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Microplastics Contamination in the Aquatic Environment of Indonesia: A Comprehensive Review

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ABSTRACT

The abundance of microplastics (MP) in the aquatic environment is increasingly disturbing for maritime countries, especially Indonesia, because it has the potential to threaten the health and sustainability of aquatic ecosystems. This review summarized and discussed the distribution of MP abundance in Indonesian aquatic ecosystems which concluded that rivers, bays and estuaries, beaches, seas, and even fish and shellfish have been contaminated. The highest contamination of MP was found in the waters of Jakarta, West Java, and East Java, which are densely populated areas. The potential threat of exposure and accumulation of MP to human health was also discussed. However, differences in the methods and units of measurement for MP as well as limited information regarding the interaction of MP with human organ functions are weaknesses in this review. The future research on the relationship between food and feeding habits of the community around contaminated waters with the accumulation of MP in the human body is needed to identify the prevention and treatment strategies.

Keywords: aquatic environment, contamination, human exposure, Indonesia, microplastics

INTRODUCTION

Plastic is a synthetic organic polymer that is light, strong, and easy to shape [Firdaus et al., 2020], then widely used for various needs of both domestic and industrial [Aliabad et al., 2019; Rios Mendoza & Balcer, 2019]. The high intensity of plastic use has not been accompanied by proper post-use management, which has increased its abundance and pollutes the environment, especially aquatic ecosystems. Plastics have been able to undergo physical, mechanical, and biological fragmentation into smaller particles which are classified into microplastics, meso-plastics, and MP with a size of < 5.00 mm; 2.50–5.00 mm; and > 2.50 mm, respectively [Alam & Rachmawati, 2020; Firdaus et al., 2020; Lestari et al., 2020; Rios Mendoza & Balcer, 2019].

MP have been found in the aquatic environment of several countries, including Iran [Aliabad et al., 2019], Bangladesh [Hossain et al., 2019], India [Sarkar et al., 2019], China [Zhu et al., 2019], Mexico [Ramírez-Álvarez et al., 2020], Canada [Anderson et al., 2016], and Indonesia [Alam et al., 2019; Firdaus et al., 2020; Lestari et al., 2020]. Therefore, other aquatic environments in Indonesia are also highly contaminated by MP, considered by Indonesia as one of the largest contributors of plastic debris to the oceans in the world, reaching 1.29 tons/year [Jambeck et al., 2015]. This condition has a negative impact because MP is hardly degraded and able to adsorb hydrophobic compounds which are persistent and toxic in aquatic environment [Rios Mendoza & Balcer, 2019].

MP also potentially becomes a vector of contaminants, because the particles may undergo biomagnification, i.e. pollutants transfer through the food chain [Aliabad et al., 2019; Caruso, 2019]. Biomagnification has been confirmed by several studies, which reported that MP was found in the fish and shellfish living in a contaminated aquatic environment [Caruso, 2019; Hossain et al., 2019; Sarkar et al., 2019], human feces [Aliabad et al., 2019; Liebmann et al., 2018], and human placenta [Ragusa et al., 2021]. These conditions indicate that MP accumulates in human tissues, which may cause various health problems, such as gut dysbiosis, impaired kidney function, and cancer [Carding et al., 2015].

In addition, the permissible levels of MP in aquatic environment have not been found, posing threat to the waters, biota, food security, and public health. It has threatened Indonesia, one of the largest maritime countries in the world, where aquatic environment is one of the main sources of life, including base water for daily consumption, aquaculture, and water recreation. The studies related to the identification of MP abundance in the aquatic environment in Indonesia have also begun, but are still partial.

Comprehensive information on the abundance of MP in the aquatic environment has not been found, which caused that its contamination characteristics in various areas could not be properly compared and identified. The information is needed for mapping the condition of aquatic environment in Indonesia and increasing the public knowledge to plan and develop mitigation of MP contamination. Therefore, the provision of comprehensive information on the MP contamination, including abundance, shape, and type of polymer in aquatic environment of Indonesia is highly urgent, which is also the aim of this review. In addition, recommendations for units of measurement to facilitate the compilation and comparison of data were also suggested in current study.

CHARACTERISTICS OF MICROPLASTICS

MP is defined as a small plastic polymer with size lesser than 5.00 mm that derives from industrial wastewater and plastic debris that ended up in aquatic environment [Anderson et al., 2016]. The industrial wastewater containing MP generally comes from the production of beauty/cosmetic materials, cleaners, plastic packaging, scrubbers, and pellets in each of their products [Alam et al., 2019; Anderson et al., 2016]. Meanwhile, the second source is the plastic debris fragmentation in the waters [Alam et al., 2019; Aliabad et al., 2019] which annually accumulates as much as 4.80–12.70 million tons, to which Indonesia has contributed almost 1.29 tons/year [Jambeck et al. 2015]. It indicates that the abundance of MP may continue to increase every year [Anderson et al., 2016].

