International Conference on Biology Education, Natural Science, and Technology
Vol. 3 No. 1 (2025)
E-ISSN : 3026-5428

Microplastics in Aquatic Environments: A Systematic Review of Distribution and Biological Effects in Waters, Sediments, and Biota

Ni Putu Sri Ayuni[1]*, Ni Luh Watiniasih[2], I Wayan Budiarsa Suyasa[2], I Gede Hendrawan[2]
[1]Chemistry Departement, Faculty of Matematics and Natural Science, Ganesha University of Education, 81116, Indonesia
[2]Enviromental Science Department, Faculty of Postgraduate Program, Udayana University, 80114, Indonesia
*Corresponding Author. E-mail address: sri.ayuni@undiksha.ac.id

KEYWORDS:
Biota, freshwaters, microplastics, sediments, water.

ABSTRACT

Currently, the issue of microplastic pollution in aquatic ecosystems is a significant cause for worry. Microplastics, which are tiny pieces of plastic, are readily absorbed by freshwater organisms, leading to detrimental impacts on their growth, reproduction, predatory abilities, and other aspects. This study aims to review the scientific literature on microplastics in freshwater environments including waters, sediments, and biota in order to identify their existence and impact. For such, a systematic review was conducted, following the PRISMA guidelines, applying a descriptive and statistical analysis to the data. The original research articles in "microplastics in freshwaters". Up to 177 papers involving microplastic in freshwaters, published between 2013 and 2023, are identified in the Publish or Perish. Of the 177 articles, 66 are excluded because they include review articles. Finally, this review will to assess the excistence and influence microplastics in water, sediment and biota, in freshwater environmental.

1. INTRODUCTION

Plastic was originally discovered in the water in the 1930s [1]. Since their commercial introduction in the 1930s and 1940s, plastics have been increasingly prominent in the consumer sector. In 2012, global plastic resin output reached 288 million MT, a 620% increase since 1975. Packaging or products designed for immediate disposal, is the largest market segment for plastic resins. Plastics accounted for less than 1% of municipal solid garbage by mass in the United States in 1960; by 2000, this proportion had grown by an order of magnitude. Plastic accounted for at least 10% of solid trash by mass in 58% (61 out of 105) of nations with statistics available in 2005 [2]. Recent estimates of marine plastic debris range from approximately 243,000 metric tons (MT) on the ocean's surface to 4.8-12.7 million MT of plastic entering the ocean annually [2], [3]. Macroplastics (>5 mm diameter) were the focus of early investigations on marine plastic litter because they are easily visible and quantifiable. However, it was recently determined that macroplastics account only 10% of plastic debris in the ocean by count, showing that the vast majority of plastic debris is microplastic (5 mm diameter) [3].

Increased scientific interest in microplastics has resulted in an expanded knowledge base over the last decade. Microplastics are mostly made from anthropogenic materials, such as friction particles in cosmetics and microfibers in fabrics. Another important source of microplastics is the progressive breakdown of bulk plastics over time via mechanical abrasion or chemical processes [4], [5]. Microplastics are most abundant along beaches and in the oceans, but the fate of these microplastics is unknown. Thus, the current study focuses on the features and sources of microplastics, bioaccumulation in waters, sediment, and biota [6].

Although the precise definition of a microplastic varies, most believe that microplastics are described as 5 mm diameter bits of plastic [7], [8]. Microplastics can be discovered in surface water and the water column due to their different densities, while denser plastics, such as PVC, can be found in the sediment [7]. Because of their small size, microplastics are easily absorbed by a wide variety of animals [9]. Previous studies on microplastics used microplastic particulates with diameters of 60 m or less [10], [11], [12], [13], [14] [15], [16]. Plastics with densities greater than seawater (>1.02 g cm3) sink and settle in sediment, whereas low-density particles float on the sea surface or in the water column. Low-density plastics, on the other hand, can reach the seafloor through density modification [16].

Several factors contribute to the large number of microplastics in freshwater environments, namely the comparison of the human population compared to the number of water sources, location of urban centers, water residence time, size of water source, type of waste treatment, and number of drains [17]. The presence of microplastics in waters will enter water bodies and eventually settle in sediment [18]. The presence of microplastics in the freshwater can occur in several ways: (1) plastic fragmentation in the sea; (2) microplastics directly into the sea; (3) microplastics that are accidentally lost in the processing process; and (4) processing results in waste that is discharged into the environment [19].

