Spatial distribution of microplastic in sediment of the Citanduy River, West Java, Indonesia

B Widigdo\textsuperscript{1}, Z Imran\textsuperscript{1,2,*}, Taryono\textsuperscript{1}, D Y Wulandari\textsuperscript{1} and A Marliana\textsuperscript{1}

\textsuperscript{1} Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, IPB University (Bogor Agricultural University), Jl. Agatis, Kampus IPB Dramaga, Bogor 16680, Indonesia
\textsuperscript{2} Southeast Asian Regional Centre for Tropical Biology (SEAMEO BIOTROP), Jl. Raya Tajur KM 6, Bogor 16134, Indonesia

*Corresponding author: zulhamsyahim@apps.ipb.ac.id

Abstract. Microplastic particles have a significant impact on freshwater environments, as well as on biota association in its ecosystems. This study aims to identify and determine the spatial distribution of microplastic in sediments in Citanduy River, West Java. Microplastic was observed by census method on the SRC (Sedgewick Rafter-Counting Cell) with the help of a micrometer at 10x magnification. Analysis of statistic using MS. Excel 2007. For statistical studies, Kruskall Wallis and Mann Whitney are used for spatial analysis using ArcMap software. The highest microplastic abundance was in the downstream area, followed by the upstream; however, the lowest value was at the center of Citanduy River sediment. Microplastic abundance in this river was ranged 18,190–70,405 particles/kg of dry sediment. The determination of microplastic type found was fragments form. The dominant microplastic color was black. The microplastic of films and fragments were dominant by range 20–40 \( \mu \)m and dominant fibers was about 500–1,000 \( \mu \)m. Spatially distribution the abundance of the microplastic average at the substation and sampling station was found to be the highest at Substation 2 in downstream area and the distribution of the average abundance of microplastics decreased towards substations 1 and 3 at the downstream station.

Keywords: Citanduy River; microplastic; sediment

1. Introduction
Waste pollution in the aquatic environment has been a problem for the community to date, and the most dominant type of waste is plastic waste [1]. According to Avio \textit{et al.} [2], the composition of plastic waste ranges from 60–80\% of the total waste produced globally. The production of plastic waste has increased since the 21st century, with a growth from 200 million tons in 2000 to 311 million tons in 2014; where China, Arab, and North America are the main contributors [3]. According to Rimadias [4], the amount of plastic waste generated in landfills (TPA) reached 175,000 tonnes per day, equivalent to 64 million in 2018 in Indonesia. This plastic waste has the potential to enter water bodies, including rivers.

According to Scherer \textit{et al.} [5], plastic waste that ends up in water when exposed to sunlight will undergo an abiotic weathering process, so that the polymer breaks down into small particles. Small particles of plastic waste that are less than 5 mm in size are called microplastics [6]. Microplastics are...
sourced from large plastic shards and plastic pellets which are produced as raw materials for the plastic industry [7].

The source of microplastics is divided into primary microplastics and secondary microplastics. Primary microplastics are microplastics that are initially produced with a size of less than 5 mm and are usually found in the textile, pharmaceuticals, and care products industries such as facial and body scrubs, while secondary microplastics are derived from large plastic pieces or debris that have been degraded due to interactions. physics, chemistry, and biology and are usually found in fishing nets, industry, household goods, and other plastic waste [8]. These primary and secondary microplastic sources will have a negative impact on the water column and sediment in the river.

The microplastic content in the sediment will have an impact on increasing the concentration of ammonium in the water column, causing the absorption of chemicals contained in these microplastics into zooplankton [9]. In addition, microplastics will also harm organisms from lower trophic levels, such as plankton, which is a filter feeder that consumes microplastics so that it will impact organisms with even higher trophic levels through bioaccumulation [10].

