and 13 have become critical focal points for research and action. Among the various issues, the impacts of floods and droughts have emerged as key concerns directly linked to SDGs 6 and 13. The research focused on floods and droughts have garnered significant attention, with half of the ten highly co-cited literature examining the changing pattern of drought, the influence of extreme events on crop yield, etc. The theoretical investigations have centered on understanding the impact of these extreme events on different regional catchment systems. Many

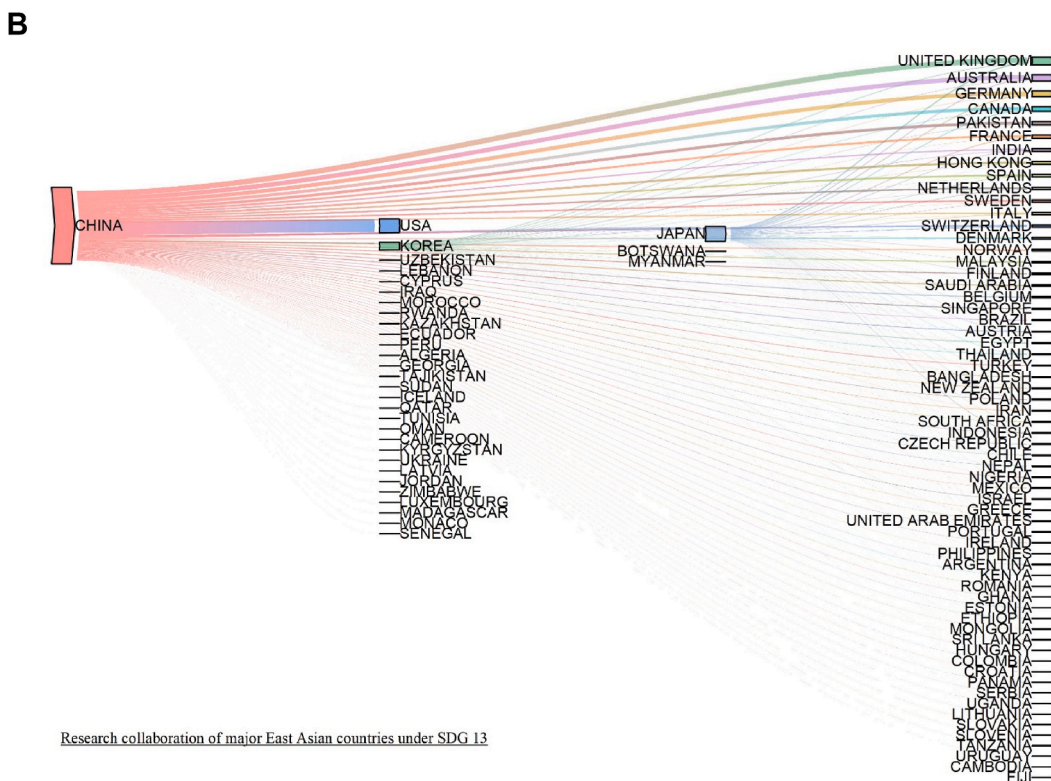
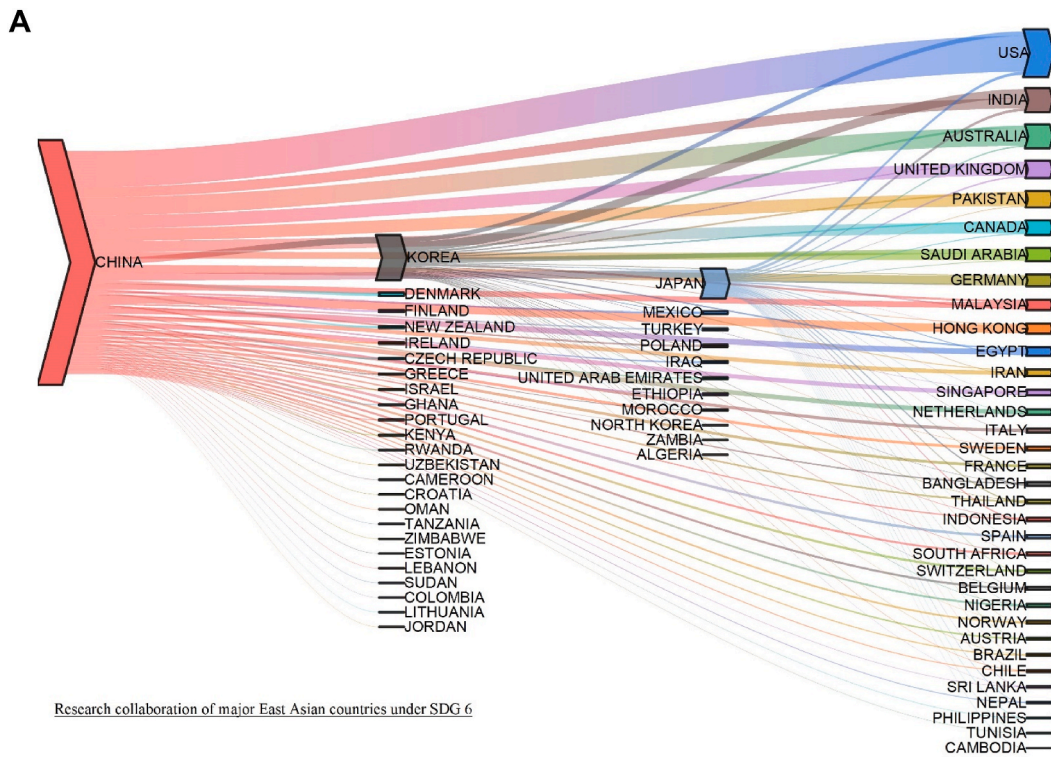


