Depik Jurnal Ilmu-Ilmu Perairan, Pesisir dan Perikanan (2023) 12(3): 259-273

DEPIK
Jurnal Ilmu-Ilmu Perairan, Pesisir dan Perikanan
Journal homepage: www.jurnal.usk.ac.id/depik

Microplastics in sediment of Indonesia waters : A systematic review of occurrence, monitoring and potential environmental risks

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ARTICLE INFO

Keywords:
Microplastics
Sediment
Indonesia Waters
Environmental Risk
Pollutant Aquatic

DOI: 10.13170/depik.12.3.34596

ABSTRACT

Microplastics, or plastic particles smaller than 5 mm, are a growing ecotoxicological problem for both human health and aquatic habitats. Even though microplastic pollution affects the air, water, and land widely, these habitats are often viewed as distinct from one another while in fact they are tightly related. The purpose of this work is to review the body of scientific literature on microplastic studies in Indonesian watershed sediment. Google Scholar has identified around 57 papers about microplastic pollution that were published between 2017 and 2023. Papers about sediment for rivers, lakes, marine, and estuaries are categorized further based on (i) their occurrence and characterization, (ii) their intake by and effects on species, and (iii) their fate and transport issues. Even at low concentrations of 10 µg/mL, microplastics cause harmful effects for people and animals, including cytotoxicity, immunological response, oxidative stress, barrier characteristics, and genotoxicity. When marine animals eat microplastics, their gastrointestinal tract physiology changes, and they also experience immune system depression, oxidative stress, cytotoxicity, differential gene expression, and growth inhibition. In addition, the bioaccumulation of microplastics in aquatic creatures' tissues may harm the aquatic ecosystem and may spread to people and birds. Through behavioural changes and policy changes, such imposing taxes, bans, or price increases on plastic carrier bags, plastic usage has been dramatically decreased to 8–85% in many different nations across the globe. The strategy for minimizing microplastics is structured like an upside-down pyramid: prevention is at the top, then reduction, reuse, recycling, recovery, and, as the least desirable alternative, disposal.

Introduction

In today's society, plastic waste is a global concern. Large pieces of plastic have been observed practically everywhere, even on the busiest beaches and isolated, deserted islands. (MacLeod *et al*., 2021). According to the report of Statista.com (2023), In 2021, 57.2 million metric tons of plastics were produced in Europe, a six percent rise from the year before. 2020 saw a decline in European plastics output due to the COVID-19 epidemic. Fossil fuels are the primary source of plastic manufacture in Europe. Thus, scientists have already alerted us to the fact that by 2050, plastics will outweigh fish in the ocean if the current rate of plastic growth continues. (Strokal *et al*., 2022). However, depending on their size, plastics found in the environment can be divided into five classes: macroplastics (>5 to 50 cm), mesoplastics (≥5 mm to 5 cm), nanoplastics (<1 µm), microplastics (≥1 µm to < 5 mm), and megaplastics (>50 cm). In addition, larger plastic debris is a global problem that precedes microplastics. (Kaandorp *et al*., 2021 ; Woo *et al*., 2021).

It has been discovered that microplastics, which are little plastic particles with a length of less than 5 mm, significantly harm both the environment and human health. The scientific community, governments, NGOs organizations, and others have become interested in microplastics. Although plastics are a relatively modern material, having just been developed in the latter half of the 20th century,

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p-ISSN 2089-7790; e-ISSN 2502-6194
Received 06 October 2023; Received in revised form 14 October 2023; Accepted 24 October 2023
Available online 17 November 2023

(Moshood *et al.*, 2022), The environment is seriously threatened by their excessive production and use in several products and sectors (Asiandu *et al.*, 2021). Primary microplastics are defined as those that are purposefully produced microscopic, such as the cosmetic microbeads found in face cleansers. (Dąbrowska *et al.*, 2022). Because of their higher abundance and reactivity than microplastics, nanoplastics are especially dangerous to living things. Their tiny size increases their potential for damage by making it easier for them to enter live cells and get to far-off places (Dang *et al.*, 2022). However, the majority of common microplastics found in the environment are categorized as pellets, fiber, and granules, with the majority of these materials being composed of synthetic polymers (Issac and Kandasubramanian, 2021). Comparatively speaking, plastic particles are lighter and can be carried by winds, currents, and even recirculate between seawater and beach sediments. However, one of the most important factors that can influence the spread of microplastics is the density of the polymer particles (Prata, 2023).

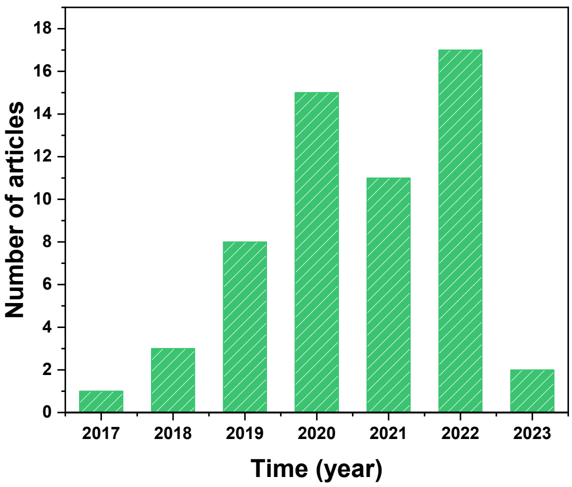


Figure 1. Number of papers on microplastics published between 2017 and 2023 in Indonesia

In addition, many aquatic and terrestrial animals, including fish, birds, turtles, mammals, zooplankton, and crustaceans, are entangled in and consuming microplastics (Montagner *et al.*, 2021). Microplastics have the ability to adsorb a variety of hazardous substances, including heavy metals, viruses, and polycyclic aromatic hydrocarbons (PAH) (Akbar and Hasby, 2023). These substances could negatively affect aquatic organisms by causing oxidative stress and a decline in nutrient intake (Kim *et al.*, 2021). Aquatic creatures are severely impacted by microplastics, suffering from suffocation, hunger, abrasion damage, and restricted movement (Yu *et al.*, 2021). Additionally, it could be a major hazard to cells and tissues and interfere with sibling execution, successive reproduction, and energy reallocation (Vethaak and Legler, 2021).