The impact of microplastics on the aquatic environment is getting higher every year in several rivers, such as the Citanduy River. The increasing source of waste disposal from the Citanduy River is due to the high activity of the community and industrial activities around the river. The increase in microplastics in the Citanduy River flow was caused by several factors, such as community activities, industrial activities, and fishing activities. Microplastic research in recent years has focused more on marine than freshwater, resulting in a lack of research data on microplastics in freshwater. So far, microplastic data in freshwater is only concentrated in lake waters [3]. The study of microplastics consists of microplastics in water, sediment, and biota. Research on sediment microplastics on the Citanduy River has never been carried out. Therefore, research on microplastics in sediments in the Citanduy River needs to be done to provide information about the microplastic content in the Citanduy River.

2. Methods

2.1. Study area
The sampling area is on the Citanduy River, West Java. The research was conducted at three locations along the river, namely the upstream station in Sukajadi Village, Sadananya District, Ciamis Regency; middle station located in Mekarharja Village, Purwaharja District, Banjar City; The downstream station is located in Kalipucang Village, Kalipucang District, Pangandaran Regency.

Sediment analysis was carried out in two laboratories. The process of reducing water content in sediment samples at the Laboratory of the Wood Quality Improvement Technology Division, Department of Forest Products, Faculty of Forestry. Microplastic analysis of sediments at the Laboratory of Micro Biology I, Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences. The sediment sampling points are presented in figure 1.

2.2. Data collection
This research was conducted from September 2019 to May 2020 which consisted of the research preparation stage, sampling, analysis of samples in the laboratory, and data analysis. Sampling was conducted three times, namely in September 2019, November 2019, and March 2020. The sampling times represented the dry season (September) and the rainy season (November and March).

The data collected is primary data by conducting field sampling (in situ) and sample analysis in the laboratory. Primary data includes current velocity, DO, pH, temperature, and the abundance of the type, color, and size of microplastics at each sampling point. Parameters, units, equipment, and information used in the study can be seen in table 1.
Figure 1. Map of sampling locations on the Citanduy River.

Table 1. Parameters, units, equipment, and description of the analysis used in the study.

| Parameter     | Unit       | Tools            | Work on   |
|---------------|------------|------------------|-----------|
| Current velocity | m/s     | Flow meter       | Insitu    |
| DO            | mg/L       | DO-meter         | Insitu    |
| pH            |            | pH-meter         | Insitu    |
| Temperature   | °C         | Thermometer      | Insitu    |
| Abundance     | particle/kg| Compound Microscope | Laboratory |

2.3. Microplastic analysis in sediments

The initial stage of microplastic analysis of the sediment was separated through several stages according to what Hidalgo-Ruz et al. [11], namely (a) drying, (b) volume reduction, (c) filtering, (d) density separation, and (e) visual sorting. The sediment sample was weighed to get the wet sediment weight and then dried using an oven with a temperature of 90°C and a maximum time of 24 hours (according to sediment conditions). According to what Nor and Obbard [12] have done, the dry sediment is weighed to obtain dry sediment weight and mashed using a mortar.

The sediment volume was reduced by filtering the refined sediment using a stratified filter with a mesh size (5 mm, 4 mm, 2 mm, 1 mm, and 500 μm). Sediment over 5 mm in size will be stuck in the filter. Sediments of different sizes are separated at different places. The sediment sizes were 4 mm, 2 mm, 1 mm, and 500 μm and were subjected to direct visual sorting without using any tools, while sediment sizes below 500 μm were carried out in a density separation stage for further analysis using a microscope.

The density separation stage is according to Hapitasari [13], by mixing 50 g of dry sediment with a size of below 500 μm into a saturated NaCl solution of 150 mL, then stirring until well blended. The sediment that has been mixed with NaCl is allowed to stand for a maximum of 24 hours until it settles and is suspended. After deposition, the microplastics that are light in size will float.
The separation stage is in accordance with Hapitasari [13], taking 1 mL of the solution that has been suspended in the top layer using a pipette then dripping it in SRC (Sedgewick Rafter-Counting Cell). After this stage, observations were made using a compound microscope with a magnification of 10x10. The SRC that has been filled with the sample is observed under a microscope with the aid of a micrometer. The microplastics observed under a microscope are of different types, colors, and sizes (table 2).

