Riwayat Korespondensi Karya Ilmiah Syarat Lektor Kepala

Penulis Pertama : Aris Ismanto

Koresponden Author : Tony Hadibarata

Judul Artikel : First evidence of microplastics in the water and sediment of Surakarta city river basin, Indonesia

Terbit (Issue) : Volume 196 November 2023

Nama Jurnal : Marine Pollution Bulletin

Alamat Situs artikel : https://www.sciencedirect.com/science/article/pii/S0025326X23011128

Terindeks Scopus : Q1 (Aquatic Science)

SJR : 1.45

No	Aktivitas Korespondensi	Waktu	Halaman
1.	Submision	11 September 2023	
2.	Cover Letter		
3.	Response to Reviewer		
4.	Manuskrip awal		
4.	Revised Manuskrip	11 Oktober 2023	
5.	Accepted	14 Oktober 2023	
6.	Available Online		
7	Published Paper		

View Submission View Decision Letter Publishing Options Send E-mail	MPB-D-23-02043	A novel report on the occurrence of microplastics in Pekalongan River Estuary, Java Island, Indonesia	18 Aug 2023	16 Sep 2023	Completed - Accept	16 Sep 2023	Accept
View Submission View Decision Letter Publishing Options Send E-mail	MPB-D-23-02260	First evidence of microplastics in the water and sediment of Surakarta city river basin, Indonesia	11 Sep 2023	14 Oct 2023	Completed - Accept	14 Oct 2023	Accept

https://doi.org/10.1016/j.marpolbul.2023.115677
Received 11 September 2023; Received in revised form 11 October 2023; Accepted 14 October 2023

View Letter

Close

Date: 14 Oct 2023
To: "Tony Hadibarata" hadibarata@curtin.edu.my
From: "Marine Pollution Bulletin" support@elsevier.com
Subject: Your Submission - MPB-D-23-02260R2

Ms. Ref. No.: MPB-D-23-02260R2
Title: First evidence of microplastics in the water and sediment of Surakarta city river basin, Indonesia
Marine Pollution Bulletin

Dear Professor Tony Hadibarata,

I refer to your manuscript entitled "First evidence of microplastics in the water and sediment of Surakarta city river basin, Indonesia", which you resubmitted to me recently for consideration in the Baseline section of the journal Marine Pollution Bulletin.

I am pleased to inform you that the manuscript has been found to be acceptable for publication, requiring relatively few further amendments. I have accepted the manuscript, and have sent it to the publishers for the preparation of page proofs. You will receive these from the publishers (Elsevier Sciences in Exeter, UK) within a couple of months (in electronic format), along with a copyright form. At that time, you should check the proofs carefully and return them without delay (and with the completed copyright form) to Elsevier.

Thank you for submitting your work to Marine Pollution Bulletin.

Comments from the Editor and Reviewers can be found below.

Please note that this journal offers a new, free service called AudioSlides: brief, webcast-style presentations that are shown next to published articles on ScienceDirect (see also http://www.elsevier.com/audioslides). If your paper is accepted for publication, you will automatically receive an invitation to create an AudioSlides presentation.

Marine Pollution Bulletin features the Interactive Plot Viewer, see: http://www.elsevier.com/interactiveplots. Interactive Plots provide easy access to the data behind plots. To include one with your article, please prepare a .csv file with your plot data and test it online at http://authortools.elsevier.com/interactiveplots/verification before submission as supplementary material.

Thank you for submitting your work to this journal.

We encourage authors of original research papers to share the research objects – including raw data, methods, protocols, software, hardware and other outputs – associated with their paper. More information on how our open access Research Elements journals can help you do this is available at https://www.elsevier.com/authors/tools-and-resources/research-elements-journals?dgcid=ec_em_research_elements_email.

With kind regards,

Paul Shin
Baseline Editor
Marine Pollution Bulletin

PLEASE DO NOT REPLY TO THIS MESSAGE

Comments from the Editors and Reviewers:

%ATTACH_FOR_REVIEWER_DEEP_LINK INSTRUCTIONS%

This journal uses the Elsevier Article Transfer Service. This means that if an editor feels your manuscript is more suitable for an alternative journal, then you might be asked to consider transferring the manuscript to such a journal. The recommendation might be provided by a Journal Editor, a dedicated Scientific Managing Editor, a tool assisted recommendation, or a combination. For more details see the journal guide for authors.

Marine Pollution Bulletin 196 (2023) 115677

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Baseline

First evidence of microplastics in the water and sediment of Surakarta city river basin, Indonesia

Aris Ismanto [a], Tony Hadibarata [a,b,*], Denny Nugroho Sugianto [a], Muhammad Zainuri [a], Risky Ayu Kristanti [c], Ulung Jantama Wisha [d], Undang Hernawan [c], Malya Asoka Anindita [a], Audrey Primus Gonsilou [e], Mohamed Soliman Elshikh [f], Amal M. Al-Mohaimeed [g], Arshad Mehmood Abbasi [h,i]

[a] Department of Oceanography, Faculty of Fisheries and Marine Science, Diponegoro University, Semarang 50275, Indonesia
[b] Environmental Engineering Program, Faculty of Engineering and Science, Curtin University Malaysia, CDT 250 Miri, Malaysia
[c] Research Center for Oceanography, National Research Center for Oceanography, Jakarta 14430, Indonesia
[d] Research Institute for Coastal Resources and Vulnerability, Ministry of Marine Affairs and Fisheries, Jl. Raya Padang-Painan KM. 16, Bungus, Padang – Sumatera, Barat 25245, Indonesia
[e] Department of Water and Environmental Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia
[f] Department of Botany and Microbiology, College of Science, King Saud University, Riyadh 11451, Saudi Arabia
[g] Department of Chemistry, College of Science, King Saud University, P.O. Box 22452, Riyadh 11495, Saudi Arabia
[h] Department of Environmental Sciences, COMSATS University Islamabad, Abbottabad Campus, 22060, Pakistan
[i] University of Gastronomic Sciences, Piazza Vittorio Emanuele II, 9, 12042 Pollenzo, CN, Italy

ARTICLE INFO

Keywords:
Microplastics
Surakarta river basin
Sediment
River water

ABSTRACT

The main aim of this study was to assess the presence of microplastics in the water and sediments of the Surakarta city river basin in Indonesia. In order to accurately reflect the river basin, a deliberate selection process was employed to choose three separate sampling locations and twelve sampling points. The results of the study revealed that fragments and fibers were the primary types of microplastics seen in both water and sediment samples. Furthermore, a considerable percentage of microplastics, comprising 53.8 % of the total, had dimensions below 1 mm. Moreover, the prevailing hues identified in the water samples were blue and black, comprising 45.1 % of the overall composition. In contrast, same color categories accounted for 23.3 % of the microplastics found in the soil samples. The analysis of microplastic polymers was carried out utilizing ATR–FTIR spectroscopy, which yielded the identification of various types including polystyrene, silicone polymer, polyester, and polyamide.