Indonesia's tropical coastal waters and ecosystems are currently threatened by pressures related to anthropogenic activities (human activities), such as agriculture, mining, fishing and settlements. As a unified ecosystem, the coast and sea are influenced by various environmental variables and the surrounding ecosystem. One of these variables is waste input from land (land-based) and from the sea (sea-based) which contains heavy metals and plastic waste (Akbar and Rahayu, 2023). After China, Indonesia is the world's second-largest producer of plastic garbage. An estimated 0.62 million tons, or 9% of this uncontrolled plastic garbage, is exiled to Indonesian waterways and oceans. This information comes from data obtained by the Indonesian National Plastic Action Partnership (2023), which indicates that about 4.8 million tons, or 70% of all plastic waste in Indonesia, is not managed. 7,400 to 10,304 pieces of floating plastic debris are present per km^. Because plastic debris can break down into microplastics, the large amount of plastic waste in Indonesian seas has the potential to pollute the marine. In addition, Making Oceans Plastic Free (2017) reports that Indonesia uses about 182.7 billion plastic bags annually. This indicates that 1,278,900 tons of plastic bag garbage are generated in Indonesia annually. Plastic bag waste accounts for at least 40% of all plastic waste in Indonesia. 511,560 tons of plastic bags used by Indonesian people end up in the ocean. Based on data from NPAP (National Plastic Action Partnership) it is stated that An estimated 4.8 million tonnes of plastic garbage are produced nationally each year, of which 70% is improperly managed. Of this, 48% is burned in open spaces, 13% is improperly managed in official waste disposal facilities, and the remaining 9% pollutes streams and seas (equaling around 620,000 tons of plastic waste). Data from the Ministry of Environment and Forestry (KLHK) notes that waste production in Indonesia reached 68.5 million tons in 2021. Of this amount, 11.6 million tonnes or approximately 17 percent was contributed by plastic waste. The national plastic waste production data report in 2021 also states that the type of plastic material that is often found is Polyethylene Terephthalate (PET). This material is disposable bottled drinking water (AMDK).

With the development of microplastic research in Indonesia, a gap analysis is needed regarding the status of microplastic research in Indonesia. It is intended that this study will provide an overview of the state of microplastic research in Indonesia and identify future research directions. Thus, it is envisaged that the diversity of microplastic research conducted in Indonesia would help to advance and address the problems associated with microplastic pollution there. Therefore, it is hoped that this paper can provide information and understanding related to the abundance of microplastics, such as the definition of microplastics, types of microplastics, identification of microplastics, and the development of studies of microplastics in sediments carried out in western and eastern Indonesia, so that research related to microplastics in sediments can be further developed in the future.

Materials and Methods

In this study, we collected the references (papers) from Indonesia in Google Scholar. Recent references published between 2017 until 2023 were retrieved using some keywords "mikroplatik sedimen Indonesia". After a thorough evaluation of the references, the information gathered from them is imported into Microsoft Excel for further analysis. There are 57 published articles in the journals (Figure 1). This review covers a number of topics related to microplastics, such as their creation, concentration, sample and extraction techniques, shape, plastic polymers, and color. toxicological profile, harmful health effects, biological detection, and possible therapies. This article also discusses the causes of microplastics, their impacts on the environment and human health, international efforts and solutions to lessen their release, the public's perception and understanding of microplastics, and many strategies that can be used to change this. The scope of this review is restricted to investigating Indonesia's microplastic pollution distribution, particularly in sediments.

Results

The data obtained were described qualitative. All exploration data is presented in Table 1 and Table 2.

Table 1. Indonesian distribution of mcroplastics in the sediment

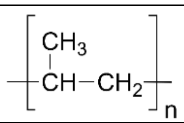
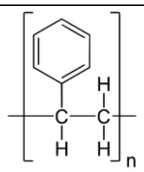
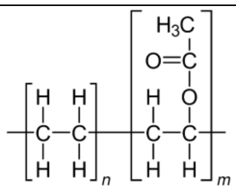
Location		Sampling Device	Microplastic Parameters					Reference
Sampling	Province		Size	Abundance	Shape*	Polymer **	Color ***	
Coast	Central Java	Sedimen core	6,21 –208,29 µm	438 – 643 particle/50 g	FB, FG, FL, PL	–	C, MM	(Azizah *et al.*, 2020)
Coast	Central Java	Pipe	28 – 390 µm	3.584 –8.106,67 particle/m³	FB, FG, FL, PL	–	B, M, HT	(Laila *et al.*, 2020)
Coast and Estuary	Central Java	Sediment grab	36,43 – 280,35 µm	1.858 – 2.577 particle/kg	FB, FG, FL, PL	–	HT, C, M, K, P, HJ, U	(Ibrahim *et al.*, 2020)
Coast	East Java	Ekman Grab	–	363 particle/g	FB, FG, FL	–	–	(Joesidawati, 2018)
Coast	East Java	–	–	52 – 588 particle/m³	–	–	–	(Labibah and Triajie, 2020)
Coast	East Java	Grabber / van ven	–	–	FB, FG, FL, GA	PET, PE, EPDM PEG, PES, PVC	–	(Rahmadhani, 2019)
River	Central Java	Shovel	–	13 – 18 Microplastics/150g	–	PS, PP, EVA	–	(Ayun, 2019)
Coast	Central Java	Sediment grab	1,14 – 214,4 µm	526 particle/25 g	FB, FG, FL, PL	–	–	(Laksono *et al.*, 2021)
River	Special Region of Yogyakarta	Shovel	–	357 particle/kg	FB, FG, FL, PL	–	M, HT, B, C	(Prabowo, 2020)
Mangrove	West Kalimantan	Coring	–	0,327 – 0,707 particle/gr	FB, FG, FL, MI	–	B, M	(Simamora and Nurdiansyah, 2020)
Coast	Central Java	Iron pipe	–	578 particle	FB, FG, FL	PP, PE	C, HT, M, U, HJ, K	(Ridlo *et al.*, 2020)
Marine National Park	Central Java	SCUBA set and sediment grab	–	96 particle/kg	–	–	–	(Muchlissin *et al.*, 2020)
Coast	North Sumatra	–	–	243,75 particle/Kg	FB, FG, FL, PL, GA, FA	PP, PS, PE	–	(Addauwiyah, 2021)
Bay	Bali	Plankton net	90 µm – 2 mm	73 – 113 particle/kg	FB, FG, FL	–	–	(Nugroho *et al.*, 2018)

