

## MICROPLASTIC AND HEAVY METAL TOXICITY: A BIBLIOMETRIC ANALYSIS ON MARINE ENVIRONMENT

NUR AFIFAH A. RAHMAN, SHAMILA AZMAN\* AND ABILA HENA ANAYET

Department of Water and Environmental Engineering, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 80300 Skudai, Johor, Malaysia.

\*Corresponding author: [shamila@utm.my](mailto:shamila@utm.my)

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**Abstract:** Research on microplastic and heavy metal pollution in marine environments has rapidly expanded, with key publications and institutions contributing to the development of standardised methodologies and definitions. This study employs bibliometric analysis to evaluate research trends, using tools such as VOSviewer and Microsoft Excel to systematically analyse 147 publications from the Scopus database (2014-2024). Accordingly, the analysis reveals significant growth in the field, particularly driven by research from China and India. In addition, the findings indicate that China and India are leading contributors, with a substantial increase in research output since 2018. Recent trends focus on microplastics in wastewater, human consumption, and emerging sources such as synthetic fibres. Furthermore, the study identifies Estuarine, Coastal, and Shelf Science as the most cited journal and highlights the dominance of environmental and marine science in the research landscape. Overall, these results underscore the increasing significance of addressing these pollutants and offer valuable insights for guiding future research and policy development in the management of microplastic and heavy metal pollution in marine environments.

Keywords: Microplastic, heavy metal, marine pollution, aquatic life, fish.

### Introduction

The issue of plastic pollution in the ocean was initially identified by scientists in the 1970s (Bergmann *et al.*, 2015), yet in recent years it has drawn tremendous attention from the media, the public, and an increasing number of scientists spanning diverse fields. This includes polymer science, environmental engineering, ecology, toxicology, marine biology, and oceanography. Notably, plastic materials pose a serious threat to the marine environment when not properly disposed of or recycled. Correspondingly, the widespread presence of plastic pollution in the marine environment has emerged as a pervasive environmental problem lately due to the slow rate at which plastic degrades (Avio *et al.*, 2017; Lear *et al.*, 2021). As plastics enter marine ecosystems, they undergo physical and chemical breakdown processes, leading to the generation of microplastics in sizes that are now found extensively in marine environments (Barnes *et al.*, 2009).

Plastics are synthetic organic polymers that differ in chemical composition and density such as Polystyrene (PS), Low-Density and High-Density Polyethylene (LDPE and HDPE), Polypropylene (PP), Polyethylene Terephthalate (PET), Polyvinyl Chloride (PVC), Polyurethane (PU), Polyester (PES), and Polyamides (PA) (Dube & Okuthe, 2023). Building on this, plastic manifests in diverse forms, spanning from macroplastics to microplastics and even nanoplastics. Essentially, macroplastics represent larger fragments of plastic debris, easily observable such as bottles, bags, and fishing gear.

Microplastics can emerge through the breakdown of larger plastic items such as monofilament and nylon fishing nets, which are often disposed of at harbour operations (Thushari & Senevirathna, 2020). These nets, once afloat, drift across the ocean surface, driven by currents, and gradually degrade into smaller plastic particles. As they disperse to various

locations, they contribute to microplastic pollution across marine environments or they can be intentionally manufactured for specific purposes. This includes the cosmetics and personal care industry (Rahim *et al.*, 2022), where they are used as microbeads in exfoliating products.

Meanwhile, in the textile industry (De Falco *et al.*, 2019), synthetic fibres shed from clothing during washing contribute to microplastic pollution. The automotive industry (Jan Kole *et al.*, 2017) also contributes through the wear and tear of tyres, which release microplastics into the environment. Due to their small size, microplastics can act as vectors for various contaminants, including heavy metals, Persistent Organic Pollutants (POPs), and pathogens. These contaminants adhere to the surface of microplastics and are transported across marine environments, where they can be ingested by marine organisms. This, ultimately, leads to bioaccumulation and potential toxic effects up the food chain.

Meanwhile, nanoplastics, even smaller particles measuring less than 100 nanometres, can originate from the further degradation of microplastics. It can also be produced through industrial processes such as the manufacturing of nanocomposites used in electronics and automotive industries (Cerasa *et al.*, 2021; Zhan *et al.*, 2022). Additionally, the diminutive size of these particles allows them to penetrate biological membranes, raising significant concerns in environmental research due to their potential to cause cellular and molecular damage to marine life.

