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Global Research Trends on Coastal Climate Change: A Bibliometric Review Toward Supporting Mitigation Strategies

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ABSTRACT

This study uses a bibliometric approach to analyze the causes and solutions to climate change. Keyword visualization indicates that recent research has focused on blue carbon and remote sensing as key methods for monitoring climate change. The countries with the highest research contributions are the United States, China, Germany, the United Kingdom, and Australia. Leading authors in this field include Agneta Andersson, Jianfeng Li, Ning Lin, and Marta Marcos. The findings identify the primary causes of climate change, which include greenhouse gas emissions, energy use, land-use change, industry, and transportation, with the highest percentage attributed to energy consumption and natural resource exploitation (35.2%). The use of fossil fuels, coal, gas, and overall energy consumption are identified as major contributors to climate change in coastal regions. As solutions, four main approaches have been identified: adopting renewable energy, sustainable practices, policy and regulatory measures, and environmental restoration. This study concludes that green technologies, supportive policies, and energy efficiency are crucial to mitigating climate change. These findings provide a comprehensive perspective on the causes and solutions to climate change, serving as a valuable reference for global environmental policy formulation.

KEYWORDS: bibliometric analysis, climate change, coastal regions, causes, mitigation

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INTRODUCTION

Climate change has become one of the most pressing global challenges, particularly for coastal regions, which are highly vulnerable to its negative impacts. Coastal areas play a crucial role in supporting human populations through economic activities, biodiversity, and cultural heritage (Axon et al. 2024). However, these regions face numerous threats, including sea-level rise, coastal erosion, and increasingly unpredictable weather patterns (Dar et al. 2024; Thorne et al. 2024). These impacts not only threaten natural environments but also jeopardize the socioeconomic stability of communities that depend on coastal ecosystems. Although the significance of these challenges is widely recognized, a comprehensive understanding of the specific causes of climate change in coastal areas remains limited. This gap hinders effective mitigation efforts and the development of targeted prevention strategies (Adshead et al. 2024; Zhang et al. 2024).

While the impacts of climate change on coastal regions have been extensively studied, there remains a significant gap in the literature regarding the specific causes of climate change in these environments. Most existing research has focused on the consequences of climate change, such as sea-level rise and increased storm intensity, rather than delving deeper into the underlying factors driving these changes (Sobel et al. 2016; Wu et al. 2022). The lack of in-depth understanding of these causative agents hampers the formulation of more targeted prevention strategies. Furthermore, existing mitigation efforts are often generalized and fail to consider the unique vulnerabilities and characteristics of coastal regions pesisir (Ahmed et al. 2022; Bukvic et al. 2020; Zhang et al. 2024). Therefore, a comprehensive analysis of the existing literature is crucial to identifying the key drivers of climate change in coastal areas. This understanding will be essential for developing more effective policies and interventions to address the challenges faced by coastal regions.

As an initial step to address this knowledge gap, this study seeks to conduct a bibliometric analysis of scientific literature on the causes of climate change in coastal areas, with a specific focus on identifying the most frequently cited factors and understanding the geographical and temporal trends of these causes. By mapping the existing knowledge, this research seeks to uncover patterns and gaps in current studies and provide a comprehensive overview of the factors contributing to climate change in coastal environments. This gap in literature poses challenges for researchers and policymakers in designing targeted interventions to mitigate climate change impacts in coastal regions. By applying a bibliometric approach, this study seeks to bridge this gap through a comprehensive analysis that not only synthesizes existing knowledge but also identifies neglected or underexplored factors contributing to climate change in these areas. Additionally, this study aims to offer evidence-based recommendations on preventive measures to address the specific challenges facing coastal ecosystems. In doing so, it is expected to contribute to the development of more targeted strategies to mitigate the negative impacts of climate change in coastal regions and support the resilience of coastal communities and ecosystems.

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This research offers a novel contribution to the field by employing a bibliometric approach to analyze the causes of climate change in coastal areas—an approach that remains underexplored. While previous studies have primarily examined the impacts of climate change, this study focuses on understanding the factors driving these changes, thus providing a fresh perspective on a pressing global issue. The bibliometric approach enables the identification of research trends, influential studies, and knowledge gaps, offering a structured and data-driven understanding of climate change in coastal regions. The findings from this study are expected to be a crucial starting point for policymaking and decision-making, as they will provide a clearer picture of the scientific consensus on the causes of climate change and highlight areas requiring further research. By deepening the understanding of underlying drivers, this research not only contributes to scientific literature but also supports the development of more effective interventions to protect coastal ecosystems and the communities that depend on them.

RESEARCH METHODS

Research Design

To achieve the research objective of gaining a deeper understanding of the causes of climate change in coastal areas and their prevention strategies, this study employs a bibliometric analysis using the keyword search string: ST: TITLE-ABS-KEY (coastal AND climate AND change AND (cause OR prevention)). The dataset in .csv format was extracted on October 10, 2024, at 20:18 (GMT+7). The combination of these keywords aims to capture various dimensions of research related to climate change in coastal areas, including studies focusing on both its causes and mitigation or prevention efforts. This approach is expected to provide a more comprehensive understanding of trends, patterns, and research contributions in this field. The study population consists of all publications retrieved based on the specified search keywords within the Scopus database. Scopus is one of the largest and most reputable academic indexing databases, making it highly relevant for this research. The selection of Scopus as the primary data source is justified by its extensive coverage across multiple disciplines and its reputation for providing high-quality, globally indexed scientific literature. Consequently, the research population includes thousands of scientific articles published by researchers worldwide that are relevant to the topic of climate change in coastal regions.