Table 2. The division of types, colors, and sizes of microplastics.

| Characteristics | Classification | Information |
|-----------------|----------------|-------------|
| Type (Hastuti et al. [14]). | Fiber | Secondary sources with elongated shape derived from the fragmentation of monofilament nets, ropes, and synthetic fabrics |
| | Fragment | Secondary sources of plastic cuttings with strong or weak polymer properties |
| | Pellets | Primary sources that are directly produced by the factory as raw material for the manufacture of plastic products |
| | Film | Secondary plastic polymer which has low density and comes from fragmentation of plastic bags or plastic packaging |
| Color | Blue | The colors found in microplastic observations |
| | Brown | |
| | Green | |
| | Black | |
| | Red | |
| | Yellow | |
| | White | |
| Size (Nor and Obbard [12]) | Group 1 | 20–40 μm |
| | Group 2 | 40–60 μm |
| | Group 3 | 60–80 μm |
| | Group 4 | 80–100 μm |
| | Group 5 | 100–500 μm |
| | Group 6 | 500–1,000 μm |
| | Group 7 | 1,000–2,000 μm |
| | Group 8 | 2,000–5,000 μm |

2.4. Data analysis
2.4.1. Abundance of microplastics. Observation of the abundance of microplastics under a microscope using the SRC (Sedgewick Rafter-Counting Cell). The method used in SRC in microplastic enumeration is the census method. The microplastic abundance calculation formula is calculated from the APHA [15] which refers to the plankton abundance formula as follows.

\[
\text{No} / \text{mL} = \frac{C \times 1000 \text{ mm}^3}{L \times D \times W \times S}
\]  

Information:
C : The number of particles counted
L : Length of S-R strip (mm)
W : Width of each strip (mm)
D : S-R strip depth (mm)
S : The counted number of strips
The formula for the abundance of microplastics for each sediment sample uses a modified formula from the APHA [16].

\[ N = \frac{N_0}{\text{mL}} \times \frac{V_s}{V_a} \times \frac{1}{B_t} \]  \hspace{1cm} (2)

Information:
N : Abundance of microplastics in the sediment (particles/kg of dry sediment)
N0/mL : Observed number of micropastics (particles)
V_s : Volume of saturated NaCl solution (mL)
V_a : Volume of the suspension solution in SRC (mL)
B_t : Weight of sediment dissolved with NaCl (kg)

2.4.2. Analysis of difference test. Microplastic abundance data were analyzed using non-parametric analysis. The Kruskal-Wallis test was used to determine significant differences in the abundance of microplastics by type, observation station, and sampling time. If the test results are indicated to be significantly different, the Mann Whitney test is used to identify significant differences between the two types of groups, stations, and sampling time. This statistical analysis was carried out using SPSS and Microsoft Excel 2007 software which can be used in statistical analysis processing [17].

2.4.3. Spatial distribution analysis. The results of the microplastic analysis obtained were then analyzed spatially using ArcMap software, which is a software used to see the spatial distribution of data at observation stations on the Citanduy River. Spatial analysis is a technique that can be used to explore data related to spatial data that has a coordinate system. The spatial analysis in this study was conducted to visualize the distribution of the average abundance of microplastics at the stations and substations of the observation on the Citanduy River.

| Table 3. The range of values for the distribution of the average microplastic abundance at the observation substation. |
|---|---|
| No. | Value Range (Particles/kg of dry sediment) |
| 1. | 8,000–10,500 |
| 2. | 10,500–13,000 |
| 3. | 13,000–15,500 |
| 4. | 15,500–18,000 |
| 5. | 18,000–20,500 |
| 6. | 20,500–23,000 |

| Table 4. Range of values for the distribution of the average microplastic abundance at the observation station. |
|---|---|
| No. | Criteria | Value Range (Particles/kg of dry sediment) |
| 1. | Low | 28,000–38,000 |
| 2. | Moderate | 38,000–48,000 |
| 3. | High | 48,000–58,000 |