1. Introduction

Water pollution from human activities is a growing environmental concern, with industrial and agricultural practices releasing various harmful pollutants, including emerging compounds, heavy metals, and microplastics (MPs) (Bashir et al., 2020; Karing et al., 2023; Hadibarata et al., 2011; Hadibarata et al., 2012; Lee et al., 2022; New et al., 2023; Khori et al., 2018). Among these pollutants, plastic waste accumulation has become a global issue due to its production, disposal, and human behaviors. MPs, in particular, have gained significant attention due to their widespread presence and adverse effects on water ecosystems, agriculture, and human health (Tang, 2022). These minuscule particles, varying in size, shape, color, and polymer composition, are found in oceans, rivers, lakes, mangroves, air, snow, polar sea ice, and even within aquatic organisms. They pose a substantial threat to marine life, often being mistaken for food sources. Recent investigations have detected MPs in various seafood items, including fish, squid, scallops, crabs, shrimp, and mussels Despite ongoing research, the full ecological and toxicological impact of MPs remains unclear, making their global presence a cause for concern (Lim et al., 2023; Zhang et al., 2021).

Indonesia, a country located in Southeast Asia, is known to be one of the largest producers of plastic waste in the region. The country generates a massive amount of waste due to its high population density and rapid economic growth (Ng et al., 2023). Surakarta, located on Java, the

* Corresponding author at: Environmental Engineering Program, Faculty of Engineering and Science, Curtin University Malaysia, CDT 250 Miri, Malaysia.
E-mail address: hadibarata@curtin.edu.my (T. Hadibarata).

https://doi.org/10.1016/j.marpolbul.2023.115677
Received 11 September 2023; Received in revised form 11 October 2023; Accepted 14 October 2023

world's most populous island, is a significant city with an intricate network of rivers. Among these waterways, the Solo River stands out as the island's longest, stretching approximately 540 km from its source in the Lawu Mountains to its mouth in the Java Sea. The Solo River spanning multiple provinces in Java, including Central Java, East Java, and Yogyakarta Special Region. This river plays a vital role in providing water for irrigation, domestic use, and industrial needs to millions of residents in the surrounding regions. With an annual discharge of approximately 4900 million m^3, the Solo River ranks among the region's most significant water resources (Veiga et al., 2023; Yuen et al., 2023). Despite its importance, the Solo River, like many rivers worldwide, faces a pressing pollution challenge due to the increasing inflow of waste from various sources, including industrial effluents, agricultural runoff, domestic garbage, and plastic waste. This plastic waste was not just from

