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Microplastic pollution in the sediment of Jagir Estuary, Surabaya City, Indonesia

Muhammad Firdaus, Yulinah Trihadiningrum*, Prieskarinda Lestari

Department of Environmental Engineering, Faculty of Civil, Planning, and Geo-engineering, Institut Teknologi Sepuluh Nopember, Kampus ITS Sukolilo, Surabaya 60111, Indonesia

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ABSTRACT

This study was aimed to investigate the abundance and characteristics of microplastics (MP) in the sediment of Jagir estuary and Wonorejo coast, Surabaya, Indonesia. Sediment samples from 5 sites in the estuary and the adjacent coast were collected in replicates using Ekman dredge sampler. The MP particles were extracted using density separation method. Then the MP particles were counted and categorized according to shape, size, and color under a Zeiss Discovery V.12 stereomicroscope. Identification was done using Thermo Scientific Nicolet iS10 FTIR Spectrometer. The MP shapes comprised fiber (57%), film (36%), and fragment (7%). Abundance of the MP was highest in the Wonorejo coast sediment (590 particles/kg dry weight). The MP particles consisted of 68% large and 25% small sizes and comprised 56.7% polyester, 24.6% low-density polyethylene, and 18.8% polypropylene. The MP colors were 43% transparent, 21% black, 14% blue, 10% white, 8% red, and 4% yellow.

1. Introduction

Plastics as synthetic organic polymers have long-lasting, light, strong, easily shaped, and persistent properties (Li et al., 2016; Verma et al., 2016; Leslie et al., 2011). These characteristics have caused plastic material to be widely used in various applications (Wiley-VCH, 2016). Thus, the world's plastic production continues to grow, from 1.5 million tons in 1950 to 359 million tons in 2018 (Statista, 2018, Plastics Europe, 2018). The number of plastic industries in Indonesia is about 925 with annual production of 4.68 million tons. This production rate showed a 5% increase in the last five years (Ministry of Industry of the Republic of Indonesia, 2017). Without effective plastic use and waste management, plastic pollution will increase in the environment. Subsequently, large-sized plastic can be degraded into small-size through mechanical abrasion, UV radiation, and biological processes (Hernandez et al., 2017; Horton et al., 2017; Napper and Thompson, 2016; Yang et al., 2015; Andrady, 2011; Thompson et al., 2004). Plastics of < 5 mm size are classified as microplastics (MP).Those with larger size are named mesoplastics (5 mm–2.5 cm), and macroplastics (> 2.5 cm) (Crawford and Quinn, 2017; Baztan et al., 2016; Wright et al., 2013; Arthur et al., 2009).

Based on its sources, the MP can be divided into primary and secondary particles (Duis and Coors, 2016; Peng et al., 2017). The primary MP is plastic particles manufactured in microscopic size. These MP commonly used in personal and health care products. Thus, these MP may pollute the environment through wastewater discharge (GESAMP, 2015; Cole et al., 2011; Carr et al., 2016; Duis and Coors, 2016). The secondary MP is formed as the result of complex degradation of larger plastic in the environment.

MP pollution in the marine environment has become main concerns of the researchers, authorities, and communities both locally and globally. MP has been found in all marine environments, not only in the coastal zone, water surface, and water column, but also in the sediments (Andrady, 2011; Cole et al., 2011; Ling et al., 2017; van Cauwenberghe et al., 2013). Several types of MP with higher density than seawater can easily sink and accumulate in sediments. Lighter particles can also reach the sea bed after degradation, aggregation and biofouling (van Cauwenberghe et al., 2013). Bixler and Bhushan (2012) defined biofouling as accumulation of biological matter on surfaces, with created biofilms by microorganisms. In aquatic habitat the type and extent of biofouling depend on the local environment, and organisms. van Cauwenberghe et al. (2015) added that biofouling may cause the increase of MP density, which resulted in the MP sinking. Marine sediments provide habitats for several important species, in which MP has been proven in causing detrimental effects to benthic biota (Wright et al., 2013; Ugolini et al., 2013).

Because of the size, MP can easily enter the food chain in the ocean. Various marine organisms, such as zooplankton, shrimp, bivalves, fish,

* Corresponding author.
E-mail address: yulinah_t@enviro.its.ac.id (Y. Trihadiningrum).

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and whales, have been reported to ingest MP (Cole et al., 2013; Lusher et al., 2015; Ferreira et al., 2016). These MP particles can cause significant damage, such as: pathological stress, oxidative stress, reproductive complications, and growth rate inhibition, to these organisms. In addition, toxic chemicals can be attached to MP due to its large specific surface area and strong adsorption ability. Consequently, these attached chemicals might pose a substantial risk to marine organisms (Reisser et al., 2015). As a pathogen and toxic pollutant vector, the MP accumulation in animals can eventually be transferred to human through food chain, and may cause severe health problems (Wang et al., 2016).

