

Microplastics in Sea Water: Contamination and Environmental Risk

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ABSTRACT: Plastic microplastics are widespread, found in both aquatic and terrestrial ecosystems, and can even be found in Antarctica and deep-sea sediments. Microplastic has become a major pollutant of marine and ocean waters in recent decades and poses a serious threat to the environment and human health. An estimated 5.25 trillion plastic particles float in the world's seas and oceans, releasing up to 23 600 tonnes of dissolved organic carbon per year. Microplastic pollution is a serious phenomenon affecting marine ecosystems, aquatic life and human health. Toxins and chemicals from the environment settle on its surface and can carry them up the food chain. Given the different dimensions, shapes and densities of MPs, it is difficult to predict their behaviour in a dynamic marine environment. The potential toxic properties of microplastics are mainly due to the additives and monomers they contain. The widespread occurrence of microplastics in the marine environment and the need to reduce the associated risks have been the subject of intensive research in recent years. Recently, the study of the source, amount and distribution of microplastic contamination has become the focus of much research. This paper aims to discuss the sources of microplastic pollution in the marine environment and discuss their potential risks in the environment.

1 INTRODUCTION

Plastics have found their way into hostile environments due to their unique properties: extraordinary material flexibility, low density, mechanical stability and excellent electrical and thermal insulation properties [1]. Plastic is non-toxic, corrosion-resistant, bio-neutral and has high thermal insulation properties. In addition, the production cost of plastic is relatively low, it is a low-density material and it provides a barrier to gases and moisture. All these characteristics have led to plastics replacing other packaging materials such as glass and paper.

The annual global production of plastics in 2023 was 413, 8 million tonnes continuously increasing year

on year [2]. Figure 1 shows the changes in plastic production volumes between 2018 and 2023.

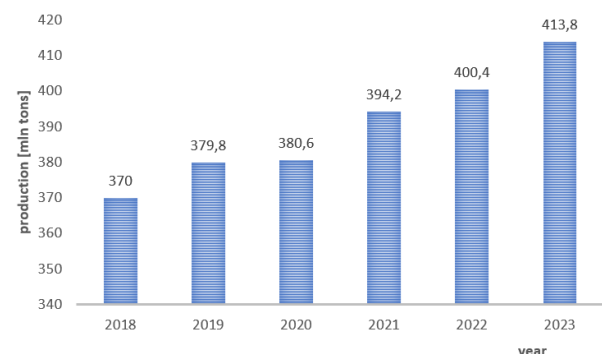


Figure 1. Global world plastic production 2018-2023. Source: [2].

Global demand for plastics has increased over the past decades as they have found widespread use in many areas of the economy. Currently, the majority of plastic produced is a synthetic organic polymer made by polymerising monomers extracted from fossil fuels, coal or gas. While conventional, fossil-based plastics are made from oil and natural gas, bioplastics are emerging on the market, which are made wholly or partly from renewable raw materials such as maize, wood. These raw materials contain biomass such as cellulose, starch or sugar. They can also be manufactured from waste and by-products [Fig. 2]. Bio-plastics that are produced from renewable resources ('bio-based') are biodegradable. However, it should be stressed that bio-plastics do not have to be biodegradable, as they can be designed to be sustainable like other plastics.

Degradable plastics can have a negative impact on the environment, as can non-degradable plastics, because they take time to degrade and sometimes require different conditions from those found in nature. It is therefore important that no plastic of any kind ends up in the environment.

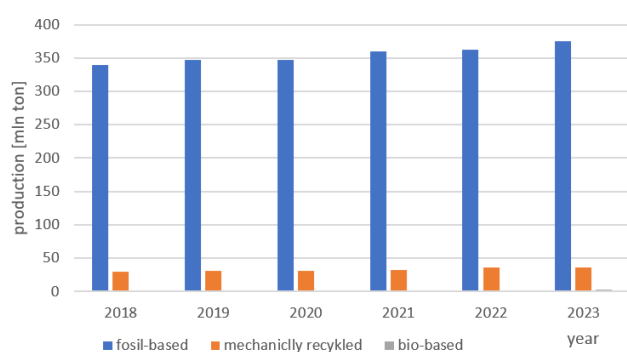


Figure 2. Materials used in the production of plastics. Source: [2].

