EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology, 25(12), 40–54
https://doi.org/10.12912/27197050/193810
ISSN 2299–8993, License CC-BY 4.0

Received: 2024.09.18
Accepted: 2024.10.15
Published: 2024.11.01

Characteristics and Abundance of Microplastics Pollution in Water and Sediment in the Bogowonto River

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ABSTRACT

The plastic debris that breaks down smaller than 5 mm is defined as microplastics and the source of these microplastics can come from daily products used like laundry activities. Bogowonto River is a vital component of the aquatic ecosystem that provides water for domestic, agricultural, and industrial needs. This study aimed to determine the abundance and characteristics of microplastics in Bogowonto River. Sampling was conducted in December 2023, totaling 15 water samples and 15 sediment samples with 3 repetitions at 5 stations. Determination of the location point using purposive sampling method in which the sampling station was selected by considering anthropogenic activities. Water sampling was carried out using a plankton net and subsequent destruction of organic matter and filtration. A grab sampler (Van Veen, Hydro-Bios, Germany) was used to take sediment samples, which were then separated by density, and filtered. MP abundance in water samples ranged from 126.67 ± 11.55 to 253.33 ± 64.29 MPs/m^3 ($\bar{x}$ ± SD) and sediment samples ranged from 100.00 ± 45.83 to 236.67 ± 126.62 MPs/kg ($\bar{x}$ ± SD). The shape of microplastic fiber is the most dominant in the sample, while the red and blue colors are the most dominant colors and consistently appear in all samples. Testing to determine the type of polymer in the sample using the FTIR-ATR method. Polyamide and polypropylene are the two most dominant types of polymers. Waste discharges from the agricultural, construction, hospital, tourism, market, and residential sectors all contribute to microplastic pollution of the river. The meander pattern of the river between stations 3 and 4 has an impact on the transportation of microplastics, which affects their abundance.

Keywords: microplastics, anthropogenic, Bogowonto River, environmental pollution, FTIR-ATR.

INTRODUCTION

The global population, which currently stands at 7.7 billion people, is predicted to grow to around 9.7 billion according to estimates made by the United Nations in 2019, with the estimated year of the increase being 2050 (United Nations, 2019). As the global population increases, projected to reach around 9.7 billion people by 2050, the need for consumer goods grows as well. This means more plastic packaging, disposable appliances and other products, leading to an increase in plastic waste. The link between a growing population and increased plastic waste is also influenced by economic growth and changing consumption patterns, particularly in developing countries where waste management may not be as efficient or effective as in developed countries. This has led to an increase in the generation of plastic waste that is not properly managed and can eventually end up in the environment, including the oceans. Growing global awareness of the adverse effects of plastic pollution has triggered international initiatives to address the issue, including the efforts to reduce the use of single-use plastics, increase recycling activities, and develop the policies to reduce plastic production. Indonesia ranks among the top 10 countries that produce plastic waste pollution globally, i.e. it is one of the largest plastic waste producing countries in the world. Many Indonesians live in coastal areas and inefficient waste management is the main cause of high plastic waste pollutant levels (Iskandar et al., 2022). The plastic waste that breaks down smaller than 5mm is defined as microplastics and the source of these microplastics can come from products used daily, laundry activities, or can also come from other types of plastic waste. The size of microplastics specifically consists of 3 parts, namely Large Microplastic Particles (L-MPPs) of 5 mm to 500 μm, Small Microplastic Particles (S-MPPs) of 500 μm to 50 μm, and Very Small Microplastic Particles (VS-MPPs) of 50 μm to 1 μm. Microplastics can be found in various types of aquatic environments, from the areas with high residential activity to remote areas. This proves that the wide scope of microplastic distribution after entering the water area (Riani and Cordova, 2022). Microplastics also have various forms such as fibers, fragments, foam, and films (Syafina et al., 2022). Plastic polymers can be categorized into two main types, namely thermoplastics and thermosets. Thermoplastics can be melted and molded repeatedly, whereas thermosets, once hardened, cannot be remelted. Here are some examples, as described in the sources (Grigore, 2017) and (Kumar et al., 2019); examples of thermoplastics include polyethylene (used in plastic bags, bottles, and containers), polypropylene (used in food containers, toys, and medical devices), polystyrene (an ingredient of products such as styrofoam cups and packaging), polyvinyl chloride (used in pipes, cables, and building materials), polyethylene terephthalate – commonly used for plastic bottles and textile fibers), polycarbonate (found in products such as eyeglass lenses, CDs, and building materials). Thermosets are a type of plastic polymer that, when processed and heated, undergo a chemical reaction that causes the molecular chains to bond together permanently, creating a hard, three-dimensional structure that cannot re-melt when reheated. This is in contrast to thermoplastics which can be melted and reshaped repeatedly without significant degradation. Examples of thermosets include epoxy resins (used in adhesives, composite materials for spacecraft, and electronic components), phenolic resins (used in kitchen appliance handles, circuit boards, and electrical fixtures, polyurethane resins (used for foam used in bedding, furniture, and insulation) (Grigore, 2017) (Kumar et al., 2017). PC (Polycarbonate) plastic polymers are known to absorb EDCs (Endocrine disrupting chemicals), which are chemicals that disrupt normal hormone function in humans and animals. Polycarbonate that absorbs EDCs can be dissolved in water and absorbed in sediments, which will affect aquatic biota which is its habitat. This causes EDCs to be absorbed in the body of biota, which causes disruption to the reproductive system, thyroid metabolic system, and increases the potential for cancer development which is related to hormone production. Another type of chemical, BPA (Biosphenol A), is a chemical used in the manufacture of PC-type plastics and is also known to be detrimental to health. If this substance is exposed to the human body, it will cause an imbalance in blood hormone levels and can cause cardiovascular as well as heart disease (Rai et al., 2021).