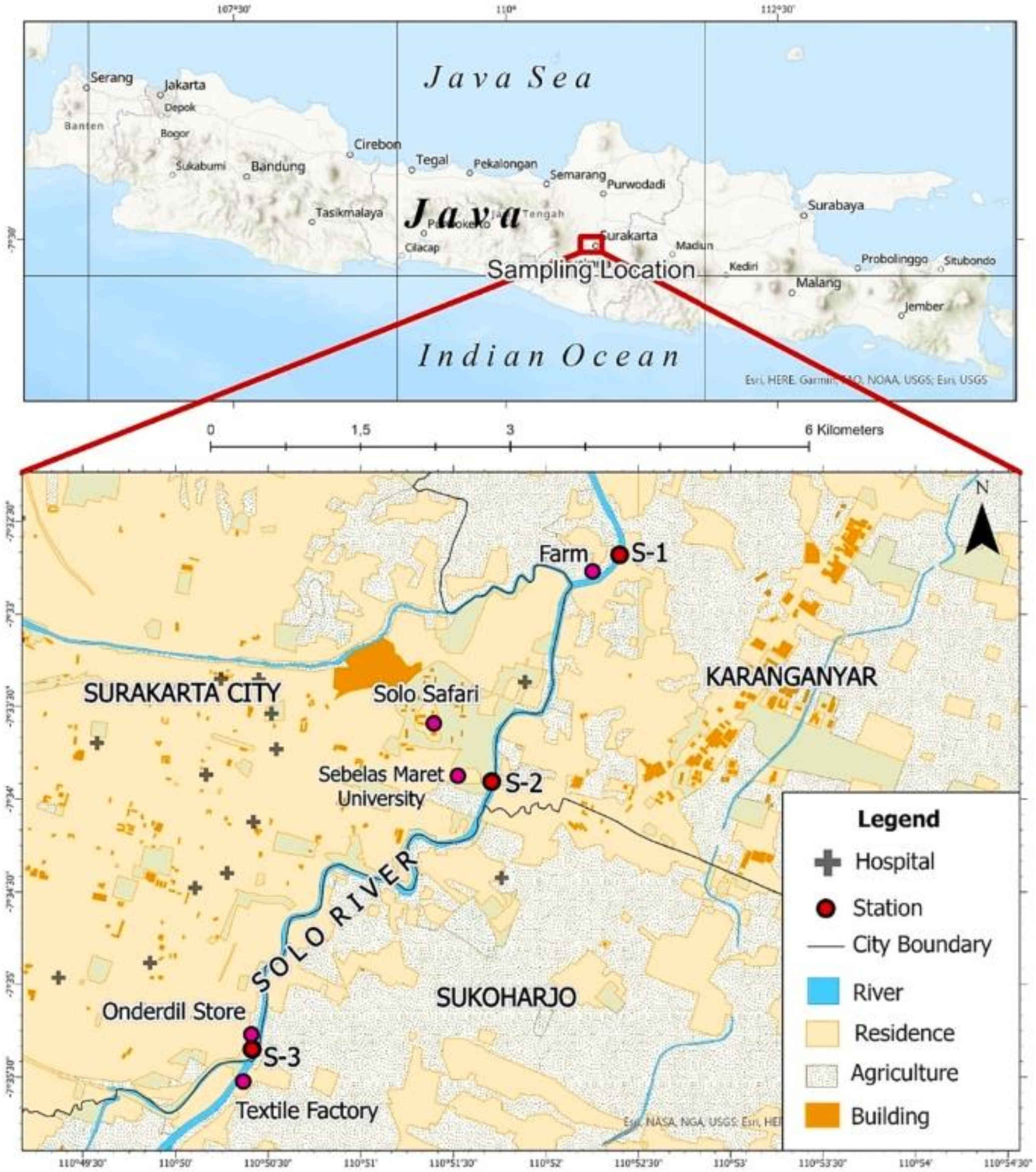

Fig. 1. Map of sampling location in Surakarta city river basin.

the local sources but also from the long-distance sources carried away by the Solo River that end in the eastern water of Java Sea (Yona et al., 2019). However, there is a notable lack of comprehensive studies addressing the presence and distribution of MPs within the Solo River. This knowledge gap is concerning, given the well-documented detrimental effects of MPs on ecosystems and the potential risks they pose to human health (Juwana et al., 2022; Veiga et al., 2023). Therefore, it is imperative to conduct research aimed at assessing the prevalence of MPs in both the water and sediments of the Surakarta city river basin. Such research endeavors are crucial for gaining deeper insights into the extent of microplastic pollution in the river and its potential repercussions for the ecosystem and human well-being.

Sampling MPs in aquatic environments was a crucial step in understanding their presence and distribution. The methods used for collecting water and sediment samples significantly impacted result accuracy. Filtration was a common technique for separating MPs from water samples, with sieve pore or mesh size influencing detection. In our study, we adopted specific procedures to obtain representative water and sediment samples (Fig. 1). At each sampling location, we collected water and sediment from four points, with two points located on each riverbank at a distance of 200 m. Two specimens of water and sediment were collected from each sampling point. The sample collection was conducted during both wet and dry seasons. For water samples, we collected 3 l of surface water (0–20 cm depth) using stainless-steel buckets. Regarding sediment samples, we collected approximately 400 g from the riverbank using an Ekman Grab sampler. To reduce sample volume, a larger sieve was used. Subsequently, we employed density separation and filtration techniques on the supernatant, with a range of pore or mesh sizes (0.3 mm to 200 mm) utilized in different studies. Various techniques were employed to analyze MPs from water and sediment samples. Wet peroxide oxidation method catalyzed by a 0.05 M Iron (II) solution was used to eliminate interfering organic materials (Masura et al., 2015). Sodium chloride salt facilitated density separation to remove inorganic matter. After drying, samples were observed using an SMZ745T Nikon Stereo Microscope with a camera. An Agilent Fourier Transform Infrared Spectroscopy equipment, with a spectral range of 700–4000 cm^{-1}, was used to examine functional groups in microplastic particles. Microplastic abundance in water and sediment samples was quantified as the mean $\pm$ standard deviation based on two data points from each site. Quantification was expressed in particle/l for water and particle/kg for sediment (Campanale et al., 2020). In this study, descriptive statistical methods were used to analyze the abundance value of MPs.

The Surakarta city river basin exhibited a notable presence of microplastic pollution, which had adverse effects on both its aquatic environment and sediment composition. The present study concentrated on three distinct sampling locations and illustrated the mean occurrence of MPs in Fig. 2. The selection of sampling location is considered according to the assumed source of MPs around the area. Station 1 represents an area of farm, residence, and agriculture. Station 2 represents the university, building, and residence. Station 3 represents the store and factory. The concentration of MPs in the water samples varied between 25.50 $\pm$ 0.50 and 52.20 $\pm$ 1.10 particles per liter, whereas in the sediment samples, it ranged from 0.55 $\pm$ 0.03 to 1.10 $\pm$ 0.04 particles per kilogram. Significantly, the presence of MPs in sediment samples was found to be higher than in water samples, which is consistent with previous studies that have emphasized the heightened levels of MPs in sediment along riverbanks as compared to river water. The notably higher concentrations of MPs in sediment samples in comparison to water samples can be attributed to various factors. Initially, MPs, owing to their lightweight nature, tend to float on the water's surface, but as time elapses, they gradually settle and accumulate within the sediment due to their small size and lower density. The sediment effectively acts as a sink for MPs, amassing them over time. Additionally, MPs can adhere to particles present in the water column, such as organic matter or minerals. These particles, once they settle, become integrated into the sediment, carrying MPs along with them. Furthermore, sedimentation processes like flocculation and coagulation can expedite the aggregation and settling of MPs within sediment as opposed to the water column (Liong et al., 2021).

The change in microplastic abundance between the two sample types can be attributed to multiple factors, such as rainwater runoff, microplastic sediment deposition, and microplastic density. The main sources of MPs in riverbank sediment are household sewage and industrial waste. It was shown that sewage treatment plants have limited effectiveness in removing MPs, leading to their accumulation in sewage sludge. The findings of recent research suggest that the presence of MPs in riverbank sediment can be attributed to various sources, among which sewage sludge has been identified as a prominent contributor (Liu et al., 2021). The act of disposing sewage sludge into the environment facilitates the interaction between microplastic particles and soil organisms, resulting in their subsequent transportation into riverbank sediment.