At the same time, this surge in plastic production has contributed to an increase in plastic waste in various environments [3,4]. Unfortunately, very little plastic waste is recycled and very little plastic waste is used for energy production. The majority of plastic waste is landfilled and still a huge amount appears in the environment [5]. The problem of plastic litter (observed both on land and in the sea) has been the subject of environmental research over many years. In recent years, scientists, the UN, also many scientific organisations and NGOs have been drawing attention to the problem of global plastic pollution [6]. Plastic waste has become a permanent threat to marine ecosystems. It is estimated that between 20 and 53 million tonnes of plastics will enter aquatic ecosystems by 2030 [7].

Fine plastic particles known as microplastics have become the subject of intensive research as a hazardous pollutant in recent years. Plastic waste when exposed to environmental conditions degrades slowly. For most plastics, microplastics can persist in the marine environment for up to centuries due to their low degradation rate. As a consequence, an enormous number of plastic microparticles are generated during the decomposition process.

Plastic microplastics are defined as plastic particles smaller than 5 mm and are a serious problem affecting marine ecosystems, marine life and human health [8,9].

Microplastics are plastic particles characterised by their shape, colour, size, and polymer composition that originate from various anthropogenic sources [10]. Microplastics come from two sources. Plastics that are produced in millimetre sizes or smaller are defined as primary microplastics. They are used in cosmetic preparations, household products, cleaning products and are also suitable as rust and paint removers, e.g. for removing rust and paint from boat engines and hulls [11]. Another important source of virgin microplastics is the raw materials from which plastic products are manufactured. Improper handling, uncontrolled emissions from processing plants and waste from plastic production are another reason for the appearance of primary microplastics in the environment.

Secondary microplastics are formed in the environment as a result of the breakdown of larger plastic components through chemical physical, and biological processes [12]. The destruction and breakdown of the structure of plastics leads to the formation of microplastics. It should be emphasised that in the case of the marine environment, the continuous effects of turbulence, wave action and abrasion increase the degradation of plastics.

In addition, physical factors such as sunlight, including ultraviolet radiation, promote the photodegradation of polymeric materials [13]. Processes degradation can also occur before plastics are in the environment. Such microplastic sparticles are formed during the use of products such as tyres, textiles, or paints. Given the large number of plastic particles that have been identified in the environment, it has been estimated that most of these are secondary microplastics [14].

Nanoplastics are tiny fragments of plastic < 100 nm in size in at least two dimensions. Nanoplastics are formed during the fragmentation of synthetic fibres when clothes are washed and during the destruction of plastic objects such as polystyrene.

Only 21% of microplastics are recycled or incinerated, with the remaining 79% accumulating in landfills or in the natural environment. Microplastic has become a major pollutant of marine and ocean waters in recent decades and poses a serious threat to the environment and human health. An estimated 5.25 trillion plastic particles float in the world's seas and oceans, releasing up to 23 600 tonnes of dissolved organic carbon per year [15]. The presence of microplastics in the ocean was first reported in the 1970s [16]. Microplastic pollution is a serious phenomenon affecting marine ecosystems, aquatic life and human health. The widespread occurrence of microplastics in the marine environment and the need to reduce the associated risks have been the subject of intensive research in recent years.

The aim of this paper is:

1. to identify the risks of plastic pollution, and in particular microplastics in water and sediments of the seas and oceans,
2. to point out research problems and gaps in current research related to the distribution, identification and harmfulness of microplastics in the aquatic environment for more focused research in the future.