The range of values at each substation is obtained from the average abundance of microplastics over the entire sampling month. The range of values used is divided into six ranges of values, each of which represents the average abundance at each observation substation on the Citanduy River. The range of criteria values at each station is obtained from the average abundance of microplastics over the entire
sampling month. The average abundance of microplastics in this study was divided into three ranges of values, where each range represents the criteria for the average abundance of microplastics. The range of values used in the distribution of the average abundance of microplastics at substations and observation stations on the Citanduy River is presented in table 3 and table 4.

3. Results

3.1. Abundance of microplastics in sediments

The results of the calculation of the total abundance of microplastics in the sediment in the Citanduy River at the upstream, middle, and downstream stations have an abundance that varies with each sampling. The abundance of microplastics based on time at each sampling is presented in figure 2.

![Figure 2](image_url)

**Figure 2.** The total abundance of microplastics in the upstream, middle, and downstream.

The value of the abundance of microplastics was different at each sampling station. The results of the abundance of microplastics ranged from 18,190–70,405 particles/kg of dry sediment. The highest abundance of microplastics in all sampling months is at the downstream. The abundance of microplastics was the highest in March compared to September and November.

Based on statistical tests using the Kruskal Wallis test, it was found that (p-value<0.05), so that each sampling station had a significantly different effect on the abundance of microplastics. A further test using the Mann Whitney test was carried out if the previous test had a significantly different effect. The Mann Whitney test shows that (p-value<0.05), so there is a difference in the abundance of microplastics at each sampling station.

The Kruskal Wallis test based on the time of sampling showed that (p-value<0.05), so that the sampling time had a significantly different effect on the abundance of microplastics. A further test using the Mann Whitney test was carried out if the previous test had a significantly different effect. The Mann Whitney test showed that (p-value<0.050), so that there is a difference in the abundance of microplastics at each sampling time.

3.2. Types of microplastics

The types of microplastics found in this study were fragments, films, and fibers. The average composition of microplastics by type in the upstream, middle, and downstream sections are presented in figure 3.

The abundance of fragment type microplastics was found to dominate at the downstream station in each sampling month. The abundance of microplastics at the upstream and middle stations showed different types that dominate at each sampling month. Overall, fragment type predominated throughout the sampling months. The three types of microplastics were found to be relatively abundant in March compared to September and November.

Statistical testing using the Kruskal Wallis test at all times shows that (p-value<0.05), so the type of microplastic has a significantly different effect on the abundance of microplastics. Further tests using the Mann Whitney test showed that (p-value<0.05), so there is a difference in the abundance of microplastics in each type of microplastic.
3.3. Color of microplastics

Color analysis on microplastics is carried out to show the colors contained in microplastics which will affect the possibility of microplastic consumption by aquatic biota. There are 7 groups of colors found in this study, namely blue, yellow, green, black, red, brown, and transparent. The percentage abundance of microplastics based on color found at three locations and three sampling times is presented in figure 4, figure 5, and figure 6.

![Figure 3](image-url) The average abundance of microplastic types in all sampling months.

![Figure 4](image-url) The percentage of color microplastics in September 2019.

![Figure 5](image-url) The percentage of color microplastics in November 2019.
The results obtained indicate that the color of the microplastics found at each station at each sampling month varies. Overall, the color of the microplastics in the film type was found to be more diverse than other types. The color of microplastics in the fiber type and fragments as a whole is dominated by black. The green color was found at least in each month of sampling.