The studies conducted by Ng et al. (2023) and Ni'am et al. (2022) have revealed that the abundance of microplastic particles in sediment

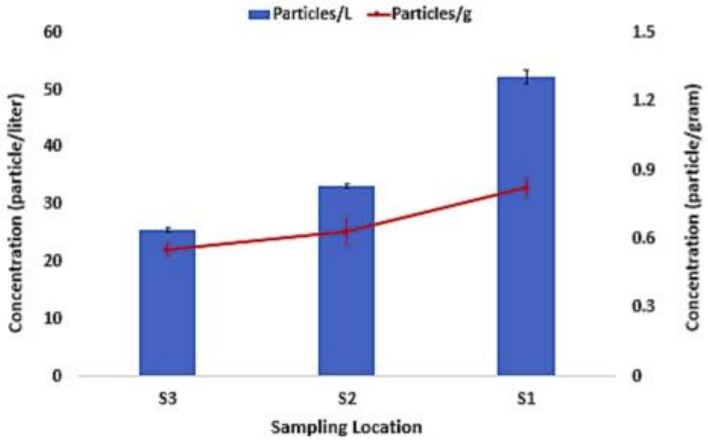

Fig. 2. The abundance of MPs in river water and sediment of Surakarta city river basin.

along riverbanks is influenced by downstream runoff events. Inadequate waste management procedures result in the significant buildup of plastic debris within terrestrial ecosystems, presenting in the shape of diverse objects such plastic bottles, woven bags, and containers. Plastic waste infiltrates freshwater ecosystems and through a sequence of events that ultimately result in fragmentation. The aforementioned processes encompass the exposure to solar radiation, the interaction with soil microbes, and the engagement with terrestrial creatures. The fragmentation of plastic materials into smaller particles is observed as a consequence of the aforementioned processes. The phenomenon of soil erosion that takes place during rainfall events has been shown to cause the release of MPs into river water, which subsequently leads to their accumulation in sediment. This observation is supported by the investigations undertaken by Alam et al. (2019) and Ni'am et al. (2022). The aforementioned findings underscore the importance of addressing waste management issues and implementing effective strategies to reduce the influx of plastic debris into freshwater ecosystems. Consequently, this will aid in mitigating the buildup of MPs in sediment along the banks of rivers. The results of this study underscore the significance of having efficient waste management and sewage disposal protocols (Rayhan et al., 2022). Table 1 provides a complete summary of prior research efforts that have investigated the occurrence of microplastic pollutants in freshwater ecosystems, including the present study.

MPs consist of small plastic particles categorized by physical attributes, including type, size, and color. They primarily fall into five categories: fibers, pellets, fragments, films, and foams. Their distribution varies in the environment, with fragments being the most commonly found type (53.5 %) in both water and sediment samples. Fibers accounted for 18.5 %, pellets for 12.1 %, films for 9.23 %, and foams for 6.7 %, as shown in Fig. 3A and B. MPs form due to various factors like the initial particle composition, plastic waste degradation, and exposure duration to the environment. Different types of MPs tend to dominate in different locations. For example, fragments were prevalent in the Ravi River, Pakistan (Sin et al., 2023), while the Can Gio Sea, Vietnam, saw fragment MPs as the dominant type (Nguyen et al., 2022). In this study, the dominant type of MPs is fragments. MPs have diverse sources depending on their type. Fragment-type MPs typically result from plastic waste degradation or fragmentation in urban, industrial, and commercial areas. Fiber-type MPs often originate from textile laundry washing, domestic sewage, and fishing activities using nets and gear. Pellet-type MPs are produced by cleansing agents, personal care products, and detergents, while foam-type MPs come from damaged styrofoam used in food packaging (Kadac-Czapska et al., 2023). Foam-type MPs were observed to be less abundant in water and sediment samples due to their small size. Importantly, the percentage of microplastic types varied between water and sediment samples. Fibers and pellets were more prevalent in water samples, whereas fragments and foam types were more abundant in sediment samples. This difference is attributed to the lower density of fibers and pellets, causing them to float on the water surface (Campanale et al., 2020).

MPs particles were categorized into five distinct size ranges, namely: less than 1 mm, 1 to 2 mm, 2 to 3 mm, 3 to 4 mm, and 4 to 5 mm. The water and sediment samples revealed that particles smaller than 1 mm had the largest proportion of MPs, accounting for 53.8 % of the total. Subsequently, there were particles of varying sizes, specifically measuring 1–2 mm (27.8 %), 2–3 mm (8 %), 3–4 mm (6.1 %), and 4–5 mm (4.2 %), as illustrated in Fig. 3C and D. These findings are consistent with prior study that also emphasized the prevalence of MPs measuring less than 1 mm. As exemplified by the findings of Park et al. (2020), it was observed that more than 90 % of MPs present in the Han River of South Korea exhibited a size less than 1 mm. Similarly, investigations conducted by Li et al. (2021) on sediment samples collected from the Pearl River estuary in China revealed that a range of 53.5 % to 73.9 % of MPs were found to possess a size smaller than 0.5 mm. The occurrence of diminutive MPs can be ascribed to the progressive deterioration of bigger plastic refuse into smaller fragments over time and under the influence of ultraviolet radiation, leading to the fragmentation of MPs into smaller dimensions (Li et al., 2022). According to Ma et al. (2019), MPs of smaller size exhibit a greater surface area, hence increasing their ability to absorb contaminants. Additionally, smaller MPs have a higher vulnerability to be transported through wind and water currents, whereas larger and more compact MPs have the tendency to either settle on the riverbed or remain suspended (Kumar et al., 2021). Furthermore, the presence of diminutive MPs presents a substantial peril to marine animals, since they have the potential to be consumed or ensnared by these organisms. The high percentage of MPs below 1 mm in size will cause more harfmful condition to river ecosystem.

MPs in both water and sediment samples were categorized into six color groups: white, green, red, blue, black, and transparent. Among these colors, blue MPs were the most prevalent, constituting 45.1 % of the total, closely followed by black MPs at 29.3 %. The remaining colors each represented less than 10 % of the total MPs. Images showcasing the various colors of MPs found in the river basin are presented in Fig. 3E and F. Similar variations in color were observed in other rivers such as the Saigon River, Pearl River, and Tebrau River in Malaysia, where colors like yellow, orange, and brown were noted. Specifically, the Saigon River exhibited a prevalence of white (47.3 %) and transparent (12.3 %) MPs. Seasonal differences in microplastic color composition were observed in the Pearl River. During the rainy season, gray and green MPs constituted 43.7 % and 21.5 %, respectively, while in the dry season, gray and white MPs dominated, making up 42.4 % and 31.4 % of the total, respectively. Additionally, microplastic color can offer insights

Table 1
Various reports on MPs pollutants in river water worldwide.