2 PRESENCE OF MICROPLASTICS IN THE SEA ENVIRONMENT

The presence of microplastics has been observed, in the seas and oceans, on the coasts of all continents, in inland waters and even in deep-sea sediments. The aquatic environment has been an area of serious risk from microplastics pollution. Microplastics are carried by wind, rivers, ocean currents over long distances, contaminating distant waters and deep and marine sediments. Compare with marine environment, the microplastics concentration in freshwater environments is less revealed [17]. Tides and ocean currents mean that much of the plastic waste in the marine environment remains in the coastal zone. It has been estimated that approximately 80% of microplastics in the marine environment comes from land-based sources [13]. Since about half of the world's population lives near coastal regions, plastic waste and microplastic sparticles resulting from anthropogenic activities enter the ocean via rivers and industrial drainage systems. It should be emphasised that shipping (commercial and passenger), coastal tourism, oil rigs and aquaculture practices are all contributors to microplastics pollution in the marine environment.

Many studies have confirmed the abundance and distribution of microplastics pollution in the seas and oceans, both in the water column and sediments (table 1, 2). A number of factors affecting the distribution and number of microplastics particles in the environment have been identified. Physical parameters such as wave action, wind intensity, turbulence, sunlight intensity, pressure, etc.,) are important factors.

In addition to this, human population, population density, anthropogenic activities, size of water bodies, waste management system and amount of sewage effluent are important factors to be taken into account [18].

Table 1. Pollution levels of microplastics in water column

Location	Particle sizes	Microplastics Abundance	Shape of materials	References
Atlantic Ocean (Portugal)	<5 mm	00-14,09 particles /m ³	fibres, fragments,	[19]
Arctic Fiord Water	>300 µm	0.15 particles / dm ³	fibers, sheets, fragments	[20]
Barents Sea	-	38-240 particles/m ³	fragments,	[21]
Black Sea	0.129 - 4.960 mm	5.58-9.17 particles /m ³	fibres, films,	[22]
Brazil	<5 mm	7,62 particles /m ³	fibres, fragments, films, fibres,	[23]
Eastern Baltic Sea	1-1000 µm	0,49 particles/m ³	fibers and fragments	[24]
Gulf of Finland	1.5 mm (1500 µm)	0,2-4,7 particles / dm ³	fibres	[25]
Monterey Bay, California	300 µm -5 mm	1,32 particles /m ³	fibres, fragments,	[26]
Persian Gulf	100-5000 µm	1500-46 000 particles /km ²	fibres	[27]
South China Sea	1 - 2.5 mm	0,7 particles /m ²	fragments, fibres,	[28]

Table 2. Pollution levels of microplastics in sediments

Location	Particle sizes	Microplastics Abundance	Shape of materials	References
Antarctica	500-999 µm and 1000-1499 µm	0.1055 particles/m ² 2.1102 particles/m ³	fibres, fragments, films	[29]
Baltic Sea	0,5-5 mm	863/ particles kg-1	kg-fibres,	[30]
Great Australian Bight	>50 µm	13,6 particles kg-1	kg-fibres,	[31]
Indian Coastline	>300 µm	12-439 particles kg-1	fibres, fragments,	[32]
Jiaozhou Bay, China,	15-8 201 µm	1.21 particles kg-1	kg-fibres,	[33]
Montenegrin Coast	0,1-1,0 mm	307 particles kg-1	filaments fragments	[34]
Reggio Calabria	0,5-1,0 mm	603-1327 particles kg-1	fibres	[35]
Yellow Sea	34-4983 µm	119 particles kg-1	foam, line, fragments,	[36]
Western Baltic Sea	0,2-5 mm	4,5 particle kg-1	fibres and fragments	[37]
Western Mediterranean Sea	0,063-5 mm	314, 53-409, 94 particles kg-1	fibres, fragments, films	[38]

Analysis of the available data indicates that the amount of plastic microplastics varies considerably between ocean regions. The largest quantities of microplastic particles are found in the coastal waters of large urban agglomerations, industrial areas with intensive human activity, near tourist attractions and harbours [39]. The amount of microplastic detected is influenced by the time of year in which measurements are taken. Vertical mixing of the water caused by waves and wind causes microplastic particles to settle in the bottom sediments. This is probably why the abundance of microplastic in the water depth is higher in spring and summer [40].