Over time, these items undergo mechanical fragmentation, breaking into smaller particles, including microplastics. Specifically, microplastics are minute particles measuring less than five millimetres (van Weert *et al.*, 2019). They can emerge through the breakdown of larger plastic items or intentional manufacturing for specific purposes. The unique challenge posed by nanoplastics lies in their minuscule size, enabling them to potentially infiltrate cells and tissues (Hirt & Body-Malapel, 2020). As a

result, this characteristic introduces additional complexities for comprehending their ecological and health implications.

Heavy metals are metallic elements that have a relatively high density compared to water (Wani *et al.*, 2017). The term heavy metals refers to metallic elements with an atomic number greater than 20. It has been redefined as those trace elements that have  $\geq 3$  g/cm<sup>3</sup> densities and may cause harmful biological effects (Banfalvi, 2011). In particular, the elements are characterised by high density and atomic weight such as lead, mercury, cadmium, and arsenic.

While these elements are naturally occurring and essential in trace amounts for biological functions, anthropogenic activities such as industrial processes, mining, and agriculture, have significantly increased their presence in the environment. Meanwhile, heavy metal contamination refers to the introduction of elevated concentrations of these elements into ecosystems, posing serious threats to environmental and human health (Rilwan *et al.*, 2021). Note that the release of heavy metals into water bodies, soil, and the atmosphere can lead to bioaccumulation and biomagnification within food webs.

Marine ecosystems are susceptible to heavy metal contamination, impacting various organisms, including fish. The high occurrence of microplastics in the gastrointestinal tracts of fish and other marine life is a clear indication that ingested microplastics (Barnes *et al.*, 2009; Ory *et al.*, 2018; De Sales-Ribeiro *et al.*, 2020; Joyce *et al.*, 2022; Foo *et al.*, 2022; Dellisanti *et al.*, 2023). In the context of research on microplastics and heavy metals in marine aquatic and fish, it is crucial to understand how these pollutants interact and potentially synergise in their effects. This phenomenon raises concerns about their bioaccumulation and subsequent impact on marine organisms, especially as these microplastics can act as vectors for various contaminants, including heavy metals.

Despite the growing body of research, there is still a lack of comprehensive understanding regarding the combined effects of microplastics

and heavy metals in marine environments. Thus, current studies often address these pollutants separately, leading to gaps in knowledge about how they interact, synergise, and the implications of their combined presence. Consequently, these gaps make it challenging to develop effective mitigation strategies and policies to protect marine ecosystems and human health. As such, this intricate interplay between microplastics and heavy metal contamination underscores the multifaceted challenges facing marine ecosystems, necessitating a comprehensive understanding of effective mitigation strategies. Therefore, the objective of this study is to investigate the worldwide scientific literature concerning the impact of microplastics and heavy metals on marine environments. This includes analysing trends through the application of bibliometric network analysis.

### Materials and Methods

Bibliometrics is indeed a valuable approach for the combination, management, and analysis of bibliographic data from scientific publications (Glenisson *et al.*, 2005; Zupic & Čater, 2015; Donthu *et al.*, 2021). This method involves the collection and examination of data related to a specific subject or a defined set of topics. It contributes to a systematic understanding of the scholarly landscape (Verbeek *et al.*, 2002), in addition to general descriptive statistics such as publishing journals, publication year, and main author classification (Wu *et al.*, 2021).

Correspondingly, an iterative sequence of suitable keywords, literature search, and analysis is required for an effective review of literature, bibliography building, and achieving reliable results, respectively (Fahimnia *et al.*, 2015). Hence, the study attempted to restrict itself to top-tier publications as they may assist in understanding the theoretical perspective regarding the evolution of the research domain. For the reasons mentioned earlier, the study depended on the Scopus database for data collection (De Stefano *et al.*, 2022). Furthermore, to guarantee the inclusion of

top-tier publications, only articles published in carefully peer-reviewed and high-quality academic journals were considered, with the exclusion of books and lecture notes (Liu *et al.*, 2015).

### Data Search Strategy

Elsevier's Scopus has a strong coverage and publications collected from 1973 to 2024 were explored for analysis. The following search was used: TS = TITLE-ABS-KEY (plastic\* AND "heavy metal" AND (fish OR "marine life" OR "aquatic life" OR "marine habitat")) outlined in Table 1. The search was conducted from 2014 to 2024. Hence, all possible references to these topics were included. However, all search terms were restricted to studies published in the English language (Table 2), yielding 147 results.

