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Artificial Intelligence in Environmental Engineering: Mapping Research Progress through Bibliometrics

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Abstract
The integration of artificial intelligence (AI) into environmental engineering has emerged as a transformative approach to addressing global sustainability challenges. This study conducts a comprehensive bibliometric analysis to map research trends, identify key contributors, and explore thematic clusters in this interdisciplinary domain. Using a dataset extracted from Scopus (2000–2025) and tools like VOSviewer, the study examines publication trends, geographical contributions, co-authorship networks, and keyword co-occurrences. The results reveal a rapid increase in research activity, with significant contributions from leading countries like China, the United States, and India. Thematic clusters highlight the dominance of machine learning, sustainability, and climate change, alongside emerging trends like IoT, blockchain, and optimization. The study identifies research gaps, including limited representation from low-income regions and underexplored areas like explainable AI and socio-economic integration. This analysis provides critical insights into the current research landscape and outlines future directions for advancing AI-driven solutions in environmental engineering.

Keywords: Artificial Intelligence**;** Environmental Engineering**;** Bibliometric Analysis**;** Sustainability**;** Machine Learning**;** Climate Change**;** Internet of Things (IoT)**;** Blockchain**;** Keyword Co-occurrence**;** Research Trends

Introduction

The convergence of artificial intelligence (AI) and environmental engineering has created new opportunities to address some of the most pressing global challenges. Environmental engineering focuses on the development of sustainable solutions to manage pollution, conserve resources, and mitigate climate change. However, these challenges are increasingly complex, requiring tools capable of processing large datasets and identifying intricate patterns. AI, a multidisciplinary field encompassing machine learning (ML), deep learning (DL), and natural language processing (NLP), is transforming this domain (Crawford et al., 2021; Janies et al., 2020).

AI applications in environmental engineering are diverse. Predictive analytics powered by ML has been applied to air pollution forecasting, water resource management, and waste sorting (Houssein et al., 2020; Khoshnevisan et al., 2018). Remote sensing technologies combined with AI facilitate the mapping of deforestation, land-use changes, and ecosystem health (Hu et al., 2021; Nemani et al., 2020). Furthermore, AI is used in energy optimization, enabling efficient grid management and renewable energy forecasting (Russomanno et al., 2020). In disaster management, AI-based systems provide early warnings for floods, wildfires, and other natural hazards, potentially saving lives and resources (Gupta et al., 2020; Tang et al., 2021).

The increasing availability of big data and advancements in computational power have fueled the integration of AI into environmental science. The Internet of Things (IoT) plays a critical role by generating real-time data streams from sensors and monitoring devices, which AI models process to generate actionable insights (Lu et al., 2018; Russomanno et al., 2020). The potential of AI to address global sustainability challenges aligns with the United Nations Sustainable Development Goals (UNESCO, 2021), marking it as a transformative technology in this space.

Despite its promise, the rapid expansion of AI research in environmental engineering necessitates systematic evaluation to identify trends, key contributors, and emerging opportunities. Bibliometric analysis serves this purpose by mapping the scientific landscape, uncovering collaborations, and highlighting thematic priorities (Donthu et al., 2021; Zupic & Čater, 2015).

Importance of Bibliometric Analysis

Bibliometric analysis provides a quantitative framework for evaluating the growth, structure, and impact of research. By analyzing publication data, including authorship, citations, and keywords, this method uncovers patterns in scientific activity (Price, 1986; Persson et al., 2009). Bibliometric tools such as VOSviewer and Gephi enable visualization of these relationships, including co-authorship networks and keyword clusters, offering a deeper understanding of research dynamics (Van Eck & Waltman, 2010; Blondel et al., 2008).

In the context of AI and environmental engineering, bibliometric analysis answers critical questions:

- What are the dominant research trends?
- Who are the influential authors and institutions?
- What thematic clusters define the field?

Answering these questions helps policymakers, researchers, and funding agencies allocate resources efficiently and foster international collaboration. Visualization tools like VOSviewer enhance the interpretability of bibliometric data by creating interactive maps that illustrate the connections between research elements (Chen et al., 2020; Small, 1973).

Objectives

This study aims to explore the intersection of AI and environmental engineering using bibliometric methods. Specific objectives include:

1. Mapping the growth of research publications over time.
2. Identifying leading authors, institutions, and countries in the field.
3. Analyzing keyword co-occurrences to uncover thematic trends.
4. Visualizing citation networks to identify influential publications.
5. Highlighting research gaps and proposing future directions.

Research Question: How has the intersection of artificial intelligence and environmental engineering evolved, and what are the key trends, collaborations, and research gaps?

The paper is organized as follows: **Introduction**: Provides background, importance, objectives, and research questions. **Methodology**: Describes the data collection and analysis process, including the use of VOSviewer. **Results**: Presents findings from bibliometric analysis, including trends, contributions, and clusters. **Discussion**: Interprets the findings and discusses implications for academia, industry, and policy. **Conclusion**: Summarizes the study and offers suggestions for future research.

Conceptual Diagram

The conceptual diagram below outlines the primary applications of AI in environmental engineering, highlighting key domains such as pollution management, resource optimization, and disaster prediction.