The initial search query yielded a total of 3,148 articles from the database, which were subsequently subjected to a systematic selection process to ensure relevance and focus. The selection process consists of two main stages: identification and screening. The identification stage aims to identify all relevant publications based on the predefined keywords. Subsequently, the screening stage is conducted to filter articles that meet the research inclusion criteria. The applied selection criteria (Figure 1), include: a) Publications from the last 10 years to ensure that the reviewed studies

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are current and relevant to present climate change conditions and challenges (n=887), particularly considering the policy dynamics initiated by the 2015 Paris Agreement (Teo, 2023). This timeframe was selected to capture the most recent scientific discourse, particularly in response to the policy shifts and global climate commitments established by the Paris Agreement. b) Only research articles are included, with other types of publications excluded (n=601). c) Articles must be written in English to ensure broader accessibility within the international academic community (n=102). d) Articles with incomplete metadata, such as missing author names or keywords, were excluded from the study (n=8). To ensure data validity and maintain data integrity, the study implemented procedures to identify and control duplicate articles or problematic entries, such as multiple publications derived from a single research output.

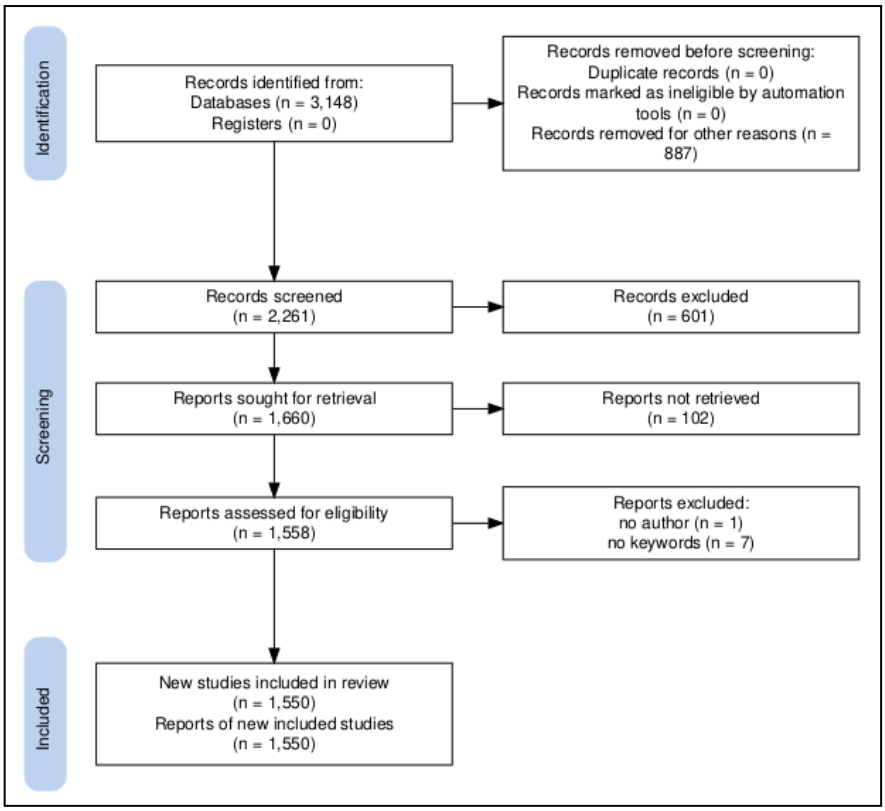

Figure 1. Research Database Collection Stages (modified from: Haddaway et al., (2022)). The figure outlines the selection process starting with 3,148 records identified from databases. After excluding irrelevant records, the final dataset consists of 1,550 studies included for analysis.

Through this selection process, a smaller yet more focused sample of publications was obtained (n=1.550). The final sample better reflects recent trends and advancements in climate change research in coastal areas. By restricting the time frame to the past decade and including only research articles, this sample is expected to provide empirically strong and policy-relevant insights for climate change prevention and mitigation. The selected articles will be comprehensively analyzed to map the causes of climate change in coastal areas and the proposed solutions, offering new perspectives that contribute to both scientific literature and public policy.

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Data Analysis

In this study, data analysis was conducted using a bibliometric approach, which enables the exploration and mapping of research trends based on predefined keywords. The data obtained from the article selection process in the Scopus database was processed using the bibliometric analysis software VOSviewer. This software was used to analyze the relationships between articles, authors, and publication trends based on keyword frequency, co-citation, and co-authorship. This analysis provides a comprehensive overview of the most frequently discussed topics, author collaborations, and the geographic regions that are the focus of research.

In this study, several specific parameters were applied to ensure the quality and relevance of the visualizations. First, the minimum occurrence threshold for each keyword was set at 14 occurrences. This parameter was chosen to ensure that only keywords with a high frequency of occurrence and considered significant would be further analyzed. Second, the types of visualization employed were network and overlay. The network visualization was used to display the relationships between keywords, authors, and countries in the form of a network structure. This network structure enables the identification of clusters or groups of interrelated topics, as well as the detection of collaboration patterns among researchers and countries. Meanwhile, the overlay visualization was applied to illustrate the temporal evolution of research trends. Third, the units of analysis in this study comprised authors, countries, and journals. Author-based analysis was conducted to identify the most productive and influential researchers in the topic of coastal climate change. Country-based analysis aimed to map the research contributions from various countries, thereby revealing the geographic regions most actively involved in coastal climate change research. Lastly, journal-based analysis was employed to identify the key journals that serve as the primary sources of research publications in this field, while also assessing the quality of sources through publication and citation counts. The combination of these three parameters allows for a comprehensive visualization, not only depicting the relationships between keywords but also linking them to researchers, institutions, and geographic regions.

The results of this analysis are expected to offer insights into how research on coastal climate change has evolved over the past 10 years. Furthermore, by examining publication trends and researcher collaborations, this study can identify research gaps that have not been extensively explored, as well as opportunities to strengthen international collaboration in enhancing the effectiveness of climate change mitigation efforts in coastal areas. These findings will also serve as a critical foundation for formulating data-driven policy recommendations for more sustainable coastal management in the future.

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RESULT AND DISCUSSION

Publication Trends

The results of the visualization using VOSviewer are shown in Figure 2. This keyword frequency analysis was conducted using Natural Language Processing (NLP) techniques, which enable the systematic extraction and processing of terms from large volumes of textual data (Townshend et al. 2013). NLP is a branch of artificial intelligence that focuses on the interaction between computers and human language, allowing for automated identification of frequently occurring terms and their contextual relationships (Röthig et al. 2023). By applying NLP to bibliographic metadata, especially keywords occurance, the analysis identifies patterns of thematic relevance and conceptual linkages, forming the basis for the co-occurrence clustering in this study.