Moreover, these general categories as defined by Scopus included: Environmental Science, Agricultural and Biological Sciences, Pharmacology, Toxicology and Pharmaceutics, Medicine, Chemistry, Earth and Planetary Sciences, Biochemistry, Genetics and Molecular Biology, Engineering, Chemical Engineering, Social Sciences, Materials Science, Computer Science, Multidisciplinary, Immunology and Microbiology, Physics and Astronomy, Energy, Economics, Econometrics and Finance, Veterinary, Neuroscience, Business, Management and Accounting, and Arts and Humanities.

The resulting studies were downloaded on January 4, 2024 for further analysis. Data included title, type of publication, year of publication, publication name, authors, address, author keywords, and abstract to name a few. Additionally, citation data from the Scopus Report feature was also downloaded. Accordingly, data was analysed using Microsoft Excel 365 and VOSviewer 1.6.20 is a software that can be used to create a map of the topmost cited publications in the database. Clustering was also used to identify the number of different topics present in the database of publications (van Eck & Waltman, 2017).

Table 1: The search string

Scopus	TITLE-ABS-KEY (plastic* AND “heavy metal” AND (fish OR “marine life” OR “aquatic life” OR “marine habitat”)) AND PUBYEAR > 2013 AND PUBYEAR < 2025 AND (LIMIT-TO (PUBSTAGE, “final”)) AND (LIMIT-TO (LANGUAGE, “English”))
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Table 2: The search selection criteria

Criterion	Inclusion	Exclusion
Language	English	Non-English
Timeline	2014 - 2024	< 2014
Publication stage	Final	In press

## Results and Discussion

### *Yearly Quantitative Distribution of the Literature*

The statistical analysis of the number of publications in the decade 2014 to 2024 provides a clear picture of trends in scientific output and the ongoing development and maturation of microplastic contamination with heavy metals in the marine aquatic research field. It offers a comprehensive insight into the trends in scientific output, reflecting the evolving landscape and maturation of research on microplastic contamination with heavy metals in marine aquatic ecosystems.

As such, numerous studies underscore the significance of investigating the most toxic and hazardous chemical substances. Note that the initial scientific investigations into marine microplastics were documented in the early 1970s. However, these studies primarily focused on microplastics and did not encompass other contaminants such as heavy metals (Pauna *et al.*, 2019). The initial review, drawing insights from 147 original articles, exclusively concentrates on microplastics and heavy metals from the marine environment in the year 2016 (Brennecke *et al.*, 2016).

The distribution of research outputs concerning microplastic contamination in marine environments, as delineated by the time series in Table 3 underscores the temporal evolution of this critical issue. From 2014 to

2017, the number of articles related to marine microplastic pollution grew slowly, with fewer than 10 articles published prior to 2017. Still, there was a high increase starting from 2021 to 2023, with annual publication volumes of 21 to 44, respectively. Conversely, research on marine microplastics contamination control accounts for 71% of the overall number of articles published in the last three years. This is attributed to the fact that these contaminants are

Table 3: Trend of research in microplastics and heavy metal contamination according to the year of publication

Year	Documents
2024 (January)	2
2023	44
2022	38
2021	21
2020	10
2019	12
2018	10
2017	5
2016	2
2015	2
2014	1
<b>Total</b>	<b>147</b>

receiving more attention due to their inherent potential to generate environmental toxicity and adverse health effects on humans and aquatic life (Narwal *et al.*, 2023). Collectively, this indicates that the microplastic contamination issue is gaining more attention from researchers, especially in the fields of environmental and marine sciences.

**Countries and Institutions**

Numerous countries and international entities have responded to the challenges posed by microplastic contamination by implementing new policies, laws, and regulations in diverse capacities. The implementation of policy measures holds significant potential in strengthening preventive actions against microplastics. Figure 1 displays the number of articles published each year by the top 10 countries or regions in terms of the total number of articles published that year. Notably, the top 10 countries are based on the number of documents, with China leading at nearly 30 documents, followed by India with about 27 documents, and Italy, Malaysia, Portugal, the United States, and Spain with about 11 documents each.