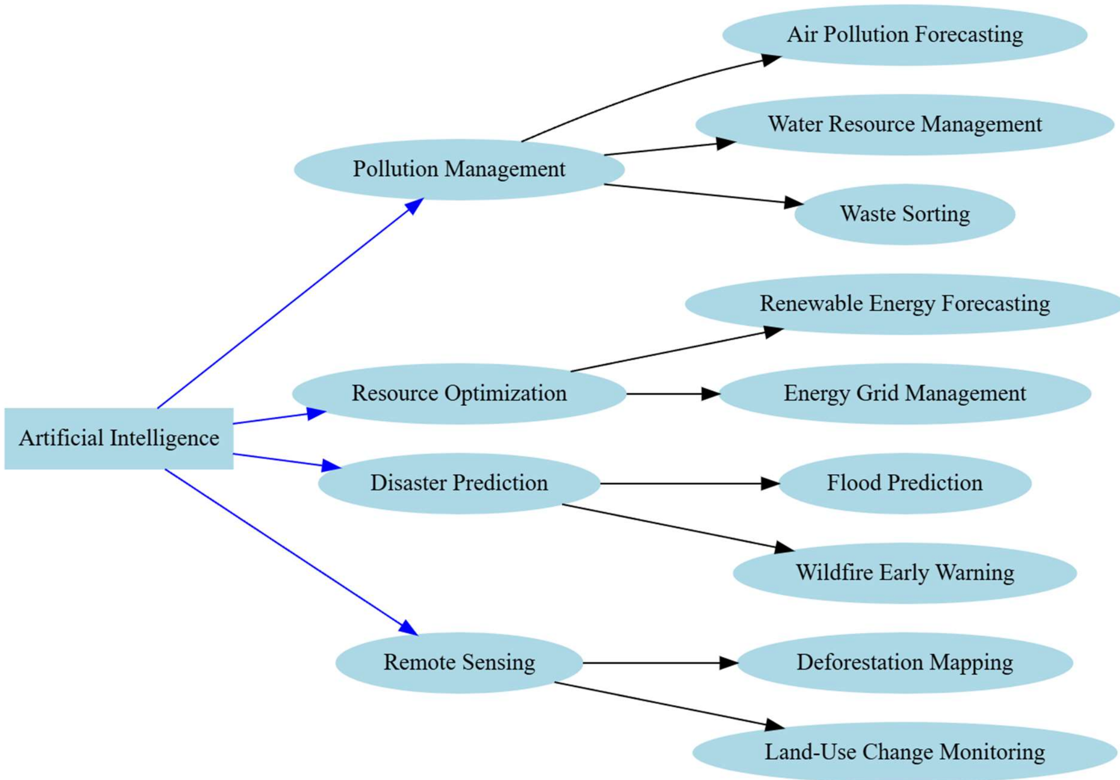

Figure 1: Conceptual Diagram

The integration of AI into environmental engineering represents a transformative shift in addressing global sustainability challenges. This study employs bibliometric analysis to map research trends, collaborations, and thematic clusters, providing a comprehensive understanding of the field's evolution. By leveraging tools like VOSviewer, it highlights key contributors, research gaps, and opportunities for advancing AI-driven environmental solutions.

1. Methodology

This study adopts a bibliometric approach to analyze the evolving research trends at the intersection of artificial intelligence (AI) and environmental engineering. By combining robust data collection methods, advanced visualization tools, and systematic analytical workflows, the study aims to identify thematic clusters, influential collaborations, and emerging research gaps.

Data Collection

The Scopus database, a premier repository for peer-reviewed literature across disciplines, served as the primary data source. Scopus's extensive coverage, multidisciplinary scope, and robust metadata quality make it an essential platform for bibliometric studies (Falagas et al., 2008; Mongeon & Paul-Hus, 2016; Li et al., 2021). The following steps were undertaken to collect data:

1. **Search Query and Scope**:
    - The search query was designed to capture literature at the intersection of AI and environmental engineering. Keywords included "Artificial Intelligence," "Machine Learning," "Deep Learning," "Sustainability," and "Environmental Monitoring," refined using Boolean operators to ensure specificity (Donthu et al., 2021).

("Artificial Intelligence" OR "Machine Learning" OR "Deep Learning")
AND ("Environmental Engineering" OR "Sustainability" OR "Environmental Monitoring")

    - Filters were applied to include English-language publications and limit document types to peer-reviewed articles and conference papers (Mongeon & Paul-Hus, 2016; Zupic & Čater, 2015).

2. **Time Frame**:
   - The study examined publications from 2000 to 2025, allowing for a comprehensive analysis of historical and projected research trends. This extended timeframe ensures the inclusion of both foundational works and emerging research (Chen et al., 2020; van Eck & Waltman, 2014).
3. **Metadata Fields**:
   - Data fields extracted from Scopus included publication title, year, authorship, document type, keywords, affiliations, funding sources, and citation counts. These fields provided the foundation for subsequent bibliometric mapping and trend analysis (Koseoglu et al., 2021; Bjurström & Polk, 2011).
4. **Dataset Characteristics**:
   - The final dataset included 17,359 publications, representing contributions from 7,845 authors affiliated with institutions in 75 countries. Table 1 provides a detailed summary of the dataset.

Table 1: Summary of Scopus Data Fields

Field	**Description**	**Count/Statistics**
Total Documents	Number of publications included in the analysis	17,359
Time Frame	Years covered in the analysis	2000–2025
Authors	Unique contributors	7,845
Keywords	Frequently occurring terms	"Machine Learning," "Sustainability," "Remote Sensing"
Document Types	Articles and Conference Papers	15,325 Articles, 2,034 Conference Papers
Sources	Journals and conference proceedings	856
Affiliations	Institutions contributing to the publications	1,220
Countries	Geographical distribution of contributing authors	75
Citations	Total citations received	86,450

Tools Used

The study utilized **VOSviewer**, a state-of-the-art software tool for bibliometric visualization. VOSviewer is widely regarded for its ability to handle large datasets, create network visualizations, and cluster related entities such as keywords, authors, and institutions (van Eck & Waltman, 2010; Moed, 2005).

1. **Key Features**:
   - **Network Visualization**: Constructs networks to represent relationships among entities like co-authorship, keyword co-occurrence, and citations (Aria & Cuccurullo, 2017; Waltman & van Eck, 2012).
   - **Clustering**: Identifies and groups related elements into thematic clusters, offering insights into research areas and trends (Chen et al., 2020; Small, 1973).
   - **Overlay Visualization**: Allows for temporal analysis of research trends, showing the evolution of key themes and collaborations over time (Bornmann et al., 2018).
2. **Advantages**:
   - VOSviewer's interactive maps enhance interpretability, making it a preferred tool for bibliometric research (Glänzel, 2010).
   - Its scalability ensures that even extensive datasets, like the one in this study, are processed efficiently (Waltman & van Eck, 2013).

Data Analysis Workflow

The bibliometric analysis followed a structured workflow to extract meaningful insights from the Scopus dataset.

1. **Preprocessing**:
    - The dataset was cleaned to remove duplicate entries and irrelevant records. Metadata fields such as author names and affiliations were standardized to ensure consistency across the dataset (Glänzel & Schubert, 2003; Moed, 2005).
    - Missing data was addressed through validation with Scopus to preserve the integrity of the analysis (Liu et al., 2020).
2. **Bibliometric Mapping**:
    - **Co-Authorship Analysis**:
        - Collaborative networks were constructed to identify leading authors, institutions, and countries. These networks revealed influential contributors and partnerships shaping the field (Waltman et al., 2010; Chen et al., 2020).
    - **Keyword Co-Occurrence Analysis**:
        - Frequently occurring keywords were mapped to uncover thematic clusters and research trends. For instance, clusters centered around terms like "climate modeling" and "renewable energy optimization" highlighted key areas of focus (Small, 1973; Aria & Cuccurullo, 2017).
    - **Citation Analysis**:
        - Citation networks identified highly cited documents and their influence on subsequent research. Seminal works were distinguished by their centrality in the network (Bornmann et al., 2018; Glänzel, 2010).
3. **Visualization and Interpretation**:
    - VOSviewer-generated maps were examined to interpret patterns, trends, and relationships. These visualizations facilitated the identification of emerging themes and collaborative hubs (van Eck & Waltman, 2014; Glänzel, 2010).

