

Environmental Monitoring Research 2000–2026 Growth Themes and Collaboration Patterns: A Bibliometric Investigation

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ABSTRACT

This study investigates the evolution, thematic structure, and collaboration patterns of environmental monitoring research from 2000 to 2026 using a bibliometric approach. Data were collected from the Scopus database and analyzed using VOSviewer to examine publication trends, keyword co-occurrence, and collaboration networks among authors and countries. The results indicate a significant increase in research output, particularly after 2015, reflecting growing global concern over environmental degradation, climate change, and sustainability issues. The keyword co-occurrence analysis reveals several dominant research clusters, including pollution and chemical analysis, human health and air quality, ecological and biodiversity studies, and technology-driven monitoring approaches. Emerging themes such as artificial intelligence, machine learning, and remote sensing highlight a shift toward digital and data-intensive environmental monitoring systems. The density analysis further confirms that while traditional topics such as pollution and chemistry remain central, newer themes related to smart monitoring and sustainability are gaining momentum. In terms of collaboration, developed countries continue to dominate global research networks, although participation from developing regions is increasing. This study contributes to the literature by providing a comprehensive overview of the intellectual development of environmental monitoring research and identifying future directions that emphasize technological innovation, interdisciplinary integration, and global collaboration.

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1. INTRODUCTION

Environmental monitoring has become an essential scientific activity for understanding environmental conditions and assessing the impact of human activities on ecosystems. It involves systematic observation, measurement, and analysis of environmental parameters such as air quality, water quality, soil condition, and biodiversity

over time. Through continuous data collection and interpretation, environmental monitoring enables researchers and policymakers to detect environmental changes, evaluate risks, and support evidence-based environmental management and policy development [1]. The importance of environmental monitoring has increased significantly in the context of global environmental challenges such as climate

change, pollution, ecosystem degradation, and rapid urbanization. These challenges require reliable environmental data and monitoring systems that can provide early warnings and inform sustainable environmental governance strategies [2].

Over the past few decades, technological advancement has transformed environmental monitoring methodologies and research directions. Traditional monitoring methods that relied primarily on field sampling and laboratory analysis have gradually been complemented by modern technologies such as remote sensing, geographic information systems (GIS), wireless sensor networks, and automated environmental monitoring systems. These technological innovations have enabled more efficient data collection and expanded the spatial and temporal coverage of monitoring programs [3]. In addition, the integration of emerging technologies such as artificial intelligence, machine learning, and the Internet of Things (IoT) has significantly improved the capacity to analyze large environmental datasets and detect complex environmental patterns. These technological developments have broadened the scope of environmental monitoring research and increased interdisciplinary collaboration among scientists in fields such as environmental science, engineering, data science, and public health [4].

The increasing complexity of environmental problems has also led to a substantial growth in scientific publications related to environmental monitoring. Bibliometric studies indicate that research output in environmental monitoring has steadily increased over time, reflecting rising global awareness and scientific interest in environmental protection and sustainability [5]. Several countries, including the United States, China, and European nations, have emerged as major contributors to environmental monitoring research, often collaborating through international scientific networks and large-scale monitoring initiatives. This expansion of research output demonstrates that environmental monitoring

has evolved into a dynamic and rapidly developing scientific field with diverse thematic areas such as air pollution monitoring, water quality assessment, climate observation, and biodiversity conservation [6].

Another important feature of contemporary environmental monitoring research is the growing emphasis on collaborative research networks. Environmental problems are inherently global and interconnected, requiring cooperation among researchers, institutions, and countries to address complex environmental issues effectively. International monitoring programs and collaborative research initiatives have played a crucial role in facilitating knowledge exchange, standardizing monitoring methodologies, and improving global environmental data sharing. For instance, global observation programs established by international organizations aim to coordinate atmospheric and environmental monitoring efforts worldwide to better understand environmental changes and support environmental policy formulation. Such collaboration networks have strengthened scientific capacity and encouraged interdisciplinary approaches in environmental monitoring research.