Seagrass meadows	Banten	Corer dan cetok	39,316 – 205,418 µm	93 particle	FB, FG, FL, PL	PP	HJ, HT	(Lestari *et al.*, 2021)
River	Special Region of Yogyakarta	Pipe	21,05 – 386,62 µm	209,37 –1.173,25 particle/kg (Progo) 314,54 –3.729,67 particle/kg (Opak)	FB	–	–	(Utami, 2021)
Estuary	Central Java	Nansen Bottle	1,00-259,06 µm	400 particle/kg	FB, FG, FL, PL	PTFE, NY, PAN	C, P, M, HJ, K, U	(Pamungkas *et al.*, 2022)
Coast	Lampung	Shovel	–	93,34 particle/kg	FB, FG, FL, PL	–	B, HT, M, C	(Satiyarti *et al.*, 2022)
Coast	East Java	–	0,025 –2,975 mm	1180 – 1635 particle/kg	FB, FG, FL	–	K, B, M, HJ	(Ningrum *et al.*, 2022)
Coast	West Java	–	–	41556 particle/kg	–	PS, PU, ABS, PP	–	(Kurnia, 2019)
Bokori Island	Southeast Sulawesi	SCUBA set and sediment grab	–	9.379 –41.564 particle/kg	FB, FG, FL, FA	–	P	(Riska *et al.*, 2022)
Coast	East Java	–	2 - 5 mm	71,6 ± 28,9 particle/m^2	FB, FG, FL, FA	–	–	(Agustin, 2020)
Coast	West Sumatra	–	1-20 cm	70,83-109,17 particle/kg	–	–	HT	(Mulyadi, 2022)
Reservoir	East Java	–	–	27 – 504 particle/L	FB, FG, FL, PL	–	–	(Riskandini, 2020)
Mangroves, river, and sea	East Java	–	–	27,3 x 10^2 particle/kg	FB, FG, FL	–	B, HJ, M	(Ayuningtyas, 2018)
River	South Sulawesi	–	0,1-2 mm	1.645 particle/kg	FB, FG, FL	PET, PP	B, HT, P	(Rachmayanti, 2020)
Coast	Riau islands	–	–	1.940 particle / 1.575 gram	FB	–	P	(Al Aminin, 2020)
River	East Java	Ponar grab	–	220 – 32.720 particle/kg	FM, GA, FG, FL	–	–	(Santoso, 2019)
River	South Sulawesi	–	–	12,2 – 32,2 particle/100 gr	FB, FG, FL, MI	–	–	(Riswanto, 2022)
Coast and Harbor	Central Java	–	–	590 – 1048 Microplastics	–	NY, PE, PP	–	(Arif, 2019)
Coast	East Java	–	–	1525,33 particle/kg	FB, FG	–	HT	(Lorenza, 2019)
Coast	East Java	Pipe	–	24 – 342 particle/kg	FL, FB, FG	–	–	(Ritonga, 2019)
Coast	East Java	–	–	0,07 – 4,07 particle/liter	FB, FG, FL, PL	–	–	(Siallagan, 2021)
Coast	Central Java	Plankton net	–	181,38 particle/kg	FB, FG, FL		–	(Nasution, 2020)
Coast	Central Java	Pipe	–	3.584 – 8.106,67 particle/m^3	FB, FG, FL, PL	NY	B, M, HT	(Laila *et al.*, 2020)
Coast	East Java	Pipe PVC	–	4 43 particle/3 kg	FB, FG, FL	–	–	(Syafitri and Joesidawati, 2021)
River	Special Region of Yogyakarta	–	–	465 – 1155 particle/100 gram	FB, FG, FL, PL, FM	–	HT, B, P, M, HJ	(Putro, 2021)
River	Special Region of Yogyakarta	–	–	1534 – 1966 particle	FB, FG, FL, PL, FA	PAc	T, M HT, B, HJ, U, O, K	(Nouqih, 2022)
Mangroves	Riau islands	–	–	206,67 –1034,70 particle/g	FB, FG, FL, PL	–	CK	(Hamza, 2022)
River	East Java	Long Stick Tire Strap (LST)	101 – 500 µm	670 – 5.130 particle/m^3	FB, FG, FM	–	B, HT	(Pradiptaadi and Fallahian, 2022)
Coast	West Sumatra	–	–	9150 – 18250 particle/kg	FB, FG, FL	PE, PP, PA	HT	(Febriani, 2022)
Coast	North Sumatra	Hand	–	17-36 particle/50 g	FB, FG, FL	–	–	(Susanto *et al.*, 2022)
Bay	DKI Jakarta	Plankton net and Shovel	–	34667 – 45067 particle/kg	FB, FG, FL, PL	PP, PE, PS, PA	–	(Setyowati, 2021)
Coast	South Sulawesi	–	1-5 mm	49 Microplastics	FG, FL, FA	NY, PET	B, K, A, T, P	(Humairah, 2022)