2. MATERIALS AND METHODS

The protocol for this systematic review was developed using the standards outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Figure 1), which involves three distinct steps. The review protocol is outlined in S1 Protocol (http://prisma-statement.org/) [20]. The literature data on microplastics in freshwater were obtained from the Scopus database with Publish or Perish, which is known for its large coverage of scientific literature. This database is considered more complete and extensive than the Web of Science [21], [22]. In addition, Google Scholar was not utilized due to its lack of comprehensive data required for network research, such as the bibliometric approach [22].

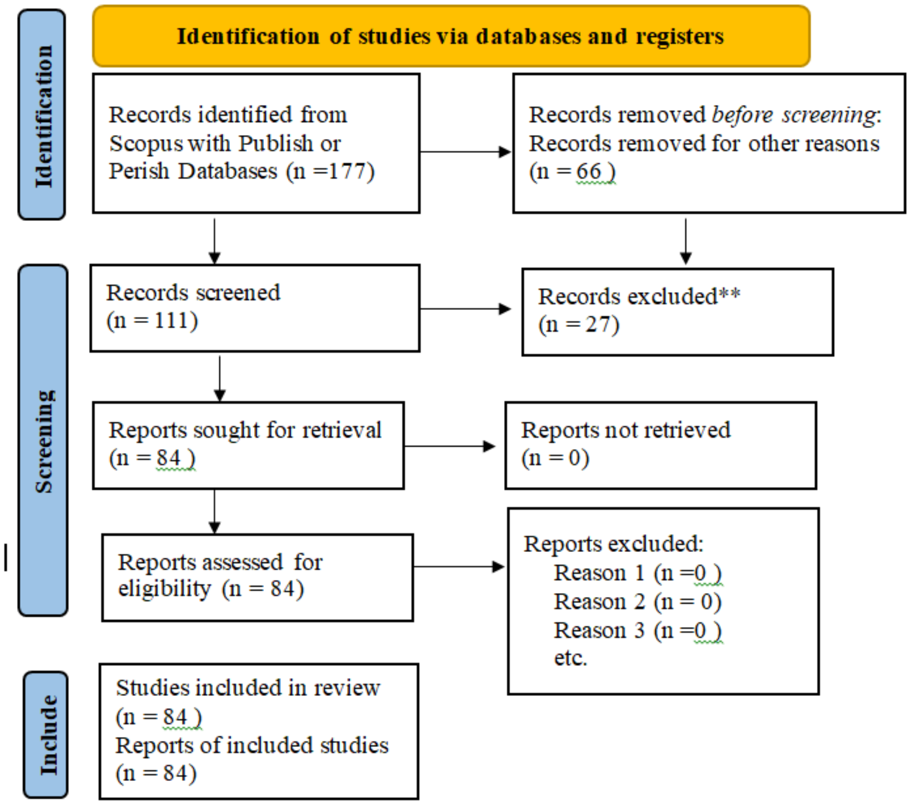

Fig.1. PRISMA Flowchart for The Keywords Used in The Literature Review: Microplastics AND Freshwater

We conducted a search in the Scopus database using the specified keywords: "microplastics" AND "freshwater". The scientific literature that was searched had any of these keywords, terms, or phrases in its title, abstract, or keywords. The analysis would be conducted on the whole texts that satisfied the eligibility criteria based on the specified inclusion and exclusion conditions. The inclusion criteria encompassed literature sourced from the Scopus database, specifically focusing on original articles or conference papers written exclusively in English. Additionally, the criteria required the studies microplastics in freshwater.

The terms that appeared in the title, abstract, and keywords of eligible literature were extracted and analyzed using VOSviewer software, and the findings were shown as bubble maps that indicated a term or phrase. The manual review was carried out in order to exclude generic or irrelevant phrases. The size of the bubble represented the number of terms found in the literature. The color of the bubble represented the number of citations per publication including the phrase, as well as the proximity of two bubbles if two terms occurred together more frequently [23].

3. RESULTS AND DISCUSSION

An examination of the most influential works and their network of co-citations The VOSviewer enabled the study of the most frequent occurrences of keywords in a particular collection of publications. VOSviewer mapped the authors' keywords in the title and abstract fields in this review. Figure 2 depicted a network map of keywords in which color, node sizes, font widths, and the thickness of connecting lines illustrated the interaction with other keywords [24].