Location	Sample	Sample method	Identification	Abundance	References
Gresik, Indonesia	Sediment	Ekman grab sampler	microscope	896.96 ± 160.28 particles/kg	Yona et al., 2019
Cisadane River, Indonesia	Surface Water	Stainless-steel bucket	Nikon Eclipse Ni—U microscope	13.33 and 113.33 particles/m^3	Sulistyowati et al., 2022
Citarum River, Indonesia	Surface Water	Manta trawl	Nikon Eclipse Ni - U microscope	8.47 ± 2.93 particles/m^3	Cordova et al., 2022
Sago River, Indonesia	Sediment	Ekman grab sampler	microscope	14,000 particles per kg of dry sediment	Priyambada et al., 2022
Kemena River, Malaysia	Water and sediment	Stainless steel bucket and Ekman grab sampler	Nikon SMZ745T stereomicroscope	60–128 particles/l (water), 21–40 particles/kg (sediment)	Karing et al., 2023
Niah River, Malaysia	Water and sediment	Water and sediment	Stainless steel bucket and Ekman grab sampler	46–76 particles/l (water), 45–125 particles/kg (sediment)	Karing et al., 2023
Chao Phraya River, Thailand	Water and sediment	Manta trawl net & Van Veen grab sampler	Optical microscope & ATR-FTIR	48 ± 8 items/m3 and 39 ± 14 items/kg	Ta and Babel, 2020
Zhangjiang River, China	Water	Manta trawl net	Microscope & micro-Raman spectroscopic	50 to 725 items/m^3	Pan et al., 2020
Surakarta city river basin, Indonesia	Water and sediment	Stainless steel bucket and Ekman grab sampler	Stereo Microscope equipped with camera & ATR-FTIR	25.5 ± 0.5 to 52.2 ± 1.1 particles/l (water) and 0.55 ± 0.03 to 1.1 ± 0.04 particles/g (sediment)	This study

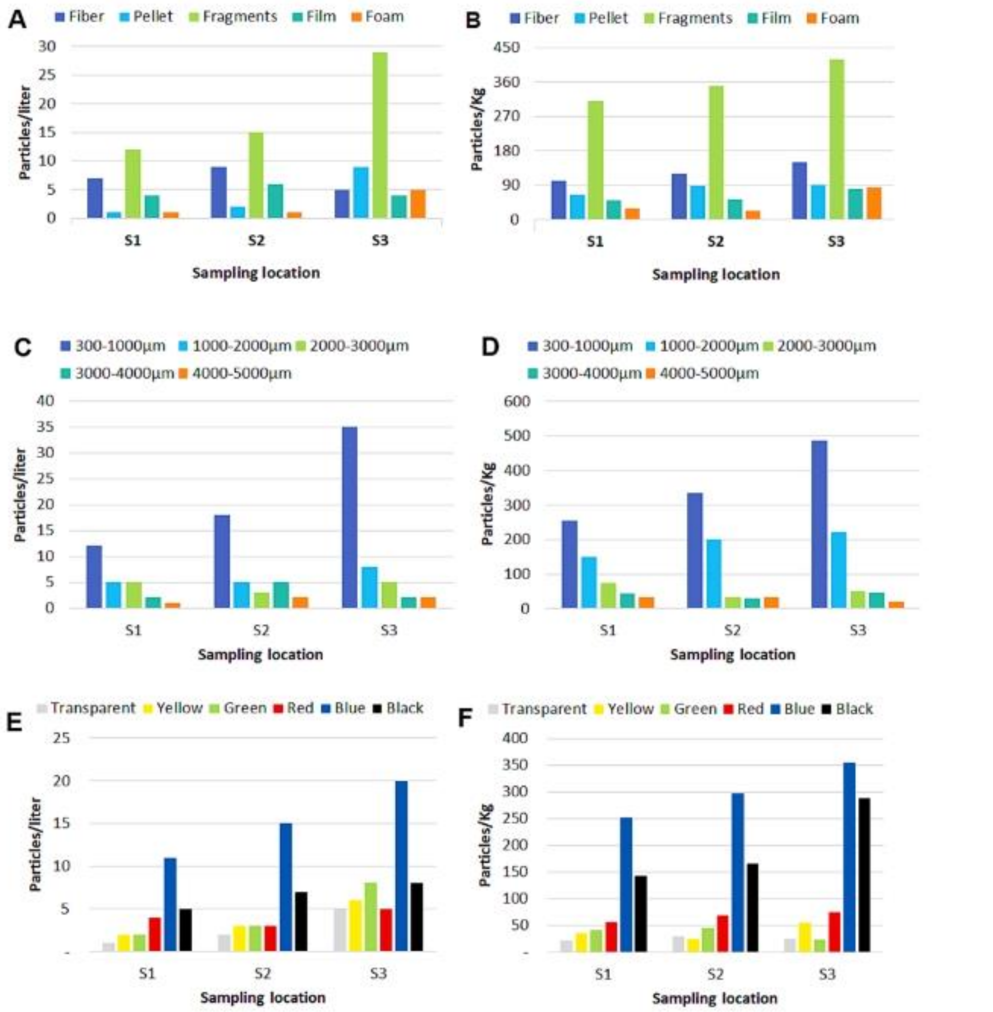

Fig. 3. MPs occurrence in Surakarta river basin: Type of MPs found in river water (A) and sediment (B); Size of MPs found in river water (C) and sediment (D); Colour of MPs found in river water (e) and sediment (f).

into their sources. Transparent MPs typically originate from plastics with shorter lifespans, while colored MPs often derive from packaging materials, waste, and cosmetic products with longer lifespans (Yu et al., 2018).