Fig. 5. a) International collaboration of East Asian countries under SDG 6. **Fig. 5b:** International collaboration of East Asian countries under SDG 13.

indices such as Standardized Precipitation Index (SPI) and Palmer Drought Index (PDSI) are developed for assessing drought and flood occurrences [43,80–84]. To enable integrated and effective water resource management, it is necessary to consider both floods and droughts simultaneously [42]. The indices may characterize hydrological and meteorological droughts using numerous hydrometeorological variables. Although floods and droughts have significantly different evolutionary mechanisms in onset and duration, the events are still thought to occur alternately in a region by emphasizing systematic transitions between climate extremes [85,86].

An index or a model should explicitly specify droughts and floods and be included in techniques for modeling water quality. In East Asian countries, certain studies explore the relationship between water quality and climate extremes, highlighting the challenges and their meaningful assessment. For instance Ref. [87], examine a highly contaminated downstream watershed in South Korea using water quality metrics and drought index. Likewise [87,88], used SPI and water quality parameters to investigate the water quality changes. This research is central to recognizing genetic diversity [89]. The findings indicated that genetic diversity contributes to an increase in biomass sources, a crucial characteristic for adaptation to withstand heat and drought conditions. Therefore, addressing the complex interplay between floods and droughts is crucial for achieving SDGs 6 and 13. Through a dedicated emphasis on sustainable water management practices and climate action, we can endeavor to secure access to clean water, to safeguard water-related ecosystems, and to bolster resilience against the consequences of floods and droughts in inland regions.

3.4. Contributions and challenges

The East Asia has made significant contributions to SDGs 6 and 13 by concentrating on improving water and sanitation access, improving water quality, managing water shortages, strengthening water management practices, and a solid commitment to tackling climate change. The region has enhanced access to clean water and improved sanitation facilities through infrastructure development, sanitation efforts, and public awareness campaigns. Water shortage has been addressed by water resource management, conservation measures, and rainwater collection, all of which have led to more sustainable water usage. The region continues to achieve significant progress toward SDG 6 by implementing integrated water resource management systems and strengthening transboundary water cooperation. Similarly, East Asian countries are making substantial contributions to the global battle against climate change through their initiatives to reduce greenhouse gas emissions, advance renewable energy, improve climate resilience, and encourage international collaboration.