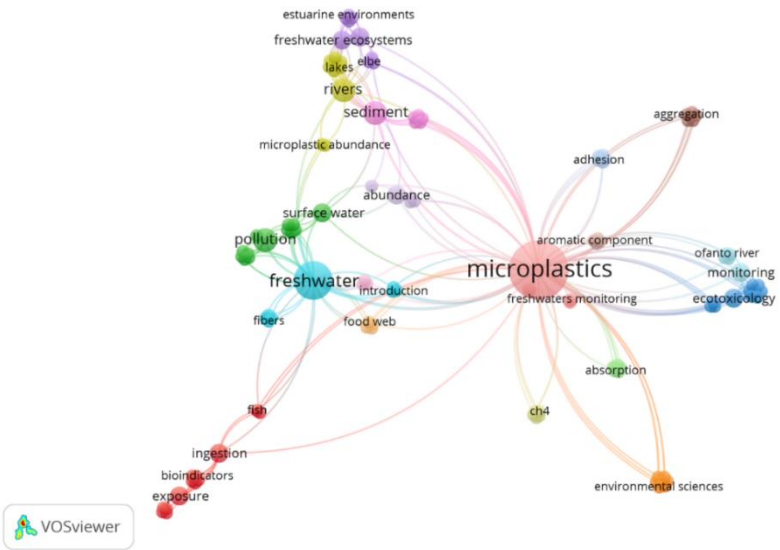

Fig.2 Keyword Co-Occurrence Network

Large-scale plastic waste is decomposed into secondary microplastics through processes in garbage disposal plants, wastewater treatment plants and the effects of photooxidative degradation in the environment. When plastic is processed in combustion, solid particles account for 30% and 50% of the exhaust gas. Through rainfall, surface water erosion, sedimentation, and other routes, microplastics enter the atmosphere, soil, water, and sediments. However, the proportion of microplastics entering each route is still unknown. The possibility of microplastic pathways entering freshwater ecosystems is shown in Figure 3 [25].

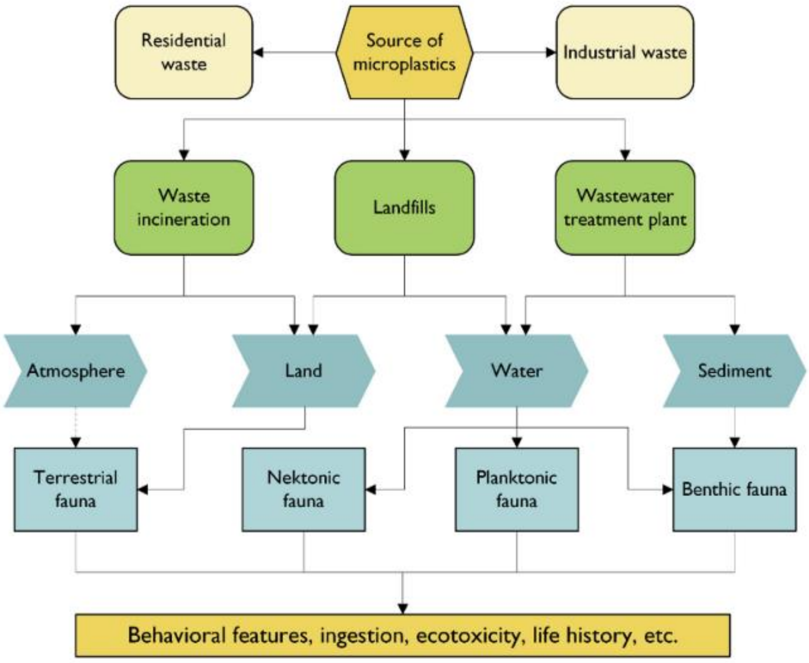

Fig. 3. Land-based sources, pathways into local freshwater ecosystems and relevant ecological effects of microplastics. The dotted line indicates a potential pathway that lacks direct evidence [25].

3.1. The Excistence Microplastics in Waters

Microplastics have been found in various places in the water column. Microplastics were found in all sampling sites, with abundances ranging from 8800 to 32,050 items/m^3, with a mean of 18,620 7120 items/m^3 [26]. Microplastic concentrations were higher in this urban reservoir than in other natural floodplain lakes along the Yangtze River basin, such as Tai Lake and Hong Lake in China [27], [28]. Microplastic concentrations in the Dafangying Reservoir were likewise substantially higher as compared to other non-urban area reservoirs [29]. The average amount of microplastics in freshwater was found to be 2753 (2173–3998) particles L^{-1}, whereas in treated distribution water and residential tap water, the average amounts were 351.9 (338–400) and 343.5 (267–404) particles L^{-1} [30]. With the exception of Las Vegas Wash, where the concentration was 9.7 particles/m^3, microplastic concentrations in water samples ranged from 0.44 to 1.99 particles/m^3 [31]. The Pearl River's waters are contaminated by microplastics. In the GUS, the microplastic abundance ranged from 8725 to 53,250 items/m^3, while in the PRE, it was between 7850 to 10,950 items/m^3 [32]. the Ofanto River has a large amount of microplastics, with values ranging from 0.9 ± 0.4 p/m^3 to 13 ± 5 p/m^3, which are comparable to or higher than those found in previous investigations topic [33].