Despite China being the world’s leading plastic producer (Osman *et al.*, 2023), China has implemented legal measures that prohibit and restrict the manufacturing, sale, and utilisation

of non-degradable plastic bags and other disposable plastic products (J. Liu *et al.*, 2022). Conversely, efforts to address the detrimental effects of plastic waste in India began in 1998. By December 31, 2022, regulations were enforced to prohibit the manufacturing of carry bags from virgin or recycled plastics with a thickness below 120 microns. Additionally, there were public outreach and awareness campaigns aimed at informing the public about the diverse measures implemented (Singh & Biswas, 2023).

The Malaysian government initiated a strategy titled “Malaysia’s Roadmap to Zero Single-Use Plastics” spanning from 2018 to 2030 (Ma *et al.*, 2020). In alignment with this plan, a “No Plastic Bags” campaign (Cheng *et al.*, 2022) has been organised to bolster the nation’s objective of eliminating single-use plastics. If effectively implemented, this endeavour is expected to gradually raise awareness among Malaysians. Countries such as Denmark, Portugal, and England, which have witnessed a positive impact with a reduction of plastic use exceeding 50%, serve as examples illustrating the potential success of such initiatives (Sulaiman *et al.*, 2023).

The United Kingdom, Australia, and France complete the top 10, with the number of documents ranging from seven to 11 documents each. Although these countries make a significant

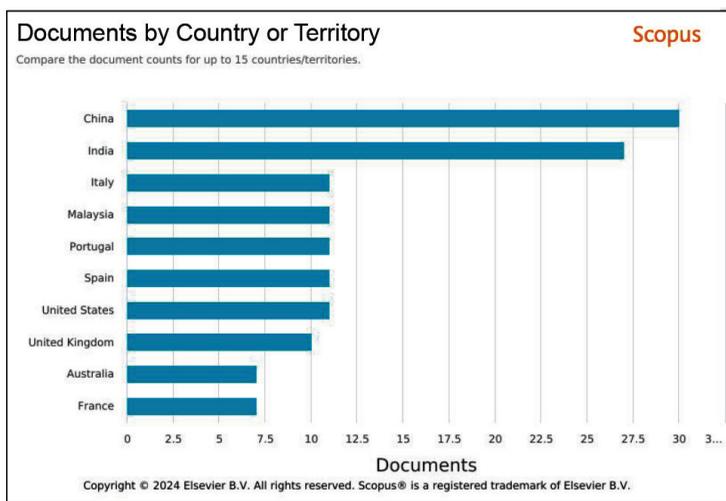


Figure 1: The top 10 most published articles according to countries

contribution, it is essential to remember that a total of 53 countries contributed to the dataset. This illustrates a geographically diverse research landscape, though some countries are more productive than others. For example, the Australian government is working towards implementing regulations concerning plastic waste and gradually eliminating PVC plastic labels (Soenmez *et al.*, 2024). At the same time, national laws prohibiting the use, sale, and/or production of microbeads in personal care products have been introduced by France, Italy, the Republic of Korea, New Zealand, Belgium, Brazil, India, Ireland, and Sweden (Hettiarachchi & Meegoda, 2023).

One promising alternative to microbeads is the use of biodegradable microbeads in personal care products (Ju *et al.*, 2021; McMackin *et al.*, 2024). Essentially, these natural materials can perform the same function as microbeads without contributing to microplastic pollution. Additionally, promoting the use of biodegradable materials through economic incentives and regulatory measures could encourage innovation and reduce environmental impact. Notably, removing existing microplastics from the marine environment is a significant challenge. Hence, policies should also consider strategies for reducing and managing microplastic pollution already present in the environment (Prakash *et al.*, 2024).

However, the diagram does not specify the types of documents included (e.g., journal articles, conference papers, books). Consistent with this, knowing the type of document can provide a deeper insight into the research activities of each country. For example, a country with a high number of journal articles may be strong in basic research while a country with many conference papers may be more focused on applied research or technology development.

### Publication Outputs

The total number of publications was 147, which included 104 articles, 28 reviews, 12 book chapters, two proceeding papers/conferences, and 1 data paper (Figure 2). The exploration of microplastics and efforts to mitigate their contamination are relatively recent developments, commencing in 2014. Meanwhile, the volume of publications pertaining to the removal of microplastics was initially minimal, with only one publication each in 2014 and 2015. Nonetheless, there has been a substantial surge in research output in recent times (Osman *et al.*, 2023).

