Distribution and Characteristics of Microplastics in Nhue - Day River Basin, Vietnam

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ABSTRACT

The prevalence of microplastics (MPs) in the environment has had a significant impact on ecosystems and posed a major threat to human health. This study investigated the distribution and characteristics of MPs in the Nhue - Day River basin in Vietnam, which is a critical source of biodiversity and used to support the economic growth of about 12 million people. The effect of seasonal variation and anthropogenic activities on the MP abundance was assessed. The findings revealed that the MPs abundance was significant in this study area. The average abundance of MPs in the dry season (754 items/m^3) was insignificantly higher than that in the rainy season (706 items/m^3) with n=9. The range in the abundance of MPs in the dry and rainy seasons was 49-2,827 and 400-1,133 items/m^3, respectively. Microplastics in fiber forms were dominant in both seasons. The majority of the collected MPs were in the 0.5-2.0 mm size range, varying from 71% to 100% of the total MPs depend on sampling point. The total percentage of MPs size 0.3-0.5 mm in the dry season was 56.97% compared to 119.85% in the rainy season, indicating that the MPs were broken into smaller pieces due to UV exposure and weather conditions. Colored items occupied the majority of the MPs. This study can be used to gain a better knowledge of MP pollution in Vietnam's river water.

1. INTRODUCTION

Due to its potential harm to aquatic ecosystems and human health, MP contamination has recently become a much more concerned issue on a global scale (Wanner, 2021). Microplastics (MPs) are defined as plastic particles with a diameter of less than 5.0 mm, comprising primary MPs discharged during industrial production and secondary MPs produced during the breakdown of more substantial plastic products (De Falco et al., 2019). Because of the ability to absorb toxic chemicals or pathogens that can then be transferred to living organisms through the food chain, MPs are considered as a contaminant (Baldwin et al., 2020; Dai et al., 2022; Sulistyowati et al., 2022). Wang et al. (2018a) examined the chemical distribution and adsorption behavior of MPs. In China, Greece, and Portugal, polychlorinated biphenyl (PCB) congeners, polycyclic aromatic hydrocarbon isomers, hexa-chlorocyclohexane isomers, and dichloro-diphenyl-trichloroethane metabolites were discovered in plastic pellets. Chemical PCB congeners are more concentrated on black or aged MPs than on colored or white MPs (Beckingham and Ghosh, 2017). It has been reported that MPs can travel long distances in the water flow because of their small size and their ability to remain in the environment for long periods of time due to their resistance to degradation. Microplastics have recently been discovered and traced in a variety of environments, including drinking water (Schymanski et al., 2018), the atmosphere (Liu et al., 2019), soil (Nizzetto et al., 2016), food (Vitali et al., 2022), and even human bodies (Wright and Kelly, 2017). Therefore, it is critical to understand the occurrence, abundance, behavior, and fate of MPs in the natural environment.

Numerous studies on MPs in the marine environment (water, sediment, and biota) have been conducted. However, it remains limited for freshwater

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environments, particularly in Asia, where significant plastic pollution has been observed because of rapid economic and demographic growth, as well as urbanization development (Wang et al., 2018b). Furthermore, it has been demonstrated that rivers are not only important sinks of MPs in urban areas, but they are also one of the major sources of MPs in the oceans (Eerkes-Medrano et al., 2015). The Changjiang River in China is estimated to transfer 16-20 trillion MPs weighing 537.6-905.9 tons to the ocean through the surface water layer each year (Zhao et al., 2019); the Saigon River in Vietnam annually transports 115-164×10^{12} items of synthetic fibers to the sea (Strady et al., 2020). As a result, it is obvious that knowledge of MP pollution in urban freshwater bodies is essential for establishing efficient plastic waste management methods in both metropolitan regions and the oceans. Nonetheless, evidence of MP pollution in inland freshwater bodies is more restricted than in marine areas (Eerkes-Medrano et al., 2015).

Vietnam is one of the top 20 countries in terms of plastic waste input into the ocean, with approximately 1.8 million tons of plastic waste discharged each year, which is 10% more than the global average (Jambeck et al., 2015). The abundance of MP in aquatic systems in Vietnam has been reported in previous studies with the MP abundance ranging from 0.35 to 2,522 items/m^3 (Chau et al., 2020; Tran-Nguyen et al., 2022). In the Red River, the concentration of MP was 2.3 items/m^3, the lowest level among the investigated areas, while the highest concentrations were measured in urban and smaller rivers: 93.7 items/m^3 in the Nhue River and 2,522 items/m^3 in the To Lich River (Strady et al., 2021). In Danang City, the Phu Loc Channel it was reported as a MP pollution hotspot with a MP concentration of 1,482.0±1,060.4 items/m^3 in water (Tran-Nguyen et al., 2022). In the south of Vietnam, the Saigon River basin has high concentrations of fibers and fragments, 172,000 to 519,000 items/m^3 and 10 to 223 items/m^3, respectively (Lahens et al., 2018).