In recent studies, investigations on the transport of microplastics transporting and adsorbing heavy metals include Cd, Cr, Pb, Ag, Cu, Sb, Hg, Fe, and Mn (Zhou et al., 2019), persistent organic pollutants (POPs), including various types of substances such as DDT (pesticides), dioxins, PCBs (polychlorinated biphenyls), and polycyclic aromatic hydrocarbons (PAHs) (Tan et al., 2019). Rivers are often the main conduit transporting microplastics to the ocean as various anthropogenic activities on land usually end up polluting rivers. Microplastics in rivers can consist of primary microplastics, which are made to microscopic sizes for specific applications, such as granules and pellets, and secondary microplastics that result from the breakdown of larger plastics (Riskiana et al., 2021). Rivers receive water runoff containing microplastics from residential, industrial and agricultural sources. Through this transportation process, microplastics enter marine ecosystems, where they can interact with and be consumed by aquatic organisms (Kumar et al., 2021). Research on the distribution of microplastics in rivers has shown evidence of their presence in various locations. For example, all 508 water samples collected from the Langat river in Malaysia over 12 months contained microplastics, with an average concentration of 4.39 MPs/L. This rose to 90 MPs/L in some urbanized tributaries (Chen et al., 2021). Another study in Southeast Asia also showed the presence of microplastics in major rivers, such as the Chao Phraya, Citarum, and

Saigon, with the amount of microplastics varying in the urban and estuarine zones of each river (Babel et al., 2022). Another study also mentioned that in Indonesia, the prevailing monsoon circulation plays an important role in the distribution path of plastic waste in the waters (Iskandar et al., 2022). Physical factors, such as seawater movement, tides, wind direction, ocean currents affect the migration of microplastics in waters while chemical factors mainly refer to the photochemical degradation of microplastics. Microplastics in the aquatic environment undergo chemical bond breakage and structural changes under the influence of light and are gradually oxidized into low molecular weight polymers (Fan et al., 2023). Research on sample sediment and water for microplastic pollution is often conducted in December, because this period can represent certain seasonal conditions in a particular regional context. For example, in Malaysia, which has similar weather patterns to Indonesia, there are only two clear seasons, the dry season and the wet season. The process of microplastic transport in Malaysian rivers is highly dependent on the season, which affects the flow rate of the river and impacts the fate and transport of microplastics (Choong et al., 2021). Generally, the rainy season that lasts between November and March in most parts of Southeast Asia, including Indonesia, can increase the flow of river water and result in increased flushing of wastes and contaminants, including microplastics, from land to river systems. This means that sampling in December can provide the information on the maximum amount of contaminants carried over from land. General considerations in determining the timing of sampling in the Bogowonto River river include factors such as climatic conditions, rainy season, human activities, and the hydrological cycle. In December, which is typically part of the rainy season in Indonesia, river flows often increase, which may carry more microplastics and pollutants from upstream rivers or from urban and agricultural drainage into the water. This may increase pollutant concentrations and provide an opportunity to understand the worst-case conditions or maximum loads of microplastics in river systems. In addition, the human activities and consumption levels associated with year-end celebrations may also influence the amount of microplastics entering the environment due to increased waste production. Sampling in December can also be used to assess the impact of waste management interventions or policies implemented throughout the year. By considering all these factors, a more comprehensive picture of microplastic distribution and concentration in a temporal context specific to the region and local conditions in the Bogowonto River can be better understood (Echeverría-Sáenz et al., 2012; Sameera and Aruna, 2019; Dumbili and Henderson, 2020; Mihardja et al., 2021; Lewoyehu et al., 2022). Sampling for microplastic abundance analysis in various studies also usually takes into account various factors, including the time of year. If sampling is conducted in December, this coincides with the northwest monsoon season in Indonesia, which generally occurs between November and March. During this season, monsoon winds usually bring heavy rains and can increase river flows as well as bring more waste and pollutants to aquatic systems, including microplastics. Increased river flow can lead to increased dispersion and transport of microplastics in water and sediment. This means that the samples collected may show higher levels of microplastic abundance during or after monsoon rains. In addition, heavy rainfall can affect the distribution and redeposition of microplastics, especially in estuaries and coastal areas. The presence of dense human activities from upstream to downstream is thought to have a significant impact on the presence of microplastics in the Bogowonto River and may act as a potential source of microplastics that flow into the sea. In this research hypothesis, the abundance of microplastics in Bogowonto River increases over time due to several factors, namely population activities, agricultural land, and also tourism. A knowledge gap that needs to be bridged is the first discovery of the presence and characteristics of microplastics in the Bogowonto River. Therefore, it is imperative to conduct the research that aims to determine the presence of microplastics in both water and sediment and FTIR-ATR testing is expected to help identify the source of microplastics present in the Bogowonto River. Such research efforts are essential to gain deeper insights into the extent of microplastic pollution in the Bogowonto river and its potential impact on ecosystems and human well-being. After conducting an in-depth review of the literature, it was discovered that no prior research has been conducted regarding the initial findings on the abundance and characteristics of microplastics specifically in the Bogowonto River. Consequently, this study aimed to determine the presence and characteristics of microplastics in the aquatic ecosystem of the Bogowonto River, with the research being carried out in December 2023 (Fig. 1). This knowledge gap is particularly important, given the well-documented adverse effects of microplastics on ecosystems and the potential risks they pose to human health. Table 1, which compares microplastic abundance across different countries, is presented below.

MATERIAL AND METHODS

Study area

The Bogowonto River is located in three districts, namely Wonosobo District, Magelang District, and Purworejo District. Wonosobo Regency and Magelang Regency are located in the upper reaches of the river, while Purworejo Regency is located in the southern part as the downstream which is a densely populated residential area. Bogowonto River has a watershed area of 58.571 hectares and has its headwaters in the highlands of Kedu region, precisely in Sumbing Mountain, Banyumudal Village, Sapuran District, Wonosobo Regency. The Bogowonto River fulfils diverse important functions for the local community of Purworejo Regency, such as providing fishery resources, irrigation, ruwatan (one of the purification rituals that are still widely practiced by most Javanese people), and tourist facilities. In addition, the Bogowonto River is also utilized by the local community for traditional fisheries resource management or by fishing. The large amount of