Estuary is an MP transport route from river to sea. About 80% of the plastic found in the sea comes from land via rivers (Andrady, 2011; Mehlhart and Blepp, 2012). Most of the land-based sources come from the widely use of plastics in daily life, and improper SW disposal (Blettler et al., 2017). When reaching the estuary, the hydrodynamic force influences the path of deployment, deposition, trajectory and velocity of MP particles when entering the marine environment (Bessa et al., 2018). Thus, estuary will be contaminated with plastic and should be considered as MP hot spots (Wright et al., 2013; Browne et al., 2010).

Due to ineffective solid waste (SW) management, plastic waste in developing countries with large population like Indonesia, needs special attention (Syakti et al., 2017). It was estimated that Indonesia generated around 3.9 million tons of plastic waste in 2010, 11% of the total SW (Jambeck et al., 2015). About 3.22 million tons were not appropriately managed. This has caused approximately 0.48–1.29 million tons of plastic waste from Indonesia to end up in the sea through the river. This amount has placed Indonesia in the second rank of most plastic waste polluting country to ocean after China (Jambeck et al., 2015). As a matter of fact, the population of Indonesia was 258.705 millions in 2016, with a growth rate of 1.36% per year during 2010–2016 (Statistics of Indonesia, 2017).

The World Bank Group (2018) reported that with a total population of 2,853,661, Surabaya City generated 2482.7 tons of SW daily. Among this SW amount, only 1562.2 tons was managed, leaving 920.5 tons, or 37.10%, unmanaged. Additionally, the SW generation was reported to increase 76% by 2025, with plastic waste component of 13.16%. As a consequence, the risk of MP pollution in Indonesian marine waters through rivers could become more severe.

Surabaya City is crisscrossed by various rivers and drainage channels. Before entering this city, the main river (Brantas) splits to the Porong and Surabaya Rivers at Mlirip Dam in Mojokerto town. The Surabaya River then flows to Wonokromo, and branched into the Mas and the Jagir Rivers. About 32.5% of the population who live within 500 m distance from the Surabaya River, disposes their domestic waste into the river body (Suwari et al., 2011). Therefore, it was reported that the river has been severely polluted by domestic SW, including plastic waste (Doaly, 2017).

The Jagir River was actually a floodway, which was built in 1917 after the Jagir Dam. This river ends in Madura Strait (Fig. 1), which is situated in the Java Sea. Research on the Jagir River quality is of great importance, because this river is larger than the other tributary (Mas River). The lower basin of Jagir River is used for various uses, such as mangrove ecotourism, fish farming, and fishing grounds for local fishermen. However, the Jagir estuary has been heavily polluted (Kusmana et al., 2018; Jaakola et al., 2017, and Hayati et al., 2017). The BOD value was up to 49 mg/L and that of the COD was 104 mg/L, far exceeding the quality standards (Hayati et al., 2017). Kusmana et al. (2018) investigated that Cu concentration in sediment of Jagir estuary was 35.65 to 49.08 mg/kg, with an average of 44.73 mg/kg. Based on these facts, the Jagir estuary and the receiving coast, Wonorejo, are susceptible to MP pollution from anthropogenic sources. Aim of this study is to investigate the abundance and characteristics of the MP in the sediment of the Jagir estuary and Wonorejo coast. This research is meant to provide most recent plastic pollution data, which can be used by policy makers to set up strategic solution for coping with the problem.

2. Materials and methods

2.1. Study area and sampling

The study area was divided into two main areas, the estuary and the coast, following salinity gradient and geomorphology (Lima et al., 2015). Salinity would affect water density, and influence the MP buoyancy and distribution in the sediment. From a total 5 sampling sites (Fig. 1), sites 1, 2, and 3 represented the Jagir estuary, while Sites 4 and 5 were located in the coast. Water salinity at Site 1 was the lowest (0.91–1.01%), and increased to 0.94–1.43% at Site 2, and 1.85–2.37% at the river mouth (Site 3). The water salinity values in the coastal sampling sites were much higher than those of the estuary (3.33–3.47% and 3.50–3.57% at Sites 4 and 5, respectively).

Sediment samples were collected in replicates using Ekman dredge sampler. Each sample of Sites 1, 2 and 3 was collected by grab sampling method in both sides and middle part of the estuary (Mani et al., 2015). Sediment samples of Sites 4 and 5 were also collected by grab method during tide time. Each sample (about 3 kg weight) was freezed-dried before laboratory analysis (Vianello et al., 2013).