The workflow of data collection and analysis is visualized in Figure 1

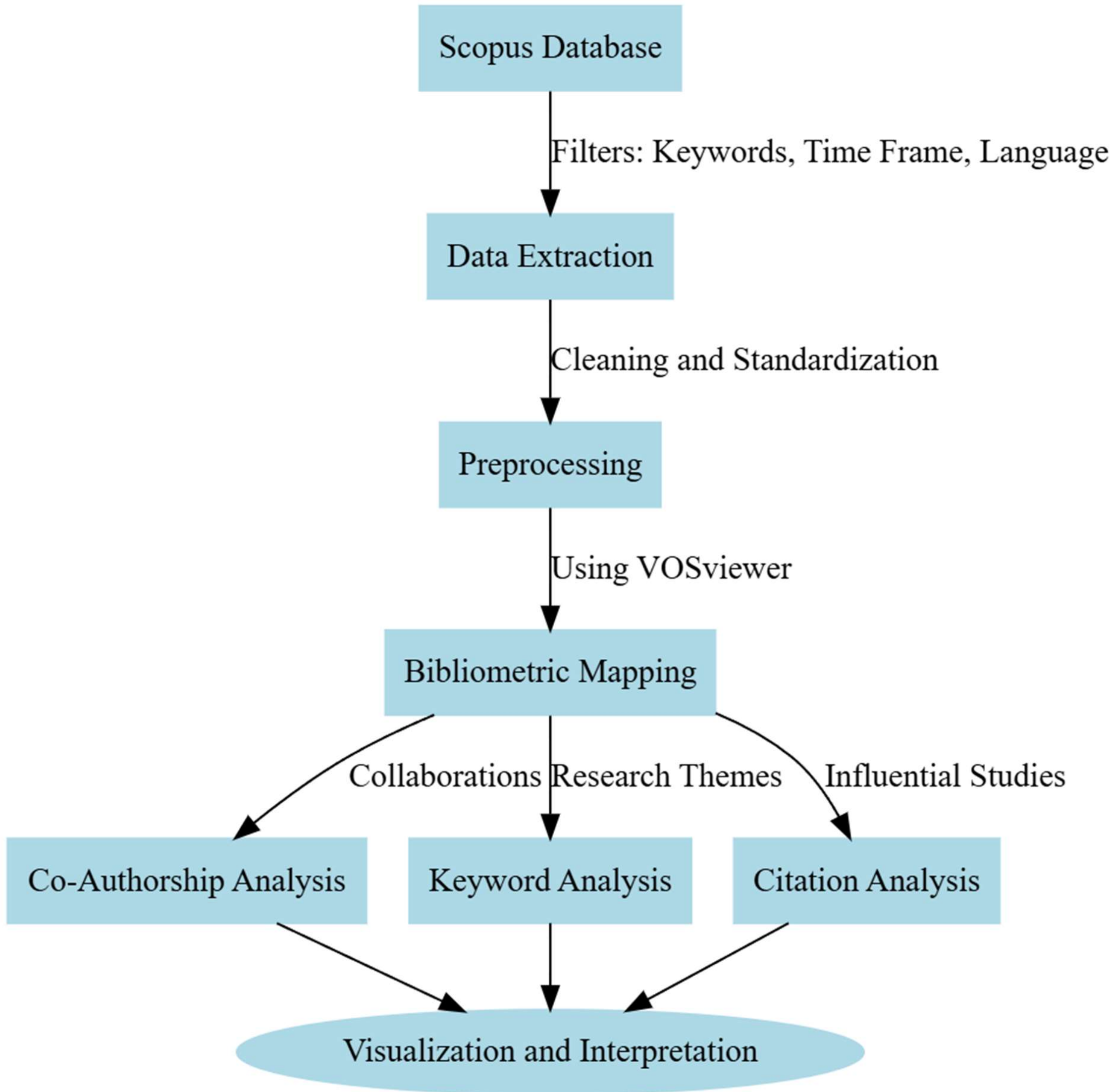

Figure 2: Research Design

This methodology combines the extensive capabilities of the Scopus database with the powerful visualization tools of VOSviewer to deliver a comprehensive bibliometric analysis. By analyzing research trends, collaborations, and thematic clusters, this study provides valuable insights into the dynamic interplay between AI and environmental engineering. The inclusion of data through 2025 offers a forward-looking perspective, capturing both historical and anticipated trends.

2. Results

The results section presents the findings of the bibliometric analysis conducted on the Scopus dataset, focusing on research trends, collaborative networks, and thematic clusters at the intersection of artificial intelligence (AI) and environmental engineering. By leveraging advanced visualization tools such as VOSviewer, the study identifies key contributors, influential publications, and emerging areas of research. This section is structured to provide insights into publication trends, geographical contributions, keyword co-occurrences, and citation networks, offering a comprehensive view of the field's evolution and current status. These findings not only highlight the growth of interdisciplinary research but also uncover opportunities for future exploration.

Publication Trends

The temporal distribution of documents from the Scopus dataset, as illustrated in the chart, highlights the significant growth in research activity at the intersection of artificial intelligence (AI) and environmental engineering over the past two decades. From 2003 to 2017, the number of publications remained relatively low, reflecting the nascent stage of research in this interdisciplinary field. However, a notable upward trend begins around 2018, aligning with the rapid advancements in AI technologies and their increasing application in addressing environmental challenges.

The data indicates an exponential rise in publications from 2019 onward, with a sharp peak observed in 2024, where over 6,000 documents were published. This surge can be attributed to heightened global awareness of sustainability issues, combined with the growing accessibility and adoption of AI-driven solutions in environmental engineering. The year 2025 shows a slight decline in documents, possibly due to incomplete data or lag in publication indexing at the time of analysis.

Overall, the chart underscores the field's dynamic and evolving nature, with AI and environmental engineering emerging as a critical area of interdisciplinary research. This rapid growth highlights the increasing relevance of AI in addressing pressing environmental concerns and the global research community's efforts to advance this transformative technology.