The visualization results categorize the keywords into six clusters based on co-occurrence. The first cluster is "Precipitation and Salinity," with the most frequently occurring keyword being "climate change," appearing 451 times. Climate change has become a significant and complex global issue, affecting various environmental aspects, including precipitation patterns, salinity levels, and sea level rise. The increase in global temperatures due to higher concentrations of greenhouse gases in the atmosphere has caused significant changes in precipitation patterns across different regions of the world. These changes not only affect freshwater availability but also contribute to increased salinity in marine and coastal ecosystems (Balakrishnan et al. 2024; Jeppesen, Beklioğlu, and Zadereev 2023; Lorrain-Soligon et al. 2023; Röthig et al. 2023). Additionally, sea level rise, a direct consequence of global warming and polar ice melting, exacerbates problems in coastal areas, which are increasingly threatened by erosion, flooding, and saltwater intrusion (Adshead et al. 2024; Axon, Chapman, and Light 2024). The interrelationship between changes in precipitation, salinity levels, and sea level rise has become a key topic in climate change studies, where their cumulative impacts have the potential to cause serious consequences for biodiversity and the sustainability of natural resources. This cluster indicates a dominant research focus on the hydrological consequences of climate change, particularly the interplay between altered precipitation patterns, salinity shifts, and sea level rise in coastal ecosystems.

The second cluster is "Coastal Management and Erosion," a crucial topic in addressing the impacts of global environmental changes and adapting to climate change in coastal communities. The main keyword in this cluster is "erosion" (49 times). Coastal management plays a significant role in mitigating the intensifying risk of erosion due to climate change and human activities. To enhance the effectiveness of coastal management, technology-based approaches such as Geographic Information Systems (GIS) and machine learning (ML) are increasingly being applied (Dal Barco et al. 2024; Shahabi and Tahvildari 2024). GIS allows for accurate mapping and monitoring of coastal dynamics, while ML contributes to predicting erosion patterns and environmental impacts in the future. The combination of these technologies enables more effective adaptation planning for coastal

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communities, helping them to proactively address the challenges posed by climate change. The core research direction in this cluster centers around the development and application of spatial and predictive technologies—such as GIS and machine learning—for managing coastal erosion and supporting adaptive planning in vulnerable regions.

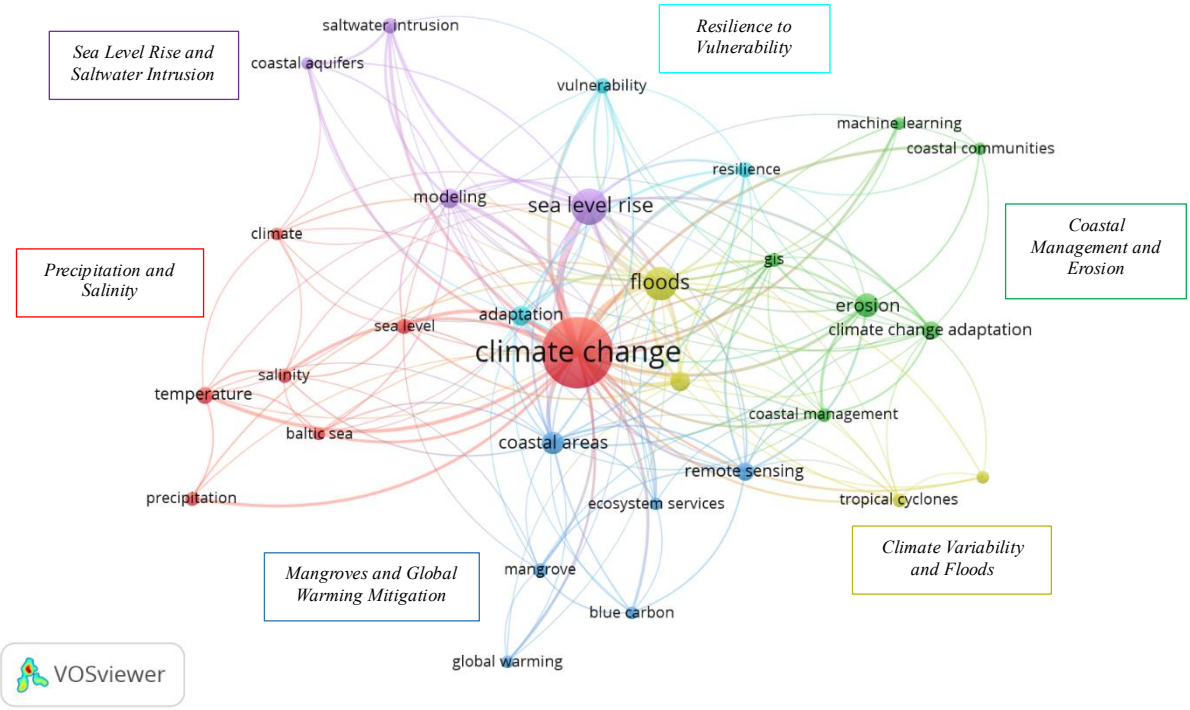

Figure 2. Co-occurrence Keyword Map of Climate Change Research in Coastal Areas. The size and proximity of the nodes indicate the frequency of keyword occurrences and the strength of conceptual linkages within the dataset.

The next cluster is "Mangroves and Global Warming Mitigation." Mangrove appears 20 times, highlighting its crucial role in climate change mitigation through blue carbon storage and the provision of vital ecosystem services in “coastal areas”, where the keyword appears 47 times. As one of the most productive coastal ecosystems, mangroves can absorb and store large amounts of carbon, contributing significantly to the reduction of atmospheric carbon concentrations, which are the primary cause of global warming (Asante et al. 2024; Lovelock et al. 2024). Furthermore, mangroves provide various ecosystem services, such as coastal protection from erosion, habitat for biodiversity, and pollutant filtration from water (Sarkar et al. 2024; Seydi et al. 2024). Monitoring coastal ecosystems and the services they provide has become increasingly important in the context of global warming, and remote sensing technology offers an effective tool for mapping and measuring blue carbon reserves and assessing the condition of coastal areas, which is a key keyword in this cluster. The use of this technology enables more accurate and sustainable evaluations of ecosystem functions, supporting climate change mitigation efforts while maintaining the sustainability of coastal ecosystems. Research in this cluster emphasizes the role of mangrove ecosystems in climate

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mitigation, with a strong focus on blue carbon sequestration, coastal protection services, and the integration of remote sensing for ecosystem monitoring.