Most microplastics detected are colourless, white, blue or red. colour and range in size from hundreds of microns to a few millimetres. There are far fewer reports on nanoplastics, probably due to the difficulties probably due to the difficulty in detecting them [41]. Microplastic particles of five microplastic shapes (fiber, film, fragment, foam, line) were detected in the water samples. Study results suggest that the amount of microplastic particles with a specific shape depends on the particle fraction, with fibres being detected more frequently than other shapes, such as fragments and films, which only occur in a range of larger sizes

Fibre microplastics are likely to come from textiles, materials used in fishing activities, and granular plastic microplastics are mainly from human personal care products. Microplastics of polyethylene, polypropylene, polystyrene and PET are present in the marine environment because plastic products are widely used in the economy and therefore there is a high likelihood of them entering the marine environment.

3 IMPACT OF MOICROPLASTICS ON THE MARINE ENVIRONMENT

The smallest plastic fragments in the form of micro- and nanoplastics, which remain in the marine environment for a long, unknown period of time, raise

concerns about their potentially hazardous effects on the environment. Plastic microplastics are widespread, found in both aquatic and terrestrial ecosystems, in fish, birds, and can even be found in arctic water and ice and deep-sea sediments [42]. Microplastics particles have been detected in human food, air and drinking water, raising concerns about the potential for Microplastics to negatively impact human, animal and ecosystem health [43].

Microplastics pollution is a serious phenomenon affecting marine ecosystems, aquatic life and human health. Toxins and chemicals from the environment settle on its surface and can carry them up the food chain [44]. Given the different dimensions, shapes and densities of microplastics, it is difficult to predict their behaviour in a dynamic marine environment.

Microplastics particles are relatively persistent in the marine environment and their small size makes them bioavailable to fish, lobsters, corals, zooplankton and other marine organisms. Microplastics particles are a growing global problem that pose a threat to various marine organisms through their ingestion and possible accumulation in the food chain. Studies of marine biota have shown that exposure is most likely to be due to Microplastics ingestion, as confirmed by the presence of plastic fragments in animals throughout the marine food chain, including zooplankton, fish, marine mammals and seabirds [45]. Microplastics particles in an aqueous environment can be broken down into smaller plastic fibres and fragments, or even nanoplastics. They can be readily absorbed by many organisms and can also penetrate cell membranes. The potential toxic properties of microplastics are mainly due to the additives and monomers they contain.

Due to their specific physico-chemical properties, microplastics have a surface on which contaminants and microbial communities can absorb and accumulate. The small size of microplastic particles and their hydrophobic surfaces give them the ability to adsorb contaminants present in the marine environment, including persistent and bioaccumulative toxic substances, metal ions, antibiotics and polycyclic aromatic hydrocarbons (PAHs). A number of studies have shown that various contaminants are deposited on the surface of microplastics particles, with the most important and dangerous being:

- persistent organic pollutants, such as PCBs, PAHs, and OCPs, etc.,
- algae, fungi, bacteria etc.,
- different heavy metals such as Cu, Pb, Cd, Zn,
- antibiotic and metals resistant genes,
- pathogenic bacterial strains

An ecologically important issue is the adsorption of persistent and toxic organic pollutants onto microplastics particles. A number of studies that have confirmed adsorption on the surface of microplastics particles for toxic pollutants such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and organochlorine pesticides (OCPs). Hydrophobic microplastics particles have a high surface-to-volume ratio, making them ideal for the chemical adsorption of organic compounds. Microplastics are derived from different plastics, and have distinct chemical compositions that can also affect

the adsorption of organic pollutants. For example, microplastics derived from high-density polyethylene, low-density polyethylene, and propylene adsorb higher concentrations of PAHs and PCBs than particles derived from polyethylene terephthalate and polyvinyl chloride [42].

