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Emerging trends in pollution prevention: social implications and sustainable solutions

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Abstract. Pollution remains the leading environmental cause of premature death and the problem that affects us the most. This study employed a bibliometric analysis using the Web of Science Core Collection to identify emerging trends in pollution prevention and their social implications. A Boolean query retrieved 23 open access, English-language articles published between 2021 and 2025, which were further analyzed with Vos Viewer through co-authorship, country collaboration, and keyword co-occurrence maps. Results show that England, the USA, and China lead research production, forming strong international networks, while smaller nations such as Estonia and Portugal contribute to the diversity of perspectives. Co-authorship analysis revealed dense interdisciplinary collaboration, while keyword mapping identified four thematic clusters: hazardous material management, digital and AI-driven solutions, sustainability and social responsibility, and traditional environmental issues such as water quality. These findings indicate a growing integration of technological innovation and social justice concerns in pollution prevention research, underscoring the need for equitable, community-driven strategies to address the persistent disproportionate impact of pollution on marginalized groups.

1 Introduction

Pollution is the largest environmental cause of disease and premature death in the world today. Almost every human-based activity that results in degradation of the quality of the natural environment is regarded as pollution. Pollution is not a new phenomenon, and it remains the greatest world problem. Diseases caused by pollution were responsible for an estimated 9 million premature deaths in 2015, 16% of all deaths worldwide, three times more deaths than from AIDS, tuberculosis, and malaria combined and 15 times more than from all wars and other forms of violence [1-2]. The World Health Organization highlights that air

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pollution is responsible for an estimated 7 million premature deaths annually, making it the single largest environmental health risk worldwide [3]. Pollution in the environment can occur in different forms including air pollution, water pollution, soil pollution, and noise pollution [4]. The purpose of this article is to examine what are the emerging trends in pollution and how specialized literature has evolved regarding pollution prevention.

1.1 Innovations and Technological Solutions in Pollution Prevention

Each type of pollution is prevented nowadays through new methods. Researchers are developing new technologies to reduce and prevent pollution. A 2020 study analyzed 52 emerging technologies designed to either prevent plastic from entering waterways or collect plastic waste from oceans and rivers. This comprehensive analysis, covering devices such as river litter separators and filtration systems, filled a critical information gap for policymakers by centrally tracking available solutions and their scope, highlighting technological gaps in preventing plastic pollution. These types of innovations emphasize the need for plastic spills before they turn into marine pollution [5].

In order to mitigate the effects of air pollution, many Internet of Things (IoT)-related technologies have been developed to evaluate and monitor various parameters of air quality. IoT generally refers to the goals achieved by following established network communication protocols, connecting items through various networks and using radio frequency identification (RFID) technology, various sensors, location recognition systems, and information processing mechanisms. Finally, information exchange and item identification, tracking service and real-time management are realized. These systems enable real-time monitoring of pollutants and data-driven control strategies; for instance, automatically adjusting traffic flows or industrial processes in response to sensor data [6]. This trend reflects a powerful move towards tech-based pollution prevention.

Emerging research highlights the potential that AI has in pollution prevention and remediation. A 2025 narrative review explores the transformative potential of artificial intelligence in optimizing bioremediation systems for river pollution control. AI technologies like machine learning algorithms, neural networks, optimization algorithms and reinforcement learning systems, can identify patterns in water quality data and dynamically adjust bioremediation strategies for maximum efficiency. Integrating artificial intelligence with traditional pollution prevention methods could significantly change the effectiveness of sustainable pollution prevention and management [7]. Introducing tools like AI reflects an extensive trend digital innovation in pollution prevention and mitigation.

1.2 Environmental and social justice. Involving citizens.

Generally, environmental pollution is greater in middle- and low-income countries than in developed countries, possibly due to poverty, poor legislation, and being unaware of pollution forms. It is likely that humans face pollution daily without knowing it or we may have possibly become immune to it in our fast-paced lives [8]. Emerging attention to global climate change has emphasized environmental justice related concerns, such as sea level rise impacts on small island states and agricultural impacts for indigenous communities related to a warming climate, predominately driven by greenhouse gas emissions generated by wealthier and industrialized economies [9]. The Lancet Commission reported that over 92% of all pollution-related deaths occur in low- and middle-income countries, and within every country the poorest and most vulnerable groups suffer the highest exposure to toxic air, water, and soil pollution [10]. Those located in marginal communities, the poor, certain minority and indigenous groups face something called “disproportionate poisoning of the poor,” a global environmental injustice. This inequity violates basic human rights, marginal

communities do not have clean waters, safe environments and their overall health is at risk [10].