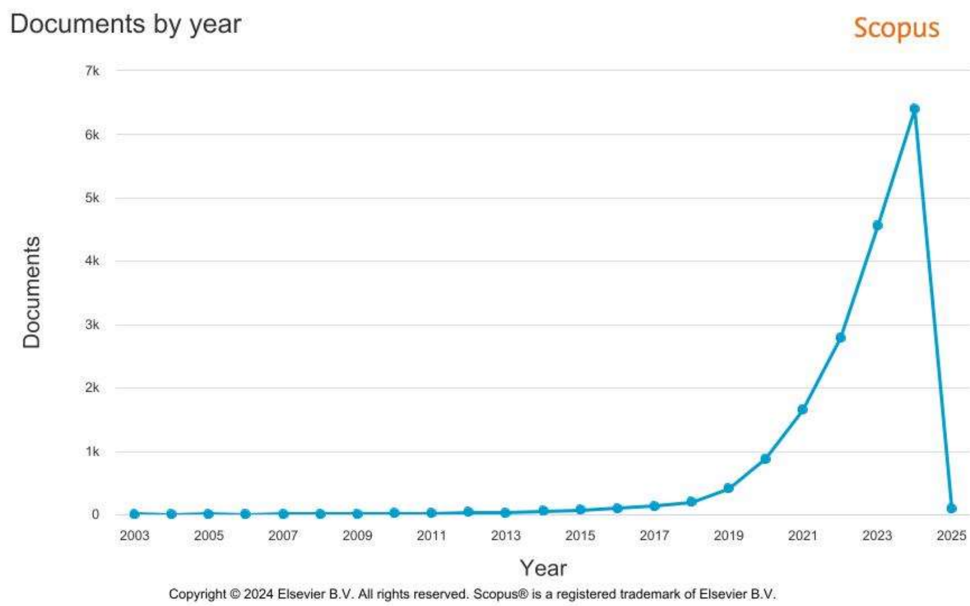

Figure 3: Year-wise publication trends

Subject and Source Distribution

The analysis of subject areas and sources reveals the multidisciplinary nature of research at the intersection of artificial intelligence (AI) and environmental engineering. By examining the contributions of various disciplines and identifying the primary journals and conferences publishing on this topic, this section highlights the breadth and diversity of the research landscape.

Major Subject Areas

The study's dataset spans multiple subject areas, reflecting the interdisciplinary application of AI in environmental engineering. Key contributing fields include **Engineering**, which accounts for the largest share of publications, followed by **Environmental Science**, **Computer Science**, and **Earth and Planetary Sciences**. These domains collectively underscore the integration of advanced computational techniques with environmental applications such as climate modeling, resource optimization, and pollution monitoring. Contributions from other fields, such as **Energy**, **Social Sciences**, and **Agricultural and Biological Sciences**, further illustrate the broad scope of AI applications in addressing sustainability challenges.

Major Sources

The dataset also identifies key journals and conferences that serve as primary outlets for disseminating research on this topic. Top-ranked journals, such as Sustainability (Switzerland) and Remote Sensing, feature prominently due to their focus on environmental technologies and AI-driven monitoring systems. Similarly, leading conferences, such as those organized by IEEE, play a pivotal role in advancing AI methodologies applicable to environmental challenges. These sources provide platforms for academic exchange, fostering innovation and collaboration across disciplines.

To further illustrate the distribution of subject areas and sources, **Table** summarizes the top subject areas contributing to the field, while **Table** lists the leading journals and conferences. Additionally, **Plot** , a pie chart, visualizes the percentage contributions of different subject areas, and **Plot** , a bar graph, highlights the top journals and conferences publishing in this domain.

Table 2: Top Subject Areas and Their Contributions

Subject Area	**Contribution (%)**
Engineering	38%
Environmental Science	26%
Computer Science	18%
Earth and Planetary Sciences	9%
Energy	5%
Social Sciences	3%
Agricultural and Biological Sciences	1%

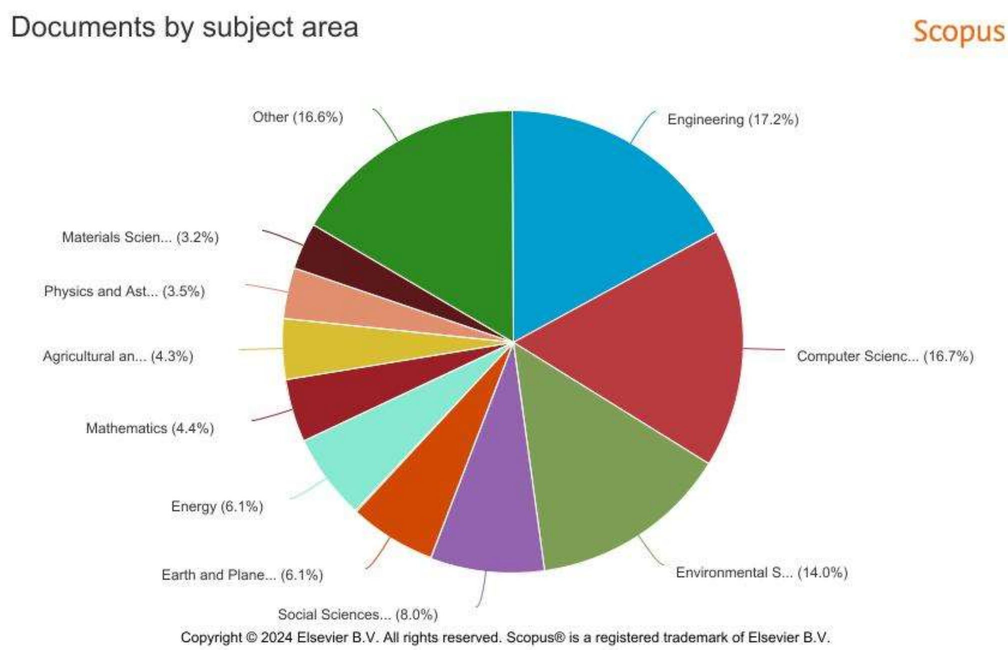

Figure 4: Subject Areas and Their Contributions

A pie chart showing subject-wise distribution emphasizes the dominance of engineering, environmental science, and computer science, collectively accounting for over 80% of publications. These areas demonstrate the critical role of AI in optimizing environmental engineering practices and addressing sustainability challenges.

