A graphic review of studies on microplastic in water

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Vol. 33.1 / 2023, 85-94

Published:

25 September 2023

DOI:

10.4316/GEOREVIEW.2023.01.08

ABSTRACT: There are thousands of scientific studies that deal directly or indirectly with the microplastic in water, from tap water to seawater. The aim of this study is to find the main research interests in the specific scientific literature, based on its most frequent words and by using graphical representations to better understand their linkage. Of interest for most studies are some details or processes around which similar groups of articles are written: the identification of the microplastic type (based on various criteria such as shapes, size, color or chemical composition (e.g.: polypropylene, polystyrene, polyethylene, polyester), the microplastic removal mechanisms (under natural conditions, through deposition, or at wastewater treatment plants), the degree of microplastic contamination in the aquatic environment (e.g.: in oceans or in rivers), the effects of microplastic pollution on various organisms, especially marine life and humans, after microplastic ingestion or food chain alteration. There are already hundreds of reviews that analyze articles dealing directly or indirectly with the problem of microplastics in water; these reviews are interested mostly in defining microplastic categories, abundance, sources and impact. Also, the reviews highlight the need to standardize the sampling and pretreatment methods used when measuring the concentration of microplastics in order to obtain comparable results.

KEY WORDS: bibliometric analysis, cluster, microplastic varieties.

1. Introduction

Microplastic is a microscopic plastic (solid material) produced as good or waste by humans and acts as a pollutant in the natural environment, affecting humans both indirectly, by altering environmental conditions (Koelmans et al., 2019), and directly by entering into the human body (Leslie et al., 2022). A widely accepted definition of microplastic has yet to be created, and the definitions of microplastic based on its size can vary broadly: ISO standards specify the interval 1 µm – 1 mm (I.S.O., 2020), while United Nations admit larger particles, of 5 mm or less (U.N.E.P., 2015). Plastic debris is often categorized as macroplastic (such as plastic bottles, some pieces of ropes or nets), mesoplastic, microplastic and nanoplastic (Allen et al., 2022).

Plastic waste is degraded over time by UV photooxidation, mechanic stress and biodegradation (Gewert et al., 2015). The number of microplastics increases in time as their size decreases because they originate from the fragmentation of bigger plastics and because more and more plastic waste is created every day. The plastic material decomposes into a different matter during several decades or hundreds of years, depending on environment (Hoornweg and Bhada-Tata, 2012). Because plastic from various products in use or in waste degrades, plastic microparticles (as secondary plastic – not intended by humans) are continuously generated in populated spaces, especially in landfills with no sorting policies or in waste water (both treated and untreated). Water behaves as both a transporter and a collector of microplastics – the water cycle is the mechanism that collects plastic from higher elevations and dumps it into the seas. Concentrations of microplastics in water vary greatly depending on the characteristics of many environmental factors and pollution sources, often from one piece to several thousand pieces per cubic meter when comparing different regions (e.g., seas) or even the same region during different months (Kye et al., 2023). These values are increasing over time due to the explosion of plastic use around the world in the last quarter of a century.

The aim of this study is to investigate the recurrent themes and key words in geoscience studies that directly or indirectly deal with microplastics in water and to provide some graphical representation of their relevance and relationships.

2. Method

The beginning of the XXIst century marked the articles about microplastics in water as research that is of urgent need not only for scientists, but also for the society itself. This kind of articles started being produced en masse (from tens and hundreds of articles to over one thousand articles per year) approximately ten years ago. The scientific literature on microplastics in water already contains thousands of specialized studies that address the problem of microplastics directly or indirectly.

The bibliometric analysis is today a powerful method to sample details from the scientific literature by using dedicated software and the very large databases of the published scientific articles (Vasconcelos et al., 2023). A bibliometric analysis can provide some quantitative data on the aspects that are frequent in the scientific research (e.g., spaces of interest, dominant research direction, research methods). VOSviewer, created by Van Eck and Waltman (2010) - https://www.vosviewer.com, is a software that is often used in the bibliometric analysis of studies in geosciences (Herrera-Franco et al., 2022) and generates bibliographic diagrams, named co-frequency maps, of most frequent terms in a database of scientific articles, and the terms are grouped based on their co-occurrence.