2.2. Sample preparation and extraction

Sediment samples were treated using modified NOAA laboratory methods for bed sample analysis (Masura et al., 2015). About 500 g wet sediment sample was first homogenized by stirring with a stainless-steel spoon and then dried at 90 °C for 24 h. The dried sample was then reweighed, disaggregated by adding 400 mL of sodium hexametaphosphate (5.5 $g{\cdot}L^{-1}$), and stirred for 1 h at 450 rpm. After disaggregation, the samples were sieved by using 5.0 mm and 0.3 mm filters. Further, retained particles in the filter were treated with wet peroxide oxidation (WPO) using 30% H_2O_2 and 0.05 M Fe(II) catalyst. The WPO treatment was performed at approximately 75 °C for 5 min until it started to boil. The objective of WPO was to remove organic contaminant in the samples. When gas bubbles appeared, the sample was removed from the hot plate, and placed in the fume hood until boiling subsided. Then it was reheated up to 75 °C for an additional 30 min until no organic material left. Then density separation was done by adding 6 g sodium chloride per 20 mL of sample solution, or 5.13 M concentration, to increase its density. This solution was heated until 75 °C for dissolving all sodium chloride. Then the solution was placed in a density separator for 24 h for settling. The aqueous part was separated using 0.3 mm filter. The MP particles were separated from the filter and placed in a clean petri dish for further color and size identifications.

2.3. Characterization and identification of MP

The MP particles from sub-samples of each site were composited and counted. They were photographed under a Zeiss Discovery V.12 stereomicroscope. For observing the particles, the microscope was moved in a "zigzag" pattern from left to right. The MP particles were categorized according to shape, size, and color. Shapes of MP were categorized as fragment, foam, line/fiber, pellet, or film (Free et al., 2014). Based on its size, the particles were categorized as large MP (LMP) and small MP (SMP). The size of LMP is between 1 and 5 mm, and the SMP is shorter than 1 mm, but longer than 1 μm (Vianello et al., 2013). The MP were then classified into six color categories according to Peng et al. (2017): namely blue, black, yellow, transparent, white and red. Description of each color category is shown in Table 1. The selected MP particles from each sample group were used for determining polymer types using Thermo Scientific Nicolet iS10 Fourier-Transform Infrared Spectrometer (FTIR), which was equipped with polymer type database.

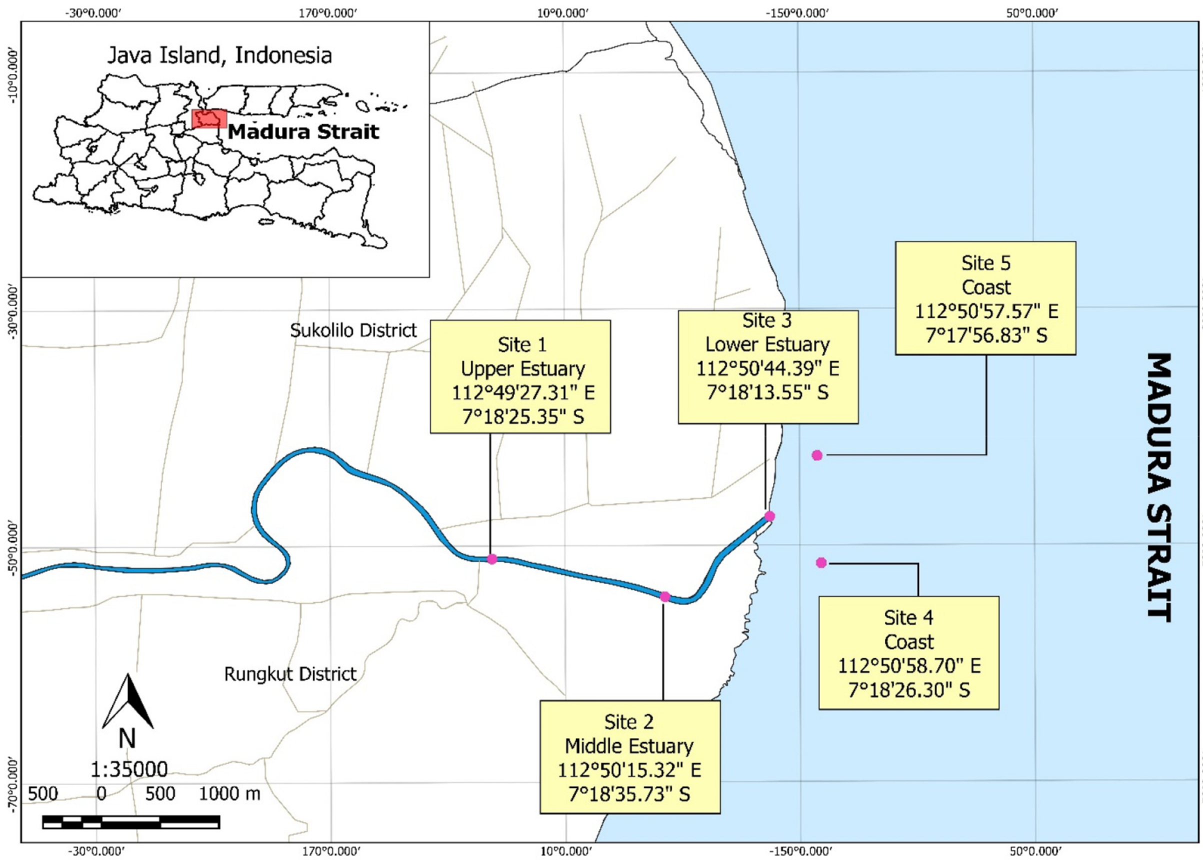

Fig. 1. Map of study area.