The fourth cluster focuses on "Climate Variability and Floods," with the largest keyword (89 occurrences) being "floods." Increasing climate variability has significantly impacted the frequency and intensity of floods in various parts of the world (Chen et al. 2023; Kim et al. 2024). Changes in global weather patterns influenced by phenomena such as El Niño and La Niña have caused extreme fluctuations in precipitation, increasing the risk of severe flooding, especially in low-lying and coastal areas (Mayta et al. 2024; Wang and Yuan 2024). Additionally, major storm events, such as tropical cyclones, often trigger storm surges, exacerbating the risk of flooding, particularly in vulnerable coastal regions. Floods caused by tropical cyclones are not only due to heavy rainfall but also by the temporary rise in sea level caused by storm surges. In the context of climate variability, flood risks are becoming increasingly difficult to predict, requiring more effective adaptation and mitigation strategies. This cluster is thematically oriented toward understanding the relationship between climate variability and extreme hydrometeorological events, especially floods, and developing improved forecasting and response mechanisms for coastal resilience.

The next cluster is "Sea Level Rise and Saltwater Intrusion." The most prominent keyword in this group is "sea level rise," which has the second-highest frequency in this study, appearing 117 times. Sea level rise is one of the most significant impacts of climate change, threatening coastal areas worldwide, including coastal aquifers that serve as an important source of freshwater for local communities (Gumuła-Kawęcka, Jaworska-Szulc, and Jefimow 2024; Su, Befus, and Hummel 2024). One of the main issues arising from sea level rise is the increased risk of saltwater intrusion into coastal aquifers (Porru et al. 2024). This phenomenon occurs when seawater infiltrates freshwater groundwater layers, reducing the quality and availability of freshwater for human and ecosystem needs. The impact of sea level rise on saltwater intrusion becomes more complex due to other factors, such as over-exploitation of groundwater resources in coastal areas. Modelling saltwater intrusion due to sea level rise is essential for predicting the scale and impact of this event. By using appropriate models, researchers and policymakers can develop more effective mitigation and adaptation strategies to protect coastal water resources and prevent long-term damage to communities dependent on these aquifers (Cherubini, Sathish, and Pastore 2023; Emara et al. 2023). The main focus here is on the impacts of sea level rise on coastal freshwater systems, highlighting research on saltwater intrusion modeling, aquifer vulnerability, and the development of mitigation strategies to protect water resources.

The final cluster is "Resilience to Vulnerability." Adaptation to climate change has become a key element in enhancing the resilience of communities and ecosystems to increasing risks, such as natural disasters, global temperature rise, and extreme weather changes. The resilience of a system is determined by its ability to respond, recover, and adapt to pressures and disturbances, while vulnerability refers to the extent of exposure of a community or ecosystem to these risks. The most

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vulnerable communities often experience the greatest impacts from climate change, requiring more intensive adaptation efforts to reduce risks and strengthen resilience. Effective adaptation strategies focus not only on mitigating direct impacts but also on building long-term capacity to reduce vulnerability, minimize losses, and enhance recovery capabilities after disaster events (Hung, Hung, and Hsu 2024). This cluster reflects a growing emphasis on socio-ecological resilience, exploring how communities and ecosystems adapt to climate risks through long-term capacity building, vulnerability reduction, and integrated adaptation strategies.

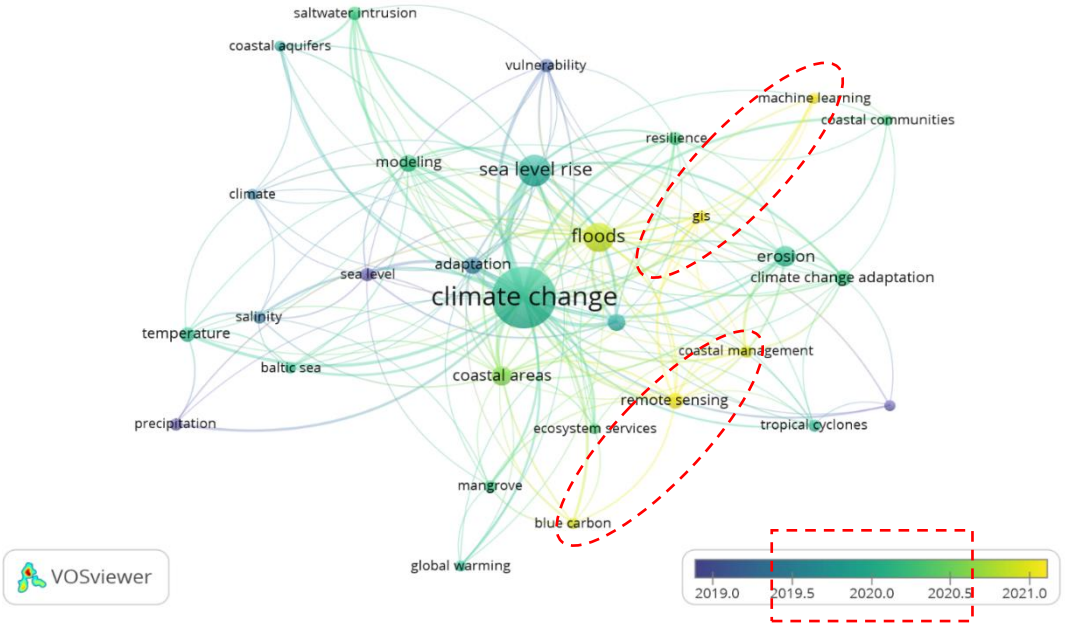

Figure 3. Overlay Visualization of Keywords. The visualization highlighting the evolving focus areas. More recent studies indicate a growing emphasis on blue carbon, machine learning, and remote sensing.