3.4. Microplastic size

The size of the microplastics that have been found in sediments has various sizes. The microplastics are grouped into 8 size groups presented in figure 7, figure 8, and figure 9. The abundance of microplastics in all months of sampling was found to be the highest size abundance in March with fragment and film types found to dominate at the size of 20-40 μm while the fiber type was found to dominate at the size of 500-1000 μm. Based on statistical tests using the Kruskal Wallis test shows that the sampling station (p-value > 0.05), the sampling month (p-value > 0.05), and the sampling season (p-value > 0.05) did not have a significantly different effect on the size abundance of microplastics.

The highest microplastic abundance based on the size of the fiber type is in the size_500-1000 μm. The highest microplastic abundance in film and fragment types was found at the size of 20-40 μm. The difference in size of microplastics varies depending on the type and size. The microplastic fragment and film types were found to be smaller than the fiber size.

Figure 6. The percentage of color microplastics in March 2020.

Figure 7. The average abundance of microplastics in each month of sampling based on size at the upstream station.
3.5. **Microplastic spatial distribution**

The abundance of microplastics based on substations and sampling stations was analyzed spatially using ArcGIS software. The spatially obtained distribution of the microplastic average abundance is presented in figure 10 and figure 11.

The distribution of the highest microplastic average abundance is found at substation 2 which is at the downstream Station and the distribution of the average abundance of microplastics decreases towards substations 1 and 3 at the downstream station. The distribution of the lowest average microplastic is found in substation 1, which is at the middle station.

The highest abundance of microplastics is at the downstream station, namely in Pangandaran Regency with the amount of 57,043 particles/kg of dry sediment. The lowest abundance of microplastics is at the middle station, namely in the City of Banjar, which is 31,322 particles/kg of dry sediment. The abundance of microplastics at the upstream station, namely in Ciamis Regency, was found with moderate criteria of 38,150 particles/kg of dry sediment. The average abundance value is different at each sampling station.
4. Discussion
The abundance of microplastics in this study ranged from 18,190–70,405 particles/kg of dry sediment. This abundance is higher than research conducted by Ayuningtyas [18] in the waters of Banyuurip,
Gresik, East Java with an abundance of 711–1,044 particles/kg of dry sediment, and Kurnia [19] in the downstream area of the Cimanuk River, Indramayu, West Java with abundances range from 10,000–41,556 particles/kg of dry sediment. The difference in the abundance of microplastics in the sediment is thought to be the difference in the size of the sediment particles, the type of substrate, the method used in each study, the number of populations, the source of microplastics, and the natural conditions in each water. The different methods include oven drying at different temperatures and adding different solutions.

The abundance value of microplastics in this study found that the downstream station has a higher abundance than the upstream station and the middle station. According to Thompson et al. [20], microplastics are more easily trapped and sink in soft and wet sediments because of the gravity and density forces on the microplastics. The difference in abundance at each station is thought to be influenced by the type of sediment in the Citanduy River. The type of sediment at the upstream station is sand, the middle station is sand, the downstream station is mud.

The downstream station has the highest microplastic abundance compared to the upstream and middle stations. It is suspected that there are many community activities around the research location, such as fishing, agriculture, sea transportation activities, and people who throw garbage in rivers and near rivers. According to Dai et al. [21], microplastics will settle higher in waters that are deep enough because the waters tend to be calm. In addition, the greater water depth at the downstream station can affect the high microplastic abundance in the area.

The abundance of microplastics in March 2020 has a higher abundance compared to September and November 2019. This can be caused by the intensity of rainfall in March 2020 which is higher than in September and November 2019. According to Piehl et al. [22], stated that microplastics can be transported and settled through water overflow after rain occurs. BMKG data at the Bandung Geophysical Station shows that March 2020 has medium to high rainfall intensity (290 mm). The high intensity of rainfall causes plastic waste around the river to be transported and carried by river currents, thereby increasing the input of microplastics into river waters.