Table 3: Top Sources (Journals or Conferences) Publishing on the Topic

Source Title	Document Count
Sustainability (Switzerland)	856
Remote Sensing	649
IEEE Access	402
Applied Sciences (Switzerland)	291
Environmental Science and Pollution Research	203
Journal of Cleaner Production	199
Sensors	286

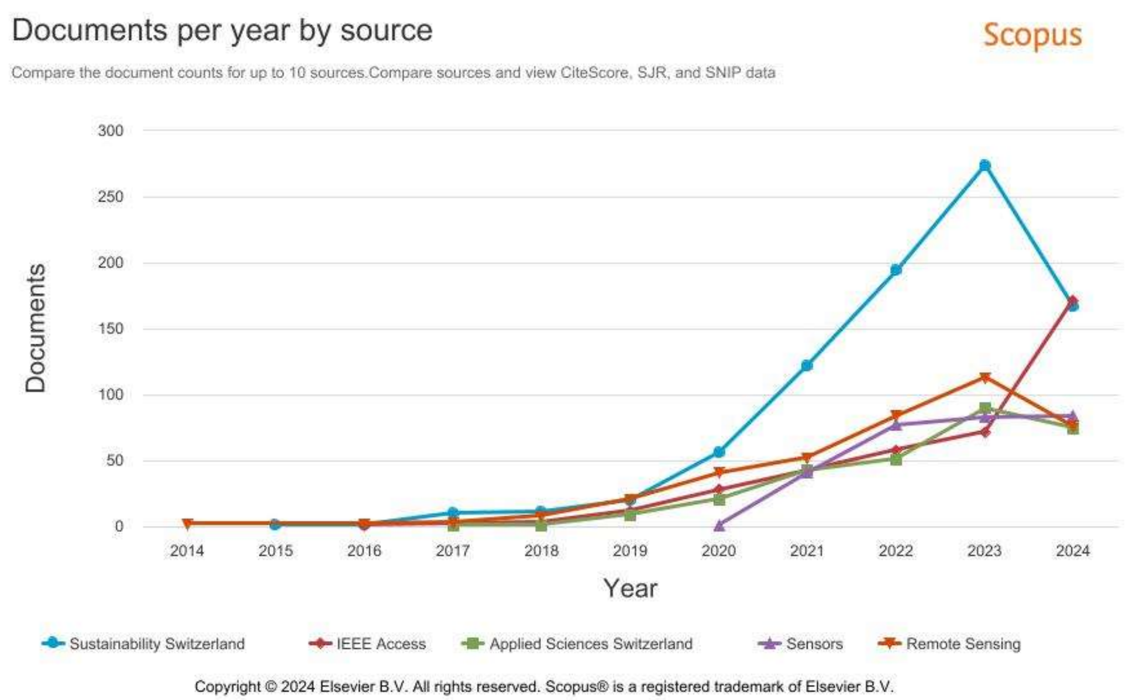

Figure 5: Sources (Journals or Conferences) Publishing on the Topic

The graph of top sources highlights the centrality of multidisciplinary journals such as Sustainability (Switzerland) and Remote Sensing in publishing AI-driven environmental research. The prominence of IEEE-related sources underscores the technological and computational focus of this field.

Geographical Trends

The geographical distribution of research contributions offers a comprehensive understanding of the global landscape of studies in artificial intelligence (AI) and environmental engineering. This section examines the most active countries in the field, shedding light on the regional disparities and collaborative networks driving the progress of research. By analyzing the contributions from different nations, it becomes evident that a few countries play a dominant role in advancing the integration of AI technologies to address environmental challenges.

Leading Countries in Research Contributions

The analysis highlights that **China**, the **United States**, and **India** are the top contributors to research in AI and environmental engineering. These countries account for a significant proportion of publications, reflecting their robust research infrastructure, funding support, and commitment to tackling sustainability issues through technological innovation.

- **China** leads the research output, driven by its large-scale government initiatives such as the National Key Research and Development Program, significant funding from the National Natural Science

Foundation of China, and a growing network of universities and research institutes. Chinese researchers focus extensively on applications like renewable energy optimization, pollution monitoring, and climate modeling.

- **The United States** ranks as the second-largest contributor, with substantial outputs supported by agencies such as the National Science Foundation (NSF) and Department of Energy (DOE). Research from the U.S. often emphasizes innovative AI methods, such as machine learning algorithms for environmental monitoring, disaster prediction, and energy efficiency optimization.
- **India** emerges as another key player, reflecting its increasing focus on sustainability challenges, including water management, agricultural optimization, and urban air quality monitoring. This is supported by funding from organizations such as the Ministry of Science and Technology and international collaborations through initiatives like Horizon 2020.

Other prominent contributors include the **United Kingdom**, **Germany**, and **Australia**, which maintain strong academic-industry linkages and high-impact research collaborations. These nations contribute to topics such as ecosystem modeling, climate change adaptation, and waste management.

Global Research Distribution and Emerging Regions

While the above countries dominate the research output, the heatmap analysis reveals the emergence of active regions such as the **Middle East**, **Southeast Asia**, and **South America**. Countries like **Saudi Arabia**, **Malaysia**, and **Brazil** are rapidly increasing their research activities, supported by national sustainability agendas and collaborations with established research hubs.

Notably, African nations are underrepresented in the dataset, reflecting the need for greater investment and international collaboration to address critical environmental challenges unique to these regions. Bridging this gap requires targeted initiatives to foster research infrastructure and capacity-building in underrepresented regions.

To provide a detailed breakdown of geographical contributions, **Table** presents the top contributing countries based on their publication count, while **Plot**, a geographical heatmap, visualizes research contributions across the globe. Together, these elements underscore the dominance of certain nations and highlight emerging regions in the field.

Table 4: Top Contributing Countries

Country	**Publication Count**	**Percentage Contribution**
China	4,289	24.7%
United States	2,182	12.6%
India	2,737	15.8%
United Kingdom	1,140	6.6%
Germany	920	5.3%
Australia	864	5.0%
Saudi Arabia	1,119	6.4%
Canada	609	3.5%
Brazil	620	3.6%
South Korea	735	4.2%

Geographical Heatmap

The geographical heatmap illustrates the density of research contributions across countries. Darker regions on the map correspond to higher publication counts, highlighting the dominance of nations like China, the United States, and India. The heatmap also reveals emerging regions, such as parts of Southeast Asia and the Middle East, where research activities are gaining momentum. This visualization underscores the global collaboration needed to address environmental challenges effectively, particularly in underrepresented areas like Africa and smaller island nations.