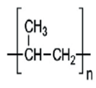
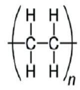
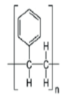
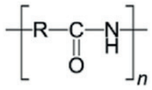
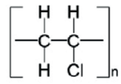
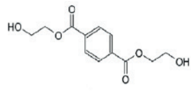
On the basis of the shape, MP is divided into fragment, fiber, filament, film, foam, and pellet [Widianarko & Hantoro, 2018; Yona et al., 2020]. MP is also classified according to the polymer types of polyvinylchloride (PVC), polyethylene (PE), polystyrene (PS), polypropylene (PP), and polyester (PES) [Aliabad et al., 2019; Anderson et al., 2016]. Each type of polymer has a different density, which affects its fragmentation and position in the water column (Table 1). Table 1 shows that PP and PE float in all types of water, but it still tends to sink like PS, PVC, and PES when subjected to biofouling, which increase their density [Anderson et al., 2016; Andrady, 2011].

Plastic polymers may undergo various fragmentation mechanisms, such as PE and PP can be fragmented into MP through photo-oxidation and thermo-oxidation [Anderson et al., 2016; Andrady, 2011]. Given the small size of MP, it may be biodegraded by bacteria over a long time due to its complex structure [Barnes et al., 2009], where the carbon is converted into carbon dioxide and biomass [Andrady, 2011]. Therefore, MP may become persistent in aquatic environment and has a tendency to bioaccumulate in aquatic biota when ingested [Anderson et al., 2016; Rios Mendoza & Balcer, 2019].

MICROPLASTIC IN INDONESIAN WATERS

Identification of MP abundance has been carried out in various Indonesian aquatic environments, in terms of East Kalimantan, DKI Jakarta, Central Java, West Java, Yogyakarta Special Region, Bali, South Sumatra, North Sumatra, West Sumatra, East Nusa Tenggara, South Sulawesi, Southeast Sulawesi, Riau, and Maluku which dominated by East Java (see Table 2). Table 2 shows that the abundance of MP has been found in the water column, sediment, and aquatic biota, as described by [Andrady, 2011].

Table 1. Types and Density of Microplastic Polymers

Polymer Types	Polypropylene (PP)	Polyethylene (PE)	Polystyrene (PS)	Nylon/Polyamide (PA)	Polyvinylchloride (PVC)	Polyester (PES)
Chemical structure						
Polymer Density (kg/m^3)	900	910-970	1050	1160	1330	1370
Water density (kg/m^3)	1000					
Brackish water density (kg/m^3)	1005–1024					
Sea water density (kg/m^3)	1025					
Position	Float	Float	Float	Sink	Sink	Sink

Adapted from Anderson et al. (Anderson et al., 2016)

MICROPLASTICS IN RIVER ECOSYSTEMS

The MP abundance reaching as much as 0.55–0.90 particles/L to 0.13x10^6 particles/L has been found in the water column of 9 rivers in Indonesia (Table 2). The highest abundance of MP in river water column was found in the Cimandiri watershed, followed by the Surabaya River and Banyuurip Estuary with the number of 3.45–63.38x10^3 particles/L and 7.78x10^3 particles/L, respectively. Meanwhile, the lowest MP abundance was found at the Bengawan Solo River.

Table 2 shows that the MP abundance in the Surabaya River in 2019 and 2020 was different; there was an increase from 0.52–2.53x10^3 particles/L to 0.76–43.11x10^3 particles/L, respectively. The dominant shape of MP found there is fragment and film that may be formed through photo-degradation and thermo-oxidation of plastic waste in the waters [Barnes et al., 2009]. The condition is relevant to the continuity of plastic waste that ends up in rivers every day, but this cannot be fully handled by the self-purification ability of the river which leads to MP accumulation. Continuity and accumulation due to plastic waste disposal is in line with the predictions by World Bank as stated by Firdaus et al. [2020] that in 2025 there will be a 76.00% increase in plastic waste, which simultaneously increases the risk of MP abundance in the Indonesian rivers. This condition is emphasized by Yudhantari et al. [2019] that 92.40% of plastic waste particles is < 5.00 mm and categorized as MP. In addition, laundry wastewater is another source of MP contamination in rivers[Andrady, 2011].

MP abundance in several river sediments in Indonesia were found at Deli, Muara Badak, Bengawan Solo, Ciwalengke, and Musi with a total of 0.09–0.36x10^3; 0.04–0.19x10^3; 1.95–2.70; 0.30±0.16; and 1.78x10-3 particles/kg, respectively. MP has also been found in the sediment of the Tuban River amounting to 0.52–5.88 x10^3 particles/m^2, but it cannot be compared, because it has different units of measurement. This difference is one of the main obstacles to identify the abundance of MP in the waters, because the compilation and comparison cannot be carried out [Rios Mendoza & Balcer, 2019].

The abundance of MP in the water column and sediment of rivers in several areas shows different amounts due to the population and public activities around the area [Barnes et al., 2009; Joesidawati, 2018]. The higher the population and public activities around the river, the more unmanaged plastic waste and laundry wastewater are generated [Manalu, 2017]. Piles of unmanaged plastic waste in rivers cause a decrease in flow velocity and water movement down to 0.00–0.10 m/s [Barnes et al., 2009], causing fragmentation and centralized accumulation as found in this review in the Ciwalengke River.