3.2. The Excistence Microplastics in Sediments

Microplastic (MP) concentrations were determined, for the first time, in surface sediment of seven streams around the lagoon of Bizerte (Northern Tunisia) using a saturated NaCl flotation technique. The greatest MP abundance was observed at Jedara stream (6920 ± 395.98 items kg−1 dry weight), while the lowest mean value was 2340 ± 227.15 items kg−1 dry weight at Khima stream [34]. The total number of MPs of Zahuapan River, Atoyac River, Confluence Zone and Valsequillo Dam were 1633.34 ± 202.56; 1133.33 ± 72.76; 833. 33 ± 80.79; 900 ± and 346.12 units kg-1. MP concentrations were found to be higher in the downstream sections of the river confluence zone: ,833.33 ± 80.79 and Valsequillo dam: ,900 ± 346.12 units kg^{-1}). This is due to the influence of population density and rivers [35]. The concentrations of microplastics in surficial sediment samples were highest at Las Vegas Boat Harbor (440 particles/kg dw) and Gregg Basin

(1,010 particles/kg dw) [31]. Microplastics were present in all sediment samples from one tidal flat and six urban river sites, albeit in different amounts. In comparison to the tidal flat in Shanghai's rural districts, the amount of microplastics in rivers close to heavily inhabited areas was one to two orders of magnitude higher [25].

3.3. The Excistence Microplastics in Biota

Concerns regarding the persistence and complexity of microplastics in aquatic species have been raised by their discovery in freshwater systems. Although plastics are generally thought of as inert materials, it is unclear whether extended exposure to plastics combined with organic compounds can result in organism mortality. When consumed with another contaminant, microplastics can change the host microbiome apa saja, which can impact the fitness of the host organism [36]. In general, predictions about the percentage of freshwater and marine fish, non-urbanized versus urbanised streams, and trophic guilds that consume microplastics were supported. Within the modest range of reported plastic ingestion elsewhere [37], [38], the percentage of microplastic ingestion among freshwater fish (8%) and marine fish (10%) in the research area was observed. Fish consumption of microplastics in non-urbanized streams was found to occur in less than half as often (5%) as in one urbanised stream (the Neches River, at 29%). The percentage of microplastic ingestion in urbanised streams (estimates ranging from 6.8 to 29%) was comparable to those of other urbanised streams 2% (Sanchez et al., 2014). Only 8% of fish belonging to the pelagic habitat guild and 19% of fish belonging to the benthic habitat guild consumed microplastics in urbanised streams. Within non-urbanized streams and the maritime system (10–12%), benthic and pelagic guilds were similar (<6%), which is consistent with prior research that found no differences in habitat or trophic guilds [39].

Microplastics synthesis accelerates the ingestion of smaller microplastics particles and inhibits the ingestion of larger particles by the freshwater rotifer B. calyciflorus. Therefore, variation in microplastics size may lead to increased interactions between smaller particles and aquatic consumers. To test the response of aquatic organisms to microplastics, it is essential to account for increases or decreases in microplastic ingestion [40]. The presence of microplastics and other anthropogenic materials at three trophic levels of the freshwater food web in an elevated lake in the national park, supporting studies recently revealed the global distribution of microplastics [41].

Microplastics were present in the digestive tracts of two different species of fish from a small lowland river in southwest Poland, the Widawa R. 202 gudgeons and 187 roaches in total were gathered; of these, 54.5% and 53.9%, respectively, had consumed microplastics-like particles. The quantity of fish with microplastics-like particles was unaffected by the type and behavior of feeding, sex, or the location of the capture (above or below the dam reservoir) Beratan [42]. Taihu Lake's organisms included large concentrations of microplastics in addition to the water. As far as we are aware, Taihu Lake has the highest microplastic concentrations in plankton net samples of any freshwater lake in the world. We must remain vigilant regarding the microplastic pollution in Taihu Lake and the potential connection to health hazards to humans from eating fisheries products. We suggest that the common Asian clam could be a valuable bio-indicator for freshwater and estuary microplastic pollution [27].