Table 1
Color category of MP.

Color category	Color of MP particle
Blue	Blue, dark blue, light blue, dark green and light green
Black	Black, transparent black, gray and white with black stripes
Yellow	Yellow, orange and brown
Transparent	Colorless particles
White	White and silver
Red	Red, pink and purple

Table 2
The abundance of MP in Jagir estuary and Wonorejo coast.

Sites	MP abundance (particles·kg^{-1} sediment, DW)
1	92
2	146
3	414
4	484
5	590

Peng et al., 2017.

Table 1 Color category of MP.

3. Results and discussion

3.1. Abundance of MP in sediment

The highest MP abundance was 590 particles·kg^{-1} DW, as observed at Site 5, followed by the second highest (484 particles·kg^{-1} DW) at Site 4. Both sites were located in the sea. The MP abundance at Sites 1–3 in Jagir estuary sediment showed lower values. The upper Site 1 showed lowest MP abundance (92 particles·kg^{-1} DW). The MP concentration increased to Sites 2 and 3 with 146 particles·kg^{-1} DW and 414 particles·kg^{-1} DW, respectively (Table 2). These data showed that the MP abundance in the sediment increased toward the mouth and the sea. This condition might occur due to the estuary position, which is affected by dynamic fluctuating current, tides, and free connection to sea (Sadri and Thompson, 2014; Day et al., 2012). The hydrodynamic force in estuary influences the MP particle distribution path, trajectory and velocity when it enters the marine environment (Bessa et al., 2018). Thus, the estuary is prone to MP contamination, and should be considered as one of MP hotspots (Wright et al., 2013; Browne et al., 2010).

One of the main reasons of the significant MP pollution in the study area is the high municipal SW generation rate. Surabaya City, and the considerably high plastic waste component. The insufficient SW management infrastructure and services have caused high amount of the municipal SW to be improperly disposed of. Additionally, the lacks of community involvement in reducing the SW has become another important issue. For example, 63% of the communities in Tenggilis Mejoyo District in East Surabaya City stated that they did not reduce and segregate their residential SW at source (Trihadiningrum et al., 2017). Dhokhikah et al. (2015) also stated that 52.3% of the respondents in East Surabaya did not sort the household SW. Additionally, the coverage of SW management service was still limited as reported by the World Bank Group (2018). This situation made a large part of the SW, including the plastic waste, to be disposed of into rivers, as reported by Mediana and Gamse (2010). As a consequence, the Jagir River, which flows through densely populated human settlements, becomes one of SW disposal sites in Surabaya City.

Table 2 The abundance of MP in Jagir estuary and Wonorejo coast.

Data of MP abundances in Indonesia are still limited. Until to date only 10 studies have been conducted in different islands and seas in

Indonesia. These studies revealed that the sediment of all coasts being researched was polluted by MP (Lestari and Trihadiningrum, 2019). Among these studies, only one research was performed in Jakarta Bay, which is located in the Java Sea, where the Wonorejo coast, and the Madura Strait are also situated. Therefore, data in the Jakarta Bay were the most close to compare to the results of this study. The coastal sediment of Jakarta Bay contained 18,405–38,790 MP particles·kg^{-1} DW (Manalu et al., 2017), much higher than that in Sites 4 and 5 in Wonorejo coast (484–590 particles·kg^{-1} DW). Apart from the differences in shoreline morphology in these study areas, which affected the MP transport in sea water, the high concentration of MP in Jakarta Bay sediment is mainly caused by the higher population (3.6 times) than in Surabaya City. Other studies in North Sumatera, East Kalimantan, Sunda Strait, and southwestern Sumatera showed lower MP concentrations of 64–173.3; 57.53–91.80; 6; and 3 particles kg^{-1} DW, respectively (Bangun et al., 2018; Dewi et al., 2015; Cordova and Wahyudi, 2016), when compared to the results of this study. These low MP concentrations were related to the lower population number, which corresponded to lower plastic generation rate.

3.2. Shapes of MP

Fiber was the most dominant shape (57%) in the study area, followed by film (36%), and fragment (7%) (Fig. 2). Distribution of the MP differed from one site to another (Fig. 3). Sediment samples from the upper estuary (Sites 1 and 2) showed higher fiber compositions (79–83%) than the other three samples in the coast (50–55%). Shapes of the MP particles are shown in Fig. 4.