An environmental justice analysis from 2024 made in the United States shows a very clear pattern in pollution and socioeconomic or racial inequities. In the 40 years (1970-2010) since the Clean Air Act began reducing air pollution in the US, researchers have observed that people from wealthier counties enjoyed much larger declines in emissions than poorer, minority-populated counties [11]. In the same article, researchers highlight that in urban settings, communities of colour are more likely to live near highways, power plants, or waste sites and thus breathe more polluted air. These findings underscore that pollution prevention policies must explicitly address equity, because the simple raising of environmental standards is not enough if the benefits bypass those who need them most [11].

A 2022 scoping review shows that involving citizens directly in pollution monitoring and solution-finding can be a powerful strategy, especially for air quality issues [12]. The review highlighted that deeper forms of participation, communities co-design interventions or have a word in decision-making, tend to produce more meaningful health and environmental improvements than one-way communication or top-down approaches [12]. Meegoda et al. present a case study of a community-driven pollution prevention program in two urban communities from USA. This study examines the effect of a community-based approach designed to emphasize the benefits to the health and economic well-being of urban communities when source reduction practices are implemented by businesses in the community. The results were tangible over the course of the program, participating businesses collectively *eliminated* approximately 932 lbs of hazardous waste and 3,917 lbs of non-hazardous waste per year, reduced greenhouse gas emissions by about 13.6 metric tons of CO_2-equivalent [13]. Pollution is not just an environmental issue but a profound social justice concern, as those deaths and diseases disproportionately affect vulnerable populations.

2 Methodology

To identify the emerging trends in pollution prevention and what are the social implications, we used a bibliometric analysis approach. The data source selected for the bibliometric analysis was Web of Science Core Collection. To ensure a comprehensive yet focused retrieval of relevant studies, the search was structured using a Boolean query targeting multiple fields. The following syntax was applied:
(Topic= (“Pollution) AND Topic= (“Emerging”) AND Topic=(“Solutions) AND All Fields=(“Social))

This query allowed the inclusion of publications in which all words appeared in the title, abstract, keyword plus, and author keywords. Firstly, our literature search began with the identification of 100 publications with no duplicates. To refine the scope of the analysis and for studies to be included in the analysis a set of filters was applied: documents written only in English, documents type restricted to articles, only open access publications and articles published between 2021-2025. After applying these criteria, the final search was 23 articles. The complete analysis provided in our study was based on this final collection of 23 papers. The selection procedure made sure that the included material was suitable and relevant to the goals of the study. To complete the analysis, we must transfer the data provided from Web of Science to Vos Viewer. We will interpret a few maps based on: Countries Co-authorship, Keyword co-occurrences and co-authorship map.

2.1 Trends identified in specialized literature

The combined analysis of country-level output and collaboration provides insight into the global distribution of research efforts. The tree map (Figure 1) indicates that England holds the largest share of publications, followed closely by the USA and China, while Estonia, India, Italy, and Portugal make notable contributions as well. Germany, Belgium, and Australia also appear as relevant, though smaller, contributors

Fig. 1 Tree map- countries (Generated by the authors with Web of science)

When examined in conjunction with the country collaboration map (Figure 2), these results show that England, the USA, and China function as central hubs of research and are strongly interconnected, reinforcing their leading position in the field. Countries such as India and Italy act as connectors, linking major research hubs with other regions, while Portugal and Estonia illustrate smaller scale. The involvement of Germany, Belgium, and Australia broadens the geographic reach of research, ensuring that different regional perspectives are included. Overall, the patterns suggest a multi-polar landscape where dominant Western and Asian countries set the pace of global research, but where contributions from smaller nations increase the diversity and scope of scientific research into pollution prevention.

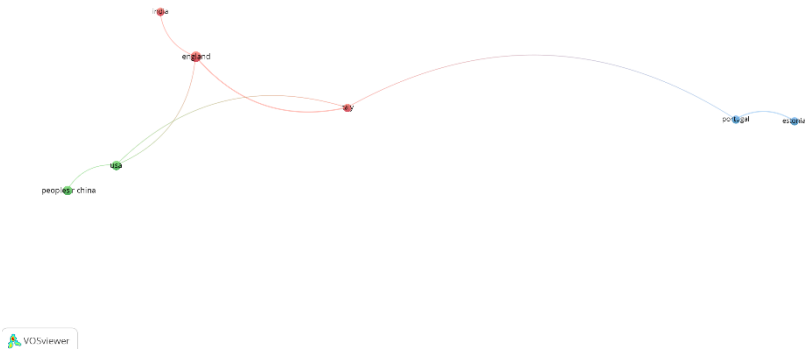

Fig. 2 Country collaboration map (Generated by the authors with vosviewer)

The co-authorship map (Figure 3) illustrates a highly interconnected network of researchers working on pollution prevention. Most authors are linked through multiple

collaborations, suggesting that the field is marked by a strong culture of interdisciplinary cooperation. Central figures such as Adam Balazs, Pavlos Kassomenos, Judita Puišo, and Hilal Zaid appear as key nodes, indicating their significant role in bridging research groups and facilitating knowledge exchange across different subfields. The dense web of connections shows that no clear divisions exist between isolated groups of authors, but rather that knowledge production in this area relies on collective efforts across institutions and regions. Such collaboration not only enhances the scientific depth of pollution prevention studies but also underscores the global dimension of environmental challenges, which require the integration of diverse expertise and perspectives.