River	DKI Jakarta	plankton net	–	316.089 ± 6883,6 kg-1	FB (29,88 %), FG (40,89%), FL (28,54%), GA (0,69%)	–	–	(Deriano dkk., 2021)
River	West Sumatra	–	1-5 mm	34,92 – 94,81 particle/kg	FB	PVC, PP, PET, PC	HT	(Farhan, 2021)
Untung Island	DKI Jakarta	grab sampler	15-900 µm	1324 particle	FB, FG, FL	–	Various	(Hafitri *et al.*, 2022)
Bay	North Sulawesi	plankton net		63,38 – 182,12 particle/kg	FB, FG, FL, FA	–	–	(Imanuel *et al.*, 2022)
River	East Java	Egman Grab and Jaring	100 –4.000 µm	28 – 87 particle/50gram	FB, FG, FL	–	M, HT, B, K, T, HJ, O	(Wijayanti *et al.*, 2021)
Pond	Central Java	–	–	68 ± 38,5 PSM/kg	FB, FG, FL	–	T, HT, M, HJ, MK, B, K, P, O	(Restiani, 2017)
Coast	West Sumatra	–	Highest percentage 101 – 300 µm (49,53%)	9.400 – 19.100 dan particle/kg	FG (58,59%), FL (38,28%), FB (3,14%)	PTFE, PA	–	(Wisna, 2022)
River	Nusa Tenggara Barat	–	0,1 – 4,75 mm	–	FB, FG, FL	–	M, HT, HJ, B, T, P, K, C	(Adela, 2020)
River	East Java	plankton net	–	62- 98 particle/ 50 gram	FL (78%), FG (17%), FM (5%)	-	HT, M, HJ, B, T	(Rohmah, 2022)
Mangroves	Central Java	–	0,357 – 4,933 mm	366,67 particle/kg	FB, FG, FL, PL	PE, PP, PET	HT, M, B, T, K	(Irsya, 2023)
Bay	Maluku	–	–	127,34 particle/m²	FB (30-33%), FG (35-38%), FL (29-33%)	PMMA, PP, ABS, PU, PVC, EVA	–	(Turnip, 2019)
Lake Like	East Java	–	180-250 µm (45%)	15.146,667 particle/kg	FB (51%),	–	T (68%)	(Sholehah, 2020)
River	Riau	Egman Grab	–	4.000 – 13.333 particle/kg	FB (15,38%), FL (40,38%), FG (44,24%)	–	–	(Nazar *et al.*, 2021)

*Fiber (FB) ; FG = Fragment ; FL = Film ; PL = Pellets ; GA = Granual ; MI = Microbead ; FA : Foam ; Filament = FM
**Polypropylene (PP), Polystyrene (PS), Ethylene Vinyl Acetate (EVA), Polyethylene (PE), Polyvinyl Chloride (PVC), Polyethylene Terephthalate (PET), Ethylene Propylene Diene Monomer (EPDM), Polyethylene Glycol (PEG), polyethersulfone (PES), Polytetrafluoroethylene (PTFE), Nylon (NY), Polyacrilonitrile (PAN), Polyurethane (PU), Acrylonitrile Butadiene Styrene (ABS), Polyacetylene (PAc), Polyamida (PA), Polycarbonate (PC), Polimer Polytmetyl Methracylate (PMMA),
*** Brown (C), Transparent (T), Red (M), Black (HT), Blue (B), Green (HJ), Purple (U), Orange (O), Yellow (K), Gray (A), White (P), brownish red (MK), Pink (MM)

Table 2. Information on the types of polymers that make up microplastics

No	Polymer	Monomer			Pubchem ID	Frequently used
		Structure	Molecular Formula	Molecular Weight		
1	Polypropylene		C_3H_6	42.08	8252	Manufacturing car batteries, bumpers, interior elements, and cladding
2	Polystyrene		C_8H_8	104.15	7501	Plastic model assembly kits, smoke detector housings, CD "jewel" cases, cutlery and crockery, and license plate frames
3	Poly(ethylene-vinyl acetate)		$C_6H_{10}O_2$	114.14	32742	Car mats, orthotics, traction pads for surfboards and skimboards, and for making certain fake flowers

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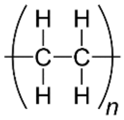
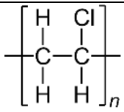
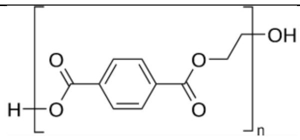
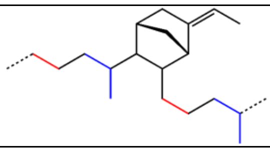
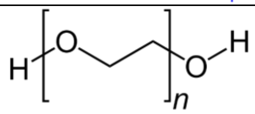
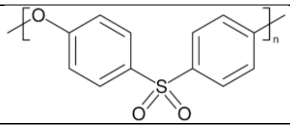
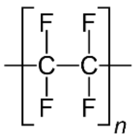
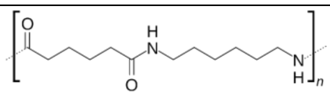
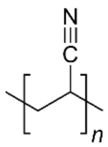
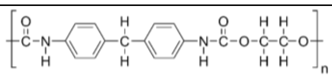
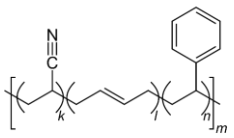
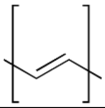
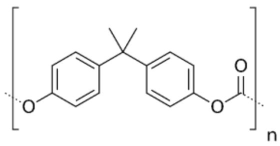
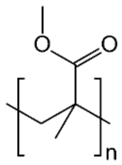
4	Polyethylene		C_2H_4	28.05	6325	Agricultural mulch, bottles, toys, houseware, rubbish bags, shopping bags, insulation for wires and cables, and packaging film
5	Polyvinyl Chloride		C_2H_3Cl	62.5	6338	Door profiles, interior and external cladding, conservatories and atriums, roofing and ceiling systems and membranes, rainwater, flooring, and wallcoverings. Data and telecom wiring and cables. Power. Cable and services ducting.
6	Polyethylene Terephthalate		$C_{10}H_{10}O_5$	210.18	174073	The most popular thermoplastic polymer resin within the polyester family, it finds application in textile fibers, food and drink containers, thermoforming, and engineering resins when combined with glass fiber.
7	Ethylene Propylene Diene Monomer		-	-	-	Roofing, sealants, pool liners, garage door sealants, and numerous more construction-related uses
8	Polyethylene Glycol		$C_2H_6O_2$	62.07	174	a lubricant applied to a variety of surfaces in both aqueous and non-aqueous conditions. Afterwards, as humectants, emulsifiers, skin conditioners, surfactants, and cleansing agents in cosmetics.
9	Polyethersulfone		$C_{12}H_{10}O_3S$	234.27	343804	The filtration industry as hollow fiber membranes as well as in respirator nebulizers
10	Polytetrafluoroethylene		C_2F_4	100.01	8301	a coating that keeps pans and other kitchenware from sticking
11	Nylon – 6,6		$(C_{12}H_{22}N_2O_2)n$	226	-	To create ropes, stockings, sleeping bags, tents, tooth brushes, and seat belts for automobiles, Additionally, parachutes and climbing ropes are made from it. Fishing nets are made with it.
12	Polyacrylonitrile		C_3H_3N	53.06	7855	in order to create other polymers, such as carbon fiber. Polyacrylonitrile fibers have been used in fiber reinforced concrete, outdoor awnings, hot gas filtration systems, and sailboat sails.
13	Polyurethane		-	-	-	Home furnishings such as furniture, bedding and carpet underlay