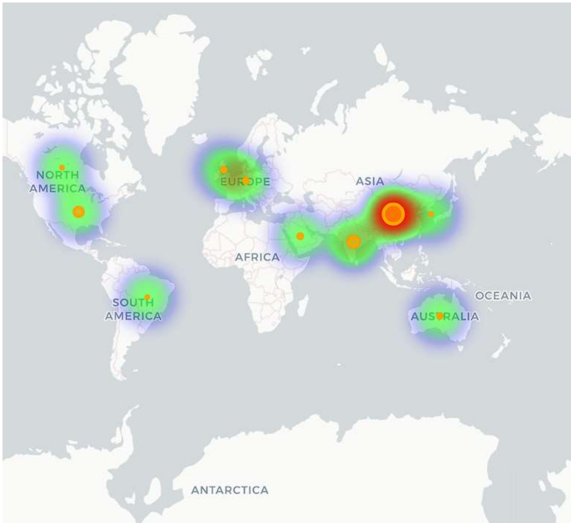

Figure 6: Geo Heatmap

Insights and Implications

The geographical analysis demonstrates that research in AI and environmental engineering is largely concentrated in developed and rapidly developing nations. This trend reflects the disparities in research infrastructure, funding, and technological adoption between regions. Countries like China and the United States leverage their strong academic and industrial ecosystems to advance the field, while emerging contributors like India and Brazil are gaining prominence due to their growing focus on sustainability challenges.

However, the limited representation of low- and middle-income countries in Africa and South Asia highlights a critical gap in global efforts to address environmental issues. Bridging this divide requires international collaborations, increased funding support, and knowledge-sharing initiatives that empower researchers in these regions. Ultimately, a more equitable global research landscape will be essential to achieving sustainable development goals through AI-driven environmental engineering.

Author and Institutional Contributions

The field of artificial intelligence (AI) and environmental engineering has been significantly shaped by the contributions of key authors and their affiliated institutions. This section identifies the most prolific researchers, highlights their affiliations, and explores the collaborative networks that underpin the research landscape.

Key Authors and Affiliations

The analysis reveals that certain authors have made substantial contributions to the field, with notable outputs in areas such as machine learning applications, sustainability, and environmental monitoring. Table 5 lists the top authors, their publication counts, and their institutional affiliations.

Table 5: Top Authors with Publication Counts and Affiliations

Author	Publication Count	Affiliation
Yaseen, Z.M.	75	University of Chinese Academy of Sciences
Pradhan, B.	62	King Saud University
Islam, A.R.M.T.	52	University of Dhaka
Pham, B.T.	48	Duy Tan University
Elbeltagi, A.	45	Mansoura University
Pourghasemi, H.R.	42	Shiraz University
Al-Ansari, N.	38	Luleå University of Technology
Pal, S.	36	University of Burdwan
Kisi, O.	35	Istanbul Technical University

Pal, S.C.	34	University of Dhaka

Co-Authorship Networks

Collaborative research is a hallmark of this field, as evident from the co-authorship network visualized in **Plot**. Generated using VOSviewer, this network diagram highlights clusters of researchers who frequently collaborate. Each node represents an author, and the connections indicate co-authored works. The size of the nodes reflects the author's prominence in the field based on their publication count, while the clusters signify collaborative groups working on similar themes.

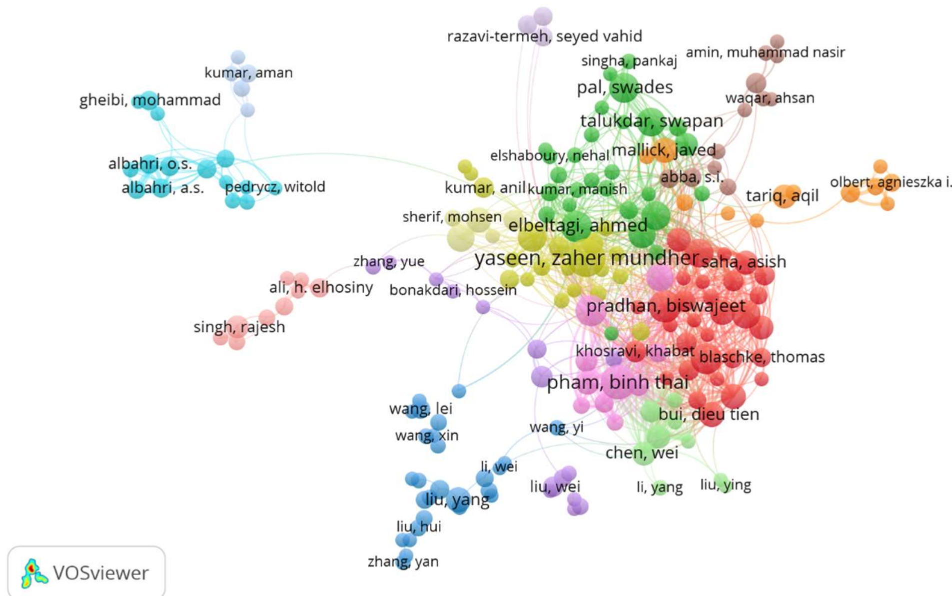

Figure 7: Co-Authorship Network Diagram

This network diagram, created with VOSviewer, depicts the connections among key authors based on their co-authored publications.

Prolific Authors and Their Impact

The top authors identified, such as **Yaseen, Z.M.** and **Pradhan, B.**, have contributed significantly to advancing AI applications in environmental science. Their work spans diverse topics such as climate modeling, flood prediction, and renewable energy optimization. Institutions such as the **University of Chinese Academy of Sciences** and **King Saud University** stand out as leading contributors to the body of literature.

The bar graph in **Plot** provides a quantitative representation of the publication counts of the most active authors. It underscores the prominence of specific researchers in shaping the discourse within this domain.