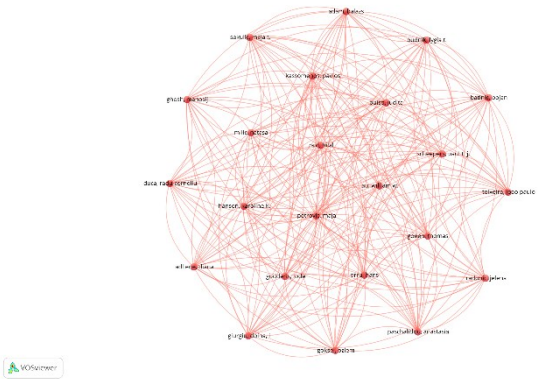

Fig. 3 Co-autorship map (Generated by the authors with Vos viewer)

The keyword co-occurrence map (Figure 4) reveals the main thematic directions of research in pollution prevention. Four clusters can be identified, each corresponding to a distinct yet interconnected area of research. The first cluster (green), centered on terms such as e-waste, heavy metals, and research and development, reflects growing attention to the management of hazardous materials and technological solutions to reduce their environmental impact. A second cluster, represented by pollution and artificial intelligence (blue), emphasizes the role of digital technologies in monitoring, modeling, and mitigating pollution, highlighting the integration of innovative tools such as machine learning in environmental management.

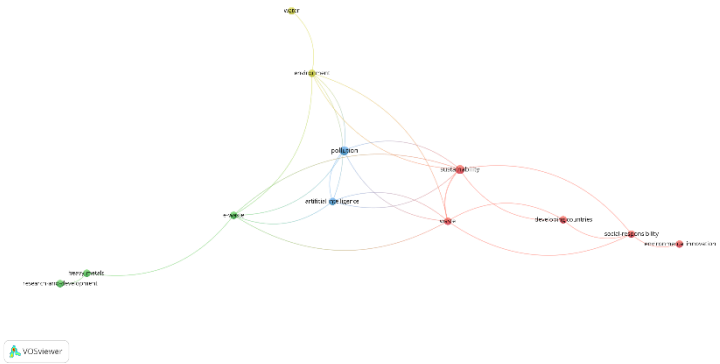

Fig. 4 The keyword co-occurrence map (Generated by the authors with Vos viewer)

The third cluster (red), built around sustainability, waste, developing countries, and social responsibility, captures the social dimension of pollution prevention, pointing to the links

between sustainable practices, equity, and community responsibility. Finally, the fourth cluster, connected to water and environment (yellow), demonstrates the persistent importance of traditional environmental themes, especially in the context of water quality and availability. The map shows that sustainability serves as a connecting point between the different clusters, reinforcing the idea that environmental, technological, and social approaches converge around the pursuit of sustainable solutions.

3 Discussions and Conclusions

Developed and developing nations share the burden of pollution, yet the latter suffer most due to weak legislation, lack of awareness, and poverty.

Pollution disproportionately affects the vulnerable groups in middle- and low-income countries [1]. Technologies regarding pollution prevention have evolved significantly in recent years, with artificial intelligence and digital monitoring tools now being applied to identify and combat pollution levels. These findings align with the results of the bibliometric analysis, which indicated strong interdisciplinary collaboration and a growing integration of technological and social dimensions. Beyond bibliometric evidence, real-world case studies further demonstrate the tangible benefits of pollution prevention strategies. In Italy, built wetlands have shown benefit–cost ratios (BCR) between 1 and 10, with values as high as 10 in the Emilia-Romagna region when ecosystem services are included [14]. Similarly, in China, retrofitting coal-fired power plants reduced mercury emissions by about 23.5 tons, producing measurable social benefits such as fewer heart-attack deaths and improved prenatal IQ outcomes [15]. These examples confirm that pollution prevention strategies not only mitigate environmental harm but also generate significant economic and public health benefits.

All these conclusions concretize the initial objective of this study: to examine how specialized literature has evolved on pollution prevention and to highlight emerging approaches that balance technological innovation with social justice concerns. The analysis of co-authorship and keyword co-occurrence maps shows that global research efforts are highly interconnected, emphasizing both sustainability and equity. However, this study is limited by its reliance on a relatively small number of articles (23), restricted to English-language and open-access publications indexed in the Web of Science. Future research could address these gaps by including a broader range of sources and by complementing bibliometric insights with qualitative investigations and long-term policy evaluations.

Ultimately, people must be involved in activities related to pollution prevention for better and more lasting results. Community-driven strategies, supported by technological innovations and robust policy frameworks, remain essential to reducing the disproportionate impact of pollution on marginalized groups.

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