14	Acrylonitrile Butadiene Styrene		$C_{15}H_{17}N$	211.30	24756	Lego toys, consumer goods, automotive components, pipe fittings, and electronic housings
15	Polyacetylene		C_2H_2	26.04	6326	Electric wiring or electrode material in lightweight rechargeable batteries
16	Polycarbonate		-	-	-	Plastic lenses are used in greenhouses, digital disks (CDs, DVDs, and Blu-ray), eyeglasses, medical equipment, automobile parts, protective clothing, and outdoor lighting fixtures.
17	Polymethyl Methacrylate		$C_5H_8O_2$	100.12	6658	In biomaterial uses such medication delivery systems, lenses, bone substitutes, and cement

Discussion

Types and sources of microplastics in the environment

Microplastics are a heterogeneous collection of particles with varying diameters, patterns, chemical compositions, and specific gravities that are produced by a variety of sources and end up in the environment (Cverenkárová *et al.*, 2021). The following subdivisions will be discussing the types and proven sources of microplastics in the natural environment.

Microplastics are divided into two major kinds, such as primary and secondary microplastics, which are described below, based on their origin and sources:

1. *Primary microplastics*

Primary microplastics are thought to make up between 15% and 31% of all plastic particles in the ocean. Primary microplastics are defined as small plastic particles that enter the ecosystem directly (Li *et al.*, 2022). However, a number of operational actions, including the emersion of particles from industrial emissions, the redemption of fibers, and the use of plastic-based compounds in cosmetics, toiletries, and safety items, can cause these primary microplastics to be purposely released (Kalman *et al.*, 2023). Additionally, the polyolefin polymers that make up these particles are lipophilic, which means that they have the ability to adsorb harmful substances from nearby water bodies onto their surface (Castelvetro *et al.*, 2021).

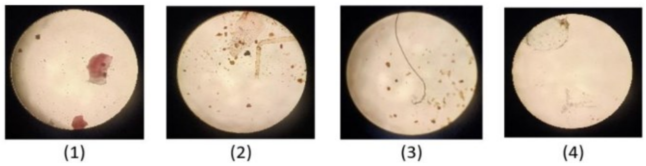


Figure 2. Results of Identification of Microplastic Types in Sukaraja Beach Sediment, Bandar Lampung City at Station III Type (1) Fragment, (2) Pellet, (3) Fiber, (4) Fragment Type. (Satiyarti *et al.*, 2022) (Copyright of The *Jurnal Kelautan Tropis)*

2. *Secondary microplastics*

Plastic bottles, fishing nets, bags, and other sorts of waste plastic materials are examples of macroplastics that break down and are poorly managed, producing secondary microplastics (Huber *et al.*, 2022). However, these abandoned plastic wastes are transformed into shreds of a different size known as secondary microplastics, which are present in both aquatic and terrestrial environments, as a result of photodegradation, wave action, and other weathering processes (Sun and Wang, 2023) (Figure 2 and Figure 3). Similarly, 5.25 trillion huge plastic particles (>250,000 tons) are thought to be floating in the world's oceans; of these, 75–90% come from land-based sources and 10–25% come from ocean-based sources. These sources are thought to be the potential radix of secondary microplastics (Ita-Nagy *et al.*, 2022).

Generally, breaking larger discarded plastics is thought to be the most significant source of secondary microplastics, while releasing shredded fibers from the synthetic textile industry is thought to be one of the significant sources of primary microplastics due to their tiny size and ineffective removal approaches.

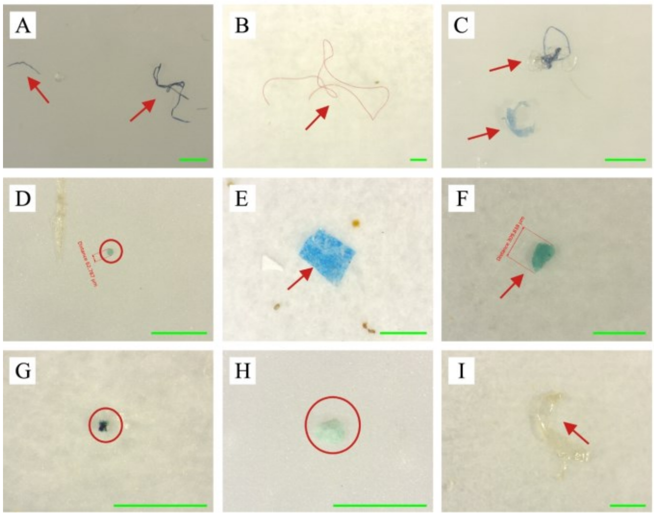


Figure 3. microplastics from beach sand in lower Sardis Lake captured in microphotographs (Gao *et al.*, 2022) (Copyright of The *Springer Nature)*

Route and fate of microplastics

In nature, microplastics are light (Ahn *et al.*, 2023). Consequently, if they are released into the environment, they may spread far. After being discharged into the environment, they may be carried by the wind, washed from the soil by precipitation or runoff from storms, and then enter an aquatic environment (Golwala *et al.*, 2021). Enormous amounts of microplastics are eventually washed into the ocean from the terrestrial environment through freshwater channels like rivers and estuaries, as well as direct washout from industrial and agricultural discharges. This entire transportation process is known as an ecocline (Enyoh *et al.*, 2020). The many paths taken by microplastics in the environment and their eventual outcomes will be covered in the section that follows.