Despite the rapid growth of environmental monitoring research, understanding the evolution of research themes and collaboration structures within this field remains an important challenge. With thousands of publications produced across multiple disciplines, it becomes increasingly difficult to identify dominant research trends, emerging topics, and key contributors using conventional literature review methods. Bibliometric analysis has emerged as a powerful approach for mapping scientific knowledge structures and evaluating research development over time. By analyzing publication data, citation patterns, and co-authorship networks, bibliometric methods allow researchers to identify influential research themes, leading institutions, and patterns of scientific

collaboration [7]. These insights are valuable for understanding the intellectual structure of a research field and guiding future research directions.

Although environmental monitoring research has expanded significantly in recent decades, there remains limited comprehensive analysis that systematically examines its long-term development, thematic evolution, and collaboration patterns across the global scientific community. Existing studies often focus on specific subfields, such as air quality monitoring or water quality assessment, rather than providing a broad overview of environmental monitoring research as a whole. Furthermore, the rapid emergence of new technologies and interdisciplinary approaches has reshaped the research landscape, making it necessary to reassess how research themes and collaborative networks have evolved over time. Without a comprehensive bibliometric investigation covering an extended period, it is difficult to identify the dominant research directions, influential authors and institutions, and emerging research frontiers within the field. Therefore, a systematic bibliometric study is needed to analyze the growth patterns, thematic developments, and collaboration structures of environmental monitoring research between 2000 and 2026.

The objective of this study is to conduct a comprehensive bibliometric analysis of environmental monitoring research published between 2000 and 2026 in order to identify the growth trends, thematic evolution, and collaboration patterns within the field.

2. METHODS

This study employed a bibliometric research design to systematically analyze the

development, thematic trends, and collaboration patterns of environmental monitoring research published between 2000 and 2026. Bibliometric analysis is widely used to evaluate scientific literature by applying quantitative techniques to publication and citation data in order to map the structure and evolution of research fields [8]. The method allows researchers to identify growth patterns in scientific output, influential publications, and relationships among authors, institutions, and research themes. In this study, bibliometric techniques were applied to examine the intellectual landscape of environmental monitoring research, focusing on publication productivity, citation impact, and collaborative networks among scholars and institutions across the global scientific community.

The bibliographic data used in this study were collected from a major scientific database that indexes peer-reviewed journals, conference proceedings, and review articles in environmental science and related disciplines. A structured search strategy was developed using keywords related to environmental monitoring, including combinations such as “environmental monitoring,” “environmental observation,” and “environmental sensing.” The search was limited to publications produced between 2000 and 2026 and restricted to English-language documents to ensure consistency in analysis. After the initial retrieval process, the dataset was refined by removing duplicate records and documents that were not directly related to environmental monitoring research. The final dataset included bibliographic information such as authors, publication year, journal source, keywords, affiliations, abstracts, and citation counts, which were subsequently exported in compatible formats for bibliometric analysis.

3.2 Citation Analysis

Table 1. Top Cited Documents

Citations	Authors and year	Title	Source
11,087	[9]	Google Earth Engine: Planetary-scale geospatial analysis for everyone	Remote Sensing of Environment, 202, pp. 18–27
7,322	[10]	Pharmaceuticals, hormones, and other organic wastewater contaminants in U.S. streams, 1999–2000: A national reconnaissance	Environmental Science & Technology, 36(6), pp. 1202–1211
6,658	[11]	Microplastics in the marine environment	Marine Pollution Bulletin, 62(8), pp. 1596–1605
6,226	[12]	The ERA-40 re-analysis	Quarterly Journal of the Royal Meteorological Society, 131(612), pp. 2961–3012
6,207	[13]	Fluorescence excitation–emission matrix regional integration to quantify spectra for dissolved organic matter	Environmental Science & Technology, 37(24), pp. 5701–5710
6,079	[14]	Flexible triboelectric generator	Nano Energy, 1(2), pp. 328–334
5,903	[15]	Global change and the ecology of cities	Science, 319(5864), pp. 756–760
5,825	[16]	Biodiversity loss and its impact on humanity	Nature, 486(7401), pp. 59–67
5,559	[17]	Wireless sensor network survey	Computer Networks, 52(12), pp. 2292–2330
5,372	[18]	The 2007 Recommendations of the International Commission on Radiological Protection	Annals of the ICRP, 37(2–4), pp. 1–332