Figure 3 shows the emergence of keywords from 2019 to 2021, illustrating the latest trends in themes and research topics. The trends in keywords for this research theme began to emerge in 2019, with the highest frequency of occurrences in 2020. Meanwhile, research in recent years has increasingly focused on blue carbon, machine learning (ML), and remote sensing in relation to climate change.

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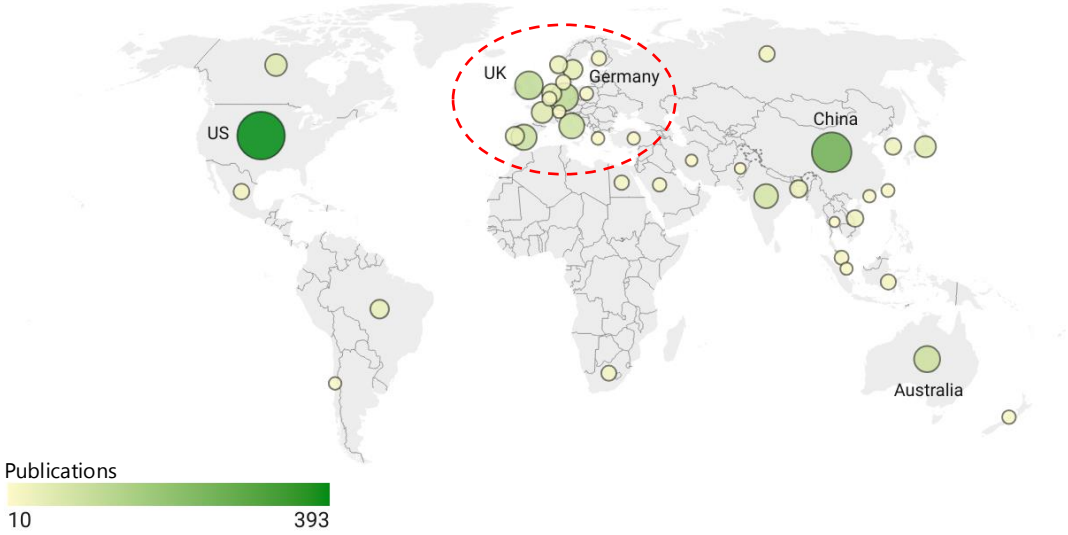

Figure 4. Countries Researching Climate Change in Coastal Areas. Circle size and color intensity represent the number of scientific publications, while the red dashed oval highlights a cluster of active research countries in Western and Central Europe.

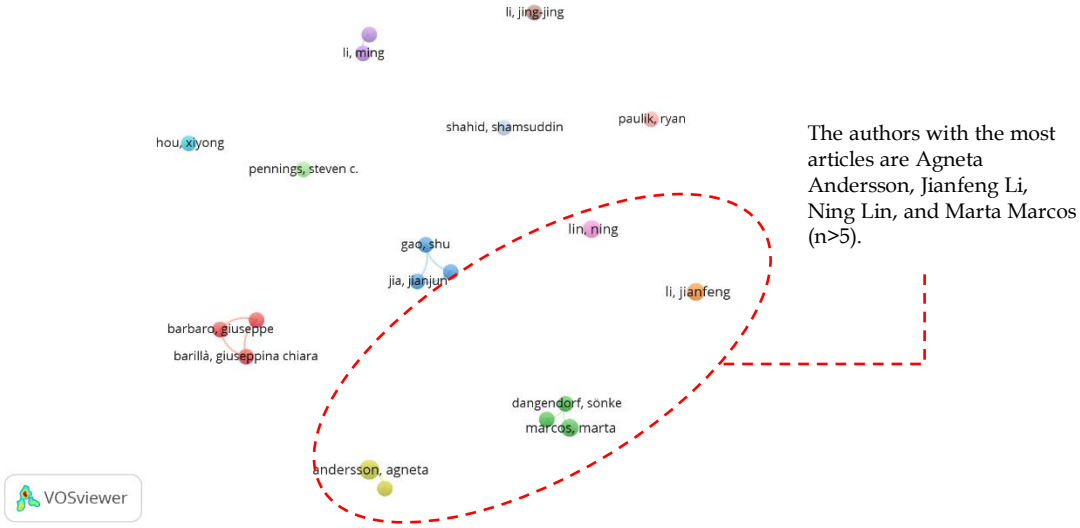

Figure 5. Authors contributing to the research topic. Each node represents an author and proximity indicates collaboration or co-publication. The size of the nodes reflects the number of publications. Highlighted within the red dashed oval are the authors with the highest number of publications (n > 5).

The top five countries with the most publications (>100 articles) on climate change in coastal areas are the United States, China, Germany, the United Kingdom, and Australia (Figure 4). A unique aspect of the data is observed in Germany, as it is a country with a coastline not as long as that of island nations (Bungenstock and Weerts 2012; Rahlf 2016). This indicates that researchers

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from this country are highly focused on the threats of climate change in coastal areas. European countries are quite competitive in conducting research on this topic, especially those from Northern, Western, and Southern Europe. In comparison, Indonesia, the largest archipelagic country (Raharja and Karim 2022), ranks only 22nd in terms of the number of articles contributed. Indonesia's low contribution to climate change research in coastal areas, despite its geographic vulnerability as the world's largest archipelagic state, may be attributed to several interrelated factors. One key limitation is the disparity in research infrastructure and funding availability, particularly when compared to high-income countries. Additionally, many Indonesian scientific publications are disseminated through national journals that are not indexed in major international databases such as Scopus or Web of Science, thereby limiting their visibility and inclusion in bibliometric analyses. Language barriers, limited international collaboration, and challenges in accessing global research networks also contribute to this underrepresentation. As a result, the scientific output from Indonesia may not reflect the full scope of local research efforts, leading to a skewed global research landscape that underrepresents vulnerable regions.