In the Ciwalengke River, similar shape and polymer type of MP, namely fiber and PES, has been found in water column and sediment. The accumulation of PES in the sediment of the Ciwalengke River was caused by higher MP density than water, amounting to 1370 kg/m^3 and 1000 kg/m^3, respectively [Anderson et al., 2016]. This condition causes an increase in MP abundance in waters, similarly to those found in Bei and Huanzi Lakes [Wang et al., 2017]. In addition, the prolonged presence of MP in water column may trigger microorganisms to form a biofilm on the surface of particle, known as biofouling, then

Table 2. Abundance of Microplastics in Indonesian Waters

Province	Area	Years	Microplastics Abundance			Reference
			River	Bay	Sea	
East Kalimantan	Badak River, Kutai Kartanegara District	2015	Sediment = 0.04-0.19 x10^3 particles/kg, dominated by fragment	–	–	[Dewi et al., 2015]
DKI Jakarta	Pantai Indah Kapuk Coast	2014	–	–	Sediment = 0.19-2.36x10^3 particles/kg, dominated by film	[Hastuti et al., 2014]
	Jakarta Bay	2017	–	Water = 2.88-7.47x10^6 particles/L, dominated by fragment Sediment = 18.41-38.79 x10^3 particles/kg, dominated by fragment	–	[Manalu, 2017]
	DKI Jakarta River-Estuaries (Tiram, Ciliwung, Sunda Kelapa, Baru, Karang, Angke, Cengkareng Drain)	2019	Water = 0.09-0.11x10^3 particles/L, dominated by fragment	–	–	[Rachmat et al., 2019]
East Java	Tuban District Estuary	2018	Sediment = 0.52-5.88x10^3 particles/m^2	–	–	[Joesidawati, 2018]
	Tuban District Coast	2018	–	–	Sediment = 73.00-256.50 particles/m^2	[Joesidawati, 2018]
	Banyuurip Waters, Gresik District	2019	Water = 7.78x10^3 partiles/L, dominated by fragment	Water in the mangrove area = 22.89 particles/L, dominated by fragment	Water = 7.11x10^3 particles/L, dominated by fragmen	[Ayuningtyas et al., 2019]
	Surabaya River, Surabaya City	2019	Air = 7.14-32.38x10^3 partikel/L	–	–	[Wijaya & Trihadiningrum, 2019]
	Gili Labak Island, Sumenep District	2019	–	–	Water = 1.89 particles/L, dominated by fiber Sediment = 65.00 particles/kg, dominated by fiber	[Lolodo & Nugraha, 2019]
	Mandangin Island, Sampang District	2019	–	–	Sediment = 0.02-0.34 x10^3 particles/kg, dominated by filament and PE Water = 2.00-24.00x10^3 particles/m^2, dominated by fragment, filament, and PVC	[Rahmadhani, 2019]
	Bentar Island, Probolinggo District	2019	–	–	Water = 0.42 particle/m^2, dominated by film dan fragment	[Germanov et al., 2019]
	Jagir Estuary, Surabaya City	2020	–	Sediment = 0.09-0.41x10^3 particles/kg, dominated by fiber and PES	–	[Firdaus et al., 2020]

Table 2. cont.

Province	Area	Years	Microplastics Abundance			Reference
			River	Bay	Sea	
	Wonorejo Beach, Surabaya City	2020	–	–	Sediment = 0.48-0.59x10^3 particles/kg, dominated by fiber and PES	[Firdaus et al., 2020]
	Surabaya River, Surabaya City	2020	Water = 3.45-63.38x10^3 particle/L, dominated by film and PP	–	–	[Lestari et al., 2020]
	Brondong Waters, Lamongan District	2020	–	–	Sediment = 0.36 particles/kg, dominated by fiber dan fragment Water = 0.44 particles/L, dominated by fiber dan fragment	[Labibah & Triajie, 2020]
	Lekok Beach, Pasuruan District	2020	–	–	Sediment = ±78.35 particles/m^2, dominated by fiber dan film	[Yona et al., 2020]
	Pasir Panjang Beach, Pasuruan District	2020	–	–	Sediment = ±47.85 particles/m^2, dominated by fiber dan film	[Yona et al., 2020]
	Watu Prapat Beach, Pasuruan District	–	–	–	Sediment = ±18.67 particles/m^2, dominated by film dan fiber	[Yona et al., 2020]
	Kapasan Beach, Pasuruan District	–	–	–	Sediment = ±18.29 particles/m^2, dominated by film dan fiber	[Yona et al., 2020]
	Kepetingan Waters, Sidoarjo District	2021	–	–	Sediment = 0.17-0.35x10^3 particles/m^3, dominated by fiber dan fragment Water = 57.00-79.80x10^3 particles/L, dominated by fragment dan film	[Firmansyah, 2021]
Central Java	Semarang Beach	2018	–	–	Water = 5.86±3.70 particles/L, dominated by fiber Sediment = 3.90±5.45 particles/kg, dominated by film	[Widianarko & Hantoro, 2018]
	Kartini Beach, Jepara District	2019	–	–	Sediment = 21.90-32.15 particles/kg, dominated by fragment	[Azizah et al., 2020]
	Bengawan Solo River	2019	- Water = 0.55-0.90 particles/L, dominated by fiber - Sediment = 1.95-2.70 particles/kg, dominated by fragment	–	–	[A'yun, 2019]
	Karimunjawa Marine National Park	2021	–	–	Sediment of coral reef ecosystem = 11.00-96.00 particles/kg	[Muchlissin et al., 2020]

Table 2. cont.