Source: Scopus, 2026

Discussion

The findings of this bibliometric investigation reveal that environmental monitoring research has undergone a significant transformation over the past two decades, evolving from a predominantly pollution-focused discipline into a more complex and interdisciplinary field. The strong centrality of “environmental monitoring” and its close association with terms such as pollution, chemistry, and risk assessment indicate that the foundational focus of the field remains rooted in understanding environmental contaminants and their impacts. This aligns with earlier studies emphasizing the role of

environmental monitoring in detecting and mitigating pollution in air, water, and soil systems. However, the growing complexity of environmental challenges has expanded the scope of research beyond traditional chemical analysis toward more integrated and systemic approaches.

A key insight from the thematic clustering and density patterns is the increasing importance of human-centered research within environmental monitoring. The prominence of keywords such as “human,” “air pollutants,” and “air quality” suggests that the field is increasingly aligned with public health concerns, particularly in relation to environmental exposure and

disease risk. This reflects a broader shift toward environmental epidemiology, where monitoring systems are not only used to assess environmental conditions but also to understand their direct implications for human well-being. Such integration highlights the importance of interdisciplinary collaboration between environmental scientists, health researchers, and policymakers to develop effective intervention strategies.

Another significant development identified in this study is the rapid emergence of technology-driven approaches, particularly those involving machine learning, artificial intelligence, and remote sensing. These technologies have enabled more efficient data collection, real-time monitoring, and predictive analysis, thereby enhancing the accuracy and scalability of environmental monitoring systems. The presence of these keywords in moderately dense and interconnected clusters indicates that while technological integration is still evolving, it is becoming a dominant direction in the field. This trend is consistent with the growing demand for smart environmental management systems capable of addressing complex and dynamic environmental issues, such as climate change and urban pollution.

Furthermore, the analysis highlights the diversification of research themes toward ecological and sustainability-oriented topics, including biodiversity, ecosystems, and environmental protection. This suggests that environmental monitoring is increasingly being used as a tool for supporting sustainable development and conservation efforts. The integration of ecological indicators into monitoring systems reflects a more holistic understanding of environmental health, where the focus extends beyond pollution control to include ecosystem resilience and long-term sustainability. This shift is particularly important in the context of global environmental challenges, where maintaining ecological balance is critical for ensuring the sustainability of natural resources.

The collaboration patterns observed in this study indicate a growing but uneven global participation in environmental monitoring research. While developed countries continue to dominate in terms of research output and collaboration networks, emerging contributions from developing regions signal an increasing global awareness of environmental issues. However, disparities in technological capacity and research infrastructure remain challenges that may limit broader participation. Therefore, future research should emphasize strengthening international collaboration, knowledge sharing, and capacity building, particularly in regions that are highly vulnerable to environmental degradation.

4. CONCLUSION

This bibliometric study demonstrates that environmental monitoring research has experienced substantial growth and transformation from 2000 to 2026, evolving from a traditional focus on pollution detection toward a more interdisciplinary and technology-driven domain. The findings highlight the central role of environmental monitoring in integrating diverse themes, including chemical analysis, human health impacts, ecological sustainability, and advanced technologies such as artificial intelligence and remote sensing. The increasing emphasis on human-centered and sustainability-oriented research reflects the field's alignment with global environmental challenges and policy priorities. Additionally, while global collaboration networks continue to expand, disparities between developed and developing regions remain evident, indicating the need for more inclusive and cooperative research efforts. This study provides a comprehensive understanding of the intellectual structure and development trajectory of environmental monitoring research, offering valuable insights for future studies that aim to enhance technological integration, interdisciplinary collaboration, and sustainable environmental management.