3.4. Types of Microplastics in Freshwater

Microplastic in surface sediment of seven streams around the lagoon of Bizerte (Northern Tunisia) are observed. The highest numbers of microplastics were from streams near populated areas and municipal and industrial effluent discharges. Samples were made up entirely of secondary microplastics mainly fibres, followed by fragments and films. The predominant colours were as follows: black > clear > white > red > blue > green > yellow for fibres, white > blue > black > red for fragments and red > white > clear > green > blue = black for films. Microplastic particles in the samples ranged from 0.2 to 5 mm in length [34]. Particles with sizes between 0.30

and 1.00 mm were the most common, followed by particles with sizes between 0.15 and 0.30 mm and particles with sizes less than 0.15 mm. By sample sites, microfragments were the most prevalent overall. Nonetheless, there was no discernible variation in the quantity of shards, coatings, and fibers found in the two rivers. On the other hand, one Tom River sample site had a noticeably greater quantity of spheres known as microbeads [43].

Colored MPs sediment sample in Atoyac River Basin were predominant accounting for 51% and white microplastics for 49% of the total microplastics. films (25.9%) and fragments (22.2%) were the most abundant type followed by fibers (14.8%) [35]. In the Las Vegas Boat Harbor, tires are widely employed as boat bumpers and to create a substantial floating breakwall that encircles the harbor, measuring about 1.5 km in length. 36.3% of the measured particles were in the 1,000–5,600 μm size range, while the majority (63.7%) were in the 355–1,000 μm range. In surficial sediment samples, the most common hues of microplastic particles were red (6.5%), blue (24.3%), black (26.2%), and clear (37.8% on average) [31]. The characteristics of microplastics in Shanghai's rivers were not the same as those in the tidal flat. In all river samples, the bulk of microplastics were white spheres; however, in the tidal flat, the proportion of fibers and pieces was greater than that of spheres [25].

The detected large numbers of PS (or PS-DVB) spheres in the sediment sample directly downstream of the Mulde confluence only. Although a clear identification of possible source area(s) remains challenging, the distribution pattern suggest that the Mulde contributes microplastics (especially spheres) to the Elbe [44]. Microplastics were discovered to be present in freshwater gastropods (F. *sumatrensis speciosa* and P. *canaliculata*) from the U-Taphao Canal that were sold for human consumption. Fibers were the most prevalent kind of MP discovered. The results demonstrated the wide variation in form, size, and polymer type among the MPs identified for P.*canaliculata* [45](Jitkaew et al., 2023).

In fish samples at Las Vegas Bay, fibers accounted for 90.7% of all microplastic particles on average. In fish samples, the most common hues of microplastic particles were red (9.3%), blue (29.5%), black (17.1%), and clear (37.2% on average).

3.5. The Influence Microplastics in Freshwaters

Microplastics, which are tiny plastic particles less than 5 millimeters in size, have gained significant attention due to their widespread presence and potential environmental impact, especially in freshwater ecosystems. These microplastics can originate from various sources such as the breakdown of larger plastic debris, microbeads in personal care products, synthetic textiles shedding fibers, and more [46].

In freshwater environments, microplastics can have several detrimental effects:

1. Water Quality: They contribute to water pollution, altering the chemical composition of the water and affecting its quality. Microplastics can absorb and concentrate toxic pollutants from the surrounding environment, potentially impacting aquatic life (Aryani et al., 2021; Buwono et al., 2021).
2. Ecosystem Disturbance: Microplastics can harm aquatic organisms directly or indirectly. Small organisms may mistake microplastics for food, leading to ingestion. This can cause physical harm, blockage of digestive systems, reduced feeding capacity, and even death. (Li et al., 2022; Neelavannan & Sen, 2023)
3. Habitat Alteration: Accumulation of microplastics in freshwater habitats can alter the natural habitats and ecosystems. They can settle in sediments, affecting the nutrient cycling and potentially disrupting the balance of these ecosystems (Issac & Kandasubramanian, 2021; Qaiser et al., 2023; Rosvita et al., 2018).
4. Human Health Concerns: There are concerns about the potential health impacts of microplastics on humans. While research is ongoing, there's evidence suggesting that microplastics can enter the food chain and subsequently be consumed by humans through

contaminated water and food, though the full extent of these risks is still being studied. Fish may be exposed to hazardous microorganisms and toxic compounds through MPs. People are exposed to plastic particles and eat fish polluted with plastic. People experience the consequences of multiple outbreaks of chronic illnesses (Curtean-Bănăduc et al., 2023; Fuschi et al., 2022; Jitkaew et al., 2023; Watiniasih et al., 2023).