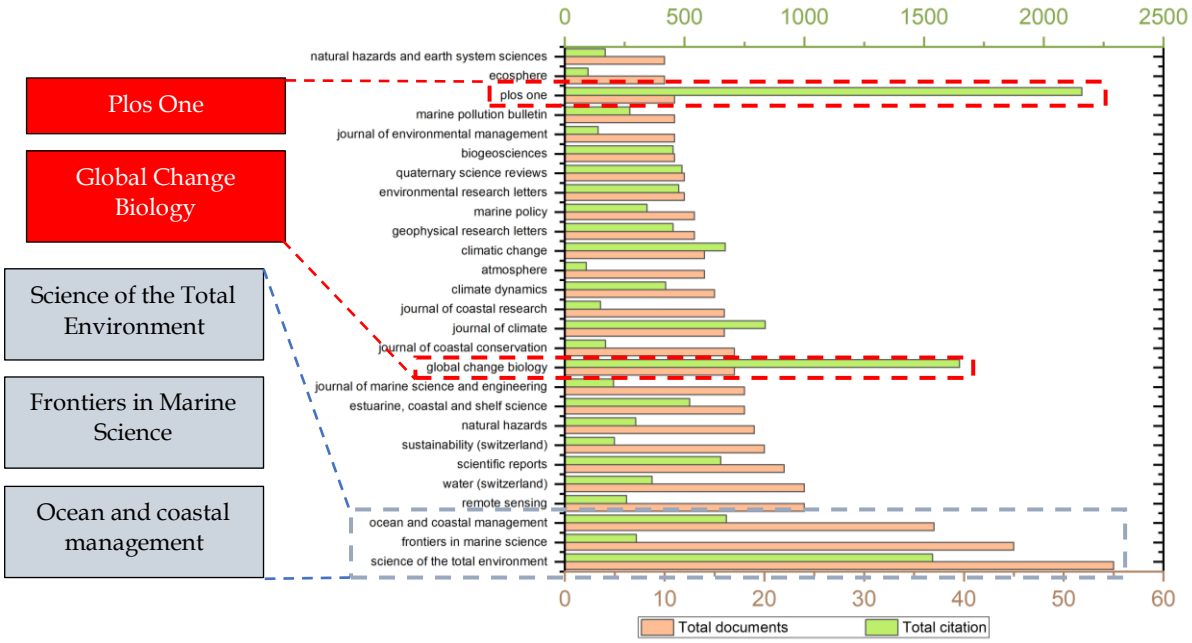

Figure 6. Leading Journals in Climate Change Research. The horizontal bar chart shows the number of total documents (orange bars) and total citations (green bars). The red and blue dashed boxes emphasize high-impact and high-output journals, respectively.

Figures 5 and 6 show the authors and journals that have contributed to the dissemination of knowledge related to the causes of climate change and its impacts on coastal areas, grouped by the number of documents published (Science of the Total Environment, Frontiers in Marine Science, and Ocean and Coastal Management) and the number of citations (PLOS ONE, Global Change Biology, and Science of the Total Environment) by other researchers. While Figure 6 illustrates the volume of publications and citation counts across leading journals, these metrics alone do not fully capture the quality and scholarly impact of each journal. To provide a more comprehensive assessment,

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bibliometric indicators such as the H-index and the Source Normalized Impact per Paper (SNIP) are considered. The H-index reflects both productivity and citation impact over time, while SNIP accounts for field-specific citation behavior, allowing more equitable comparisons across disciplines. Among the journals with the highest number of publications, Science of the Total Environment leads with an H-index of 399 and a SNIP of 1.998, indicating strong influence and cross-disciplinary reach. Frontiers in Marine Science (H-index: 118; SNIP: 0.895) and Ocean and Coastal Management (H-index: 116; SNIP: 1.330) also show consistent contributions, although with more specialized focuses. Regarding citation impact, PLOS ONE demonstrates a high H-index of 467 and SNIP of 1.084, reflecting its broad accessibility and multidisciplinary appeal. Global Change Biology stands out with the highest SNIP value (2.957) among the journals analyzed, alongside a strong H-index of 332, highlighting its relevance in high-impact climate change research. Incorporating these bibliometric indicators enhances the understanding of journal prominence, offering deeper insight into where high-quality research on coastal climate change is being published.

Causes of Climate Change

Building upon the identified global publication trends, the following section delves into the specific causes of climate change as revealed through the analysis of relevant keywords and thematic patterns within the selected studies. Data related to the causes of climate change were obtained through the collection of abstracts from various scientific studies within the research sample. Keywords relevant to the causes of climate change were identified and analyzed to calculate their occurrence percentages in the text. Subsequently, these keywords were classified into five main categories, organized based on the definition and characteristics of each cause. This approach enables a more systematic mapping of the factors contributing to climate change and provides a comprehensive overview of the contribution of each group of causes (Table 1).

Table 1. Causes of Climate Change in Research Abstracts

No	Cluster	Percentage	Causes	Sources
1	Greenhouse Gas Emissions and Air Pollution	29,9	carbon dioxide; methane; greenhouse gases; emission; pollution	(Monforti-Ferrario, Crippa, and Pisoni 2024; Zhi et al. 2024)
2	Energy Use and Natural Resources	35,2	fossil fuels; coal; oil; gas; burning; combustion; energy consumption	(Huang and Ren 2024; Yu-Ke et al. 2022)
3	Land Use Changes and Agriculture	26,7	deforestation; agriculture; land use; urbanization; mining	(Amoakwah et al. 2022; Santos Orozco et al. 2023)
4	Industry and Manufacturing	6,8	industrial; manufacturing	(Avenyo and Tregenna 2022; Shiau et al. 2022)
5	Transportation and Mobility	1,4	transportation	(Pal, Gopal, and Ramkumar 2023; Stevens 2023)

Table 1 presents a quantitative classification of the main causes of climate change based on keyword frequency analysis, identifying five dominant clusters: greenhouse gas emissions and air pollution, energy use and natural resources, land use changes and agriculture, industry and

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manufacturing, and transportation and mobility. Each cluster represents a distinct yet interconnected domain of anthropogenic impact. To complement this categorization, Figure 7 provides a qualitative cause-effect visualization. This diagram translates the clusters into broader thematic domains— Man, Machine, Method, Materials, and Environment —highlighting how specific human activities and systemic factors collectively drive climate change. For instance, the "Energy Use and Natural Resources" cluster aligns with the Machine domain in the diagram, which includes fossil fuel dependency and energy consumption. Similarly, "Land Use Changes and Agriculture" corresponds to both Environment and Man, reflecting land conversion, deforestation, and growing food demands.