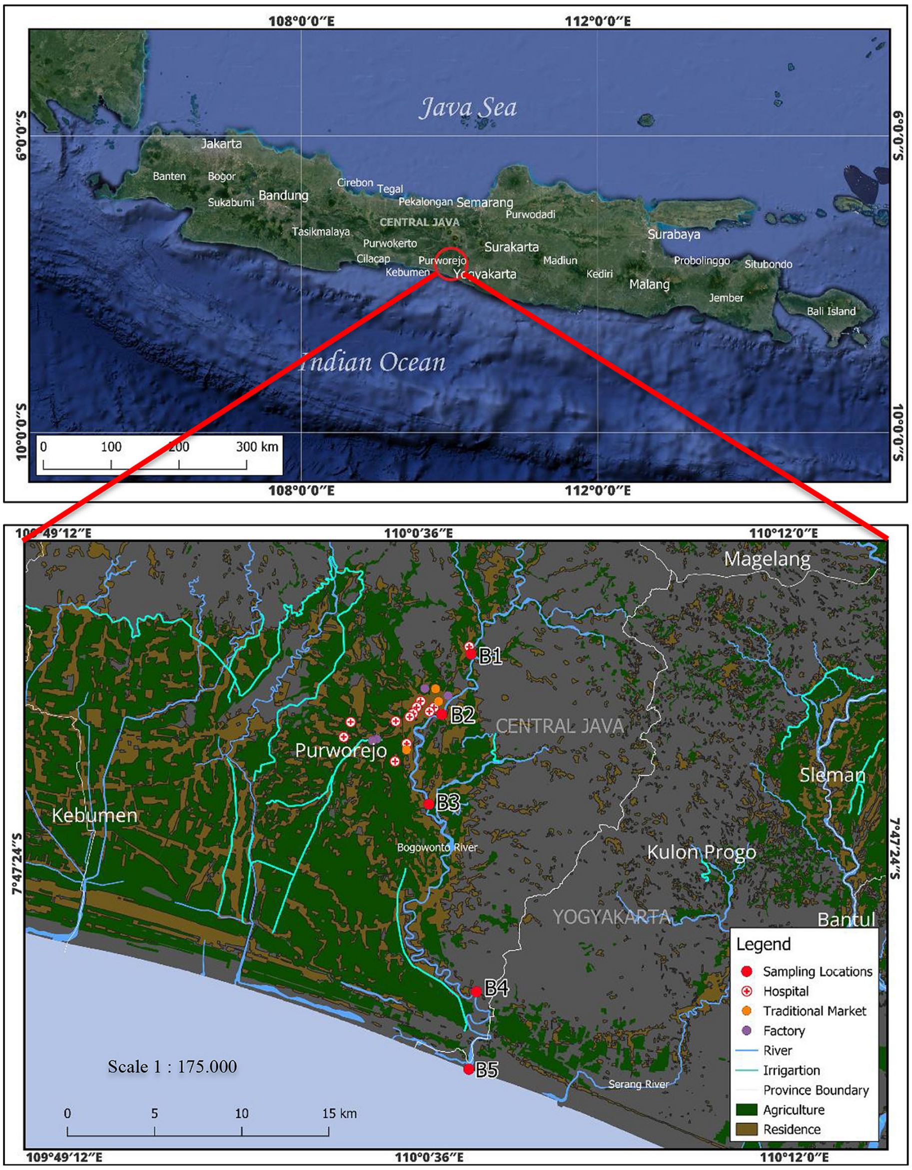

Figure 1. Map illustrating the study area and the sampling locations along the Bogowonto River in Purworejo District

Table 1. Study on the comparison of microplastic abundance in various countries

Study area	Sample type	Method	Identification	Abundance	References
Surakarta River Basin, Indonesia	Water and sediment	Stainless steel bucket and Ekman grab sampler	Stereo microscope and FTIR-ATR	Water: 25.5 ± 0.5 to 52.2 ± 1.1 particles/l Sediment: 0.55 ± 0.03 – 1.1 ± 0.04 particles/g	Ismanto et al., 2023
Jakarta Bay, Indonesia	Water	Round net	Stereo microscope, FTIR spectroscopy, and Micro-Raman Spectroscopy	Water: 48.179 ± 21.960 particles/ m^3	Purwiyanto et al., 2022
Yangtze River Estuary, China	Water and sediment	Metal cylinder and sediment corer	Stereo microscope and μ-FTIR	Water: 67.5 ± 94.4 particles/ m^3 and sediment: 28.3 ± 14.4 particles/kg; Water: 9.8 ± 12.2 particles/m^3 and sediment: 39.4 ± 16.1 particles/kg	Li et al., 2020
Jenebarang River Estuary, Indonesia	Water and sediment	Neuston net and sediment corer	Stereo microscope and FTIR-ATR	Water: 1.20–3.19 particles/ m^3 and sediment: 28.33 - 56.67 particles/kg	Wicaksono et al., 2020
Tallo River Estuary, Indonesia	Water and sediment	Neuston net and sediment corer	Stereo microscope and FTIR-ATR	Water: 0.74 ± 0.46 to 3.41 ± 0.13 particles/m^3 and sediment: 16.67 ± 20.82 - 150 ± 36.06 particles/kg	Wicaksono et al., 2020
Sado Estuary, Portugal	Water	Neuston net	Stereo microscope equipped with a camera and FTIR-ATR	Water: 0.45 ± 0.52 particles/m^3	Rodrigues et al., 2020
Yellow River Estuary, China	Water	Stainless steel bucket	Electron microscope	Water: 623–1392 particles/l	Han et al., 2020
Los Angeles River, United States	Water	Hand net, manta trawl, purse seine, rectangular net	–	Water: 0.12–2,874.23 particles/ m^3	Moore et al., 2011
Pearl River, Guangzhou, China	Water and sediment	Water sampler and Van veen grab sampler	Stereo light microscope and μ-FTIR	Water: 379–7924 particles/ m^3 and sediment: 80 - 9597 particles/kg	Lin et al., 2018
Bogowonto River, Central Java, Indonesia	Water and Sediment	Plankton net and Van veen grab sampler	Stereo microscope equipped with a camera and FTIR-ATR	Water: 126,67±11,55 – 253,33±64,29 particles/m^3 Sediment: 100,00±45,83 – 236,67±126,62 particles/kg	This study

water discharge in the Bogowonto River is also utilized for irrigation through the construction of a number of dams (Budisetyorini et al., 2022).

Sampling method

The selection of sampling points was determined using a purposive sampling method, in which locations were chosen based on anthropogenic activities and the type of river flow along the Bogowonto River. Samples were taken at five station points, with each station point being sampled three times. Water sampling was conducted using a plankton net with a mouth opening diameter of 30 cm, mesh size of 60 μm, and a 50 mL cod-end. The samples were collected by manually decanting 50 L of water using a 10 L metal bucket into the plankton net. The samples were then taken, placed into labeled glass sample bottles, and stored in a coolbox containing gel ice (Hitchcock, 2020). Sediment sampling was performed using a grab sampler. The Sediment samples of 400 g wet weight were collected. For sediment samples, NOAA recommends collecting 400 g of sediment per replicate (Masura et al., 2015). The obtained sediment samples were then placed into pre-labeled aluminum boxes and stored in a coolbox containing gel ice (Cai et al., 2023). The collected water and sediment samples were transported to the laboratory and then stored in a refrigerator at a temperature of approximately 4 °C until further processing.