In the present study, VOSviewer was used to statistically analyze terms extracted from the title and abstract of the 3432 scientific articles from the Web of Science Core Collection database (https://webofscience.com) that contain the terms "microplastic" and "water" (articles available on May 9th, 2023) and which were included in the following Web of Science categories: Water Resources, Oceanography, Limnology and Environmental Sciences. The types of articles taken into account were "article" (original research) and "review article".

The terms used in the abstracts and titles were considered common if their minimum frequency was 10 occurrences in the selected dataset (except for the analyzes on review-type articles for domains directly related to water, where the minimum frequency was 3 because the number of papers was small – tens of articles only). The counting of the common terms in these papers was binary (their presence or absence per article). The first 60% most relevant/used terms were selected for graphical representation. The grouping of terms in a cluster was achieved if the co-occurring terms were at least 10 per cluster.

The visualization scale was set to the maximum available value, 2, weighted by frequency (graphically exaggerating the importance of more relevant terms to highlight them). Labels/names in graphs/maps have a maximum size variation of 1 (only when analyzing all article types from all domains, the value 0.5 was used to reduce the graphical underrepresentation of secondary terms).

The list of terms selected for the graphs was filtered to exclude non-representative items such as: vague or contextless comparison terms (e.g.: min, semi, total, top), measurement units (e.g.: mg/L), enumeration indicators (e.g.: III, literature), narrative terms (e.g.: present study, research effort, current knowledge), simple default terms (e.g.: work, review, data, stations, author, site), terms that indicate sub-methods of an already listed method (e.g.: submethods of F.T.I.R. - Fourier Transform InfraRed).

There are many measurements units (more than 10) used to count the amount of microplastic pieces in water, such as items per liter or particles per square meter (or per km^2), mostly dependent on the sampling method, but the emerging standard unit is n/m^3, counting items per a reasonably big volume (Chen et al., 2020a; Szymańska and Obolewski, 2020).

3. Results and discussion

The co-occurrence maps were made on the basis of 2 collections of scientific works: the first collection included original research and review articles; the second collection included only review articles. Each collection was analyzed on an additive basis: the articles in Water Resources were analyzed first, then those in Oceanography and Limnology were added to the first ones and analyzed together and, finally, the articles in Environmental Sciences were added to the entire group for a total analysis.

3.1. Original research and review articles

From the first collection of papers, articles published in fields that are directly related to water (583 articles: Water Resources – 478 articles, Oceanography and Limnology) have major research interests such as (Fig. 1a,b):

- the effects of microplastic pollution, especially in terms of affecting the organisms of various living species - processes and elements frequently invoked in this case are related to ingestion, adsorption, heavy metals and the formation of biofilms. Plastics enter in marine animal species either directly or through smaller organisms, such as fish, shrimps, oysters/mussels and even zooplankton (Zara et al., 2022). The polymers that constitute the microplastics have carcinogenic effect (Lithner et al., 2011).
- the abundance of microplastic in water, especially seawater, the variation of concentration in the water column, the mechanisms of microplastic formation and the forms in which the various plastic fragments can be found. Microplastics are in many sizes and shapes: fragments, foams, microbeads, films or fibers. Fibers are very frequent, being originated in the tear and wear of various fishing materials (such as ropes or nets) and especially from terrestrial sources (such as from washing most clothes) (Cesa et al., 2017). Industrial wastewater may be rich in granule microplastic (Long et al., 2019). Industrial and commercial areas are important sources of microplastics due to various processes that involve transforming, packaging and unpackaging various materials.

- the microplastic pollution carried out by means of wastewater, treated or not, that passes through treatment plants and the identification of an efficient method of reducing this pollution with the help of treatment plants. It is estimated that fibers represent the most part of the microplastic in urban wastewater and partly remains in sludges that may then be used in agriculture (Edo et al., 2020), leading to the contamination of soils. The microplastic removal efficiency from wastewaters vary depending on the techniques used and the size and shape of the microplastic items.
- the chemical composition of the microplastic. At the ocean surface, microplastic is represented by particles made of polyethylene (PE) and polyethylene terephthalate (PET) from fishing tools and mariculture materials; mariculture is also source of polystyrene (PS), foamed polystyrene (FPS), polypropylene (PP), polyester (PES) and synthetic rubber (Chen et al., 2018, 2020b; Kozak et al., 2021); polyamide/nylon (PA)-based microplastic pollution is caused by some packaging, clothing and fishing materials, while microplastic from rubber is caused by car tires (Yan et al., 2019; Ory et al., 2020). Cigarettes contain cellulose acetate (CA) and their disposal after use contributes to microplastic pollution. PE is used as material in food recipients, bottles and bags; PP is used like PE, but also in pipes and carpets. PE and PET are the most frequent material of microplastic items in wastewaters (Lares et al., 2018).