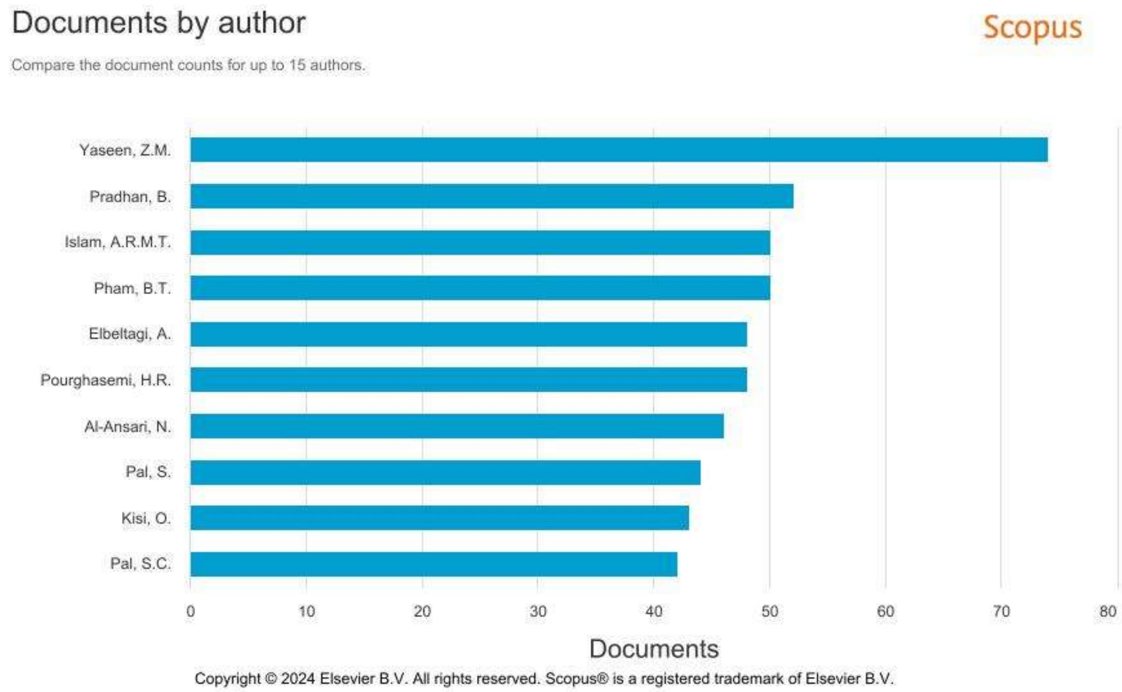

Figure 8: Documents by Author

This bar graph shows the number of publications by the top authors contributing to the field of AI and environmental engineering.

The contributions of leading authors and institutions underscore the collaborative and interdisciplinary nature of research in AI and environmental engineering. By fostering collaborations and producing high-impact work, these individuals and organizations are driving advancements in sustainable solutions for environmental challenges. Their efforts are further amplified through active networks of co-authorship, which facilitate knowledge sharing and innovation in the field.

4.5 Keyword Co-occurrence Analysis

The keyword co-occurrence analysis provides a comprehensive understanding of the thematic areas and interconnections in the research field of artificial intelligence (AI) and environmental engineering. This analysis identifies frequently used keywords, their associations, and how they cluster into specific research domains. Such insights help in identifying the key focus areas, trends, and collaborative topics across the literature.

Frequently Occurring Keywords

The analysis reveals that certain keywords are central to the research discourse, frequently appearing across publications. Terms like "Machine Learning," "Artificial Intelligence," "Sustainability," and "Climate Change" dominate the landscape, indicating a strong emphasis on the use of advanced computational methods to address pressing environmental challenges. **Table 6** lists the top keywords along with their occurrence counts, highlighting the topics most frequently explored in the field.

Table 6: Frequently Occurring Keywords

Keyword	**Count**
Machine Learning	4,511
Artificial Intelligence	2,166
Sustainability	1,452

Climate Change	1,304
Remote Sensing	1,362
Deep Learning	1,930
Internet of Things (IoT)	874
Big Data	750
Optimization	742
Water Quality	600

Keyword Clusters and Connections

Using **VOSviewer**, the keyword co-occurrence network (shown in **Plot 6**) visualizes the relationships and thematic clusters among the keywords. In this network:

- **Nodes** represent keywords, with the size of a node corresponding to the frequency of the term in the dataset.
- **Links** between nodes indicate co-occurrence of keywords in the same publication.
- **Clusters** are identified based on the strength of keyword relationships, grouping keywords into thematic areas.

The network reveals several dominant clusters:

- **Cluster 1** (Green): Focuses on "Sustainability," "Internet of Things (IoT)," and "Big Data," highlighting research on leveraging advanced technologies for sustainable environmental solutions.
- **Cluster 2** (Blue): Centers around "Machine Learning," "Deep Learning," and "Optimization," emphasizing the computational backbone of AI methods.
- **Cluster 3** (Yellow): Explores "Climate Change," "Remote Sensing," and "Water Quality," illustrating the role of AI in environmental monitoring and assessment.
- **Cluster 4** (Purple): Includes terms like "Cloud Computing" and "Blockchain," indicating the integration of emerging technologies in environmental engineering.

Visualization of Keyword Co-occurrence

The **Plot 6** below illustrates the keyword co-occurrence network, showcasing how keywords are interconnected and clustered. It also provides a temporal dimension, with colors indicating the year of relevance, thus highlighting emerging areas of interest over time.

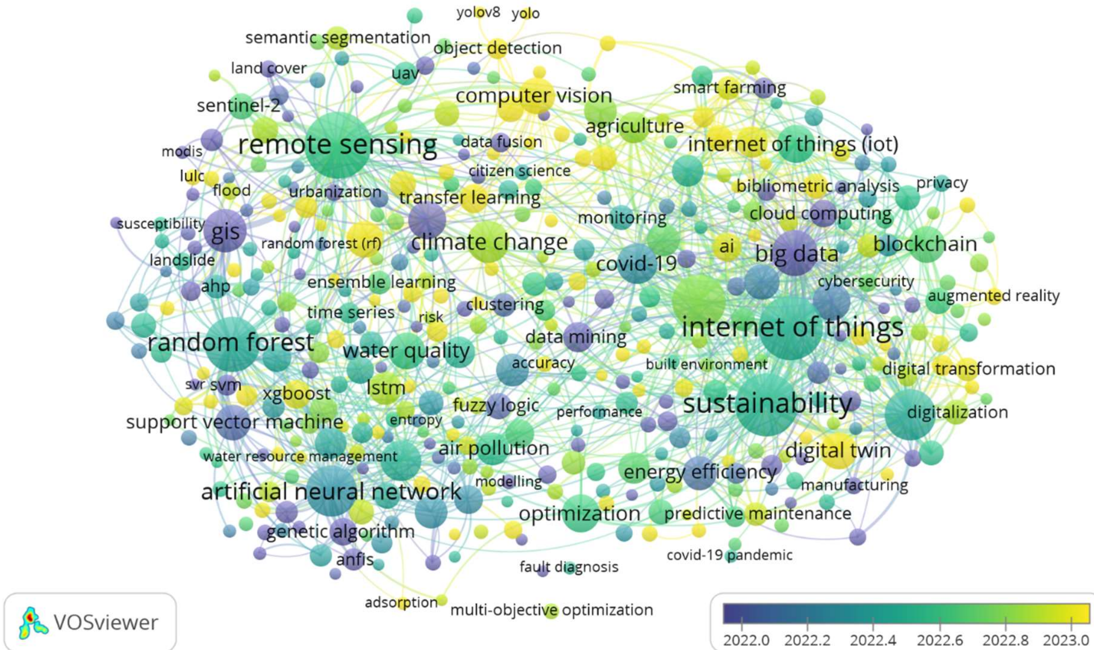

Figure 9: Keyword co-occurrence network

This network diagram, generated using VOSviewer, illustrates the frequency, interrelation, and clustering of keywords in the research field.