Province	Area	Years	Microplastics Abundance			Reference
			River	Bay	Sea	
West Java	Pangandaran Beach, Pangandaran District	2018	–	–	Sediment = 26.00-78.00 particles/kg, dominated by fiber	[Septian et al., 2018]
	Ciwalengke River, Bandung District	2019	Water = 3.28±5.85 particles/L, dominated by fiber and PES Sediment = 0.30±0.16 particles/kg, dominated by fiber and PES	–	–	[Alam et al., 2019]
	Cimandiri Watershed	2020	Water = 0,13x10^6 particles/L, dominated by film and fragmen	–	–	[Lodo Pe et al., 2020]
	Pelabuhan Ratu Estuary	2020	–	Water = 1.49x10^6 partikel/L, dominated by film dan fragment	–	[Lodo Pe et al., 2020]
Bali	Benoa Bay	2018	–	Water = 0.43-0.58x10^3 particles/L, dominated by fragment Sediment = 0.07-0.11x10^3 particles/kg, dominated by fragment	–	[Nugroho et al., 2018]
	Doublesix Beach, Badung District	2019	–	–	Sediment = 71.50±28.90 particles/kg dominated by fiber and PS	[Mauludy et al., 2019]
	Kuta Beach, Badung District	2019	–	–	Sediment = 148.90±103.80 particle/kg, dominated by fiber and PS	[Mauludy et al., 2019]
	Pantai Melasti, Kabupaten Badung	2019	–	–	Sediment = 67.20±46.10 particles/kg dominated by fiber, PP, and PS	[Mauludy et al., 2019]
	Mengiat Beach, Badung District	2019	–	–	Sediment = 95.40±52.10 particles/kg, dominated by fiber, fragment, PP, and PS	[Mauludy et al., 2019]
	Tanjung Benoa Beach, Badung District	2019	–	–	Sediment = 70.50±29.60 particles/kg dominated by fiber, fragmen, and PS	[Mauludy et al., 2019]
	Nusa Penida, Klungkung District	2019	–	–	Water = 0.04-0.90 particles/m^2, dominated by film and fragmen	[Germanov et al., 2019]
South Sumatera	Musi Estuary	2018	Sediment = 1,78x10^{-3} particles/kg, dominated by fragment and PP	–	–	[Ahmad, 2018]

Table 2. cont.

Province	Area	Years	Microplastics Abundance			Reference
			River	Bay	Sea	
North Sumatera	Sei Babura River, Medan City	2021	Water = 0.07-0.16x10^3 particles/L, dominated by film and fragment	–	–	[Harahap, 2021]
	Sei Sikambing River, Medan City	2021	Water = 0.08-0.17x10^3 particles/L, dominated by film and fragmen	–	–	[Harahap, 2021]
	Deli River	2021	Sediment = 0.09-0.36x10^3 particles/kg, dominated by film and fragment	–	–	[Addauwiyah, 2021]
West Sumatera	Naras Hilir Beach, Pariaman City	2020	–	–	Sediment = 13.24 particles/m^3, dominated by film	[Yolla, 2020]
East Nusa Tenggara	Sawu Sea	2019	–	–	Water = 18.00 particles/L, dominated by fragment	[Hiwari et al., 2019]
	Komodo National Park, Manggarai Barat District	2019	–	–	Water = 0.24-0.29 particles/m^2, dominated by film and fragment	[Germanov et al., 2019]
	Kupang Bay	2020	–	Water = 0.10-90.20x10^{-3} particles/L, dominated by fiber	–	[Kapo et al., 2020]
South Sulawesi	Burau Sea, Luwu Timur District	2021	–	–	Water = 56.20x10^3 particlesl/L	[Kama et al., 2021]
Southeast Sulawesi	Kendari Bay	2020	–	Sediment = 1.36-3.52x10^{-3} particles/kg, dominated by fragment	–	[Layn et al., 2020]
Riau	Bengkalis Island Waters, Bengkalis District	2020	–	–	Water = 19.17-80.83x10^3 particles/L, dominated by fiber	[Febriani et al., 2020]

increasing the density and accumulation of MP [Andrady, 2011; Barnes et al., 2009; Browne et al., 2011]. It can be seen at the Bengawan Solo River, where the dominance of MP in water column (fiber) and sediment (fragment) is different.

If there is no accumulation of unmanaged plastic waste, rivers can act as distribution routes for MP and other pollutants to other waters and seas, because they are interconnected [Manalu, 2017; Stolte et al., 2015]. This is due to the currents and water velocity on river of 0.10–0.20 m/s [Ayuningtyas et al., 2019; Barnes et al., 2009]. It may contributed to the low number of MP in the water column and sediments of the Bengawan Solo River, as sampling was carried out in the watershed leading to estuary.