The Nhue - Day River flow through Hanoi and four other provinces (Hoa Binh, Ha Nam, Ninh Binh, and Nam Dinh) before joining at Phu Ly City in Ha Nam Province. This river basin, which has a length of 236 km and an area of around 7,655 km^2, is a source of critical biodiversity and is used to support the economic growth of about 12 million people. The effluents from large residential areas like Hanoi, which has over 4,000 industrial facilities, about 500 traditional artisan villages, and roughly 1,400 hospitals and healthcare facilities, have a negative impact on the water quality of these rivers (Le et al., 2022). This river system provides most of the freshwater for agriculture and aquaculture in the region. The presence of MPs in this river system has been reported by Strady (Strady et al., 2021). However, information on MP pollution in these systems is still rather limited to exploring the source of MPs in the investigated area. Therefore, investigating MP pollution in this river basin is very important for a comprehensive understanding of MP content situation to provide information to trace the sources and pathways of MPs in the aquatic environment. In this study, the MPs in surface water along the Nhue - Day River Basin was investigated with an aim to explore the effects of seasonal variation and anthropogenic activities on MP contamination and characteristics in the Nhue - Day River basin. Understanding the presence of MPs in river water will help to develop workable solutions and strategies to reduce the conflicting effects of MP contamination on the ecosystem and public health. The findings from this study can be used as trustworthy support for future research on the effects of MP pollution on human health in Northern Vietnam.

2. METHODOLOGY

2.1 Sampling points and sample collection

The Nhue - Day River Basins are one of the ten major river systems in Vietnam. It includes two large rivers: Nhue - Day River. The Nhue River has a length of 74 km, taking water from the Red River and flows into the Day River at Ha Nam Province. The Day River has a length of 237 km, also taking water from the Red River and flows into East Sea. Surface water samples were collected at nine points along the Nhue - Day River Basin, including four points on Nhue River and five points on Day River. The samples were collected in March 2021 represented for dry season samples and November 2021 for the rainy season in the North Central region. Figure 1 and Table 1 describe the details of the nine sampling points.

2.2 Sample preparation

River water samples were collected using a Manta mesh (mesh size 300 µm, mouth width 15×30 cm) fitted with a General Oceanic flowmeter (ensuring the mouth of the net was completely under the surface of the water) (Dris et al., 2018) for 120-240 seconds. Depending on the conditions at the sampling location, the two below methods were applied:

- At monitoring points with large currents and wide riverbeds, samples were collected in the middle of the stream from a boat. Sampling time and boat speed are calculated to ensure that the sample volume in the net is at least 1 m^3.
- For the point with low flow and narrow riverbed area that cannot be netted, a 100-200 L sample was collected into a bucket and slowly pour into the sampling device or through a sieve with 0.3 mm mesh size.
- The sampling device, after being taken from the river, was washed with clean water from the outside to wash away the dirt as well as the MPs (if any) on the mesh wall and move to the cup at the bottom of the device. This process is repeated several times until the sampler is clean of MPs. After that, water samples were transferred to 100 mL glass vials, kept refrigerated and dark before being transported to the laboratory. Then, the water sample was refrigerated at 4^{o}C in the field for immediate analysis or stored in the refrigerator at 20^{o}C for further analysis (stored time within 15-20 days).

Map of Microplastic Monitoring Points
in the Nhue - Day River Basin

Figure 1. Microplastic sampling points in Nhue - Day River Basin

Table 1. The basic information of surface water sampling points in Nhue - Day River Basin

No	Province/city	Sample symbol	River name	Coordinate		Sampling point description
				X	Y	
1	Hanoi	ND1	Nhue River	580499.178	2332119.309	Upstream monitoring point of Nhue River to get water from the Red River
2	Hanoi	ND2	Nhue River	583181.017	2315161.439	Area receiving domestic wastewater in Cau Giay District and surrounding areas
3	Hanoi	ND3	Day River	574060.905	2300545.244	Evaluation of MP pollution at Hanoi City
4	Hanoi	ND4	Nhue River	587598.865	2298950.196	Assessment of MP pollution in Nhue River

Table 1. The basic information of surface water sampling points in Nhue - Day River Basin (cont.)