4. CONCLUSION

This systematic review highlights the widespread occurrence and significant ecological impacts of microplastics in aquatic environments, encompassing surface waters, sediments, and various aquatic organisms. Evidence across multiple studies demonstrates that microplastics are now pervasive contaminants, transported through complex environmental pathways and capable of persisting in ecosystems for extended periods. In water bodies, microplastics influence physical and chemical properties, while in sediments, they alter benthic habitat structures and nutrient cycles. Their ingestion by aquatic biota including invertebrates, fish, and even top predators poses serious biological risks such as oxidative stress, inflammation, and disruption of feeding and reproductive behaviors. Moreover, microplastics serve as vectors for other pollutants, amplifying their toxicological impact. Despite growing awareness, data gaps remain regarding long-term ecological consequences, especially in understudied regions and taxa. Future research should focus on standardized methods for sampling and analysis, deeper investigation of trophic transfer mechanisms, and the integration of microplastic monitoring into environmental policy frameworks.

5. REFERENCES

[1] C. W. Fowler. Marine debris and northern fur seals: A case study. *Mar. Pollut. Bull.* **18**. 6 (1981). 326–335. doi: 10.1016/S0025-326X(87)80020-6.

[2] J. R. Jambeck *et al.* Plastic waste inputs from land into the ocean. New York. **(2015)**. [Online]. Available: http://www.sciencemag.org/cgi/doi/10.1126/science.1260879%250Ahttps://www.sciencemag.org/lookup/doi/10.1126/science.1260352

[3] M. Eriksen *et al.* Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea. *PLoS One*. **9**. 12. (2014).1–9 doi: 10.1371/journal.pone.0111913.

[4] S. Lambert and M. Wagner. Exploring the effects of microplastics in freshwater environments. *Integr. Environ. Assess. Manag.***12**. 2. (2016). 404–405. doi: 10.1002/ieam.1754.

[5] A. Paço *et al.* Biodegradation of polyethylene microplastics by the marine fungus Zalerion maritimum. *Sci. Total Environ.* **586**. (2017). 10–15. doi: 10.1016/j.scitotenv.2017.02.017.

[6] S. Mehra, K. Sharma, G. Sharma, M. Singh, and P. Chadha, *Sources, Fate, and Impact of Microplastics in Aquatic Environment*. IndotechOpen. **(2021)**. doi: 10.5772/intechopen.93805.

[7] A. Abel, W. Kloas, C. Zarfl, S. Hempel, and M. C. Rillig. Microplastics as an emerging threat to terrestrial ecosystems. *Glob. Chang. Biol*. 24. 4. (2018). 1405–1416. doi: 10.1111/gcb.14020.

[8] N. Dikareva and K. S. Simon. Microplastic pollution in streams spanning an urbanisation gradient. *Environ. Pollut.* **250**. (2019). 292–299. doi: 10.1016/j.envpol.2019.03.105.

[9] D. K. A. Barnes, F. Galgani, R. C. Thompson, and M. Barlaz. Accumulation and fragmentation of plastic debris in global environments. *Philos. Trans. R. Soc. B Biol. Sci.* **364**. 1526 (2009). 1985–1998. doi: 10.1098/rstb.2008.0205.

[10] H. S. Jung, D. Lim, D. H. Jeong, Z. Xu, and T. Li. Discrimination of sediment provenance in the Yellow Sea: Secondary grain-size effect and REE proxy. *J. Asian Earth Sci*. **123**. (2016). pp. 78–84. doi: 10.1016/j.jseaes.2016.03.020.

[11] Y. Jin, J. Xia, Z. Pan, J. Yang, W. Wang, and Z. Fu. Polystyrene microplastics induce microbiota dysbiosis and inflammation in the gut of adult zebrafish. *Environ. Pollut.* **235.** (2018). 322–329. doi: 10.1016/j.envpol.2017.12.088.

[12] A. Karami, N. Romano, T. Galloway, and H. Hamzah. Virgin microplastics cause toxicity and modulate the impacts of phenanthrene on biomarker responses in African catfish (Clarias gariepinus). *Environ. Res.* **151**. (2016). 58–70. 2016. doi: 10.1016/j.envres.2016.07.024.