The microplastic particles' polymer composition underwent analysis using ATR–FTIR, and Fig. 4 presents the obtained results. The identified polymers predominantly included polystyrene (PS), silicone polymer, polyester (PES), and polyamide (PA). Each polymer exhibited characteristic absorption bands in the ATR–FTIR spectra of the microplastic particles. For polystyrene (PS), absorption bands were observed at specific wavenumbers, namely 3388 cm^{-1} (aromatic ring stretching), 1638 cm^{-1}, 1578 cm^{-1} (aromatic ring stretching), 1485 cm^{-1} (aromatic ring stretching), 1407 cm^{-1} (CH_2 bending), 1239 cm^{-1}, 1150 cm^{-1}, 1105 cm^{-1}, 1012 cm^{-1} (aromatic C—H bending), and 699 cm^{-1} (aromatic C—H). The primary absorption bands for polyester (PES) were observed at 1638 cm^{-1} (C═O stretching), 1485 cm^{-1}, 1152 cm^{-1}, and 1105 cm^{-1} (C—O stretching), along with 719 cm^{-1} (aromatic C—H out of plane bending). Polyamide (PA) was distinguished by peaks at 2920 cm^{-1} (aromatic C—H stretch), 1483 cm^{-1} (N—H bend, C—N stretch), 1148 cm^{-1} (CH_2 bend), and 697 cm^{-1} (N—H bend, C═O bend). Silicon polymer exhibited a prominent absorption peak at 2918 cm^{-1} (CH_3 asymmetric stretch), 1487 cm^{-1} (C—H bend), 1405 cm^{-1}, 1317 cm^{-1} (Si–alkoxy groups), and 1071–1012 cm^{-1} (Disilymethylene band). The investigation conducted by Wang et al. (2019) revealed that sediments predominantly contained PES and PS polymers. The occurrence of PES and PS in sedimentary environments can be ascribed to a multitude of causes. First and foremost, polyethersulfone (PES) is widely utilized in the fashion sector, which is recognized for its frequent rotation of

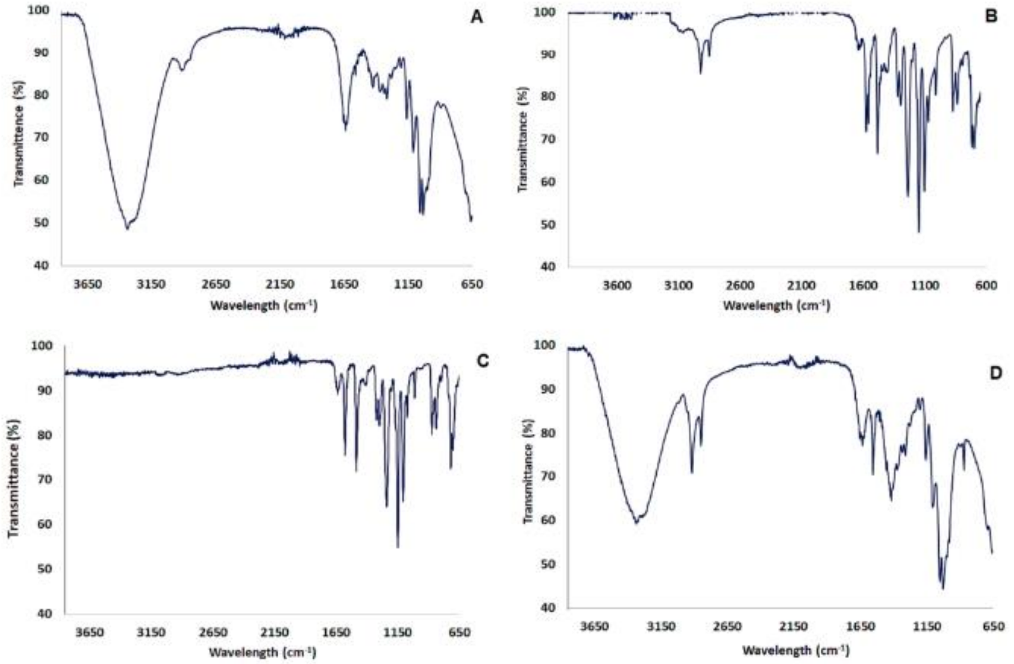

Fig. 4. FTIR spectra for analysis of water and sediments: Polystyrene (A), Silicone polymer (B), Polyester (C), Polyamide (D).

apparel products (Palacios-Mateo et al., 2021). The continuous manufacturing and disposal of garments composed of polyethylene terephthalate (PES) contribute to a substantial accumulation of waste that is ultimately deposited in landfills and subsequently enters aquatic ecosystems, including rivers and seas. Additionally, polystyrene (PS) is widely utilized in the production of various disposable products such as packaging materials, single-use plastic cups, and food containers. Over the course of time, these objects have a tendency to disintegrate into smaller bits, hence resulting in the pollution of water bodies. The persistence of polystyrene (PS) in the environment and its tendency to accumulate in sedimentary deposits have been attributed to its non-biodegradable properties (Tokiwa et al., 2009). In addition, the buoyancy of PES and PS, resulting from their low density, renders them prone to waterborne transportation facilitated by currents (Kumar et al., 2021). Hence, it is crucial to implement strategies aimed at diminishing the utilization of these substances and advocating for environmentally sustainable alternatives in order to address the escalating contamination of aquatic habitats.

To address the rising issue of plastic pollution, diverse efforts have been made, including enhancements in waste management and wastewater treatment, as well as innovative approaches to design and development. Moreover, there has been the implementation of regulations concerning single-use plastics and the industrial utilization of microbeads, which encompass measures like bans, phasedowns, or limitations on their use (Miranda et al., 2020). The implementation of plastic management in Surakarta is outlined in Surakarta City Regional Regulation Number 3 of 2010 concerning Waste Management to Realize the Zero Waste Concept in Surakarta City. MPs contamination is influenced by a multitude of factors, some of which lead to seasonal variations in their prevalence. One significant contributor to these fluctuations is rainfall. During rainy seasons, precipitation can wash MPs from urban streets, landfills, and other sources into rivers and oceans, increasing their concentration in the aquatic environment (Alam et al., 2019; Kumar et al., 2021).

CRediT authorship contribution statement

Aris Ismanto: Investigation, Data curation, Writing-original draft, Supervision, Funding acquisition. **Tony Hadibarata**: Supervision, Methodology, Writing-original draft, Resources. **Denny Nugroho Sugianto**: Writing - Review & Editing. **Muhammad Zainuri**: Writing - Review & Editing. **Risky Ayu Kristanti**: Investigation, Data curation. **Ulung Jantama Wisha**: Investigation, Data curation. **Undang Hernawan**: Methodology, Resources. **Malya Asoka Anindita**: Investigation, Data curation. **Audrey Primus Gonsilou**: Writing-original draft & Editing. **Mohamed Soliman Elshikh**: Writing - Review & Editing. **Amal M. Al-Mohaimeed**: Methodology, Visualization. **Arshad Mehmood Abbasi**: Methodology, Visualization.

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.

Data availability

Data will be made available on request.