When analyzing all types of articles from all selected fields (3432 articles, including Environmental Sciences), one can observe a split of the research core into 2 large groups (Fig. 1c) that are focused on (1) the identification of physical types of microplastics in the marine environment and on (2) the effect of microplastics on aquatic life; topics of less or more specific interest are related to the removal of microplastics and the effect of microplastics on fish.

Plastic garbage and fragments from terrestrial sources may constitute up to 90% of the total plastic in seas (Gallo et al., 2018), and this represents the reason why there is a focus today on microplastic removal from urban wastewaters. Due to the inland origin of microplastic particles, the concentrations of microplastic in the seawater is higher nearshore, in estuaries and in semi-enclosed aquatories (Zhang et al., 2020a,b). Microplastic concentrations along shores may be lowered by ocean/marine currents, which carry the debris into the high seas or in the inner waters of the ocean gyres (Jiang et al., 2020; Wang et al., 2020).

Because microplastics tend to settle over time, many particles are deposited in marine sediments. Due to their recent formation, microplastics in marine sediments are found at shallow depth (Martin et al., 2017). They are accessible to the aquatic biota, and benthic species will interact more with microplastics than pelagic species.

Microplastics are found not only at the surface or the bottom of the water bodies, but also at various depths depending on the distribution of water layers with different densities due to factors such as salinity or temperature (Uurasjärvi et al., 2021). Plastic items have different densities compared to water (higher or lower than) depending on their different chemical composition and may be found below surface and above the bottom if denser waters allow them to stay suspended inside the water body.

Water turbulence and mixing favor the resuspension of high density microplastics. Water dynamics that contribute to this are: tides, waves and currents. Storms do not only stir coastal waters, but also may also produce runoff that collects plastics from the land surfaces; the flowing water in riverbeds also displaces downward microplastics from alluvia (Hurley et al., 2018).