MICROPLASTIC IN MARINE ECOSYSTEMS

Table 2 showed that water column and sediment in several bays and estuaries in Indonesia have been contaminated by MP, with an abundance of 0.10x10^{-3} – 7.47x10^6 particle/L and 0.07x10^{-3} – 38.79x10^3 particle/kg. The lowest MP abundances for water column and sediment were found in Kupang Bay and Kendari Bay, respectively. Meanwhile, the highest MP abundance for water and sediment was found in Jakarta Bay, with the predominance of fragments, PP, and PE, which indicated that deposition was caused by biofouling.

The dominance of MP in Jakarta Bay is similar to the findings in DKI Jakarta River-Estuaries of Angke, Baru, and Ciliwung (see Table 2), which have proven that rivers are a transport route for pollutants. As reported by Manalu [2017] there was a lot of unmanaged plastic waste at the river-estuaries of DKI Jakarta, which might be broken down into fragments. It was also found in Jagir Estuary, where 52.30–63.00% of the generated domestic waste was not properly managed by the community and was disposed into rivers, thereby increasing the abundance of MP in the Surabaya River [Lestari et al., 2020] and Jagir Estuary [Firdaus et al., 2020] which is dominated by fiber, film, and PES. The dominance of MP which was found in several estuaries and bays has shown that the waste generated from waters utilization for marine transportation and aquaculture activities is another source which exacerbates the MP contamination.

Given the existence of currents and tidal waves in estuary and bay [Bessa et al., 2018], both of them have become the entry point for plastic waste or MP from river into the sea [Andrady, 2011]. As reported by Andrady [2011], 80.00% of the plastic waste found in the ocean comes from rivers, which generally occur in large rivers [Kama et al., 2021]. Therefore, it is well-earned that water column and sediment in the beach and the sea are contaminated by MP. On the basis of the data obtained, the abundance of MP in water column and sediment from several beaches and seas amounts to $1.89x10^{-3}$ – $80.83x10^{3}$ particles/L and $8.76x10^{-3}$ – $2.36x10^{3}$ particles/kg, respectively.

The highest abundance of MP in seawater column was found in Bengkalis Island Waters which were dominated by fibers and films, followed by Kepetingan and Burau Waters of 57.00–$79.80x10^{3}$ particles/L (fragments and films) and $56.20x10^{3}$ particles/L (fragments), respectively. It is caused by high utilization of the waters for marine transportation, coastal tourism, and aquaculture such as seaweed. Especially for Bengkalis Island Waters, there are also many offshore oil-rigs that may cause oil spills during the drilling and distribution activities. Meanwhile, the sediment in Pantai Indah Kapuk Coast contains the highest MP, which is 0.19–$2.36x10^{3}$ particles/kg, with film as the dominant MP. Pantai Indah Kapuk is connected to the Angke and Cengkareng Drain Estuaries which hold a lot of plastic waste. Moreover, Pantai Indah Kapuk is a densely populated area and mangrove cultivation areas [Hastuti et al., 2014].

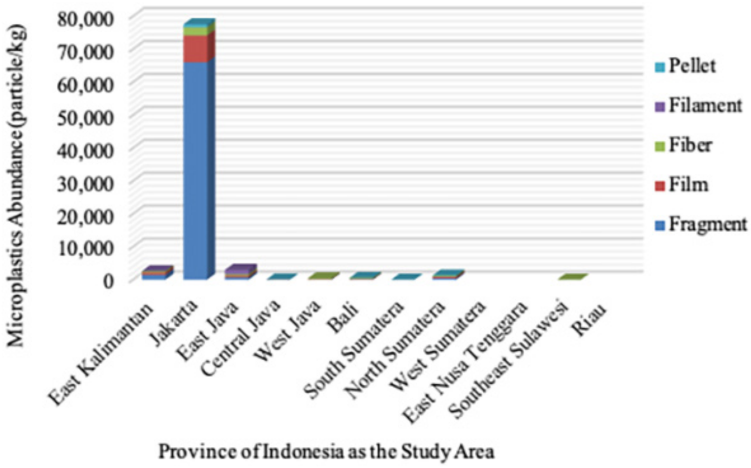
When compared, the abundance of MP based on observation location has shown that bays and estuaries have higher number of MP than rivers, beaches, and seas in Indonesia. This is because bays and estuaries are meeting points of rivers and seas, so that there are differences in the water density and its location is protected from waves which inhibit the plastic waste and MP distribution. The inhibition is also caused by the geographical characteristics of bays and estuaries which are the habitats of mangrove, where plastic waste and MP are trapped in the root areas. Mangroves are also found on the coast close to bays and estuaries. These conditions have an impact on the deposition and accumulation of plastic waste and MP in the sediment as an effect of its limited movement, as those found in Jakarta Bay, Pantai Indah Kapuk and Wonorejo Coast. It also occurs in the coral reef cultivation areas as shown in the Karimun Jawa Marine National Park.