This escalation in scholarly activity can be attributed to various factors. Among them are the available free time for researchers during the lockdowns imposed due to the coronavirus disease 2019 (COVID-19) and an increasing scientific interest in addressing the challenges

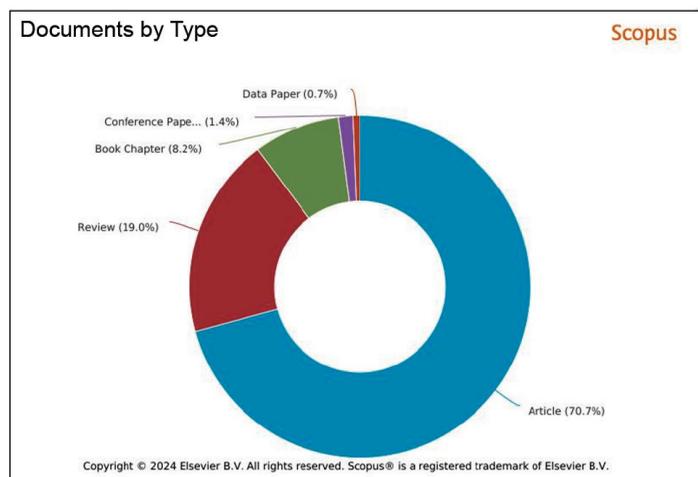


Figure 2: Publication output

associated with microplastics. This research surge aligns with global initiatives aimed at minimising plastic waste. Since then, the number of publications has increased significantly, with approximately 93% of the publications occurring during or after 2018. At the same time, a comprehensive theoretical framework has been established for the management of marine microplastic pollution. Nevertheless, only a limited number of papers have delved into the policy implications and technological innovations within this domain (Lou *et al.*, 2023). Earlier review studies, employing bibliometric analysis, addressed only a limited fraction of the specific microplastic research or assessment conducted up until 2020 (Davtalab *et al.*, 2023).

In addition, the bibliometric analysis identified authors who contributed to specific areas of research and their collaborative relationships. Specifically, a total of 159 authors were involved in microplastic and heavy metals in marine pollution control studies during the period 2014 to 2024. This figure reveals a research landscape dominated by articles (70%), indicating a strong emphasis on peer-reviewed research and a significant presence of reviews (19%) highlights active knowledge synthesis. In contrast, the less frequent occurrence of book chapters (8%) and conference papers (2%) suggests alternative dissemination avenues while emerging data papers (1%) hint at potential future trends.

### ***Citation and Keywords***

Microplastics are pervasive in numerous aquatic and terrestrial environments across the globe. Accordingly, examining the effects of microplastics in water has emerged as a significant research focus in recent years (Davtalab *et al.*, 2023). In particular, the 10 most cited articles in the field of microplastic and heavy metal contamination in marine habitats are listed in Table 4. Notably, microplastics pose a significant environmental threat due to their potential to adversely affect marine ecosystems.

Research indicates that this can contribute to a decrease in population numbers (Ghosh *et al.*, 2023). Ranked first, with 970 citations highlights the concern that microplastics can act as vectors for heavy metal contamination in the marine environment. Most of them were research articles mainly addressing heavy metal contamination in microplastics. In addition, the 10 most cited publications had an average citation count of 335.4 citations. Among the top 10 most cited microplastics papers, Environmental Research and Chemosphere stand out with two entries each, ranking within the top six. Meanwhile, Aquatic Toxicology is the second most cited paper while Estuarine, Coastal, and Shelf Science stands out as the most frequently cited, occupying the first position. Nanoscale also appears with two papers in the latter half of the ranking. These five journals publish impactful research on microplastics, though a wider search would be required to definitively crown the most cited journal in this dynamic field.

Based on Figure 3, the scientific contributions of 52 countries in microplastics research, with a particular focus on a curated selection of 16 nations. Through an examination of citation counts, valuable insights into the global landscape of this crucial field emerge. Portugal takes the lead in citations, despite contributing fewer documents compared to China or the United States.