Based on the research results, there are three types of microplastics obtained, namely fibers, fragments, and films. These three types are commonly found based on previous research. Research conducted by Dewi et al. [23] in Muara Badak, Kutai Kartanegara Regency, and Nugroho et al. [24] in the waters of Benoa Bay, Bali Province, also found fragment, fiber, and film microplastics. The type of pellets was not found in this study because there is no plastic factory around the research location.

The abundance of fragment type microplastic was highest at all stations, followed by the abundance of film and finally the abundance of Fiber. The results obtained are similar to previous research conducted by Dewi et al. [23] and Ayuningtyas [18], which obtained the most abundance of fragment type microplastics compared to other types. According to Hastuti et al. [14], fragments are very strong synthetic polymers derived from pieces of plastic products. The abundance of fragments is higher due to the proximity of the observation station to the population area. The source of microplastic pollution with the type of fragments comes from anthropogenic activities such as household waste and ecotourism activities on the Citanduy River.

The source of microplastics in this study found that the type of fragment came from the drink bottle cap and pipe cut, the film type came from plastic packaging and raflia, the fiber type came from pieces of fishing nets and yarn. Various types of microplastics originate from point sources at the sampling station as well as an abundance of plastic waste carried by river currents.

This type of microplastic can harm the waters and can cause disruption of the food chain if the microplastics accumulate in the aquatic environment. Fragment and film type microplastics can lead to trapping these types in marine sponges, which can disrupt marine sponge life. Fiber-type microplastics can cause entanglement of aquatic organisms’ necks which can interfere with the respiratory tract of these organisms.

The microplastics obtained in this study consisted of 7 color groups. According to Hidalgo-Ruz et al. [11], color is used as an early stage in identifying chemicals contained in microplastics. In general,
the types of fragments are dominated by black, yellow, brown, and transparent. The type of film is dominated by black, brown, yellow, blue. The fiber type is dominated by black and transparent.

The black color found is thought to have come from the color produced from microplastic sources as well as from contaminant absorption on microplastics. According to Hiwari et al. [25], black color can be defined due to the large number of contaminants absorbed in microplastics and other organic particles that have the ability to absorb pollutants. Other colors that were found in this study were yellow, brown, and blue. Color Particles with striking colors have a higher probability of being identified compared to microplastics with faded colors, because faded colors can be faded [11]. The thick color of the microplastic indicates that the microplastic has not undergone a drastic color change [25]. Another color that is most commonly found, namely, transparent colors. This is because the transparent color also indicates that the microplastic has undergone photodegradation by UV light.

The color of the microplastics will cause the microplastics to enter the digestive tract of aquatic organisms. White, blue, and transparent microplastics are similar to plankton which is the main food source for planktivor fish, while black microplastics are mostly found in the stomachs of mesopelagic fish caught in the English Channel [26]. According to Tourinho et al. [27] stated that light-colored and translucent microplastics are similar to jellyfish, so they can be eaten by organisms such as loggerhead turtles.

Microplastics are the result of degradation from macroplastics [28]. The size of microplastics can be different because plastics have a variety of different types. The highest abundance of microplastics based on the size of the fiber type is in the 500–1,000 μm range. Fiber is found in the large size group because of its elongated shape and comes from a plastic that has a high degree of flexibility and is strong so that it is more difficult to fragment into smaller sizes. The highest abundance of microplastics in film and fragment types was in the range of 20–40 μm.

The spatial distribution map based on the average abundance of microplastics at the observation substation shows that substation 2, which is located at the downstream station, has the highest average abundance of microplastics. This is because the depth at substation 2 at the downstream station has the highest depth compared to other substations, namely 500 cm.

Downstream stations have the highest abundance, it is assumed that more landfills are dumped at the downstream stations compared to the upstream and middle stations. This is due to the large number of tributaries that cross, so that a lot of garbage is carried by the current to the downstream station and causes the deposition of the substrate at the downstream station to get higher. Another factor that can cause the high abundance of microplastics at the downstream station, is due to the proximity of the observation station to the sea, this can allow the microplastic particles to be carried from the sea towards the observation station at the time of tides.