Most fiber shape was likely generated from textile materials and fishing gear (Andrady, 2017). About 600 laundry businesses grow in Surabaya City. More than 50% did not have operation permit and wastewater treatment facility (Anonymous, 2017). The wastewater is generally discharged to drainage canals, which ends in the river. Previous studies reported that washing process could release 1900–700,000 fibers per 6 kg of cloths to environment (Napper and Thompson, 2016; Browne et al., 2010). Hernandez et al. (2017) and Peng et al. (2017) also stated that major fiber pollutant in the environment came from domestic waste as a consequence of cloth washing activities and daily use of personal care products.

The fiber shaped MP could be originated from rope, sea traffic, and fisheries activities (Andrady, 2011; Thompson et al., 2004). Statement of these authors is supported by a fact that 254 fishermen did their activities around Wonorejo coast area (Anonymous, 2012). Fragmented particle is the results of the breakdown of larger plastic goods through mechanical and UV-weathering, which occur in river (Maes et al., 2017).

Daily use of food packaging materials, containers, toys, and other items can also be the major sources of fragment (Wang et al., 2016; Baldwin et al., 2016). In contrast, plastic bags and packaging materials, which are thinner and softer, could become main sources of film shaped MP (Teuten et al., 2007). Mulch used in agriculture is also a potential source of film (Thompson et al., 2004; Nor and Obbard, 2014). The MP with foam shape could be derived from food packaging material, whereas pellet possibly originates from plastic raw materials, or personal care products (Fendall and Sewell, 2009).

3.3. Size

Based on its size, 590 LMP particles (68%) were found in the sampling sites, and 273 particles (32%) were SMP (Fig. 5). The MP size is an important characteristic since it can potentially be ingested by various marine organisms (Cole et al., 2013; Lusher et al., 2015; Ferreira et al., 2016). When the microplastis are ingested by organism, it is possibly transfered to humans through food chain (Wang et al., 2016). It is interesting to compare these results with the MP distribution in the Rhine River that flows across several countries in Europe. The SMP abundance in the lower Rhine was more dominant than the LMP (Mani et al., 2015). Distinction between SMP and LMP distributions in these two rivers is most probably caused by the river length and hydrodynamic differences. Length of the main river, where the Jagir estuary situated, is about 320 km, whereas that of the Rhine is 1300 km (Busschers et al., 2007). The difference in the trajectory path length may affect the plastic waste breakdown level; in which the longer the river, the smaller the plastic particle size.

3.4. Polymer types

Based on the results of FTIR analyses (Fig. 6), the MP polymers were identified as polyester (PES), low-density polyethylene (LDPE), and polypropylene (PP), accounting for 56.7%, 24.6%, and 18.8%,

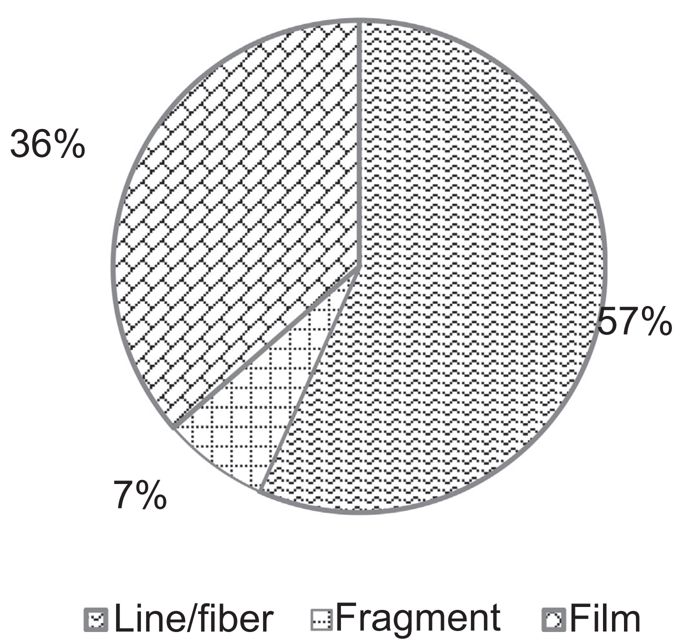

Fig. 2. Distribution of the MP shapes in all sites.

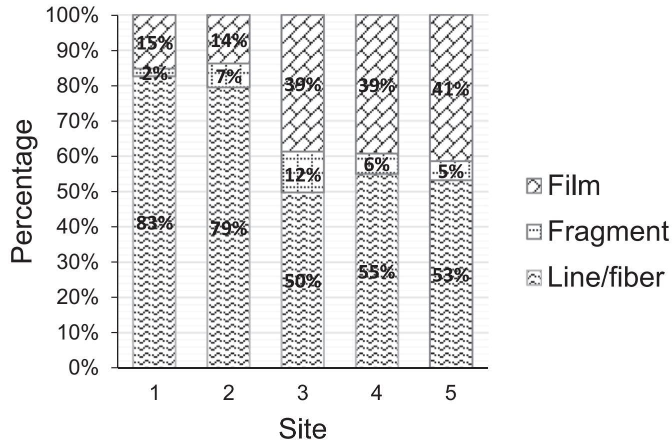

Fig. 3. Distribution of the MP shapes in each site.