Even though the East Asia region has made a positive contribution to achieving SDG 6 and 13, there remains an urgent need for a more comprehensive approach to risk management that considers climate extremes and water management-related issues (water quality, water treatment, reuse, distribution, sanitary measure) to resolve better tradeoffs and synergies across hazards and various temporal and geographical dimensions. A crucial question arises concerning who will reap the benefits in this scenario. For instance, the effects of constructing a dam and its implications on the local hydrological cycle, and the challenges of migration faced by residents and their socioeconomic factors, necessitate a comprehensive and holistic approach for effective resolution. There is a need for basic research on physical climate processes that aggravate climate extremes and study on the understanding of decision-making processes to address hazards and their exposure. Greater emphasis should be placed on guaranteeing the availability and quality of data to facilitate effective research. For instance, obtaining data spanning an extended period can be challenging. Yet, it is essential to accurately discern systematic changes in the occurrences of extreme events, a significant concern in water quality modeling, too. Obtaining constant long-term streamflow data is not always feasible for identifying hydrological droughts. Hence, proxy variables commonly represent drought and flood occurrences, and their roles are utilized in predicting water quality through climatic factors such as precipitation and temperature. The modeling approach, such as the development based on the Soil and Water Assessment Tool (SWAT), can be employed as an event-based water quality modeling technique for catchments with limited gauge data. It can serve as a valuable example in situations with insufficient observed data observations [90,91]. Moreover, it is also desirable to confine hydro-meteorological influences to symbolize the effect of land use change on water quality [92]. Thus, the challenges related to urbanization, land use, land changes, climate change uncertainty, socioeconomic vulnerability, and adaptive management could be endured by combining scientific knowledge and collaborative efforts to safeguard climate adaptation and sustainable water resources. In addition, interdisciplinary research should incorporate policy analysis, hydrology, climate science, and engineering. Researchers can solve complicated water issues that meet SDGs 6 and 13 by working across disciplines. Innovation and technology are essential for sustainable water management and climate resiliency. Thus, decentralized water systems, remote sensing and artificial intelligence should be used to develop and scale up innovative water treatment, conservation, and adaptation solutions in future studies.

4. Conclusions

Research evidence has demonstrated a global increase in the impacts of climatic extremes, such as floods and droughts, which pose significant challenges for future drinking water quality and can potentially increase health risks. This study utilized the Scopus database to extensively analyze climate extremes, explicitly focusing on droughts and floods and aimed to identify the research emphasis and contributions of East Asia towards achieving Sustainable Development Goals (SDGs) 6 (Clean Water and Sanitation) and 13 (Climate Action). Keywords and citations were employed to define the core literature, underlying knowledge, and research fields. The number of publications on droughts and floods related to SDGs 6 and 13 has an increasing trend, indicating East Asia's growing focus on water and climate sustainability.

Since 2019, there has been a massive surge in climate-related studies, with over 10,000 publications. In comparison, water-related publications are much fewer but showed an increasing pattern due to critical challenges such as water pollution and groundwater depletion. The study of climate extremes spans multiple disciplines, including water resources, agricultural sciences, and

environmental science, as evidenced by the distribution of disciplines on droughts and floods and SDGs 6 and 13. Overall, East Asia has significantly contributed to selected SDGs by concentrating on major sectors like improving water and sanitation access, water quality, managing water shortages, strengthening water management practices, and a solid commitment to tackling climate change. Moreover, a robust and comprehensive framework is essential to address the intricate interconnections between climate extremes, water quality, and soil-plant ecosystems. Such a framework will facilitate effective mitigation and management strategies to tackle the challenges posed by these interconnected factors.

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Data availability

The data used for this research is available at <https://www.scopus.com/>.

CRedit authorship contribution statement

Muhammad Abrar Faiz: Writing – review & editing, Writing – original draft, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Ning Ma:** Writing – review & editing, Visualization, Validation, Formal analysis, Data curation. **Farah Naz:** Writing – review & editing, Methodology, Formal analysis.

Declaration of competing interest

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

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