Microplastics which are consumed by aquatic organisms can cause cell damage and DNA of these organisms, damage to the liver, these organisms have less food habits so that the energy produced and their fat reserves are lower, the tissues in animals can induce an immune response which can lead to inflammation, the resulting offspring are low due to low gamete quality [8]. The dangers of microplastics are not only for the environment and biota, but for humans, as consumers, at a high level.

Countermeasures for microplastic pollution have not been found to date, due to the presence of microplastics which are unseen and easily dispersed in the water environment. Efforts that can be done by overcoming the source of microplastics, namely plastic waste.

Plastic waste management can be done by implementing the 4Rs, namely reduce, reuse, recycle, and repair. The efforts that have been made by local residents and the government in overcoming microplastic sources by cleaning garbage around the river and by socializing about waste management. Accumulation of garbage around the river can be avoided by building adequate waste dumps, large waste collection services, adequate number of personnel, and a regular solid waste disposal schedule.

5. Conclusion
The highest abundance of microplastics is at the Downstream Station. Microplastics at all stations are dominated by the type of fragment and the dominant color is black. The dominant film type and fragment
microplastics were in the range of 20-40 μm and the dominant fiber types were in the range of 500–1,000 μm. The spatial distribution of the average abundance of microplastics at the substation and sampling station was found to be the highest in substation 2 at the downstream station and the distribution of the average abundance of microplastics decreased towards substations 1 and 3 at the downstream station.

References

[1] Ryan P G, Moore C J, van Franeker J A and Moloney C L 2009 Monitoring the abundance of plastic debris in the marine environment Philosophical Transactions of The Royal Society B Biological Sciences 364(1526):1999–2012
[2] Avio C G, Gorbin S and Regoli F 2016 Plastics and microplastics in the oceans: from emerging pollutants to emerged threat. Mar. Environ. Res. 30: 1–10
[3] Peng G, Xu P, Zhu B, Bai M and Li D 2018 Microplastics in freshwater river sediments in Shanghai, China: A case study of risk assessment in mega-cities Environ. Pollut. 234:448–456
[4] Rimadas S 2019 Aspek penentu niat untuk membeli produk ramah lingkungan pengganti plastik pada milenial di Indonesia Ultima Management 11(2): 77–93 [In Indonesian]
[5] Scherer C, Brehnholdt N, Reifferscheid G and Wagner M 2017 Feeding type and development drive the ingestion of microplastics by freshwater invertebrates Sci. Rep. 7 (1):1–9
[6] Dris R, Imhof H, Sanchez W, Gasperi J, Galgani F, Tassin B and Laforsch C 2015 Beyond the ocean: Contamination of freshwater ecosystems with (micro) plastic particles Environ. Chem. 12(5): 539–550
[7] Vermaire J C, Pomeroy C, Herculgh S M, Haggart O and Murphy M 2017 Microplastics abundance and distribution in the open water and sediment of the Ottawa River, Canada, and its tributaries FACETS 2: 301–314
[8] Li J, Liu H and Paul Chen J 2018 Microplastics in freshwater systems: A review on occurrence, environmental effects, and methods for microplastics detection Water Res. 137: 362–374
[9] Shim W J and Thompsonon R C 2015 Microplastics in the Ocean Arch. Environ. Contam. Toxicol. 69(3): 265–268
[10] Joesidawati M I 2018 Pencemaran mikroplastik di sepanjang pantai kabupaten Tuban Semin. Nas. Has. Penelit. dan Pengabdi. Masy. 3:7–15 [In Indonesian]
[11] Hidalgo-Ruz V, Gutow L, Thompsonon R C and Thiel M 2012 Microplastics in the marine environment: A review of the methods used for identification and quantification Environ. Sci. Technol. 46(6): 3060–3075
[12] Nor M N H and Obbard J P 2014 Microplastics in Singapore’s coastal mangrove ecosystems Mar. Pollut. Bull. 79(1–2): 278–283
[13] Habitasari D N 2016 Analisis Kandungan Mikroplastik pada Pasir dan Ikan Demersal: Kakap (Lutjanus Sp.) dan Kerapu (Epinephelus sp.) di Pantai Ancol, Palabuhan ratu, dan Labuan [Undergraduate thesis] (Bogor: IPB University) [In Indonesian]
[14] Hastuti A R, Yulianda F and Wardianto Y 2014 Distribusi spasial sampah laut di ekosistem mangrove Pantai Indah Kapuk, Jakarta Bonorowo Wetal. 4: 94–107
[15] [APHA] American Public Health Association 2017 Stanard Method for the Examination of Water and Wastewater American Public Control Federation 23rd edition Washington (US): American Public-Control Federation
[16] [APHA] American Public Health Association 2012 Stanard Method for the Examination of Water and Wastewater 21th edition Washington (US): American Public Control Federation
[17] Wang W, Ndungu A W, Li Z and Wang J 2017 Microplastics pollution in inland freshwaters of China: A case study in urban surface waters of Wuhan, China Sci. Total Environ. 575: 1369–1374
[18] Ayuningsytas W C 2019 Kelimpahan Mikroplastik Pada Perairan Di Banyuurip, Gresik, Jawa Timur JFMR-Journal Fish. Mar. Res. 3(1): 41–45
[19] Kurnia M S 2019 Akumulasi dan Komposisi Mikroplastik pada Sedimen di Wilayah Hilir Sungai Cimanuk, Kabupaten Indramayu, Jawa Barat [skripsi] Bogor (ID): Institut Pertanian Bogor [In Indonesian]