Thus, it can be concluded that the main source of MP contamination in water column and sediment of Indonesian Waters is disposal of unmanaged domestic waste, especially plastic waste into waters, which is indicated by fragments as the dominant MP found (Figure 1). The amount of plastic waste disposal is influenced by the public activities around the waters area. As shown in Figures 1 and 2, the aquatic environment in Indonesia that are highly contaminated by MP are DKI Jakarta, West Java, and East Java, with an abundance of water and sediment reaching as much as $35.46x10^{6}$; $2.79x10^{6}$; $0.52x10^{6}$ particle/L and $77.60x10^{3}$; $0.47\ x10^{3}$; and $3.81x10^{3}$ particle/kg, respectively. These provinces are the areas with the highest population in Indonesia. The classification was carried out using the data with the same unit of measurement for water (particles/L) and sediment (particles/kg), according to Rios Mendoza & Balcer [2019] recommendation.

Moreover, the abundance of MP in waters is influenced by polymer type, pattern and speed of distribution. The type of polymer is closely related to the density and buoyancy of MP in the waters. The pattern and distribution of MP depends on the direction and flow velocity of currents, tidal waves, density, and the geographical characteristics of the waters. In addition, the direction and speed of wind are also the factors that affect the characteristics of currents and waves in the waters [Anderson et al., 2016; Andrady, 2011; Barnes et al., 2009; Bessa et al., 2018; Browne et al., 2011; Ramírez-Álvarez et al., 2020; Rios Mendoza & Balcer, 2019; Stolte et al., 2015].

MICROPLASTIC IN AQUATIC BIOTA

The MP contamination was not only found in the water column and sediment, but also in aquatic biota, especially pelagic and demersal fish of 2.00–95.65 particles/ind and 1.00–61.5 particles/ind, respectively (Table 3). The pelagic fish containing the highest amount of MP was *Frigate tuna* from Boron Beach, followed by *Anodontostoma chacunda* (77.40 particles/ind) and *Arius* a)



b)

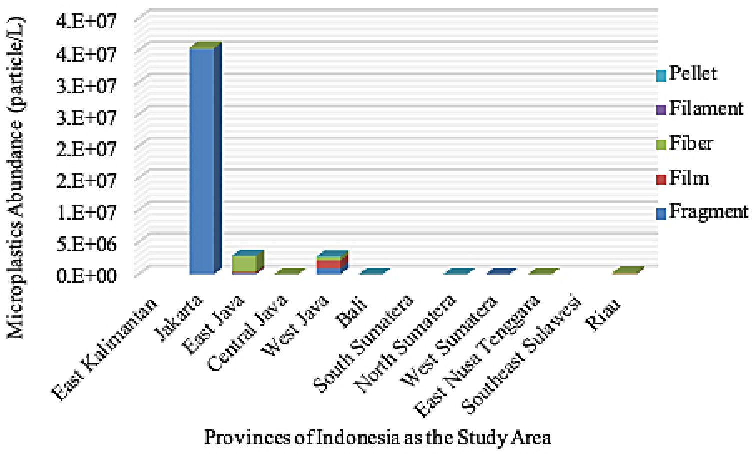


Figure 1. Microplastic shape in Indonesian waters

maculatus (72.22 particles/ind) that are found in Jakarta Bay and Bengkalis Island Waters. Meanwhile, the demersal fish which contains the highest MP were *Nemipterus marginatus* (Jakarta Bay), followed by *Japanese threadfin bream* (Boron Beach); *Eleutheronema tetradactylum* (Jakarta Bay); and *Neotrygon annotate* (Jakarta Bay) with a total of 57.50; 56.00; and 56.00 particles/ind, respectively.

The number of MP in two types of fish is influenced by several factors, including habitat, abundance of MP in the habitat (number and

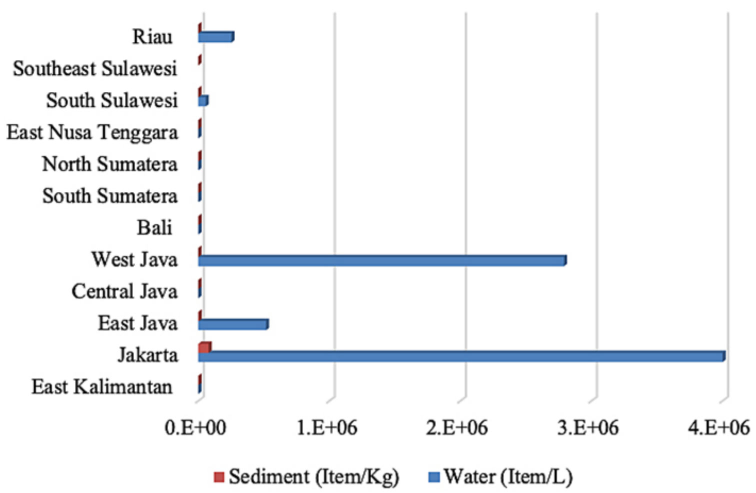


Figure 2. Distribution of microplastics abundance in aquatic environment of Indonesia

shape), feeding and food habits. Pelagic fish have a higher MP because their habitat is in the water column, which is an area with a wider distribution of MP than the bottom area of waters that is the habitat of demersal fish. The dominance of pelagic and demersal fish containing MP was found in Jakarta Bay, where the water column and sediment were contaminated by as much as 2.88–7.47x10^6 item/L and 18.41–38.79x10^3 particles/kg, respectively.