In the marine environment, micro-organisms such as bacteria, viruses fungi and algae tend to attach to and colonise both natural and synthetic surfaces and 'form a biofilm' [46]. The attachment of various chemicals, including nutrients on microplastics surfaces, ensures nutrient supply for colonising microorganisms and provides them with a stable habitat [47]. The type of microplastics particles influences the variation in microbial communities and it was shown that the variation in microbial communities forming a film on the surface depended on the composition of the microplastics particles rather than their size [48]. Microbial growth on different types of plastics can have environmental and ecological consequences. Microplastics present in the environment can favour the growth of selected microorganisms while hindering the growth of others, which can affect microbial ecological functions. The presence of microplastic particles in the aquatic environment allows the development and growth of selective microbial communities in the ecosystem, which can impair the functioning of such an ecosystem [49]. In the case of algae, even if they do not ingest microplastics, their growth and reproduction are disrupted.

Heavy metals adsorb on microplastics surfaces in marine environments. The study confirmed the presence of zinc and copper on the surfaces of microplastics derived from the breakdown of polystyrene (PS) and polyvinyl chloride (PVC) [50]. Confirmation of the sorption of heavy metals on microplastics surfaces is provided by the higher concentration of various heavy metals of the microplastics surface than from the surrounding seawater [51]. Subsequent studies showed that the concentrations of copper and zinc cations on the surface of aged polyethylene terephthalate (PET) particles were higher compared to their original counterparts in water [52]. Ingestion by aquatic organisms and entry into the food chain of microplastics that have accumulated heavy metals on their microplastics surfaces may cause additional complications.

The presence of microplastics particles not only has environmental consequences, it can affect public health. Plastics can act both as a reservoir of antibiotic resistance genes in the marine environment but can provide a breeding ground for bacteria resistant to many antibiotics. Antibiotic-resistant genes, including penicillin, tetracycline, and erythromycin, were detected in the genome of bacterial strains present on the surface of selected microplastics particles [53]. In addition to antibiotic-resistant bacteria, microplastics also harbour various strains of bacteria that are pathogenic to humans and aquatic organisms. A serious threat to ecosystems can be the fact that microplastics particles, due to their mobility, can promote the transfer of pathogens from one environment to another.

The presence of microplastics in seas and oceans poses a threat to organisms living in the aquatic environment, as microplastics can be easily ingested by animals and accumulate and bioaccumulate in their digestive, respiratory and organ systems [54]. Studies have shown that among marine animals, fish are susceptible to ingesting and ingesting microplastics [55]. A study of three species of Atlantic fish found that 49% of the animals had microplastics in their gills, digestive tracts, and back muscles [56].

In recent years, there has been increasing research on the quality of seafood, as microplastic particles can also enter the human food chain through the consumption of seafood, causing negative health effects for humans. Studies have shown that food products are contaminated with plastic polymers: PP, PE, polyethylene terephthalate (PET), PES, PVC, PS, PA and nylon [57].

4 CHALLENGES AND ADVANCEMENT

Recently, the study of the source, amount and distribution of microplastic contamination has become the focus of much research. Most of the current research on plastic microplastics in the marine environment focuses on the sources of microplastics, their identification, while less attention is paid to the interaction with contaminants and biological toxicity.

A number of problems can be identified that need to be addressed in relation to the presence of microplastics in the environment (Fig.3).

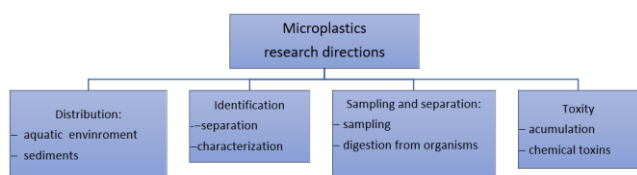


Figure 3 . Challenges and issues in research on the presence of microplastics in the environment

The presence of plastic microplastics is still a relatively new area of research, and methods to detect their presence and distribution in different areas of the marine environment have been developing for about two decades. However, the lack of standardised testing methods will lead to large knowledge gaps in the study of the type and isolation of microplastic from the environment. Thus, the development of effective analytical methods is an important and complex challenge.