1) Entry points into the surroundings

Numerous studies have reported that a significant amount of macro and microplastics are often produced on land and end up in streams that lead to the ocean (Christensen *et al.*, 2017). However, the fast production of microplastics might be attributed to either primary or secondary sources. For example, a lot of microbeads found in face wash, toothpaste, and cosmetics are released into aquatic bodies through household basins and other drainage systems. Furthermore, it has been normal practice to use sewage sludge as fertilizer on agricultural land, which raises the possibility of microplastics emerging in the soil and rivers (Rolsky *et al.*, 2020). In addition, a study on the persistence of microplastics in soil revealed the existence of synthetic fibers in agricultural soil that had last received sewage sludge application about 15 years prior (Helmberger *et al.*, 2020). These little particles will undergo the same transportation via the channels as the sediments once they find their way into the streams. However, two elements, such as the intensity of the river flow and the shape and density of the particles, affect how long microplastics stay in the sediment and how they transition (Yang *et al.*, 2021). Due to tides, winds, and a large surface area, microplastics can spread quickly once they enter the water and travel great distances from their source (Malli *et al.*, 2022). Additionally, due to biofouling, fecal pellet feeding, and marine snow absorption, microplastics may travel vertically throughout the oceans (Van Melkebeke *et al.*, 2020). Although this is a significant transit mechanism for microplastics that contributes to the greatest possible dispersion because it has no boundary of outstretching through the various environmental compartments, knowledge regarding the routes of atmospheric microplastics (indoor and outdoor air) is still limited.

2) Environmental microplastics' fates

Microplastics eventually find their way into the ocean after entering a body of water. Microplastics can easily collect in marine creatures known as tunicates, or sea squirts, which are also found at considerable depths. They can also be deposited on beaches and in subtidal sediments (Mendes *et al.*, 2021). Additionally, relatively less dense microplastics that are emitted from bare, untreated landfills may also be airborne (Anagnosti *et al.*, 2021). Since density has a major influence on microplastics' transit and fates, it is imperative to consider their flexible and steady future. Nevertheless, fragmentation, soil buildup, floating across streams, sedimentation, shoreline deposition, ingestion by creatures, and passage through the food chain are among the likely outcomes of microplastics once they are released into the environment (Cverenkárová *et al.*, 2021). For example, microplastics typically end up trapped in sediments for a very long time. After that, a number of things, including wave movement, tides, bioturbation, and any other disruptions, could cause those stuck microplastics. Moreover, organisms have the ability to consume microplastics (Bajt, 2021), then it might be eliminated by defecation or moved into the tissues, and then it may go from one trophic level to another along the food chain (Castro-Castellon *et al.*, 2022). However, there is still a great

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deal of uncertainty surrounding the rate of absorption and the confirmed fate of swallowed microplastics (Way *et al*., 2022). Given that microplastics are always moving from one area of the ecosystem to another, it makes sense that their effects or fortunes are highly dynamic.

Microplastics' effects on the environment

Microplastics have been found in all environmental matrices, including surface water, sediments, and seashores, according to streams of research (Du *et al*., 2022); freshwater systems, arctic ice, and deep oceans (Prata *et al*., 2022); earth and additional terrestrial habitats (Semensatto *et al*., 2022); and even in the food and water we consume. Furthermore, research on microplastics has been conducted on a wide range of faunal species, including huge fish, birds, mammals, and tiny plankton, indicating the detrimental effects of microplastics on ecosystems (Zolotova *et al*., 2022). The destructive index and established impacts of microplastics on the environment are described in the following subsections.

1) Chemical pollutants can be transmitted through microplastics

Microplastics' stability and persistence in the environment under varied environmental conditions are the main danger factors. Moreover, a number of studies have identified an additional concern associated with microplastics, namely that the particles are infused with hydrophobic substances and enter the body by eating (Fred-Ahmadu *et al*., 2020). Following consumption, the organisms may have negative impacts due to their physical characteristics and hazardous compounds. When microplastics are present, interior abrasion could pose a physical hazard. concurrently, the harmful substances can have a negative impact on the organisms (Mammo *et al*., 2020). In contrast to physical damage, chemical injury resulting from poisonous chemicals can be far more delicate and severe. Because of their relatively large specific surface area, microplastics can absorb a variety of organic and inorganic contaminants, which can lead to indirect toxicity. The different kinds of microplastic polymers might be more receptive to different contaminants, such as dioxins, organo-halogenated pesticides, DDT, PAHs, POPs, and PCBs, which have been found on the surface of plastic pellets that have been analyzed from different areas along the coastline (Eder *et al*., 2021).

2) Microplastics effects on the aquatic environment

Due to their tiny size and prevalence in the aquatic environment, a wide range of aquatic organisms, including benthic species like amphipods, polychaete worms, and tubifex worms, as well as pelagic species like phytoplankton and zooplankton, consume microplastics (Vivekanand *et al*., 2021). Following ingestion, the disquieting transit of microplastics along the food chain is accompanied with serious risks due to their capacity to absorb harmful substances from water and transfer them via biomagnifications to other trophic levels (Xu *et al*., 2020). Fish can consume microplastics directly or through the food chain because they are typically intermediate or top predators (Ma *et al*., 2020). Higher toxicity levels in algae could result from smaller microplastics (Hoffmann *et al*., 2020). Microplastics have been discovered in an organism's stomach, mouth, and respiratory systems. Furthermore, it is possible for these particles to be transferred and accumulated in specific tissues and cells, such as the gills and intestines of shore crabs (Carcinus maenas), the liver and intestines of zebrafish, the stomachs of seabirds, giant fish, and whales, the hemolymph and lysosomal system of mussels, and the insides of hemocytes (Wang *et al*., 2021). Microplastics in mussel tissues have the potential to be hazardous (neurotoxic & genotoxic), which might then affect the mussels' predators as well. Even though there haven't been many mechanical research done on the accumulation and ecotoxicity of microplastics in aquatic environments, microplastics can be consumed by organisms at all stages of the life cycle.