Acknowledgment

This work was supported by the Universitas Diponegoro World Class University-Adjunct Professor Program 2023 Number: 765/UN7.J7/DK/ 2023 and Staff Exchange Program 2023 Number: 125/UN7.A/HK/X/

2023 collaboration with Curtin University Malaysia. The authors also extend their appreciation to the Researchers supporting project number (RSP2023R247) King Saud University, Riyadh, Saudi Arabia. Collaboration from the National Research and Innovation Agency (BRIN) Indonesia and Universiti Teknologi Malaysia is highly appreciated.

References

Alam, F.C., Sembiring, E., Muntalif, B.S., Suendo, V., 2019. Microplastic distribution in surface water and sediment river around slum and industrial area (case study: Ciwalengke River, Majalaya district, Indonesia). Chemosphere 224, 637–645. https://doi.org/10.1016/j.chemo- sphere.2019.02.188.

Bashir, I., Lone, F.A., Bhat, R.A., Mir, S.A., Dar, Z.A., Dar, S.A., 2020. Concerns and threats of contamination on aquatic ccosystems. In: Bioremediation and Biotechnology. Springer International Publishing, pp. 1–26. https://doi.org/10.1007/978-3-030-35691-0_1.

Campanale, C., Savino, I., Pojar, I., Massarelli, C., Uricchio, V.F., 2020. A practical overview of methodologies for sampling and analysis of MPs in riverine environments. Sustainability 12 (17), 6755. https://doi.org/10.3390/su12176755.

Cordova, M.R., Nurhati, I.A., Shiomoto, A., Hatanaka, K., Saville, R., Riani, E., 2022. Spatiotemporal macro debris and microplastic variations linked to domestic waste and textile industry in the supercritical Citarum River, Indonesia. Mar. Pollut. Bull. ISSN: 0025-326X 175, 113338 https://doi.org/10.1016/j.marpolbul.2022.113338.

Hadibarata, T., Tachibana, S., Askari, M., 2011. Identification of metabolites from phenanthrene oxidation by phenoloxidases and dioxygenases of *Polyporus* sp. S133. J. Microbiol. Biotechnol. 21 (3), 299–304.

Hadibarata, T., Yusoff, A.R.M., Aris, A., Kristanti, R.A., 2012. Identification of naphthalene metabolism by white rot fungus Armillaria sp. F022. J. Environ. Sci. 24 (4), 728–732.

Juwana, I., Rahardyan, N.A., Permadi, D.A., Sutadian, A.D., 2022. Uncertainty and sensitivity analysis of the effective implementation of water quality improvement programs for Citarum River, West Java, Indonesia. Water 14 (24), 4077. https://doi.org/10.3390/w14244077.

Kadac-Czapska, K., Knez, E., Gierszewska, M., Olewnik-Kruszkowska, E., Grembecka, M., 2023. MPs derived from food packaging waste-their origin and health risks. Materials 16 (2), 674. https://doi.org/10.3390/ma16020674.

Karing, D.J., Anggiani, M., Cao, L.T.T., El-shaammari, M., 2023. Occurrence of MPs in Kemena River and Niah River of Sarawak, Malaysia. Trop. Environ. Biol. Technol. 1 (1), 1–13. https://doi.org/10.53623/tebt.v1i1.220.

Khori, N.K.E.M., Hadibarata, T., Elshikh, M.S., Ahmed, A.A., Salmiati, Yusop, Z., 2018. Triclosan removal by adsorption of using waste biomass activated carbon: isotherms and kinetics studies. J. Chin. Chem. Soc. 65, 951–959.

Kumar, R., Sharma, P., Verma, A., Jha, P.K., Singh, P., Gupta, P.K., Chandra, R., Prasad, P.V.V., 2021. Effect of physical characteristics and hydrodynamic conditions on transport and deposition of MPs in riverine ecosystem. Water 13 (19), 2710. https://doi.org/10.3390/w13192710.

Lee, K., Kristanti, R.A., Yulisa, A., Rubiyatno, Ningsih, F., Syafrudin, M., Hernandes, E., Albescu, M., 2022. Biosorption of synthetic dye by macrofungi. Ind. Dom. Waste Manag. 2 (2), 61–70. https://doi.org/10.53623/idwm.v2i2.108.

Li, S., Wang, Y., Liu, L., Lai, H., Zeng, X., Chen, J., Liu, C., Luo, Q., 2021. Temporal and spatial distribution of microplastics in a coastal region of the Pearl River Estuary, China. Water 13 (12), 1618. https://doi.org/10.3390/w13121618.

Li, C., Jiang, B., Guo, J., Sun, C., Shi, C., Huang, S., Liu, W., Wu, C., Zhang, Y., 2022. Aging process of microplastics in the aquatic environments: aging pathway, characteristic change, compound effect, and environmentally persistent free radicals formation. Water 14, 3515. https://doi.org/10.3390/w14213515.

Lim, A.H.J., Kristanti, R.A., Endrotjahyo, E., Thao, N.T.T., Adeyemi, D.A., 2023. Microplastic ingestion in aquatic animals in South East Asia. Trop. Environ. Biol. Technol. 1 (1), 25–35. https://doi.org/10.53623/tebt.v1i1.223.

Liong, R.M.Y., Hadibarata, T., Yuniarto, A., Tang, K.H.D., Khamidun, M.H., 2021. Microplastic occurrence in the water and sediment of Miri River estuary, Borneo Island. Water Air Soil Pollut. 232 (8), 342. https://doi.org/10.1007/s11270-021-05297-8.

Liu, W., Zhang, J., Liu, H., Guo, X., Zhang, X., Yao, X., Cao, Z., Zhang, T., 2021. A review of the removal of microplastics in global wastewater treatment plants: Characteristics and mechanisms. Environ. Int. 146, 106277 https://doi.org/10.1016/j.envint.2020.106277.

Ma, J., Zhao, J., Zhu, Z., Li, L., Yu, F., 2019. Effect of microplastic size on the adsorption behavior and mechanism of triclosan on polyvinyl chloride. Environ. Pollut. 254, 113104 https://doi.org/10.1016/j.envpol.2019.113104.