No	Province/city	Sample symbol	River name	Coordinate		Sampling point description
				X	Y	
5	Hanoi	ND5	Day River	578284.590	2287467.761	Assessment of MP pollution in Day River
6	Ha Nam	ND6	Nhue River	594284.270	2282200.214	Evaluation of MP pollution at Hanoi City
7	Ha Nam	ND7	Nhue - Day River Basin	596439.229	2269667.671	Assessment of MP pollution for Nhue - Day River in Ha Nam Province
8	Ninh Binh	ND8	Nhue - Day River Basin	597954.548	2247725.092	Assessment of MP pollution for Nhue - Day River at Ninh Binh Province
9	Nam Dinh	ND9	Nhue - Day River Basin	615060.390	2239898.168	Assessment of MP pollution for Nhue - Day River Basin at Nam Dinh Province

2.3 Sample analysis

A volume of 100 mL of water sample was put into a 500-mL glass beaker and dried at 40°C for 24 to 48 h. Then, 50-70 mL of 30% H_2O_2 and $FeSO_4$ 0.05 M were added to dissolve the organic matters, until the appearance of the solution was clear. After that, the solution was redried to remove water. The carbonate compounds in samples were eliminated by adding 10-20 mL of HCl 1 M solution to the glass beaker and shaking well until no bubbling before letting it dry at 40°C for 12 h.

After the drying step, a volume of 30 mL of $ZnCl_2$ solution d=1.6 g/mL was slowly added to the beaker and mixed well, then the whole mixture was transferred into 50 mL PE centrifuge plastic tubes. The mixture in the canister was centrifuged at a rotational speed of 3,000 Relative Centrifugal Force (RCF) per min to separate MPs and other solids remaining in the water. Microplastics with light density float on the surface of the $ZnCl_2$ solution. The solution at the top of the test tube will be filtered to separate the MP particles from the remaining solid layer. The $ZnCl_2$ solution containing the supernatant MPs was collected by the overflow method, placed in a 500 mL Nalgene filter cup, and then filter through grid paper with 47 mm diameter, 0.45 µm filter pore size, each piece of paper has 100 cells with the size of each cell 3.1×3.1 mm. With the smallest MP particle size of 0.35 mm, filter paper with the above pore size can be used. Filter paper was gently removed and stored in aluminum foil bags, dried at 45°C for about six hours before determining the quantity and composition of MPs.

The number of MPs in dried samples were determined using a Euromex stereo microscope, with a maximum focal length of 40x, and a DC5.0 Stereo Camera with ImageFocus 4 English Version software to determine the size, shape, color, and quantity of suspected MPs.

3. RESULTS AND DISCUSSION

3.1 Microplastic abundance

In this study, MPs in surface water were detected at each sampling and in both dry and rainy seasons. The results shown in Figure 2 and Figure 3 indicated that the distribution and abundance of MP in Nhue - Day River system was significantly affected by season and geographical location. In the dry season, the concentration of MPs in surface water ranged from 49 to 2,827 items/m^3, with an average abundance of 754 items/m^3. The sampling area with the highest abundance of MPs was the ND3. The ND3 point is at the confluence of the Day River, the section of Hoa Vien Bridge, and near ND3 market, Ung Hoa District, Hanoi. This is a high population density area. Moreover, in recent years, various kinds of trading activities along the river in ND3 point have produced untreated wastes and the survey area pollution has been quite serious. In addition, various kinds of small, scattered enterprises and industrial activities such as wool and fabric factories, garment factories, and some manufacturers and traders of plastic products have been recorded as sources of MP discharge in the area. Point ND6 was also reported to have high levels of MPs in surface water (1,423 items/m^3). Previous studies connected the presence of MPs in the aquatic environment to the effects of human activity (Zhao et al., 2020). It explained the reason for the highest MP concentration at ND6 is because it runs through a high population density area and industrial area related to engineering, electronics, assembly, food production and some light industry. Additionally, the close distance between ND6 and rubbish dumping indicated a high MP concentration at this point. The fact that intense economic activities, such as industrial discharge and land use, can cause poor water quality to some extent has raised alarm. The idea that MP abundance is driven by economic activity is indirectly supported by the potential positive association between poor water quality and high MP content.