3) The impact of microplastics on the terrestrial environment

Researchers have documented the effects of microplastics on the aquatic environment, but the potential implications of microplastics in the terrestrial environment are yet unknown. However, it is important to keep in mind that microplastics may linger in soils for more than a century due to low light and oxygen levels (Wong *et al*., 2020). The main origins of microplastics in the soil are thought to include a number of activities, including water supply, erosion, air deposition, littering, roadway runoff, and plastic mulching (Huan e al., 2020). Furthermore, microplastics can interact negatively with a variety of soil fauna, potentially disrupting various soil functions and having detrimental health effects on them. For example, microplastics in the soil can be moved by earthworms and springtails in both directions. Exposure to microplastics may lead to structural alterations in earthworm burrows, thereby impairing soil aggregation and function (He and Luo, 2020). The natural, essential ecosystem services and functions of many terrestrial creatures, including birds, invertebrates, soil microbes, plant-pollinators, and vertebrates, are being hampered by microplastics. As a result, these testimonials have highlighted microplastics as a hazard to the terrestrial ecosystem above all others.

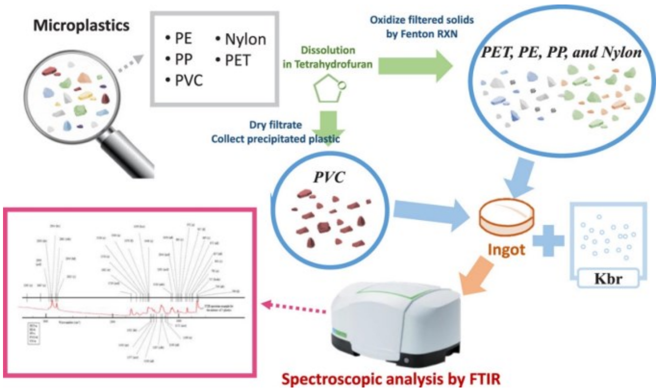

Figure 4. Graphical abstract of the FTIR measurement process of microplastic samples (Fan *et al*., 2021) (Copyright of ELSEVIER)

4) *Microplastics and human health*

Primary microplastics are thought to be the most likely sources of microplastic exposure in humans and can come from a variety of sources, including toothpaste, cleaning supplies, and cosmetics (Prata *et al*., 2020). Eight participants from Europe, Russia, and Japan had stool samples that were found to contain microplastics (Bagaev *et al*., 2021). Furthermore, out of the nine distinct microplastic kinds that were identified, with sizes ranging from 50 to 500 µm, polypropylene and polyethylene terephthalate were the most prevalent forms. Additionally, the study showed that humans could be exposed to different kinds of microplastics through the food chain and estimated that almost half of the world's population may have microplastics in their faeces (De-la-Torre, 2020). Microplastics are becoming more prevalent in seafood on a daily basis, which is detrimental to human health (Campanale *et al*., 2020). It has been shown that a variety of small aquatic species, including mussels, consume microplastics (Li *et al*., 2021), Fish, oysters, and crabs moved with the food chain (Okeke *et al*., 2022). Furthermore, a variety of fruit and vegetable plants have the potential to absorb microplastics from the soil, and humans may ingest up to 80 mg of microplastics daily through the food chain. On the other hand, there are some disagreements over how microplastics affect human health. While some research has indicated that microplastics may enter the human gastrointestinal system and have no discernible effects on health, other studies have hypothesised that microplastics may be responsible for potential health risks to humans, such as obesity, cancer, and infertility (Senathirajah *et al*., 2021). Human organs can accumulate microplastics. Thus, it is evident that microplastics can enter the human body through the food chain, but further research is necessary to confirm the impact of microplastics on human health.

Methods for identifying and eliminating microplastics

The use of hazardous materials and improper handling of the many plastic products are contributing to the growing contamination of microplastics. In addition, certain industries—such as textiles, fertilisers, medicines, cosmetics, etc.—use microplastics as a crucial component. An embargo on the use of microplastics in any form would therefore not be a financially sensible option in relation to such sectors. Future studies should therefore present comprehensive methods for identifying, characterising, and eliminating microplastics from the environment, such as economical technologies and sustainable management plans. Different polymer types make up different kinds of microplastics. Since various polymers require distinct methods for separation and quantification, polymer identification is therefore an emerging strategy. Filtration, density separation, and visual sorting are common separation procedures. Visual sorting involves density and colour and yields a less accurate and time-consuming outcome. This raises concerns regarding the visual classification of microplastics because weathering may alter the polymer characteristics (Tursi *et al*., 2022; Dey *et al*., 2021; Elkhatib *et al*., 2021). The application of Raman or infrared spectroscopy for additional investigation of any particle with a dimension of 20–100 µm is clearly evident. The most widely used methods for determining the chemical makeup of microplastics at the moment are infrared spectrophotometry and Fourier Transform Infrared Spectroscopy (FT-IR) (Figure 4) (Tirkey and Upadhyay, 2021).

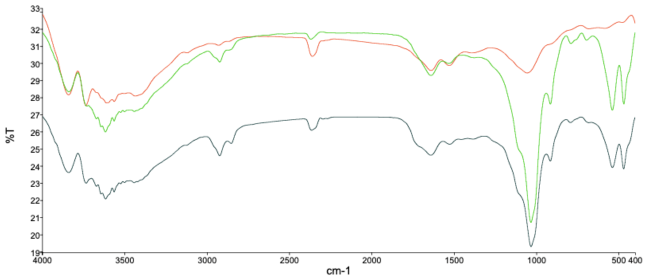

Figure 5. FTIR Spectrum of Nylon (Polyamide) (Laila *et al.*, 2020) (Copyright of The Jurnal Pasir Laut).

The results of FT-IR analysis of microplastics in sediment on the coast of Mangunharjo Village from three stations (coastal, river and mangrove areas) show the same graph peaks, namely at wavelengths of 1,640 cm^{-1}, 2,925 cm^{-1}, and 3,618 cm^{-1} and identified as Nylon (Polyamide) plastic with the FT-IR spectrum image as shown in Figure 5. Nylon polymer is generally a component of fishing nets used by fishermen.