Sample pretreatment

The laboratory procedure for assessing microplastics in the water (Covernton et al., 2019) and sediment (Cheung et al., 2023) was adopted from prior research and modified accordingly. To remove biological material from the water sample, a 50 mL was transferred to a 100 mL beaker glass and 5 mL of 10% KOH (Merck Millipore EMSURE®, ACS, ISO, Reag., Ph Eur) was added to each sample before being sealed with aluminum foil and incubated at a temperature of 60 °C for 24 hours. KOH is effective in eliminating biological material from samples (Foekema et al., 2013; Rochman et al., 2015) and a 24-hour incubation at 60 °C does not significantly affect most plastic polymers. Drying is necessary, as it can aid in reducing cross-contamination, where incubating the sample at a controlled temperature can kill and reduce microorganisms present in the sample as well as decrease the moisture in the sample. A wet sediment sample of 400 g was dried in an oven at a temperature of 60 °C for 24 hours. Density separation was performed using a saturated NaCl solution (ρ = 2.17 g/cm^3, Merck Millipore EMSURE®, ACS, ISO, Reag., Ph Eur). Density separation using NaCl is recommended by the MSFD Technical Subgroup (Hanke et al., 2013) and NOAA (Masura et al., 2015). The dried sediment was then taken in an amount of 100 g and dissolved in 300 mL of a 30% NaCl solution, then stirred with a magnetic stirrer for 2 minutes and left to settle for 24 hours. Afterward, the removal of organic material was performed by adding 30 mL of 10% KOH solution at 60 °C for 24 hours. KOH has minimal damage to microplastics and is recommended for the samples with high organic content. According to Bayo et al., (2022), adding a 10% KOH solution can remove the biofilm from the surface of microplastics. After the organic material removal stage, the sample was filtered using a vacuum pump (Rocker-300, Taiwan) through cellulose filter paper (Whatman, UK) no. 42 with pore size 2.5 μm.

Microplastic identification and quantification

The filter paper was then placed in a Petri plates for storage followed by visual identification using a binocular microscope (Olympus CX43, Japan). Observation of shapes and colors was conducted by visualizing microscope photos with 4x magnification for large microplastic particles (LMPP) and 10× magnification for small microplastic particles (SMPP) and very small microplastic particles (VSMPP) using the OptiLab Viewer 2 (Miconos, Indonesia). The sizes of the microplastics were measured using the Image Raster version 3 software (Minocos, Indonesia).

The identification process of polymer compositions in microplastic samples involves Fourier Transform Infrared Spectroscopy method. This technique uses infrared light directed at the sample, and the resulting light absorption or transmission pattern across various wavelengths is used to analyze the characteristic chemical groups within the polymer. The FTIR-ATR method is notable for its ease of use and the precision of the results. In the analysis, the FTIR spectrum is taken in the mid-infrared wavelength range from 400 to 4000 cm^{-1} with a resolution of 4 cm^{-1}. The resultant spectrum graph displays intensity as a function of wavenumber, with the x-axis representing the wavenumber and the y-axis representing intensity. The spectrum graph is generated using the Openspecy website (Cowger et al., 2021) by inputting the obtained data in CSV format.

Quality control

All equipment that comes into contact with the sample at any time is thoroughly rinsed with filtered with aquadest water using cellulose filter paper before use. KOH, NaCl, and all aquadest solutions used are filtered through cellulose filter paper before use. Measures were taken to prevent microplastic contamination during the sample collection and examination stages. All instruments applied in this study were intensively cleaned using distilled water before use. Three control petri plates containing no samples to be tested were prepared as part of the experimental procedure to ensure the absence of contaminants. Devices made of glass and stainless steel were also washed thoroughly with filtered distilled water. The tools for sampling as well as the containers used during the experiment were made of glass. To minimize microplastic particles that could become airborne, cotton laboratory clothing and cotton gloves were worn during field and laboratory sampling. Samples were wrapped tightly and individually to avoid post-collection cross-pollution.

Statistical analysis

The microplastic abundance test refers to the National Oceanic and Atmosphere Administration (NOAA);

$$C = \frac{n}{V} \tag{1}$$

where: C is the abundance of microplastics (MPs/m^3), n is the number of microplastic particles, and V is the sample volume (m^3).

$$C = \frac{n}{m} \tag{2}$$

where: C is the abundance of microplastics (MPs/kg), n is the number of microplastic particles, and m is the dry weight of the sediment (kg).

Statistical analysis was conducted using IBM SPSS software version 23.0.0.2. For the statistical analysis of microplastic abundance, tests for normality of distribution and homogeneity of variance were performed first. If the data met these tests, parametric analysis was applied. If the data did not meet the normality and homogeneity tests, non-parametric analysis was used instead. Parametric analysis involved using ANOVA to determine whether there were significant differences in the mean values between stations for each sample type. This was followed by Tukey's HSD test to identify which specific stations had significant abundance differences. A paired t-test was also performed to compare the significance between water sample groups and sediment sample groups. The paired t-test is used to compare the means of two directly related data groups, such as paired samples taken from the same station. If the data did not meet the assumptions of normality and homogeneity, the non-parametric Kruskal-Wallis test was used. The Kruskal-Wallis test is an alternative to ANOVA for data that do not meet parametric assumptions, such as non-normally distributed data or groups with non-homogeneous variances. When the abundance data of microplastics in the Bogowonto River did not meet these assumptions, the Kruskal-Wallis test was used to determine if there were significant differences in the median abundance of microplastics at various sampling points.

RESULTS AND DISCUSSION

Out of the 30 petri plates utilized for the visual observation of MPs, only two MPs with purple fiber shapes and one MP with green fiber shapes were detected in the negative control, with a final abundance of 0.03 MPs/blank.

Data analysis showed that there were significant variations in microplastic abundance across the five different water sampling stations (Fig. 2). Station 2 showed the highest abundance with an average of 253.33 ± 64.29 MPs/m^3 ($\bar{x}$ ± SD) followed by stations 1 and 4 which both had an average abundance of 226.67 ± 23.09 MPs/m^3 ($\bar{x}$ ± SD). Meanwhile, station 3 showed an abundance of microplastics with an average of 140.00 ± 20.00 MPs/m^3 ($\bar{x}$ ± SD), indicating a considerable difference with the other stations. Station 5, with a mean of 126.67 ± 11.55 MPs/m^3 ($\bar{x}$ ± SD) also showed the lowest abundance.