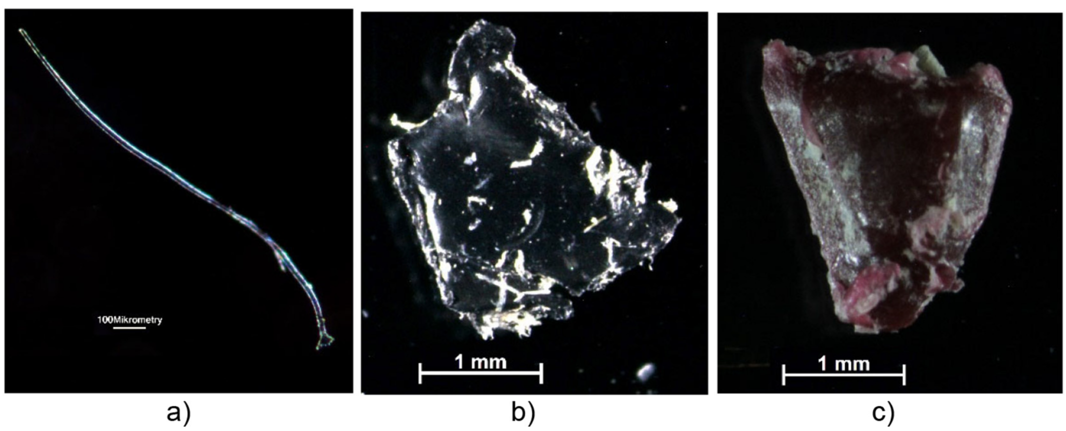

Fig. 4. Stereo shapes of MP: a) fiber, b) film, c) fragment.

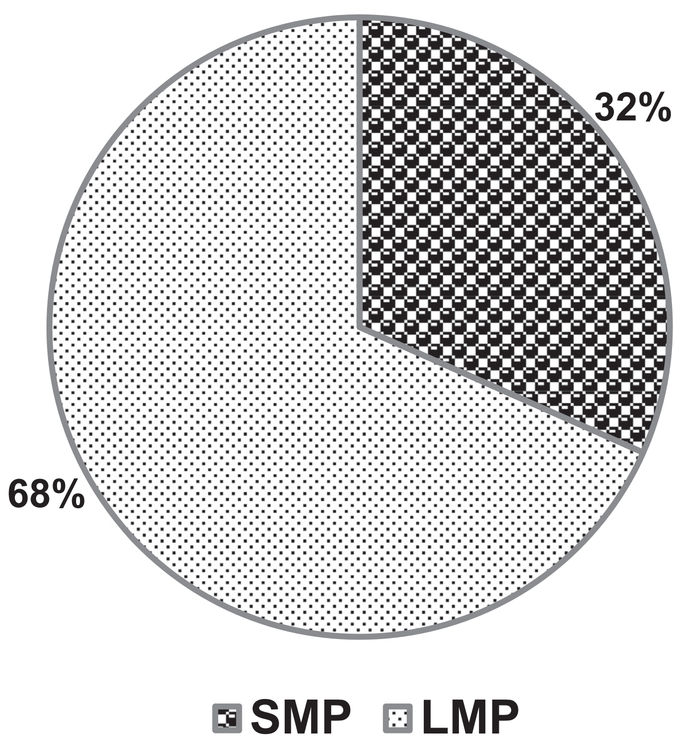

Fig. 5. Distribution of MP size.