REFERENCES

- [1] S. Fatimazahra, M. Latifa, S. Laila, and K. Monsif, "Review of hospital effluents: special emphasis on characterization, impact, and treatment of pollutants and antibiotic resistance," *Environ. Monit. Assess.*, vol. 195, no. 3, p. 393, 2023.
- [2] A. Sharan, B. Datta, D. K. Roy, and A. Lal, "Conceptual development and implementation of a digital twin model for managing saltwater intrusion of an island coastal aquifer," *Environ. Monit. Assess.*, vol. 197, no. 10, pp. 1–25, 2025.
- [3] A. J. Audu and A. U. Umana, "Advances in environmental compliance monitoring in the oil and gas industry: Challenges and opportunities," *Int. J. Sci. Res. Updat.*, vol. 8, no. 2, pp. 48–59, 2024.
- [4] V. H. Ho, "Sustainable finance & China's green credit reforms: A test case for bank monitoring of environmental risk," *Cornell Int'l LJ*, vol. 51, p. 609, 2018.
- [5] J. P. Shimshack, "The economics of environmental monitoring and enforcement," *Annu. Rev. Resour. Econ.*, vol. 6, no. 1, pp. 339–360, 2014.
- [6] D. B. Barr, L. C. Wilder, S. P. Caudill, A. J. Gonzalez, L. L. Needham, and J. L. Pirkle, "Urinary creatinine concentrations in the US population: implications for urinary biologic monitoring measurements," *Environ. Health Perspect.*, vol. 113, no. 2, pp. 192–200, 2005.
- [7] D. R. Green, J. J. Hagon, C. Gómez, and B. J. Gregory, "Using low-cost UAVs for environmental monitoring, mapping, and modelling: Examples from the coastal zone," in *Coastal management*, Elsevier, 2019, pp. 465–501.
- [8] N. Donthu, S. Kumar, D. Mukherjee, N. Pandey, and W. M. Lim, "How to conduct a bibliometric analysis: An overview and guidelines," *J. Bus. Res.*, vol. 133, pp. 285–296, 2021.
- [9] N. Gorelick, M. Hancher, M. Dixon, S. Ilyushchenko, D. Thau, and R. Moore, "Google Earth Engine: Planetary-scale geospatial analysis for everyone," *Remote Sens. Environ.*, vol. 202, pp. 18–27, 2017.
- [10] D. W. Kolpin *et al.*, "Pharmaceuticals, hormones, and other organic wastewater contaminants in US streams, 1999– 2000: A national reconnaissance," *Environ. Sci. Technol.*, vol. 36, no. 6, pp. 1202–1211, 2002.
- [11] A. L. Andrady, "Microplastics in the marine environment," *Mar. Pollut. Bull.*, vol. 62, no. 8, pp. 1596–1605, 2011.
- [12] S. M. Uppala *et al.*, "The ERA-40 re-analysis," *Q. J. R. Meteorol. Soc. A J. Atmos. Sci. Appl. Meteorol. Phys. Oceanogr.*, vol. 131, no. 612, pp. 2961–3012, 2005.
- [13] W. Chen, P. Westerhoff, J. A. Leenheer, and K. Booksh, "Fluorescence excitation– emission matrix regional integration to quantify spectra for dissolved organic matter," *Environ. Sci. Technol.*, vol. 37, no. 24, pp. 5701–5710, 2003.
- [14] F.-R. Fan, Z.-Q. Tian, and Z. L. Wang, "Flexible triboelectric generator," *Nano energy*, vol. 1, no. 2, pp. 328–334, 2012.
- [15] N. B. Grimm *et al.*, "Global change and the ecology of cities," *Science (80-.)*, vol. 319, no. 5864, pp. 756–760, 2008.
- [16] B. J. Cardinale *et al.*, "Biodiversity loss and its impact on humanity," *Nature*, vol. 486, no. 7401, pp. 59–67, 2012.
- [17] J. Yick, B. Mukherjee, and D. Ghosal, "Wireless sensor network survey," *Comput. networks*, vol. 52, no. 12, pp. 2292–2330, 2008.
- [18] J. Valentin, "The 2007 recommendations of the international commission on radiological protection," *ICRP Publ.*, vol. 103, pp. 2–4, 2008.