Both sampling and testing of marine microplastics should be carried out with great care, as samples are easily contaminated by fibres and airborne plastic particles. In addition, all equipment used in the field and laboratory should be as plastic-free as possible.

Testing and identification of microplastics samples collected in the environment is labour-intensive, and costly due to the consumables used and the testing with specialised, high-tech equipment used. Laboratory testing costs vary depending on the type of matrix tested [58]. The identification and characterization of microplastics are still limited. Microscopy is most often used to identify

microplastics. Fourier transform infrared spectroscopy (FTIR) is also used to analyze microplastics. The spectra obtained in this method show characteristic peaks that correspond to specific chemical bonds. The composition of the tested microplastic sample is identified by comparing the obtained spectrum with a database of reference spectra. The accuracy of FTIR is limited because the reference spectra are derived from pure plastic and wet-plastic samples, which do not occur naturally in the environment and are usually already contaminated. Therefore, it is necessary to develop analytical techniques to study the properties of pure and environmentally aged microplastics as well as their interactions with contaminants present in water and bottom sediments.

The development and application of various methods for sampling and identification of microplastics have made it possible to confirm the presence of microplastics in surface waters worldwide. To date, most studies have been qualitative and the differences between the methods used make it difficult to compare the results obtained [59]. Microplastic particles in seawater are collected using a variety of devices. Which results in research material being collected from different layers of the water column. Understanding the true impact and extent of the plastic particle problem is hampered by the lack of standardised analytical techniques for quantifying microplastics in water and marine sediments. The need for standardisation of methods and techniques in the study of microplastics in the environment is mainly related to measurement units and methods for isolating microplastic particles from the test material.

Most often, the amount is determined by the number of microplastic per liter or cubic meter of water. However, in the case of microplastic in sediments, the number of microplastic particles per unit of dry or wet weight is usually used. A unified standard for concentration of microplastics will be more favourable to compare the microplastic pollution levels in different areas. Standardizing the units of microplastic concentrations would facilitate comparisons of the amount of microplastic pollution in different seas and oceans.

The mechanism of adsorption of toxic organic pollutants on microplastic surfaces is relatively poorly studied, as it varies for different chemicals with complex structures [60]. As microplastic particles interact with contaminants present in the marine environment, new, unknown ecological threats may emerge. It is therefore necessary to study the combined effects of microplastics with other contaminants in the environment.

The presence of microplastics in the aquatic environment is a scientific as well as a societal problem. One of the main unresolved issues is the development of remediation methods to be implemented to remove microplastic particles from the environment, including water bodies [61].

5 CONCLUSIONS

Plastics are undeniably beneficial to society, but their waste has become an environmental hazard, as

evidenced by areas with high concentrations of microplastic particles.

Microplastic pollution in the marine environment is of concern as studies in various parts of the world. Microplastics are one of the most significant contaminants in the aquatic environment have shown that it is present in the environment. Unfortunately, there is still insufficient knowledge about microplastics in marine and inland waters, including the effects on the health of living organisms. Approaches to microplastic characterisation are still limited. Current methods for environmental sampling, identifying quantitative analysis of microplastics, are expensive and time-consuming and require specialist knowledge. In contrast, field sampling in most cases is relatively straightforward. The future standardization of microplastic concentration units will make it possible to compare the state of microplastic pollution in different seas and oceans.

Current research on the effects of microplastics on the diverse marine environment is still at an early stage and intensive research is needed to understand the impact of microplastics on the marine environment. Such studies would also determine the combined impact of plastic microplastics and other marine debris. Further research is needed to describe the mechanism of heavy metal adsorption on microplastic surfaces, as this phenomenon has health and ecological consequences.

Public awareness of the long-term, negative effects of microplastic pollution is still low. Therefore, raising awareness of how plastic waste pollutes the natural environment is an important part of reducing plastic consumption by the global community.

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