Each category encompasses specific factors contributing to the phenomenon of climate change. Factors in the Man category include human activities such as deforestation and population growth, which drive the demand for food and resources. Meanwhile, the Machine category focuses on the reliance on fossil fuels and energy consumption, which are the primary sources of greenhouse gas emissions. The Method category addresses waste management practices and water pollution, while Materials highlights the impact of greenhouse gases and the byproducts of agricultural and industrial activities. Lastly, the Environment category covers changes in land use and the loss of biodiversity. By integrating statistical clustering (Table 1) with conceptual mapping (Figure 7), the study enhances clarity in understanding how different causal domains interrelate and ultimately contribute to climate change impacts in coastal areas.

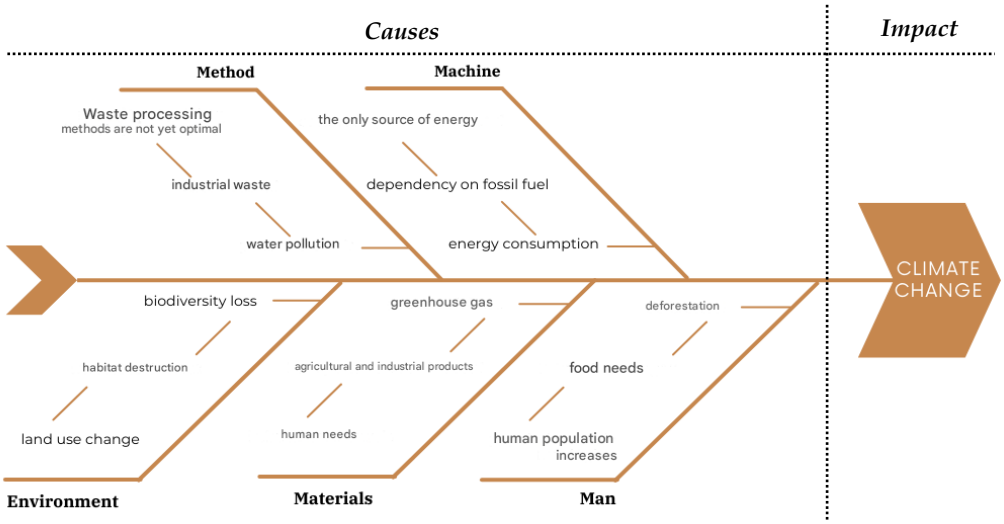

Figure 7. Causes of Climate Change in Coastal Areas (Modified Ishikawa Fishbone Chart). Categorizes the multifaceted causes of climate change affecting coastal areas into five main domains.

Mitigation Efforts in Coastal Areas

Having identified the key causes of climate change in coastal areas, the subsequent section outlines targeted mitigation efforts aimed at addressing these underlying factors. Each mitigation effort is directly linked to specific causal factors identified earlier, ensuring a coherent and targeted response to the drivers of climate change in coastal areas. Based on the identified causes of climate

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change in coastal areas, several preventive strategies and solutions are summarized to address these causes (Table 2). These strategies are categorized into four main groups: Renewable Energy and Technologies, Sustainable Practices and Efficiency, Policy Regulation and Incentives, and Environmental Restoration and Mitigation. In the Renewable Energy and Technologies category, proposed solutions include the use of renewable energy sources such as solar, wind, and geothermal energy, as well as the adoption of electric vehicles. These efforts aim to reduce dependency on fossil fuels, which are the primary contributors to greenhouse gas emissions (Saygin and Gielen 2021). These interventions directly address the over-reliance on fossil fuels and energy-intensive practices identified as major contributors to greenhouse gas emissions. The Sustainable Practices and Efficiency category highlights the importance of sustainable practices, such as energy efficiency, recycling, and resource conservation. The implementation of environmentally friendly technologies and practices can significantly reduce carbon footprints while preserving natural resources (Suresh et al. 2024). Next, the Policy Regulation and Incentives category emphasizes the critical role of government policies in driving change. Policies promoting green energy, incentives for adopting eco-friendly technologies, and strict regulations on industrial emissions are essential components of the transition toward a low-carbon economy (Dou 2015). Additionally Kim et al (2024) highlights how effective government policies have driven China's emergence as a pioneer in the commercialization of lithium-ion batteries for electric vehicles, while also illustrating the success of innovation strategies in accelerating the transition toward green technology. Lastly, the Environmental Restoration and Mitigation category underscores efforts in environmental recovery, such as reforestation and carbon capture initiatives. These measures aim to offset greenhouse gas emissions by enhancing nature's capacity to absorb carbon. Research by Bartolucci et al., (2021) highlights the benefits of restoring farmlands into wetlands, which transform carbon dioxide sources into carbon sinks, thereby reducing greenhouse gas emissions and supporting climate change mitigation efforts. This directly mitigates the environmental degradation and biodiversity loss caused by land use change and deforestation. Overall, the proposed solutions reflect an integrated and reciprocal problem-solving framework, in which each intervention is designed not only to mitigate the impacts of climate change but also to directly confront and reduce the root causes identified in coastal environments.