[20] Thompson R C, Olsen Y, Mitchell R P, Davis A, Rowland S J, John A W G, McGonigl D and Russell A E 2004 Lost at sea: Where is all plastic? Science 304(5672): 838

[21] Dai Z, Zhang H, Zhou Q, Tian Y, Chen T, Tu C, Fu C and Lou Y 2018 Occurrence of microplastics in the water column and sediment in an inland sea affected by intensive anthropogenic activities Environ. Pollut. 242:1557–1565

[22] Piehl S, Leibner A, Löder MGJ, Dris R, Bogner C and Laforsch C 2018 Identification and quantification of macro- and microplastics on an agricultural farmland Scientific Reports 8(1): 1–9

[23] Dewi I S, Budiarsa A A and Ramadhan R I 2015 Distribusi mikroplastik pada sedimen di Muara Badak, Kabupaten Kutai Kartanegara Depik 4(3): 121–131 [In Indonesian]

[24] Nugroho D H, Restu I W and Ernawati N M 2018 Kajian kelimpahan mikroplastik di perairan Teluk Benoa Provinsi Bali Current Trends in Aquatic Science 1(1): 80–88

[25] Hiwari H, Purba N P, Ihsan Y N, Yuliadi L P S and Mulyani P G 2019 Condition of microplastic garbage in sea surface water at around Kupang and Rote, East Nusa Tenggara Province Pros. Sem. Nas. Masy. Biodiv. Indon. 5(2):165–171 [In Indonesian]

[26] Boerger C M, Lattin G L, Moore S L and Moore C J 2010 Plastic ingestion by planktivorous fishes in the North Pacific Central Gyre Mar. Pollut. Bull. 60(12): 2275–2278

[27] Tourinho P S, Ivar S J A and Fillmann G 2010 Is marine debris ingestion still a problem for the coastal marine biota of southern Brazil? Mar. Pollut. Bull. 60(3): 396–401

[28] Septian F M, Purba N P, Agung M U K, Yuliadi L P S and Akuan L F 2018 Sebaran spasial mikroplastik di sedimen Pantai Pangandaran, Jawa Barat J. Geomaritim Indonesia 1(1): 1–8 [In Indonesian]