Masura, J., Baker, J., Foster, G., Arthur, C., Herring, C., 2015. Laboratory methods for the analysis of MPs in the marine environment: recommendations for quantifying synthetic particles in waters and sediments. In: NOAA Technical Memorandum NOS-OR&R-48.

Miranda, M.N., Silva, M.T., Pereira, M.F.R., 2020. MPs in the environment: a DPSIR analysis with focus on the responses. Sci. Total Environ. 718, 134968.

New, W.X., Kristanti, R.A., Manik, H., Wijayanti, Y., Adeyemi, D.A., 2023. Occurrence of MPs in drinking water in South East Asia: a short review. Trop. Environ. Biol. Technol. 1 (1), 14–24. https://doi.org/10.53623/tebt.v1i1.221.

Ng, C.H., Mistoh, M.A., Teo, S.H., Galassi, A., Ibrahim, A., Sipaut, C.S., Foo, J., Seay, J., Taufiq-Yap, Y.H., Janaun, J., 2023. Plastic waste and microplastic issues in Southeast Asia. Front. Environ. Sci. 11 https://doi.org/10.3389/fenvs.2023.1142071.

Nguyen, N.T., Nhon, N.T.T., Hai, H.T.N., Chi, N.D.T., Hien, T.T., 2022. Characteristics of MPs and their affiliated PAHs in surface water in Ho Chi Minh City, Vietnam. Polymers 14 (12), 2450. https://doi.org/10.3390/polym14122450.

Ni'am, A.C., Hassan, F., Shiu, R.-F., Jiang, J.-J., 2022. MPs in sediments of East Surabaya, Indonesia: regional characteristics and potential risks. Int. J. Environ. Res. Public Health 19 (19), 12348. https://doi.org/10.3390/ijerph191912348.

Palacios-Mateo, C., van der Meer, Y., Seide, G., 2021. Analysis of the polyester clothing value chain to identify key intervention points for sustainability. Environ. Sci. Eur. 33 (1), 2. https://doi.org/10.1186/s12302-020-00447-x.

Pan, Z., Sun, Y., Liu, Q., Lin, C., Sun, X., He, Q., Zhou, K., Lin, H., 2020. Riverine microplastic pollution matters: a case study in the Zhangjiang River of southeastern China. Mar. Pollut. Bull. 159, 111516 https://doi.org/10.1016/j.marpolbul.2020.111516.

Park, T.-J., Lee, S.-H., Lee, M.-S., Lee, J.-K., Park, J.-H., Zoh, K.-D., 2020. Distributions of MPs in surface water, fish, and sediment in the vicinity of a sewage treatment plant. Water 12 (12), 3333. https://doi.org/10.3390/w12123333.

Priyambada, G., Kurniawan, B., Sitompul, R.G., Darmayanti, L., 2022. The abundance of microplastics in Siak tributary sediments in the watershed area, Pekanbaru City, Riau (Case Study Sago River). Materials Today: Proceedings. ISSN: 2214-7853. https://doi.org/10.1016/j.matpr.2023.03.207.

Rayhan, T.H., Yap, C.N., Yulisa, A., Rubiyatno, Popescu, I., Alvarez, J.A., Kristanti, R.A., 2022. Engineered nanoparticles for wastewater treatment system. Civ. Sustain. Urban Eng. 2 (2), 56–66. https://doi.org/10.53623/csue.v2i2.113.

Sin, L.T., Balakrishnan, V., Bee, S.-T., Bee, S.-L., 2023. A review of the current state of microplastic pollution in South Asian countries. Sustainability 15 (8), 6813 (doi: 10.3390/su15086813).

Sulistyowati, L., Nurhasanah, Riani, E., Cordova, M.R., 2022. The occurrence and abundance of MPs in surface water of the midstream and downstream of the Cisadane River, Indonesia. Chemosphere 291, 133071. https://doi.org/10.1016/j.chemosphere.2021.133071.

Ta, A.T., Babel, S., 2020. MPs pollution with heavy metals in the aquaculture zone of the Chao Phraya River Estuary, Thailand. Mar. Pollut. Bull. 161, 111747 https://doi.org/10.1016/j.marpolbul.2020.111747.

Tang, K.H.D., 2022. Valorization of plastic waste through incorporation into construction materials. Civ. Sustain. Urban Eng. 2 (2), 96–109 (doi:10.53623/csue.v2i2.141).

Tokiwa, Y., Calabia, B., Ugwu, C., Aiba, S., 2009. Biodegradability of plastics. Int. J. Mol. Sci. 10 (9), 3722–3742. https://doi.org/10.3390/ijms10093722.

Veiga, J.M., van Veen, B., Buckman, L., van Gils, J., Wuriyandoko, D.T., van der Sluys, C., Philp, K., Acharya, A., 2023. Assessing plastic waste discharges into the sea in Indonesia: an integrated high-resolution modeling approach that accounts for hydrology and local waste handling practices. Water 15 (6), 1143. https://doi.org/10.3390/w15061143.

Wang, J., Wang, M., Ru, S., Liu, X., 2019. High levels of microplastic pollution in the sediments and benthic organisms of the South Yellow Sea, China. Sci. Total Environ. 651, 1661–1669. https://doi.org/10.1016/j.scitotenv.2018.10.007.

Yona, D., Sari, S.H.J., Iranawati, F., Bachri, S., Ayuningtyas, W.C., 2019. MPs in the surface sediments from the eastern waters of Java Sea, Indonesia. F1000Res 8, 98. https://doi.org/10.12688/f1000research.17103.1.

Yu, Y., Zhou, D., Li, Z., Zhu, C., 2018. Advancement and challenges of microplastic pollution in the aquatic environment: a review. Water Air Soil Pollut. 229 (5), 140. https://doi.org/10.1007/s11270-018-3788-z.

Yuen, K.W., Park, E., Hazrina, M., Taufik, M., Santikayasa, P., Latrubesse, E., Lee, J.S.H., 2023. A comprehensive database of Indonesian dams and its spatial distribution. Remote Sens. (Basel) 15 (4), 925. https://doi.org/10.3390/rs15040925.

Zhang, T., Sun, Y., Song, K., Du, W., Huang, W., Gu, Z., Feng, Z., 2021. MPs in different tissues of wild crabs at three important fishing grounds in China. Chemosphere 271, 129479. https://doi.org/10.1016/j.chemosphere.2020.129479.