Sediment sample data showed that Station 4 recorded the highest abundance with an average of 236.67 ± 126.62 MPs/kg ($\bar{x}$ ± SD), indicating the highest level of microplastic contamination among all stations. Meanwhile, Station 1 showed the lowest abundance with an average of 100.00 ± 45.83 MPs/kg ($\bar{x}$ ± SD). Stations 2, 3, and 5 each had microplastic abundances that fell between the range of Stations 1 and 4, indicating significant variation in microplastic contamination across different sediment sampling sites.

The data on microplastic abundance in water samples met the assumptions of the ANOVA test, namely normality and homogeneity of variance. In Figure 2, the abundance of water samples statistically shows that station 2 against 3 and 5 has a significant difference (< 0.05) based on the asterisks. Station 2 had a significantly higher abundance of microplastics compared to stations 3 and 5. This significant difference indicates that factors such as current patterns and proximity to

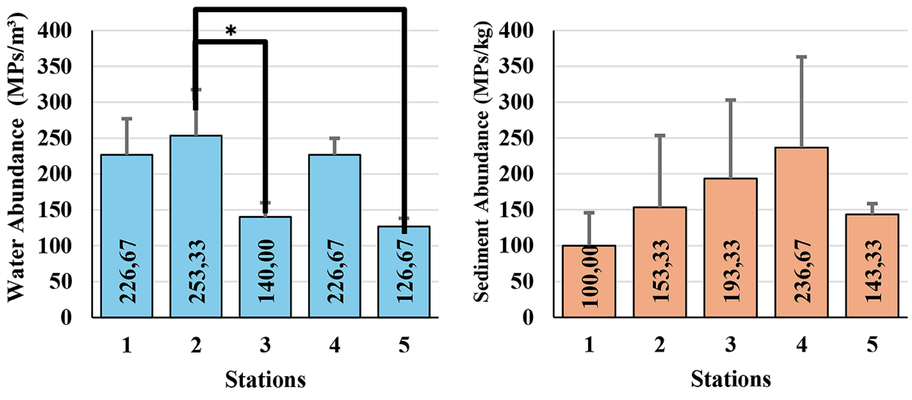

Figure 2. Average microplastic abundance in water samples (MPs/m^3) and sediment samples (MPs/kg); asterisks indicate significant differences (< 0.05) which means that based on the ANOVA test and Tukey's HSD follow-up test, the abundance data from each station gives significantly different or significant results

pollutant sources e.g. stream type, residential, or industrial also play an important role in the distribution of microplastics at these stations. Station 2, with an average microplastic abundance of 253.33 ± 64.29 MPs/m^3 is most likely exposed to higher microplastic loads, compared to Station 3 (140.00 ± 20.00 MPs/m^3) and Station 5 (126.67 ± 11.55 MPs/m^3).

Analysis of microplastic data in sediments also fulfills the assumptions of the ANOVA test, namely normality and homogeneity of variance. However, Figure 2 statistically indicates that the variation between stations is not significant enough to be considered statistically different. A p value greater than the significance level (> 0.05) indicates that the data reject the null hypothesis. This means that there is statistically insufficient evidence to suggest that there is a difference in the mean abundance of microplastics in the sediment between stations. The result of showing no significant difference between stations also explains that the distribution of microplastics in the sediment is relatively homogeneous statistically among the five stations. Although this result is different from the results of the analysis on water samples, it suggests that the dynamics of microplastics in the sediment may be more detailed. Factors such as sedimentation processes, faster degradation of microplastics in sediments due to interactions with microorganisms, and different chemical conditions, or differences in sediment characteristics between stations may affect the ability of sediments to accumulate microplastics.

The paired t-test results showed that there was no statistically significant difference between the mean abundance of microplastics in water and sediment samples taken from the same station. This is indicated by the value of $p = 0.237$ ($p > 0.05$). Although the average abundance of microplastics in water samples was slightly higher than that in sediment samples, the difference was not statistically significant. The paired t-test results also showed that there was a correlation between the abundance of microplastics in water and sediment samples showing a positive, but fairly weak relationship, indicating that when the abundance of microplastics increases in water samples, there is a tendency to also increase in sediment samples, and vice versa. However, the significance value for the correlation is 0.252, which is greater than the commonly used alpha value of 0.05, indicating that the relationship is not statistically significant.

River meander patterns can affect sediment and microplastic transport due to complex flow and sedimentation mechanisms. At stations 3 and 4 (Fig. 1) with long meanders (21.8 km), low current velocities and shallow depths allow fine sediments and microplastics to settle. Geographical location and human activities play a role in the distribution of microplastics at each station. The overall process of microplastic transport and sedimentation in river systems is influenced by a variety of factors, including river morphology, hydrodynamics, sediment type and pollution sources in the areas surrounding the stations. Certain river meanders can harbor more microplastics in areas of slow flow, where these particles can sink and settle into the sediment. This is corroborated by the studies which indicate that hydrodynamic conditions such as lower flow velocities can influence the accumulation of microplastics in sediments (Al-Zawaidah et al., 2021). Long meanders can also increase the retention time of particles in river ecosystems, and can interact with organic matter, which can increase microplastics in the sediment (Blettler et al., 2018). In turn, in the areas with faster currents, microplastics may be more easily transported and accumulate less in the sediment. In a broader context, in highly polluted urban and industrialized areas such as the Manila river study, rivers may act as the main conductor transporting plastic waste from land to sea, which can be attributed to rapid development and inefficient waste management (Van et al., 2020). Ultimately, however, a comprehensive understanding of the behavior of microplastics in rivers requires more intensive field research, standardized quantification methods, and accurate mapping of pollution sources to complement existing models and effective management strategies (Al-Zawaidah et al., 2021). Paula Martínez Silva and Mark A. Nanny's study of the Magdalena River also showed an increase in the concentration of microplastic particles in line with the direction of river flow, which could be indicated as a result of processes such as deposition in slow flow zones (Silva and Nanny, 2020). Similar conditions may occur in the Bogowonto River, where meander patterns influence sediment dynamics and the dispersal of pollutants, including microplastics (Fig. 3).