[13] L. Lei *et al.* Microplastic particles cause intestinal damage and other adverse effects in zebrafish Danio rerio and nematode Caenorhabditis elegans. *Sci. Total Environ.* **619–620**. (2018). 1–8. doi: 10.1016/j.scitotenv.2017.11.103.

[14] M. A. Oliver. Precision agriculture for sustainability and environmental protection. *Precis. Agric. Sustain.*

Environ. Prot. **2** (2013).1–283. doi: 10.4324/9780203128329.
[15] C. M. Rochman, E. Hoh, T. Kurobe, and S. J. Teh. Ingested plastic transfers hazardous chemicals to fish and induces hepatic stress. *Sci. Rep.* **3**. (2013). November doi: 10.1038/srep03263.
[16] L. Van Cauwenberghe and C. R. Janssen. Microplastics in bivalves cultured for human consumption. *Environ. Pollut.* **193. (2014).** 65–70. doi: 10.1016/j.envpol.2014.06.010.
[17] C. J. Moore, G. L. Lattin, and A. F. Zellers. Quantity and type of plastic debris flowing from two urban rivers to coastal waters and beaches of Southern California. *Rev. Gestão Costeira Integr.* **11.** (2011), no. 1, pp. 65–73, 2011, doi: 10.5894/rgci194.
[18] S. Wright, R. C. Thompson, and T. Galloway. The physical impacts of microplastics on marine organisms: a review. *Environ. Pollut.***178**. (2013). 483–492. doi: 10.1016/j.envpol.2013.02.031.
[19] A. Anderson, J. E. Baker, A. L. Andrady, and H. Bouwman. Sources, fate and effects of microplastics in the marine environment: a global assessment. **2015**. doi: 10.13140/RG.2.1.3803.7925.
[20] D. Moher, A. Liberati, J. Tetzlaff, and D. G. Altman. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *BMJ*. **339**. (2009).. 332–336. doi: 10.1136/bmj.b2535.
[21] U. Bamel, S. Kumar, W. M. Lim, N. Bamel, and N. Meyer. Managing the dark side of digitalization in the future of work: A fuzzy TISM approach. *J. Innov. Knowl.* **7**. (2022). 4. 100275, 2022, doi: 10.1016/j.jik.2022.100275.
[22] F. Khitous, F. Strozzi, A. Urbinati, and F. Alberti. A systematic literature network analysis of existing themes and emerging research trends in circular economy," *Sustain.* **12**. (2020). 4. doi: 10.3390/su12041633.
[23] K. Hafezad Abdullah. Publication Trends of Leadership Excellence: A Bibliometric Review Using VOSviewer. *Adv. Bus. Res. Int. J*. 7. (2021). 1.
[24] W. M. Sweileh, S. W. Al-Jabi, A. S. AbuTaha, S. H. Zyoud, F. M. A. Anayah, and A. F. Sawalha. Bibliometric analysis of worldwide scientific literature in mobile - health: 2006-2016. *BMC Med. Inform. Decis. Mak.* **17**. (2017). 1. 1–13. doi: 10.1186/s12911-017-0476-7.
[25] G. Peng, P. Xu, B. Zhu, M. Bai, and D. Li. Microplastics in freshwater river sediments in Shanghai, China: A case study of risk assessment in mega-cities. *Environ. Pollut.* **234**. (2018). 448–456. doi: 10.1016/j.envpol.2017.11.034.
[26] Y. Chen *et al.* Microplastics pollution in the soil mulched by dust-proof nets: A case study in Beijing, China. *Environ. Pollut.* **275**. (2021). 1–8. doi: 10.1016/j.envpol.2021.116600.
[27] L. Su *et al.* Microplastics in Taihu Lake, China. *Environ. Pollut.* **216**. (2016). 711–719. doi: 10.1016/j.envpol.2016.06.036.
[28] W. Wang, W. Yuan, Y. Chen, and J. Wang. Microplastics in surface waters of Dongting Lake and Hong Lake, China. *Sci. Total Environ*. **633**. (2018). doi: 10.1016/j.scitotenv.2018.03.211.
[29] X. Wu. Humic Acid and Fulvic Acid Hinder Long-Term Weathering of Microplastics in Lake Water. *Environ. Sci. Technol.* **55**. (2021). 23. 15810–15820. doi: 10.1021/acs.est.1c04501.
[30] M. Shen. Smoked cigarette butts: Unignorable source for environmental microplastic fibers. *Science of the Total Environment*. **791**. (2021). doi: 10.1016/j.scitotenv.2021.148384.
[31] A. K. Baldwin, A. R. Spanjer, M. R. Rosen, and T. Thom. Microplastics in Lake Mead National Recreation Area, USA: Occurrence and biological uptake. *PLoS One*. **15**. (2020). 5. 1–20. doi: 10.1371/journal.pone.0228896.
[32] M. Yan *et al.* Microplastic abundance, distribution and composition in the Pearl River along Guangzhou city and Pearl River estuary, China. *Chemosphere*. **217**. (2019). 879–886. doi: 10.1016/j.chemosphere.2018.11.093.
[33] C. Campanale, C. Massarelli, and G. Bagnuolo. The Problem of Microplastics and Regulatory Strategies in Italy. *Handb. Environ. Chem.* **112**. (2019). 255–276. doi: 10.1007/698_2019_419.
[34] H. Toumi, S. Abidli, and M. Bejaoui. Microplastics in freshwater environment: the first evaluation in sediments from seven water streams surrounding the lagoon of Bizerte (Northern Tunisia). *Environ. Sci. Pollut. Res*. **26**. (2019). 14673–14682. doi: 10.1007/s11356-019-04695-0.
[35] V. Shruti, M. P. Jonathan, P. F. R. Espinosa, and F. R. Gonzalez. Microplastics in freshwater sediments of Atoyac River basin, Puebla City, Mexico. *Sci. Total Environ.* **654**. (2019). 154–163. doi: 10.1016/j.scitotenv.2018.11.054.
[36] J. E. Varg and R. Svanback. Multi stress system: Microplastics in freshwater and their effects on host microbiota. *Sci. Total Environ.* 856. (2023). 1–10. doi: 10.1016/j.scitotenv.2022.159106.
[37] D. V. Dantas, M. Barletta, and M. F. da Costa. The seasonal and spatial patterns of ingestion of polyfilament nylon fragments by estuarine drums (Sciaenidae). *Environ. Sci. Pollut. Res*. **19**. (2012). 2. doi: 10.1007/s11356-011-0579-0.
[38] F. E. Possatto, M. Barletta, M. F. Costa, J. A. Ivar do Sul, and D. V. Dantas. Plastic debris ingestion by marine catfish: An unexpected fisheries impact. *Mar. Pollut. Bull.* **62**. (2011). 1098–1102. doi: 10.1016/j.marpolbul.2011.01.036.
[39] C. M. Boerger, G. L. Lattin, S. L. Moore, and C. J. Moore. Plastic ingestion by planktivorous fishes in the North Pacific Central Gyre. *Mar. Pollut. Bull*. **60**. (2010). 12. 2275–2278, 2010, doi: 10.1016/j.marpolbul.2010.08.007.
[40] C. Drago, J. Pawlak, and G. Weithoff. Biogenic Aggregation of Small Microplastics Alters Their Ingestion by a Common Freshwater Micro-Invertebrate. *Front. Environ. Sci.* **8**. (2020). 1–11. doi: 10.3389/fenvs.2020.574274.
[41] S. C. Driscoll. Presence of microplastics in the food web of the largest high-elevation lake in north america. *Water*