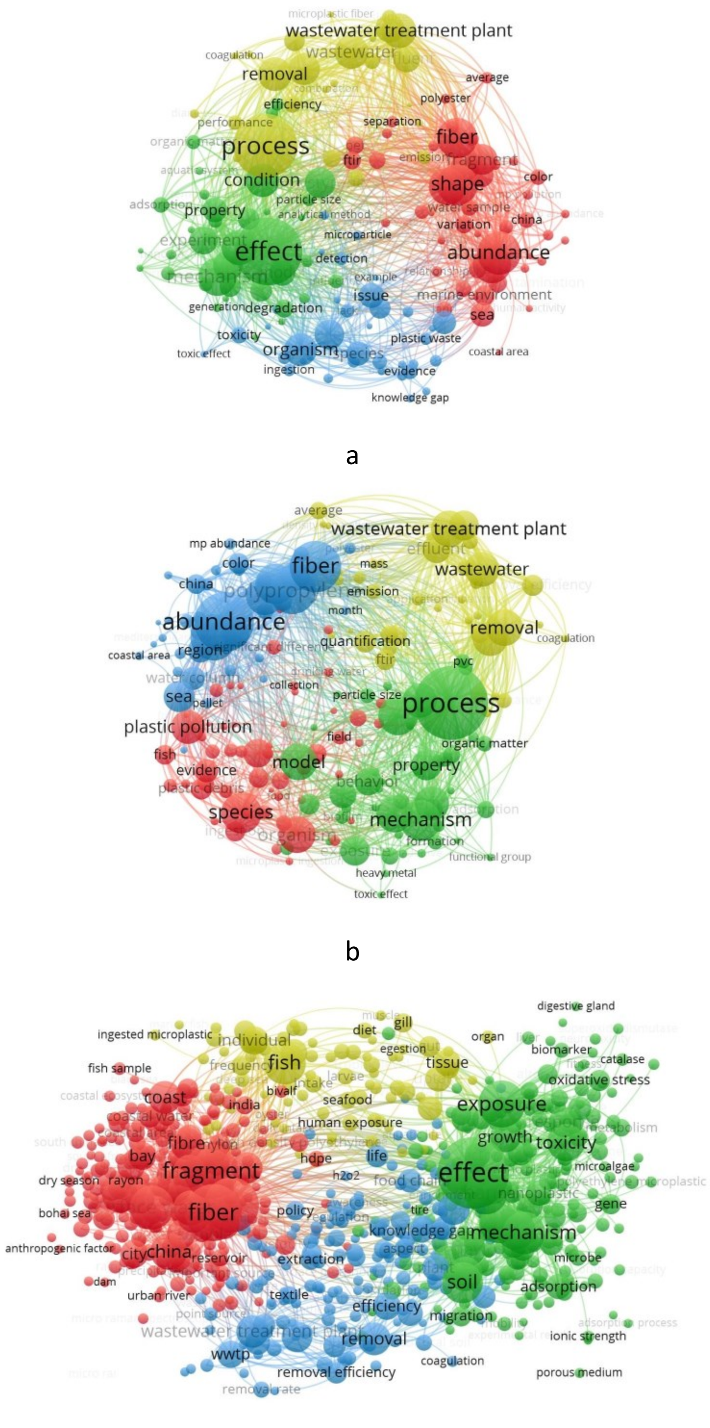


Figure 1 Bibliographic diagrams/co-occurrence maps of various terms from the scientific articles of original research and review types published in the categories: a. Water Resources; b. Water Resources, Oceanography and Limnology; c. previous categories and Environmental Sciences (lines indicate links, colors indicate groups).

Many microplastic particles are small enough to be a persistent atmospheric pollutant in populated areas and are found in raindrops (Abbasi, 2021) or, after being transported over large distances from pollution sources, in glaciers (Stefánsson et al., 2021). The small size of some particles often helps them enter into the groundwater (Viaroli et al., 2022). The contamination of drinking water (bottled or tap) with microplastics is no longer something rare or negligible (Kirstein et al., 2021).

Due to the high number of researchers interested in microplastic pollution, China is the most studied area in studies about microplastics in water (Figure 1b,c), especially regarding seawater and freshwater. European states, USA, Canada and Australia prevail in studies about wastewater and microplastic (Kye et al., 2023).

3.2. Review articles

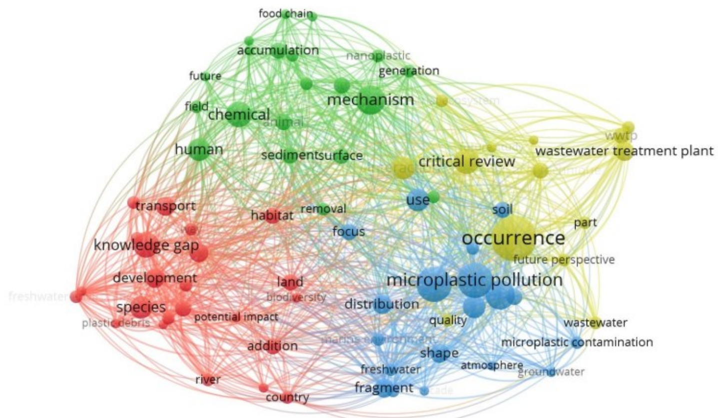
From the second collection of papers, one can notice, in the case of articles published in fields that are directly related to water (53 articles: Water Resources – 45 articles, Oceanography and Limnology; Fig. 2a,b) a lot of attention given to the fact that there are still not enough studies to fully understand the extent of microplastic pollution, mostly the mechanisms of microplastic transport and accumulation, and its wide impact.

Reviewers highlight the necessity to standardize the methods used in analyzing microplastics in water (Szymańska and Obolewski, 2020; Kye et al., 2023) – this unregulated field of research has as symptom his high number of measurement units for the same parameter. Microplastic counting may be biased due to various factors. More particles may be added in samples by air pollution and less particles may be collected by some techniques. The methods of water sampling for microplastic analysis are represented mainly by using a net to capture particles from the surface layer of a water body (advantage: covers large surfaces; disadvantage: depends on the net openings size) or by using a pump to extract water from various depths (filters large volumes of water, but difficult to move to different locations) or by filtering/sieving small volumes of water (higher precision, but lower spatial relevance) (Prata et al., 2019). After sampling, a pretreatment method is often necessary, especially where aquatic microorganisms are abundant; the pretreatment involves two significant steps: the digestion of the organic matter (usually using H_2O_2) and the density separation of plastics (usually using NaCl to increase water density) from the removed organic matter (Kye et al., 2023).