Small pelagic fish such as *A. chacunda*, and *A. maculatus* are classified as filter feeders, that preys on zooplankton through water suction, potentially ingesting very small MP at the same time [Manalu, 2017]. Zooplankton is also a filter feeder (Andrady, 2011; Germanov et al., 2019); therefore, very small MP may be consumed and accumulated in its tissues because there is no enzymatic reaction of digestion, which is commonly known as bio-inert [Andrady, 2011; Carbery et al., 2018; Fackelmann & Sommer, 2019]. Desforges et al. [2015] reported that the zooplankton in the Northeast Pacific Ocean contains 0.03–0.06 particles/ind with a size of 556.00–816.00 μm. Therefore, small pelagic fish may be affected by double consumption of MP. In addition, zooplankton is able to retain MP in its tissues for up to several hours, then die and accumulate in sediment. This threat also concerns other organisms at different durations, for instance, crabs are capable of retaining MP for to 14 days.

Meanwhile, large pelagic fish showed a higher level of food and feeding habits than small pelagic fish which are mostly omnivores preying on detritus, zooplankton, small pelagic fish, insects, and shrimp. Given the shape of elongated fiber is similar to that of prey, the fish tend to approach it [Foley et al., 2018] and it may be accidentally ingested by large pelagic fish [Andrady, 2011; Yudhantari et al., 2019]. A similar accident due to MP misrecognizing also occurs in demersal fish [Nie et al., 2019] because its feeding habits are carried out by filtering sediment to catch the prey [Manalu, 2017]. This is consistent with the data shown in Table 3, that fiber has been demonstrated as dominant MP in fish. The mechanism suggests that the MP pathway in large pelagic and demersal fish is through the trophic transfer and inadvertent ingestion of MP which is similar in appearance to prey.

MP is also found in shellfish at contaminated waters, because they are one of the filter feeders and also act as hyperaccumulator organisms [Listiani & Nugraha, 2021; Wahdani et al., 2020]. The amount of accumulated MP in a shellfish depends on their size, where the larger shellfish size, the more MP might be accumulated, as found in *Anadara granosa* [Listiani & Nugraha, 2021]. The *A. granosa* on Semarang Beach, with a size of less than 3.00 cm, contained 6.00±3.70 particles/ind of MP which were dominated by fiber that was similar to the findings in the water column. Meanwhile, the *A. granosa* from Kwanyar and Tanjung Tiram Water, with a size of more than 3.00 cm, s contained 20.20–26.80 and 20.33–120.00 particles/ind of MP, respectively. In addition, MP was also found in other marine organisms, namely Echinoidea of 22.30 particles/ind, which was also dominated by fiber.

The MP contained by aquatic biota could potentially interfere with the absorption of nutrients, because it is hydrophobic, since hydrocarbons as polymer plastic constituent are one of the POPs [Andrady, 2011; Bellasi et al., 2020; Carbery et al., 2018]. Due to its hydrophobic properties, MP is able to absorb toxic compounds such as polychlorinated biphenyls and dioxins from water column as well as act as a transporter in the food chain [Engler, 2012].

LONG-TERM HAZARDS POTENTIAL

Indonesia is one of the largest marine mega biodiversity areas in the world, where aquatic biota become one of the main foods for people, especially those on the coast and islands. On the basis of these food habits, biomagnification became the main process for MP transport to human. MP will eventually accumulate in human body tissues, especially macrophages that affect metabolic processes due to it is bio-inertness [Anderson et al., 2016; Moore, 2008; Widianarko & Hantoro, 2018]. The MP in the human body may become resistant when accumulation reaches a point of equilibrium [Fackelmann & Sommer, 2019].

The MP in macrophages is adsorbed and migrated to lymph nodes, then translocated to other organs through the blood [Anderson et al., 2016]. The MP in the blood is able to replenish proteins and glycoproteins, which may cause decreased immunity and intestinal dysbiosis to diarrhea [Carding et al., 2015; Fackelmann & Sommer, 2019]. It has been proven by the findings of PP, PS, and PE in human feces [Liebmann et al., 2018]. Furthermore, MP may disrupt the reproductive system that