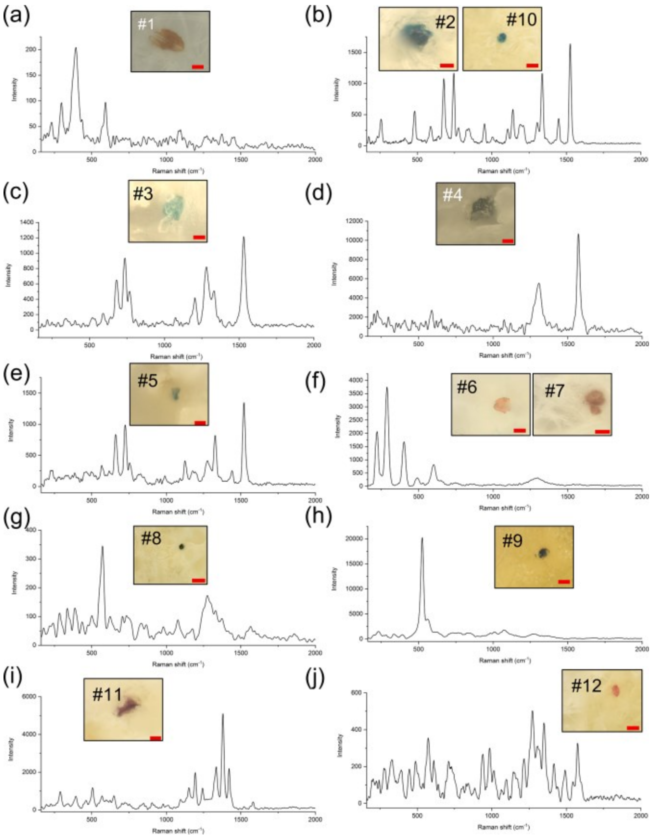

Figure 6. Raman spectra and microphotographs of the microplastics in human placenta (Ragusa *et al.*, 2021) (Copyright of ELSEVIER)

Some other methods namely: Transmission electron microscopy (TEM), Energy disperse X-ray spectroscopy (EDS), Scanning electron microscopy (SEM), Atomic force microscopy (AFM), X-ray photo electron spectroscopy (XPS), Stereomicroscope and others are also promising alternatives (Bhagat *et al.*, 2022; Karbalaei *et al.*, 2020; Li *et al.*, 2020; Akhatova *et al.*, 2022; Huang *et al.*, 2023) (Figure 6).

In addition, removal strategies are required in addition to identification in order to eliminate microplastics from the various environmental compartments. Membrane bioreactors outperform other treatment methods and typical activated sludge among all of these removal techniques in terms of efficiency (Mishra *et al.*, 2022). The biological degradation method, on the other hand, has the lowest efficiency rate. However, since biological elimination procedures are still in their infancy, more research can be done to significantly enhance this strategy's performance (Cherniak *et al.*, 2022). Extremely sophisticated and successful eradication techniques are impractical for use on a global scale. As a result, scientists and policymakers ought to create a standardised removal plan that would be simple and successful to implement globally.

Research Gaps on MPs Research in Indonesia

The scarcity of resources, such as costly chemical reagents and specialized analytical instrumentation that are not readily accessible in Indonesia, has resulted in a lack of polymer analysis in most studies on microplastics conducted in the country. Studies that do not identify the polymer content of microplastics often result in an overestimation of their concentration. The concentration of microplastics in Indonesian waters exhibits significant variability. In addition, these studies did not include the blank procedure during sampling and laboratory analysis, making it difficult to conduct comparative studies with other research conducted in Indonesia (Adela, 2020).

The microplastics research in Indonesia primarily concentrated a lot of on the western region of the country, specifically Java Island. More than half of the data originated from the western region of Indonesia (Table 1). Concurrently, investigations carried out in the eastern region of Indonesia primarily focused on rural areas and small islands, which are highly susceptible to the detrimental effects of marine plastic pollution as a result of inadequate waste management practices. The source of plastic pollution in Indonesia can be traced back to rural areas and small to medium-sized urban centers. The presence of inadequate waste management on small islands leads to the accumulation of plastic waste in mangrove areas. Insufficient data exists on the distribution of microplastics in Indonesia's sediment. The dearth of research in the field of sedimentology in Indonesia is a noteworthy observation. Despite the scarcity of sediment data, multiple studies have forecasted the potential for significant sediment accumulation.

This concise review also emphasizes that the prevailing research in Indonesia primarily focuses on the dissemination and accumulation of microplastics. Comprehensive data regarding the analysis of how microplastics travel and eventually reach the bodies of organisms or humans, as well as research on the mechanisms of microplastic transportation, seems to be lacking in Indonesia. Moreover, given the elevated levels of microplastics found in Indonesian sediment at certain sites, we suggest conducting research on mitigating the presence of microplastics in the environment.

Conclusion

This review investigates the kinds, shapes, sources, and worldwide reaction of microplastics. Microplastics have been detected in a number of human biological specimens, including the placenta, sputum, saliva, blood, bronchoalveolar lavage fluid, and feces. These findings raise the possibility that these particles could have a negative impact on human health. Potential health hazards such as cancer, immunotoxicity, lung, intestinal, and cardiovascular disorders, as well as negative effects on pregnancy and the mother's exposure to her offspring, can all be a result of these impacts. In order to create appropriate substitutes for single-use face masks and the plastic waste produced by the medical profession, further study is also required to comprehend the acute and long-term hazardous effects of microplastics on people and animals. Microplastics need to be better separated from other pollutants, turned into useful byproducts, and have their environmental destiny determined. While creating recycling and reuse strategies for plastic waste from the medical industry, it is imperative to find appropriate substitutes for single-use face masks. In order to maximize the positive effects and minimize the negative effects of microplastic removal, efforts should also be made to integrate microplastic treatment technologies and increase the quality and effectiveness of plastic alternatives, such as bioplastics. Ultimately, while choosing a plan to cut back on plastic consumption, one should take into account things like the state of the economy, the infrastructure, the kinds of microplastics that are discharged into the environment, other possibilities, and the public's readiness to move away from a plastic-dependent economy.

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How to cite this paper:
Akbar, S.A., S. Afriani, C. Nuzlia, S. Nazlia, S. Agustina. 2023. Microplastics in sediment of Indonesia waters : A systematic review of occurrence, monitoring and potential environmental risks. Depik Jurnal Ilmu-Ilmu Perairan, Pesisir dan Perikanan, 12(3): 259-273.