Film and fiber microplastics, the most common forms of microplastics, were seen to dominate in the sediment and water, indicating the great potential hazards faced by aquatic ecosystems

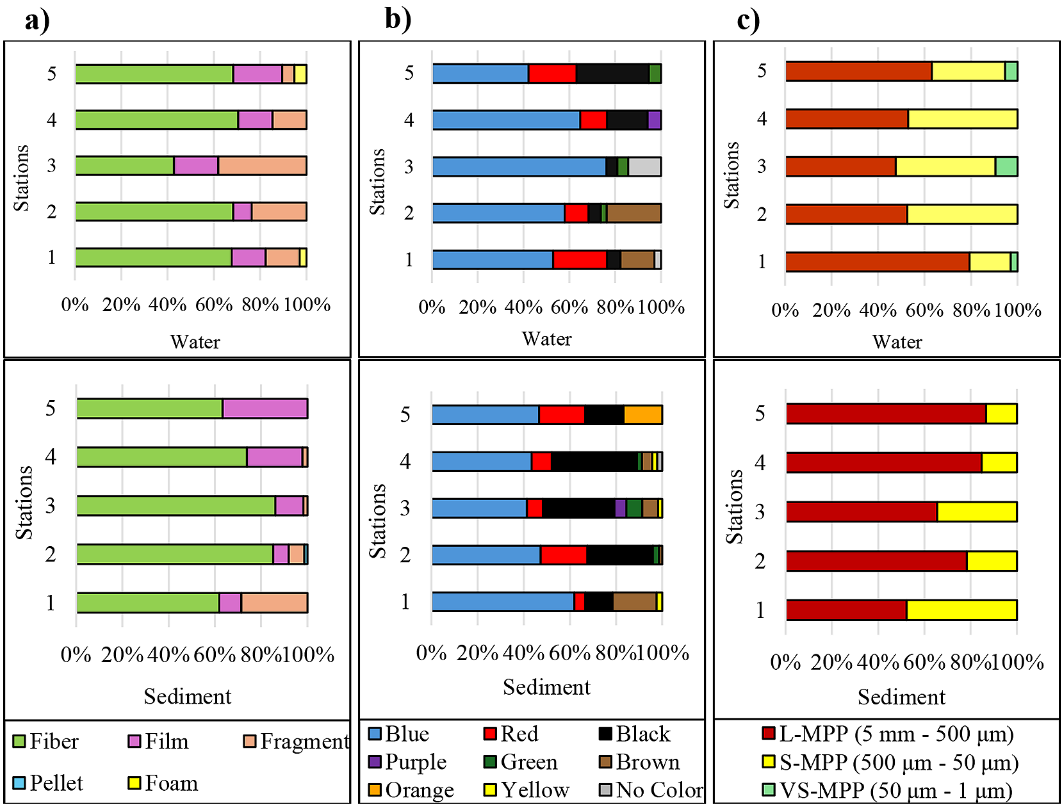

Figure 3. Percentage of microplastic shape (a) color (b) and size (c) of the Bogowonto River, Purworejo District

due to microplastics. Station 2 showed significant levels of microplastics, mainly influenced by fibers and fragments. At station 2, the average concentration of fiber-type microplastics was quite high in the sediment samples, while film and fragments also had a significant contribution. However, notable differences were also observed among the other stations. For example, at station 3, the high contribution of fiber showed a similar pattern but with slightly different levels. Meanwhile, microplastic forms such as foam and pellets, although identified in the samples, tended to have minimal contributions. For example, in station 1, foam and pellets were not found, whereas in stations 2 and 5, they only made a small contribution. This suggests differences in their transport or deposition behavior in aquatic and sediment environments. Fragment and fiber microplastics, as the most common forms of microplastics, were seen to dominate in the sediment and water, indicating the great potential hazards faced by aquatic ecosystems due to microplastics. Station 2 showed significant levels of microplastics, mainly influenced by fibers and fragments. At station 2, the average concentration of fiber-type microplastics was quite high in the sediment samples, while film and fragments also had a significant contribution. However, notable differences were also observed among the other stations. For example, at station 3, the high contribution of fiber showed a similar pattern but with slightly different levels. Meanwhile, microplastic forms such as foam and pellets, although identified in the samples, tended to have low contributions. For example, in station 1, foam and pellets were not found, while in stations 2 and 5, they only made a small contribution. This suggests differences in the transport or deposition behavior of such particles in aquatic and sediment environments.

On the basis of the average color data of microplastics in water and sediment from five sampling stations, the distribution pattern of microplastics shows significant variations at each location. The average color data of microplastics in water and sediment samples showed a complex and diverse pattern at various stations. Station 2 was the station with the highest levels of microplastics, with brown dominating, followed by red and blue. On the other hand, station 5 displayed a fairly low contribution in all colors, indicating a marked difference in the level of microplastic pollution at the site. Red and blue, despite variations in relative contribution at each station, appear to be the consistent colors found in both samples suggesting the presence of widespread microplastics with variable color properties in the environment. In addition, the distribution of microplastics in water and sediment samples can also be reflected by the variation across stations. Stations 1 and 3 showed relatively similar patterns, with fairly even contributions from different colors of microplastics, while station 4 showed more prominent contributions from blue, red, and black colors. Sediment samples revealed complex and diverse patterns at various stations.

Station 2 was the station with the highest level of microplastics, especially in the dominating brown color, followed by red and blue. Station 5 displayed fairly low contributions across all colors, indicating a marked difference in the level of microplastic pollution at the site. Red and blue, despite variations in relative contributions at each station, appear to be the consistent colors found in both samples, suggesting the widespread presence of microplastics with variable color properties in the environment. In addition, the distribution of microplastics in water and sediment samples can also be reflected by spatial variations across stations. Stations 1 and 3 showed relatively similar patterns, with fairly even contributions from different colors of microplastics, while station 4 showed more prominent contributions from blue and black colors.

In water samples, Station 1 showed dominance by L-MPPs with a proportion reaching 79.41%, followed by S-MPPs at 17.65%, and VS-MPPs at 2.94%. Station 2 showed a more even distribution between L-MPPs (52.63%) and S-MPPs (47.37%), while no VS-MPPs was detected. Stations 3 and 4 showed a similar pattern, with a somewhat lower dominance of L-MPPs than Station 1, followed by S-MPPs, with a small number of VS-MPPs. Station 5 displayed a different comparison, with L-MPPs still dominating, but with a lower proportion of S-MPPs and a slight increase in VS-MPPs. Meanwhile, in sediment samples, Station 1 showed an almost even distribution between L-MPPs and S-MPPs, with no detectable VS-MPPs. Station 2 displayed a high dominance of L-MPPs, with a proportion of more than three-quarters of the total microplastics, while Station 3 displayed a lower proportion of L-MPPs, but still a majority of the total microplastics. Stations 4 and 5 displayed a similar trend to station 2, with a very high proportion of L-MPPs.