Table 3. Microplastics in Aquatic Biota

Province	Area	Aquatic Organisms			Sumber
		Pelagic Fish	Demersal Fish	Other Organisms	
DKI Jakarta	Jakarta Bay	*A. chacunda* = 42.60–77.40 particles/ind *Selar boops* = 65.00 particles/ind Shape dominated by fragment	*Eleutheronema tetradactylum* = 56.00 particles/ind *Neotrygon annotate* = 56.00 particles/ind, *Nemipterus marginatus* = 61.50 particles/ind Shape dominated by fragment	–	[Manalu, 2017]
East Java	Gili Labak Island, Sumenep District	–	–	Echinoidea = 22.30 particles/ind, yang didominasi bentuk fiber	[Lolodo & Nugraha, 2019]
	Mandangin Island, Sampang District	*Euthynus* = 2.00–5.00 particles/ind *Sardinella lemuru* = 3.00–5.00 item particles/ind Shape dominated by film	*Epinephelus* = 1.00–3.00 particles/ind *Nemipterus* = 1.00–6.00 particles/ind Shape dominated by filament	–	[Rahmadhani, 2019]
	Brondong Coast, Lamongan District	*Priacathus tayenus* = 13.00–15.33 particles/ind Shape dominated by fiber	–	–	[Labibah & Triajie, 2020]
	Kwanyar Waters, Bangkalan District	–	–	*A. granosa* = 20.20–26.80 particles/ind Shape dominated by fiber	[Listiani & Nugraha, 2021]
Central Java	Semarang Beach	*Chanos chanos* = 3.36±1.02 particles/ind Shape dominated by fiber	–	*A. granosa* = 6.00±3.70 particles/ind Shape dominated by fiber	[Widianarko & Hantoro, 2018]
	Bengawan Solo River	*Mugil cephalus* = 3.40–6.40 particles/ind Shape dominated by fiber	–	–	[A'yun, 2019]
Yogyakarta	Boron Beach, Gunung Kidul District	*Skipjack tuna* = 21.90±11.94 particles/ind *Frigate tuna* = 95.65±38.80 particles/ind Shape dominated by fiber	*Japanese threadfin bream* = 57.50±37.61 particles/ind *Large–scale croaker* = 7.35±4.48 particles/ind *Shape dominated by film*	–	[Suwartiningsih et al., 2020]
Bali	Bali Strait	*S. lemuru* = 7.03±0.62 particles/ind, shape dominated by film *Decapterus russelli* = 4.23±1.23 particles/ind, shape dominated fiber *Rastrelliger kanagurta* = 5.03±0.76 particles/ind, shape dominated by fiber	*Trichiurus lepturus* = 3.83±1.01 particles/ind, shape dominated by fiber	–	[Sarasita et al., 2020]
South Sulawesi	Maccini Baji Waters, Pangkajane and Island Regency	–	–	*V. philippinarum* = 1.09–1.21 particles/ind, shape dominated by fiber	[Wahdani et al., 2020]
Riau	Bengkalis Islands Waters, Bengkalis District	*Arius maculatus* = 72.22 particles/ind *Setipinna breviceps* rata–rata = 61.06 particles/ind Shape dominated by fiber	*Harpodon nehereus* = 55.56 particles/ind Shape dominated by fiber	–	[Febriani et al., 2020]
Maluku	Tanjung Tiram Waters, Ambon Bay	–	–	*A. granosa* = 20.33–120.00 particles/ind, dominated by fiber	[Tuhumury & Ritonga, 2020]

affect the development of sex cells, embryos, hormone production, and organ dysfunction [Carding et al., 2015; Fackelmann & Sommer, 2019] which could potentially affect pregnant women and children. As reported by Ragusa et al. [2021], 3 particles of MP-fragments were found in the placenta with the size of 5.00–10.00 μm.

Organ dysfunction is a dangerous health problem that causes systemic inflammation and growth hormone resistance of IGF-1. Systemic inflammation may also cause anemia, which has been a trigger for stunting [Prendergast et al., 2015]. This condition may be closely related to the high prevalence of stunting in Indonesia, reaching 30.80% in 2018 [Budiastutik & Rahfiludin, 2019; Rahmawati et al., 2020], especially in coastal areas. Although the association between the MP exposure to interference above has not been proven, but the potential of long-term effects needs to be the focus of attention. Therefore, a further study of translocation, retention time, and accumulation of MP in humans is needed to determine the potential threat and prevention strategies.

CONCLUSIONS

There is no doubt that MP was found in all elements of aquatic ecosystems in Indonesia of water column, sediment, as well as aquatic biota such as fish and shellfish. Great abundance of MP was found in the areas with high population and activity, thereby increasing the domestic waste disposal to the river which is one of the sources of MP in aquatic ecosystem. The distribution of MP in the waters was influenced by the type of polymer (density), geographical conditions and the hydrodynamic characteristics of waters. The results showed that the highest abundance of MP in Indonesia was found in water column, followed by accumulation in sediment and aquatic biota. The abundance of MP was dominated by fragments.

MP is able to penetrate the food chain through the food-feeding habits of organisms. In fish, MP is transported through trophic transfer, which led to biomagnification and ended up being accumulated in human tissues. The MP in human tissues may be also caused by water consumption, considering the MP contamination in many public water sources in Indonesia. Since MP is hydrophobic and able to bind other toxic organic compounds, they have the potential to transmit such compounds and cause various organ dysfunction for aquatic biota and humans.

Therefore, further research about quantification of MP abundance (amount, size, and polymer type) in public water sources and determination of the permissible MP abundance limit are urgently needed to reduce the health risk potential. Therefore, the role of government and society in managing waste is very important to reduce the plastic waste disposal in the waters.

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