(Switzerland). **13**. (2021). 3. 2–8. doi: 10.3390/w13030264.
[42] N. Kuśmierek and M. Popiolek. Microplastics in freshwater fish from Central European lowland river (Widawa R., SW Poland). *Environ. Sci. Pollut. Res*. **27**. (2020).10. 11438–11442, 2020, doi: 10.1007/s11356-020-08031-9.
[43] Y. A. Frank *et al.* Preliminary screening for microplastic concentrations in the surface water of the ob and tom rivers in Siberia, Russia. *Sustain*. **13**. (2021). 1–14. doi: 10.3390/su13010080.
[44] H. Laermanns *et al.* Microplastic in Water and Sediments at the Confluence of the Elbe and Mulde Rivers in Germany. *Front. Environ. Sci*. 9. (2021). 1–11. doi: 10.3389/fenvs.2021.794895.
[45] P. Jitkaew *et al.* Occurrence of microplastics in freshwater gastropods from a tropical river U-Taphao, southern Thailand. *PeerJ*. **11**. (2023). doi: 10.7717/peerj.14861.
[46] T. Atugoda, H. Piyumali, and S. Liyanage, *Handbook of Microplastics in the Environment*, no. January. Switzerland AG: Springer Nature Switzerland. **(2020)**. doi: 10.1007/978-3-030-10618-8.