The percentage size of large microplastic particles tends to be higher in sediment samples, compared to water samples. This can be attributed to differences in environmental dynamics between water and sediment. In water, lighter microplastic particles can be easily carried by currents across stations. Meanwhile, larger and heavier particles settle to the bottom faster and accumulate in sediments (Bayo et al., 2019). This likely illustrates why the sediment samples had a higher percentage of L-MPP. In addition, the sediment may act as a catcher for larger microplastic particles, which sink faster and become trapped there compared to smaller, lighter particles (Fig. 4).

Polyamide, polypropylene, and polystyrene had significant percentages in the water samples, with 41.84%, 42.55%, and 42.26%, respectively. On the other hand, polyethylene and polyethylene terephthalate had lower percentages of 0.71% for each polymer. Polyether ether ketone, polytetrafluoroethylene, and poly (methyl vinyl ether) were also detected in the water samples, although with smaller percentages of 4.96%, 2.13%, and 2.84%, respectively. While sediment samples showed a different distribution, in sediment samples, Polyamide and Polypropylene were the two most dominant polymers, with percentages of 39.69% and 47.08%, respectively. Polyethylene, polystyrene, and poly (ether ether ketone) were also detected in the samples, but with lower percentages of 6.61%, 6.23%, and 0.39%.

The concentration of polymers in microplastic water samples reflects the source of use of

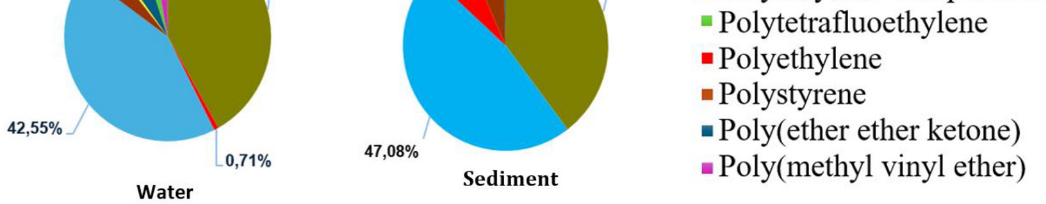

Figure 4. Average microplastic polymer in Bogowonto River, Purworejo Regency

these polymeric materials in daily life, as well as their stability in the aquatic environment. Polyamide, polypropylene, and polystyrene, which were detected at 41.84%, 42.55%, and 42.26%, respectively, are polymers frequently used in textile materials, household appliances, and packaging, indicating their widespread use and possible release into waters due to product degradation. Polyethylene and polyethylene terephthalate, at only 0.71% each, may be less stable in aquatic environments or their sources more controlled, thus contributing less to microplastic pollution (Pathak and Bithel, 2017; Thushari and Senevirathna, 2020; Hossain et al., 2020; Chen et al., 2021; Issac and Kandasubramanian, 2021).

Polyether ether ketone and polytetrafluoroethylene, contributing 4.96% and 2.13% respectively, are engineering polymers with high chemical and thermal stability, which are often used in specialized applications, where they may degrade less into microplastics compared to the wide consumer use of other polymers. Poly (methyl vinyl ether) at 2.84% was also present in the microplastic water samples, possibly due to specific applications in products such as adhesives or release agents.At station 1 in the water samples (Fig. 5), there was a