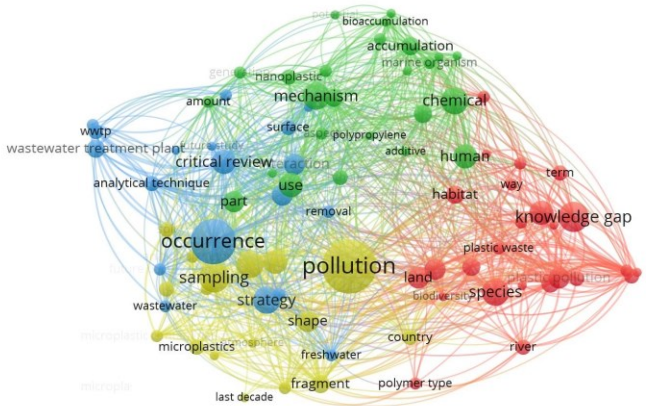
The counting of plastic particles is done using mostly a simple optical microscope or various F.T.I.R. or Raman spectroscopy methods (Prata et al., 2019). Often, sampling various materials containing plastics is necessary (alongside the use of data libraries) in order to discover the origin of the multitude of microplastics in water.

PE and PP have density/specific gravity lower than water (fresh or marine) and tend to float; PET, polyvinyl chloride (PVC) and cellophane have higher density compared to water and sink in water bodies (Kye et al., 2023).

The extensive use of NaCl in the separation method leaves high density microplastics not taken into account; also, the solutions used in the digestion method may alter the color of the particles – the color is often used to do some statistics and deduce their provenience. Microplastic that is less dense than water floats for variable periods ranging from a few months to a few years until biological contaminations make plastic sink (Kozak et al., 2021). The biofouling and accumulation of organic waste are reducing the buoyancy of microplastics (Cole et al., 2016; Rummel et al., 2017). FPS that has been weathered will sink as it will lose porosity.



a



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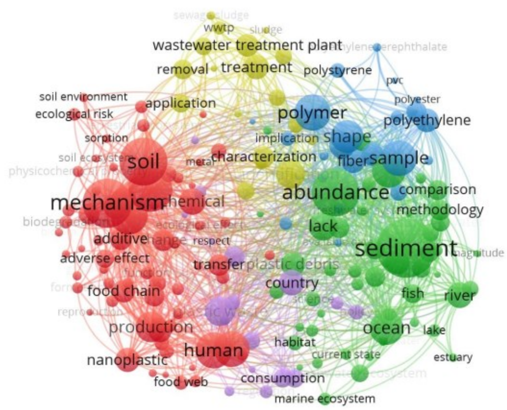

c

Figure 2 Co-occurrence maps of various terms from the review-type scientific articles published in the categories: a. Water Resources; b. Water Resources, Oceanography and Limnology; c. previous categories and Environmental Sciences (lines indicate links, colors indicate groups).

High-density plastics and very small microplastics may have escaped counting in many studies because of the sampling methods (e.g.: when using nets with different opening sizes) and because of the separation methods, which mostly use NaCl.

As in the case of the original research articles, the measurements, analysis and treatment at treatment plants tend to be approached slightly separately from the core of microplastic research due to the special type of waters analyzed and due to the greater engineering possibilities for interventions to remediate the pollution.

When reviewing reviews from all categories selected for this study (428 articles, including Environmental Sciences), one can observe concerns regarding the abundance/level of concentration of microplastics in oceans and sediments and regarding the transfer mechanisms of microplastics between various environments, including in soil and in human body (Fig. 2c). The interest in water treatment remains important and similar is the need to identify to the constituents of microplastic debris in order to indicate pollution sources.

4. Conclusions

Microplastics have been found in all types of water bodies across the world (even in uninhabited areas) and are present in very variable concentrations. Urban areas are a major source of microplastic injected unintendedly into the water cycle. Oceans and their sediments are the final destination of the plastic leakage from the oikumene.

Studies on microplastic in water tend to group in different clusters based on their major research interests such as the identification of physical types of microplastics in the marine environment or the effect of microplastics on aquatic life. The reviews on studies about microplastic in water highlight the need to define standard sampling and pretreatment methods in order to obtain comparable results as much as possible and to make results repeatable and, thus, verifiable.

The number of studies on microplastics in water is increasing due to an increasing annual production, caused both by the increase in scientific production, in general, and by the increasing awareness of the impact of plastic pollution.

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