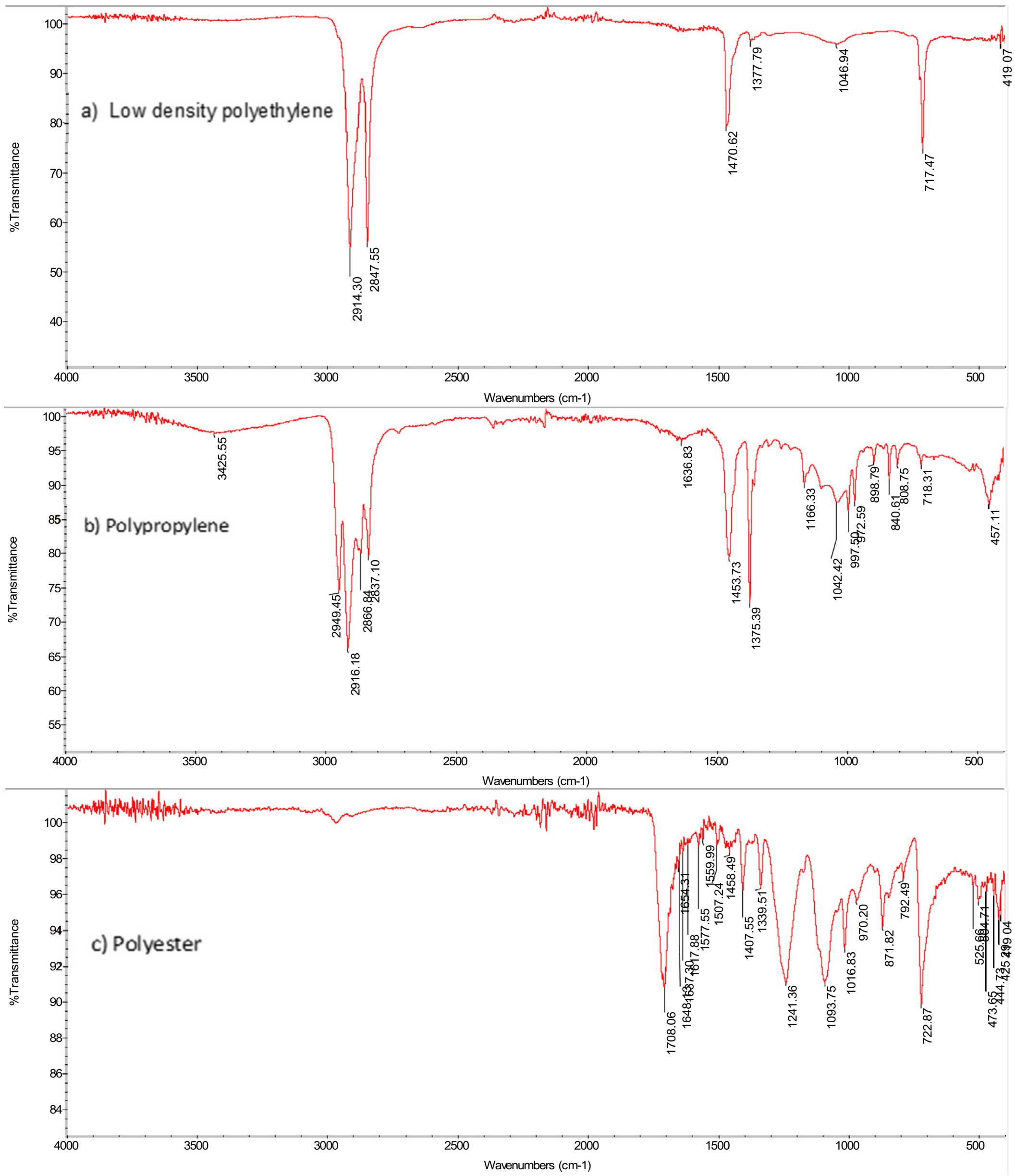

Fig. 6. FTIR spectra of selected microplastics: a) LDPE, b) PP, and c) PES.

respectively (Fig. 7). Polyester was the highest in abundance when compared to LDPE and PP. This is because PES has higher density (1370 kg·m^{-3}) than the seawater. In contrast, the densities of LDPE (940 kg·m^{-3}) and PP (900 kg m^{-3}) are lower than seawater. However, the PP and LDPE particles were also found in sediment. The reason could be caused by biofouling. Biofouling could settle the particles into the sea bed, because it might increase the MP density and weight (Andrady, 2011; Cole et al., 2011; Corcoran, 2015).

3.5. Color

Using the MP color category of Peng et al. (2017) as shown in Table 1, transparent MP was the most abundant (43%), followed by black (21%), blue (14%), white (10%), red (8%), and yellow (4%) particles (Fig. 8). Colors of the MP make it possibly ingested by biota due to its attractiveness and similarity to original prey or food items (Wright et al., 2013; van Cauwenberghe et al., 2015). Together with its tiny size and the high buoyancy, the attractive colors make the MP become available for fish (Chatterjee and Sharma, 2019). The MP with various colors in the sediment is originated from the use of colored plastic products in the daily life, such as clothing, packaging, fishing (Wang et al., 2017; Zhang et al., 2015). However, the colors can change due to weathering (Kalogerakis et al., 2017; Wu et al., 2018) during transport in the surface water.

Results of FTIR analysis showed that colors of the MP were not specifically related to a particular polymer type (Table 3). The film shaped transparent MP was identified as LDPE, and that of the black and red colors (fiber shaped) were close to PES. The white, blue, and yellow MP particles with film shaped were identified as PP. The blue colored fragment was identified as LDPE.

Table 3. Recapitulation of characteristics of MP in sediment samples.