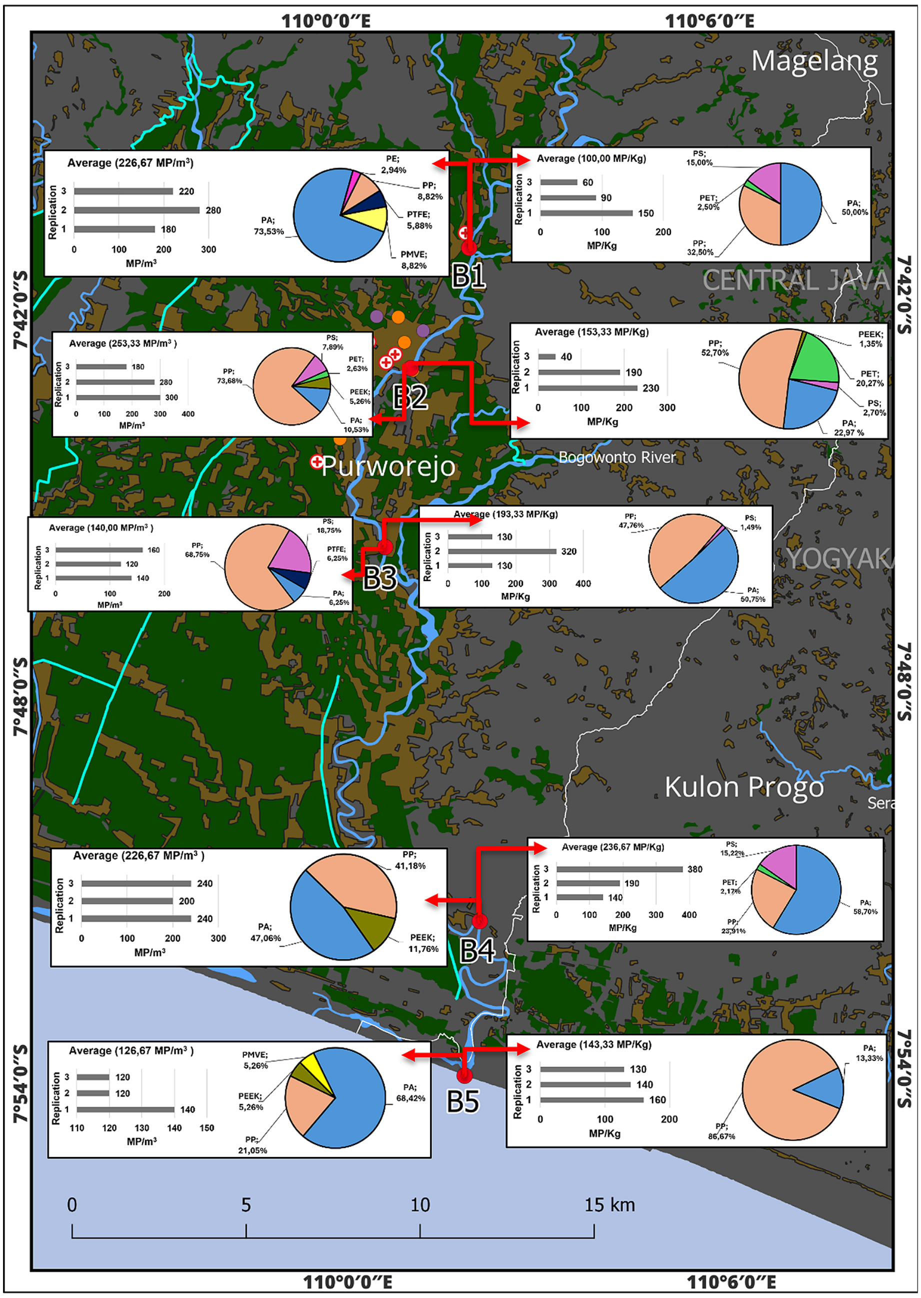

Figure 5. Results of MPs polymer identification in water and sediment

high concentration of polyamide (73.53%), which is generally derived from textile products, such as nylon. Polyethylene which persists for a long time in the environment due to its high chemical resistance was present in 2.94%. Polypropylene (8.82%) and polymethyl vinyl ether (8.82%) are used in various applications, ranging from automotive products to medical devices. Polytetrafluoroethylene (5.88%), better known as Teflon, is used in the products that require high heat resistance. At station 2, the water samples showed a high level of Polypropylene (73.68%), indicating the widespread use of this material which is often utilized to make consumer goods such as food containers and plastic parts. Polyamide was quite low at 10.53%, in contrast to station 1. Polystyrene (7.89%), which is often found in Styrofoam packaging, and PET (2.63%) from plastic bottles, were also found at this station, along with Polyether ether ketone (5.26%), which is commonly used in high temperature and chemical resistant applications. Station 3 had significant amounts of polypropylene (68.75%) and polystyrene (18.75%) in the water samples. This may reflect the heavy use of food containers and disposable packaging. Polyamide (6.25%) and polytetrafluoroethylene (6.25%) were also recorded, representing synthetic fibers and materials resistant to high temperatures, respectively. For station 4, the high proportion of polyamide (47.06%) in the water samples may indicate the presence of a large source of synthetic textiles, such as textile mills, while polypropylene (41.18%) indicates the use of conventional plastics remains high. Polyether ether ketone (11.76%), with its exceptional temperature and chemical resistance, suggests the presence of specialized technical or industrial applications in the region. Entering station 5, it was found that Polyamide was again dominant with 68.42% in the water samples, indicating a large prevalence of textile products or nylon-based materials. Polypropylene, at 21.05%, and similar percentages of polyether ether ketone and polymethyl vinyl ether at 5.26% each signaled the use of these materials in different applications, ranging from furniture manufacturing to engineering plastics.

In the sediment samples (Fig. 5) station 1 was seen to have polyamide and polypropylene as the majority, 50.00% and 32.50% respectively, which could come from textile waste and plastic packaging. Polyethylene terephthalate with 2.50% and polystyrene with 15.00% were also present, where PET is commonly used in beverage bottles and food packaging, while polystyrene is often found in electronic product packaging and photo frames. Station 2 in the sediment samples displayed polypropylene as the majority (52.70%) with polyamide at 22.97% which was lower than the water samples, hinting at lesser degradation under soil conditions. PET was recorded at 20.27%, indicating buried plastic bottle waste, while polystyrene (2.70%) and polyether ether ketone (1.35%) were in lower amounts indicating more limited use or faster degradation in sediment conditions. For station 3 in the sediment samples, polyamide (50.75%) and polypropylene (23.91%) dominated, with polystyrene (15.22%) again indicating the presence of consumer and packaging waste. The sediment conditions that may be more anaerobic or have less microbial activity may slow down polymer degradation. Sediment samples at station 4 were similar to station 3. Polyamide at 58.70% was the most abundant polymer, indicating a large accumulation of waste associated with nylon or similar materials. Polypropylene was present at 23.91%, which is consistent with its presence as a material often used in various products. Polyethylene terephthalate (2.17%) and polystyrene (15.22%), both of which are common in consumer packaging, were also found. Finally, station 5 in the sediment samples showed an overwhelming dominance of polypropylene (86.67%), which could indicate a location close to a plastic processing industry or a high domestic waste disposal site for polypropylene-based products. Polyamide only amounted to 13.33%, indicating a decrease in its presence compared to the water samples from the same location.

CONCLUSIONS

The preliminary findings indicate the presence of microplastic particles scattered at various locations along the Bogowonto River, suggesting a potential threat to the river ecosystem's health. The Bogowonto River in Purworejo Regency already contains microplastic pollutants. The abundance of microplastics in the river is influenced by waste originating from Purworejo City, including hospital, tourism, and residential waste. The highest abundance in water samples is observed in urban areas, while sediment samples show the highest abundance downstream. The lowest abundance in water samples is found in the estuary area, while sediment samples have the lowest abundance upstream. The river meander pattern between stations 3 and 4 creates various hydrological conditions that affect microplastic abundance. The characteristics of microplastics in water include blue fiber shapes, LMPP size, and Polypropylene and Polyamide polymer types as the most dominant, followed by blue film shapes, LMPP size, and Polyamide polymer type. Blue-colored, LMPP-sized Polypropylene fragments were found at all water sampling stations. The smallest percentage included blue-colored foam, LMPP-sized polyethylene polymer type. In sediments, microplastics with blue fiber shapes, LMPP size, and polypropylene polymer type dominated at all stations, followed by blue-colored film, LMPP size, and polypropylene polymer type. Blue-colored, LMPP-sized polypropylene fragments were also found at all sediment sampling stations, while blue-colored pellet forms, LMPP size, and polyethylene terephthalate polymer type were found in smaller percentages. Despite limitations in the data obtained, the methods employed in this study offer a more accurate interpretation of ecological hazards. Future research should aim to collect additional information and design more detailed spatio-temporal models, considering seasonality and impacts on biota, to improve the accuracy of risk predictions. Essentially, this work advances the approaches to assessing ecosystem hazards and enhances the understanding of microplastic contamination in riverine habitats, such as those found in the Bogowonto River.

Acknowledgements

This research fis unded by Rekognisi Tugas Akhir (RTA) Universitas Gadjah Mada Tahun 2024 (5286/UN1.P1/PT.01.03/2024). This research is part of projects titled “Korea-Indonesia Marine Technology Cooperation Research Center (20220512)” and “Establishment of the Integrated Ocean Fisheries Technology Training Center and Enhancing Capacity Building in Indonesia (PG54000)” which are funded by the Ministry of Oceans and Fisheries, Korea.

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