Table 2. Climate Change Solutions and Mitigation Strategies

Solution	Preventing	Sources
Renewable Energy and Technologies	renewable, solar, wind, geothermal, clean energy, electric vehicles	(Chen, 2024; Choi et al., 2024)
Sustainable Practices and Efficiency	sustainable, energy efficiency, recycling, conservation, green energy	(Chen et al., 2023; Massoud et al., 2023)
Policy, Regulation, and Incentives	green energy policies, eco-tech adoption incentives, industrial emission regulations	(Sentman, Del Percio, and Koerner 2008; Townshend et al. 2013)

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Solution	Preventing	Sources
Environmental Restoration and Mitigation	afforestation, reforestation, mitigation, adaptation, carbon capture	(BenDor, Kwon, and Lester 2023; Pausch et al. 2024)

Recommendations Based on Previous Studies

Building upon the proposed mitigation efforts, the following section presents evidence-based recommendations for future research, derived from the insights gained through the analysis of previous studies on this topic, including:

1. Scientific Knowledge Gaps: Investigate the interactions between climate, rainfall, salinity, and sea-level rise to enhance understanding of global environmental dynamics and support the development of integrated models for predicting coastal ecosystem responses; and examine the relationship between climate variability and hydrometeorological disasters, particularly in coastal zones, to improve scientific forecasting, hazard assessment, and risk modeling efforts.
2. Policy Gaps: Assess the effectiveness of current policies and regulatory frameworks related to aquifer management and coastal resilience in the context of climate change, particularly in low-lying and vulnerable countries; and evaluate how policy instruments can support adaptive capacity in addressing the socio-economic dimensions of climate vulnerability, ensuring that climate action is inclusive and responsive to community-level needs.
3. Technical Implementation Gaps: Promote the integration of GIS and ML technologies in coastal management to enhance data-driven decision-making and improve adaptive responses to coastal erosion and sea-level rise; and expand the use of remote sensing and blue carbon monitoring tools to improve the accuracy of carbon accounting in coastal ecosystems and support scalable climate mitigation strategies through nature-based solutions.

Based on recent bibliometric analyses, research on climate change increasingly focuses on contemporary topics such as blue carbon and remote sensing, as well as the use of machines and software in mitigating climate change impacts. Keyword visualizations indicate that technological advancements are closely tied to climate change, especially in managing emissions and environmental impacts. Globally, the United States, China, Germany, the United Kingdom, and Australia are identified as the top five contributors to research in this field, highlighting the active role of developed nations in tackling the climate crisis. Additionally, experts consistently publish their work in reputable international journals. In terms of causes, greenhouse gas emissions, energy use and natural resources, land use changes and agriculture, industry and manufacturing, and transportation and mobility are identified as the primary drivers of climate change. Among these factors, energy use and natural resource exploitation contribute the most (35.2%), with keywords such as fossil fuel, coal, gas, burning, combustion, and energy consumption being highly relevant to this research. To mitigate climate change, the identified solutions fall into four main strategies. First, adopting renewable energy and environmentally friendly technologies, such as solar power and

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electric vehicles. Second, implementing sustainable practices and energy efficiency in industries and daily life. Third, formulating and enforcing policies, regulations, and incentives that support emission reductions and green energy use. Lastly, emphasizing environmental restoration through reforestation, carbon capture, and adaptive mitigation of climate change impacts. The combination of these solutions is critical to slowing the pace of climate change and ensuring sustainability for future generations.

To enhance the practical value of these recommendations, future research efforts may benefit from adopting a structured conceptual framework that links climate change drivers, system vulnerabilities, and adaptive responses. One such framework could be the DPSIR model (Drivers–Pressures–State–Impact–Response), which provides a holistic approach to understanding environmental problems and informing interventions. This model can help guide the formulation of research questions, facilitate interdisciplinary integration, and connect scientific findings with actionable policies. From a methodological perspective, researchers are encouraged to apply mixed-method approaches that combine bibliometric analysis, geospatial techniques (e.g., GIS, remote sensing), and empirical fieldwork to validate patterns observed in large datasets. The integration of scenario-based modeling and stakeholder engagement methods can also support the development of more context-sensitive and implementable climate adaptation strategies in coastal areas. Using these methodological tools will enable a more comprehensive and grounded understanding of the complex interactions between climate systems, ecosystems, and human communities.

CONCLUSION

Based on the results of this study, it can be concluded that climate change is influenced by several key factors, including greenhouse gas emissions, energy use and natural resource exploitation, land use changes, industrial activities, and transportation. Among these factors, energy use and natural resource exploitation contribute the most, accounting for 35.2% of the total impact. This research also highlights the significant role of blue carbon and remote sensing in climate change mitigation. Developed countries such as the United States, China, Germany, the United Kingdom, and Australia are the primary contributors to climate change research. Leading authors in this field, such as Agneta Andersson, Jianfeng Li, Ning Lin, and Marta Marcos, have enriched the scientific literature with numerous impactful articles. In terms of methodological contribution, this study employs a bibliometric approach, which enables a systematic and quantitative mapping of the scientific landscape related to climate change in coastal areas. Unlike traditional review methods, bibliometric analysis uncovers patterns of authorship, collaboration, and thematic trends over time, offering a macroscopic perspective that supports evidence-based decision-making in climate-related research and policy formulation. To address the challenges of climate change, effective solutions include adopting renewable energy, implementing sustainable practices, developing supportive

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policies and regulations, and undertaking environmental restoration efforts. The implementation of these strategies is expected to significantly minimize the impacts of climate change while promoting sustainability for the future.

However, while these strategies offer promising pathways for climate action, it is also important to recognize the limitations inherent in the present study. Despite providing valuable insights into the causes and solutions for climate change, this study has several limitations. First, it is bibliometric in nature, meaning that its findings heavily rely on data available in scientific publications. As a result, countries with high scientific publication rates are better represented, while contributions from developing countries may be inadequately captured. This imbalance may skew the global perspective and reduce the generalizability of the conclusions drawn. It potentially overlooks locally specific climate challenges and innovative adaptation strategies emerging in underrepresented regions, thereby highlighting the need for more inclusive and regionally sensitive research frameworks. Second, although blue carbon and remote sensing are prioritized, practical applications and the effectiveness of these technologies in global climate change mitigation remain limited. The study does not fully explore the causal relationships between climate change drivers and their impacts, making it difficult to measure the individual contributions of each factor. A more in-depth analysis is needed to understand the interactions among interrelated factors, such as energy use, policies, and industrial impacts. Another limitation is the lack of empirical data on the effectiveness of proposed solutions, particularly regarding the implementation of policies and eco-friendly technologies across different countries. Further research is required to address these gaps, including more contextual and field-based studies to validate findings comprehensively.

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