As such, Portugal stands out with the highest overall citation count (1,637). This indicates that Portuguese research in this domain deeply resonates with the broader scientific community, possibly owing to its specific focus areas or the expertise of its researchers. Moreover, Portugal faces the potential impacts of marine litter, influenced by the extensive coastal areas and demographic pressures. Additionally, being a European Union Member State, Portugal is obligated to adhere to the Marine Strategy Framework Directive, necessitating the monitoring of coastal area quality, encompassing the assessment of marine litter presence (Prata *et al.*, 2020).

Table 4: The top 10 most cited articles on microplastic and heavy metal contamination in marine habitats

Rank	Title	Year	Source Title	Cited by	Document Type
1	Microplastics as vector for heavy metal contamination from the marine environment	2016	Estuarine, Coastal and Shelf Science	970	Article
2	Microplastics cause neurotoxicity, oxidative damage and energy-related changes and interact with the bioaccumulation of mercury in the European seabass, <i>Dicentrarchus labrax</i> (Linnaeus, 1758)	2018	Aquatic Toxicology	424	Article
3	A review of the fate of micropollutants in wastewater treatment plants	2015	Wiley Interdisciplinary Reviews: Water	272	Article
4	Virgin microplastics cause toxicity and modulate the impacts of phenanthrene on biomarker responses in African catfish ( <i>Clarias gariepinus</i> )	2016	Environmental Research	262	Article
5	Influence of microplastics on the accumulation and chronic toxic effects of cadmium in zebrafish ( <i>Danio rerio</i> )	2018	Chemosphere	255	Article
6	Single and combined effects of microplastics and cadmium on the cadmium accumulation, antioxidant defence and innate immunity of the discus fish ( <i>Symphysodon aequifasciatus</i> )	2018	Environmental Pollution	238	Article
7	Microplastics in eviscerated flesh and excised organs of dried fish	2017	Scientific Reports	221	Article
8	Bioaccumulation of polystyrene nanoplastics and their effect on the toxicity of Au ions in zebrafish embryos	2019	Nanoscale	212	Article
9	Microplastic and mesoplastic contamination in canned sardines and sprats	2018	Science of the Total Environment	207	Article
10	Combined effects of polystyrene microplastics and natural organic matter on the accumulation and toxicity of copper in zebrafish	2019	Science of the Total Environment	180	Article

While China leads in document volume with 30 papers, its total citation count (1,363) falls behind that of Portugal. Similarly, the United States, with 11 documents, achieves a substantial 1,131 citations, highlighting robust research output, though still below the impact of Portugal. Furthermore, noteworthy examples such as Malaysia (988 citations) and the United States (1,131 citations) strike a balance between producing a significant number of documents and

attracting substantial citations. Malaysia, among the Southeast Asian nations including Indonesia, Thailand, Vietnam, and the Philippines, ranks among the top five producers of large municipal solid waste. Notably, Malaysia has repatriated 4,120 tonnes of plastic waste to 13 countries and since 2019, has officially closed down 200 illicit plastic recycling centres (Ng *et al.*, 2023). Remarkably, the United States is known for pioneering the production of the first synthetic

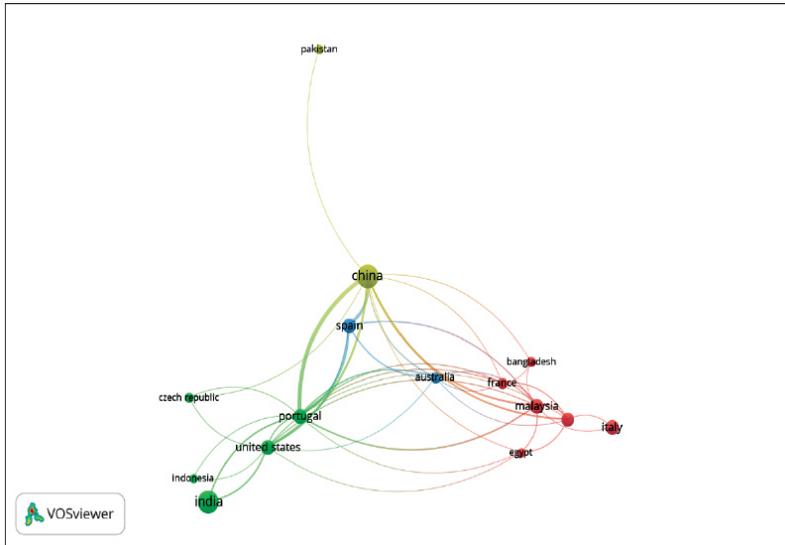


Figure 3: Citation network of the topmost cited publication by country

plastic. From 2014 to 2022, in efforts to address the issue of plastic bags, the United States has implemented laws that prohibit the use of single-use plastic bags (Usman *et al.*, 2022). Together, these countries provide insights into research efficiency and impactful communication.