Results of this study reveal that the Jagir estuary and the adjacent coast have been polluted by MP. The limited municipal SW management facilities and service coverage undoubtedly become the main cause of the MP pollution in the study area (Lestari and Trihadiningrum, 2019). Yunus (2019), Fatmawati (2019), and Wijaya (2019) reported that the upper parts of the river had been polluted by

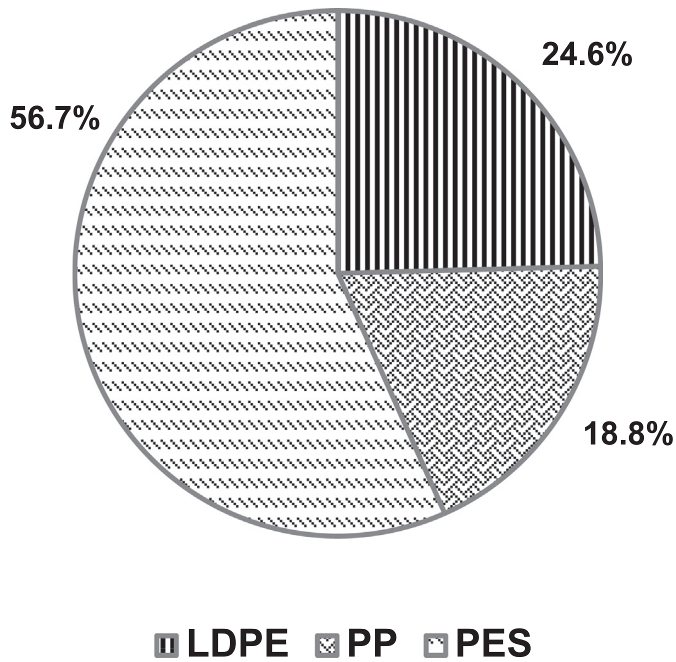

Fig. 7. Distribution of MP abundance based on polymer types.

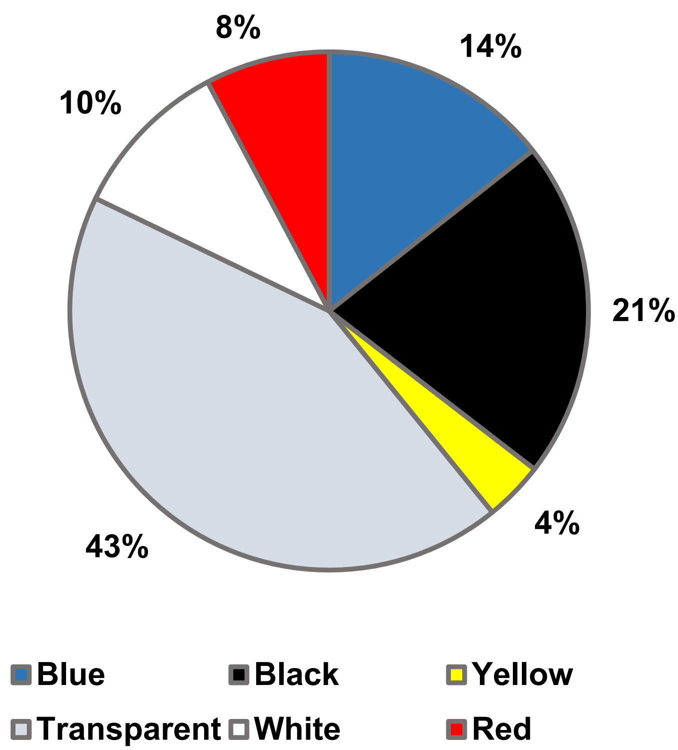

Fig. 8. Distribution of MP colors in all sites.

MP, which was caused by SW improper disposal from various sources. This problem requires a strategic solution, which includes active participation of the communities as SW generators to manage the SW properly.

4. Conclusions

The sediment of Jagir estuary and the Wonorejo coast have been polluted by MP. The highest MP abundance was found in the coastal area (up to 590 particles·kg^{-1} sediment DW), followed by the lowest end of estuary (414 particles·kg^{-1} sediment DW). The MP in all sampling sites were dominated by fiber (57%), followed by film (36%), and fragment (7%). The main colors of MP particle were: 43% transparent, 21% black, and 14% blue. The dominant size type of MP was LMP (68%), and the other 32% was SMP. The MP polymer type was dominated by PES (56.7%), with fiber shape. The main reason of the MP pollution in the study area is the SW improper disposal into the river by the generators.

Table 3
Recapitulation of characteristics of MP in the sediment samples.

No.	Shape	Color	Polymer identification results using FTIR	
			Type of plastic	% polymer similarity
1	Film	Transparent	LDPE	82,05
2	Film	White	PP	81,68
3	Film	Blue	PP	88,81
4	Film	Yellow	PP	88,77
5	Fragment	Blue	LDPE	84,50
6	Fiber	Red	PES	54,83
7	Fiber	Black	PES	54,63

Author contribution statement

Muhammad Firdaus: funding acquisition, concept development, methodology development, investigation, writing original draft, revision.

Yulinah Trihadiningrum: conceptualization, supervision, data curation, reviewing and editing.

Prieskarinda Lestari: resource management, data analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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