The keyword co-occurrence analysis highlights the multidisciplinary and interconnected nature of research in AI and environmental engineering. The prevalence of terms like "Machine Learning," "Sustainability," and "Climate Change" reflects the growing emphasis on leveraging AI to address global environmental challenges. The identification of clusters further underscores the diversity of research topics, ranging from computational techniques to practical applications in environmental monitoring and sustainable resource management. This analysis also reveals emerging trends and potential areas for future research, such as the integration of IoT, blockchain, and advanced optimization techniques.

The results highlight the rapid growth and interdisciplinary nature of research in AI and environmental engineering, driven by increasing global focus on sustainability and advanced technologies. Key findings reveal dominant contributions from leading countries like China, the U.S., and India, strong collaborations among researchers and institutions, and thematic focus on areas such as machine learning, sustainability, and climate change. Keyword analysis underscores emerging trends, including IoT, blockchain, and optimization, indicating promising avenues for future research. Overall, the results emphasize the dynamic progress and collaborative efforts shaping the field to address global environmental challenges.

3. Discussion

The findings of this study shed light on the dynamic and evolving intersection of artificial intelligence (AI) and environmental engineering, offering critical insights into research trends, gaps, and future opportunities. This discussion section contextualizes the results, interprets key trends, identifies research gaps, and compares the findings with existing bibliometric studies in similar domains.

Trends in AI Applications within Environmental Engineering

The results reveal a significant and accelerating growth in research activity in AI applications for environmental engineering, particularly since 2019. This trend aligns with global efforts to combat climate change and enhance environmental sustainability through advanced computational tools (Chen et al., 2020; Donthu et al., 2021). AI techniques such as machine learning, deep learning, and optimization methods are widely employed in areas like environmental monitoring, climate modeling, and water resource management, as evidenced by frequently occurring keywords such as "Machine Learning," "Climate Change," and "Sustainability." These findings underscore the increasing reliance on AI to address complex environmental challenges, ranging from predictive analytics for disaster management to energy efficiency optimization (van Eck & Waltman, 2014; Small, 1973).

Notably, the dominance of keywords like "Internet of Things (IoT)" and "Blockchain" indicates a growing interest in integrating AI with emerging technologies to develop smart environmental systems. For example, IoT is increasingly used for real-time environmental monitoring, while blockchain ensures transparency in sustainable resource management (Zupic & Čater, 2015; Glänzel, 2010). These technological synergies highlight the multidisciplinary nature of the field and its potential to revolutionize traditional approaches to environmental engineering.

Research Gaps and Future Opportunities

Despite the promising growth and advancements, several research gaps remain. First, the geographical analysis revealed a significant imbalance in research contributions, with most publications originating from developed and rapidly developing countries like China, the United States, and India. This disparity points to a lack of participation from low- and middle-income countries, particularly in Africa and South Asia, where environmental challenges are often most severe. Addressing this gap requires increased international collaborations, capacity-building initiatives, and funding for researchers in underrepresented regions (Mongeon & Paul-Hus, 2016; Bornmann et al., 2018).

Second, the thematic clusters identified through keyword co-occurrence analysis indicate a focus on traditional AI methods such as machine learning and optimization, while emerging techniques like federated learning, explainable AI, and quantum computing are underexplored. These areas represent significant opportunities for future research, particularly in developing explainable models for environmental decision-making and leveraging quantum algorithms for computationally intensive tasks (Aria & Cuccurullo, 2017).

Furthermore, while the results emphasize AI's application in monitoring and modeling, there is limited research on its integration with socio-economic factors, policy-making, and governance. Future studies should aim to bridge this gap by exploring how AI can inform sustainable development policies and foster community-level interventions for environmental resilience (Moed, 2005; Liu et al., 2020).

Comparison with Other Bibliometric Studies

When benchmarked against other bibliometric studies, this research demonstrates notable advancements in mapping the interdisciplinary nature of AI and environmental engineering. For instance, previous bibliometric studies on AI in environmental sciences have primarily focused on individual applications such as climate modeling or disaster management (Chen et al., 2020). In contrast, this study adopts a more holistic approach, analyzing thematic clusters, co-authorship networks, and keyword interconnections to provide a comprehensive overview of the field.

A comparative table highlights how this study differs from prior bibliometric analyses in terms of scope, data sources, and analytical tools.

Table 7: Comparative Benchmarking of Bibliometric Studies

Aspect	**This Study**	**Previous Studies**
Scope	AI in Environmental Engineering	AI in Climate Science, IoT in Sustainability
Data Source	Scopus	Web of Science, Google Scholar
Timeframe	2000–2025	2000–2020
Tools Used	VOSviewer, Heatmaps	VOSviewer
Focus Areas	AI methods, sustainability, monitoring	Climate modeling, disaster management
Key Findings	Keyword clusters, gaps in geographical focus	Application-based trends

The keyword co-occurrence network and co-authorship network generated in this study complement the comparative analysis, providing visual insights into the interdisciplinary collaborations and thematic diversity within the field. These visualizations not only validate the findings of prior studies but also offer new perspectives on emerging research trends.

The discussion highlights how this study contributes to the understanding of AI's role in environmental engineering by identifying key trends, gaps, and opportunities for future research. While significant progress has been made in applying AI to address environmental challenges, the results underscore the need for more inclusive and multidisciplinary approaches to ensure global impact. By bridging geographical and thematic gaps, fostering collaborations, and integrating emerging technologies, the field can continue to advance toward sustainable and innovative solutions.

4. Conclusion

This study provides a comprehensive bibliometric analysis of the intersection of artificial intelligence (AI) and environmental engineering, highlighting significant trends, collaborations, and thematic focus areas. The results underscore the exponential growth in research activity, driven by global sustainability challenges and advancements in computational technologies. Key findings reveal dominant contributions from countries like China, the United States, and India, emphasizing the need for more inclusive representation from underrepresented regions. The analysis of keywords and co-authorship networks highlights the interdisciplinary nature of the field, with emerging themes such as IoT, blockchain, and optimization techniques gaining prominence. Despite significant progress, research gaps persist in areas like integrating socio-economic dimensions and exploring advanced AI methodologies. The insights provided in this study not only map the current research landscape but also outline opportunities for future exploration, fostering innovation in sustainable and data-driven environmental solutions.

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