**Subject Area**

Figure 4 illustrates the distribution of published documents across various subject areas related to environmental research. Specifically, 147

articles on microplastic contamination research, the top 10 journals offer clues to key subject areas. Science of the Total Environment leads with 21 articles, focusing on broad environmental impacts. It is also at the forefront of the publication, according to the bibliometric analysis of the global trends and prospects of microplastic pollution in agricultural soils (Nosova & Uspenskaya, 2023). Additionally, Chemosphere follows with 11, delving into the chemical aspects. Following this,

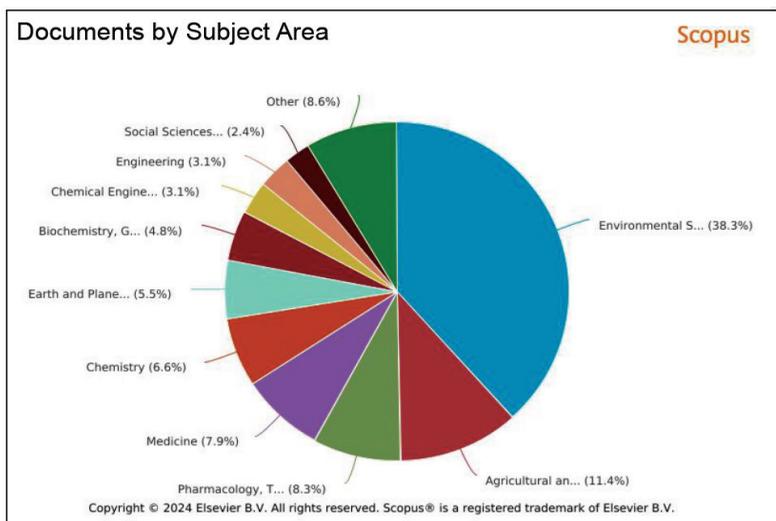


Figure 4: Distribution of published documents across various subject areas related to environmental research



still require research (Lou *et al.*, 2023). These keywords were further categorised into three clusters, represented by assorted colours (red, green, and blue), indicating potential thematic groupings.

The larger the circle, the more the keyword is selected in the bibliometric articles' publications. Specifically, the keywords bibliometric analysis and bibliometric exhibit the strongest link. The relative strength and similarity between the topics are exhibited by the distance between the two keywords. Circles of the same colour represent the similarity of the topic among different published articles (Dulla *et al.*, 2021).

In particular, Cluster 1, represented by the colour red, encompasses 76 items. Examples of keywords within this cluster include "toxicity", "animal", and "article". This cluster likely delves into studies assessing bioaccumulation, potential harm to organs, and overall toxicological risks. Meanwhile, Cluster 2, identified by the green colour, consists of 70 items. Key terms within this cluster comprise "fish", "plastic waste", and "environmental monitoring". This cluster might encompass research on plastic distribution in marine environments, its effects on specific organisms such as fish, and the overall pollution burden associated with microplastics.

Moreover, Cluster 3, represented by the blue colour, comprises 61 items. Keywords in this cluster include "heavy metal", "environment", and "pollutant". This cluster could involve studies on the adsorption of pollutants onto microplastics, their potential role in metal transport, and the broader water quality concerns associated with microplastic contamination. A map of the top keywords is present in Figure 5. Notably, the size of the circle demonstrates how frequently the term was used as a keyword in the various publications.

In this study, 174 publications on microplastic and heavy metal contamination in marine life were indexed in the core database Scopus. The published literature covers the following three aspects: Microplastics, heavy

metals, and marine life. In fact, the term "microplastic" is the most common keyword and is closely related to the terms "plastic" and "toxicity." Essentially, China and India provided the most significant contributions in this notable field. The intention and attitude towards microplastic contamination could be among the hotspots in the future. The absence of these articles is likely due to the keyword search parameters requiring the words to be present in the title, abstract and/or the keywords.

On the other hand, the word microplastics, for example, did not even exist in the 70s and 80s (Sorensen & Jovanović, 2021). The term smallest plastic particles found has been referred to as "microplastics" was first used in 2004 (Frias & Nash, 2019). Most publications, as with any new field, rely predominantly on articles. Despite being a relatively new discipline, 12 book chapters have been written on these topics. Concurrently, this further serves to highlight the significance of this discipline. At present, research publications addressing the issues of microplastic and heavy metal contamination in marine ecosystems have been documented in 53 countries. This emphasises even more how crucial these issues are on a global scale. This further signifies the aspect these are of global concern. This underscores the global significance of these concerns. It is essential to note that the specific count of articles may vary, as Scopus considers the country of the reprint address as one record, potentially leading to variations when authors relocate and update publication addresses.

Nevertheless, the topmost publishing countries were China and India. These countries will likely pave the way for the standardisation of research methodologies. Nonetheless, it is worth noting that some of the topmost publishing universities are not located in the top three publishing countries. CSIC-IEO-Instituto Español de Oceanografía, Spain, the University of Trás-os-Montes, and Alto Douro, Portugal are among the top publishing institutions that are in the top 10 publishing countries. It is likely that if their publication trends continue Spain and

Portugal may soon outrank in the total number of publications.

Bibliometric analysis is not without its limitations. As Scopus consistently updates its database, data that is downloaded for a specific time frame may have other publications added to it after a period of time. The trends of the research are more robust than the specific numbers per category. Most of the top publication citations were sufficiently high that it is unlikely that the addition of a new paper would change the top-cited papers, authors, and countries. This observation is supported by the persistence of key trends in keywords, countries, and journal sources, as observed in other subject-based bibliometric analyses (Sorensen & Jovanović, 2021). This is evident in the fact that some of the most popular trends such as keywords, nations, and journal sources, continue to be comparable in other bibliometric analyses that are more subject-based.

However, bibliometric analysis may be used to assist policymakers, stakeholders, or scientists regarding laws, policies, or future directions of research. Moreover, it is not restricted to journals that focus on information science. Rather, it is present in subject-based journals and is considered a tool in all of science, especially multidisciplinary science. For multidisciplinary studies, bibliometric analysis is deemed to have some of the highest citation ratings per bibliometric analysis article. This highlights the role and usefulness of bibliometric analysis in numerous fields (Ellegaard & Wallin, 2015). While this research is a multidisciplinary topic, bibliometric analysis is likely to influence a variety of scientific fields and audiences.

## Conclusions

A thorough analysis of papers on microplastics and heavy metal contamination from the Scopus database (2014-2024) reveals significant growth in research since 2018, particularly booming after 2021. Specifically, China and India play a crucial role in this research, actively contributing across environmental science, marine science,

engineering, and chemistry. Despite this, there is room for more global collaboration, as some countries work independently. This study emphasises key research areas such as quantification, traceability, and control, providing a guide to grasp the intricate link between microplastics and heavy metal pollution. It also identifies crucial research directions, aiding targeted resource allocation and effective problem-solving.

Moreover, the research promotes international collaboration, fostering partnerships between authors and countries, thus, strengthening global cooperation in managing marine and environmental pollution. Through analysing journal relevance and co-citation relationships, the study identifies influential publishing platforms, enhancing impact and visibility. In addition, this study offers a novel approach using bibliometric analysis to map the landscape of research on microplastics and heavy metals and to uncover trends in thematic progression, methodological evolution, and interdisciplinary approaches.

These unique insights distinguish this work from previous reviews and contribute significantly to the literature by revealing deeper patterns in research development and collaboration. It also provides insights for forming effective management policies and strategies. While current policies focus on reducing plastic waste and increasing recycling, it is recognised that these measures alone would not entirely solve plastic and marine litter issues. Therefore, future research should explore policy implications and technological innovation, emphasising the need for scientific and technological progress to support research on marine microplastic pollution.

This includes conducting risk assessments, developing removal technologies, addressing challenges in transitioning materials, promoting alternatives to plastics, and influencing production and consumption patterns. According to the results of bibliometric analysis, the systematic summary of information indicates that the study extensively explores the presence

of heavy metals cadmium, copper, and lead, investigated concurrently with the use of both microplastics PS and PE. Collectively, this comprehensive approach is vital for advancing scientific understanding and guiding the management of microplastic pollution in marine ecosystems, a crucial research topic.

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### Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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