In the rainy season, the abundance of MP in Nhue - Day River ranged from 400 to 1,133 items/m^3, with an average abundance of 706.67 items/m^3 which was lower than that in the dry season. It is clear that the MPs are distributed more evenly along the river basin due to the influence of the river flow in rainy season instead of concentrating at some points in dry season. This phenomenon indicates that the abundance of MPs was gradually diluted when the water volume increased. The two survey points with the largest concentration of MPs were recorded at ND2 and ND6 with the corresponding value of 1,133 and 1,066 items/m^3, respectively. This difference in distribution pattern of MPs may be due to hydraulic and flow conditions that were significantly affected by season factor. In the rainy season, tributaries, and overflows in residential areas on both sides of the river are formed. This may partly explain why in the rainy season the number of MPs at the lower limit increases and the recorded upper limit decreases. The increase in hydrology is also a factor governing the distribution of these plastics.

(a)

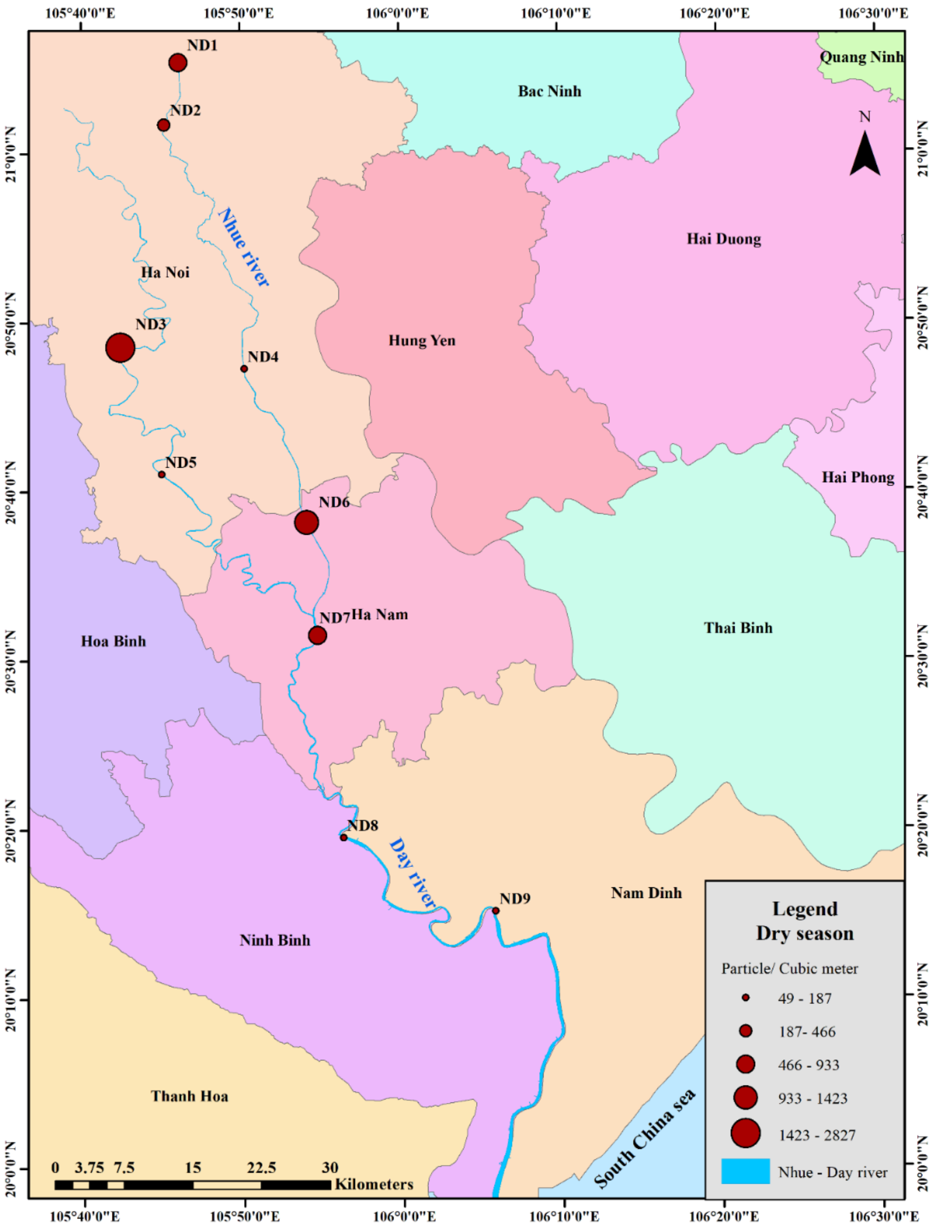

Figure 2. Distributions of MP contamination in surface water of Nhue - Day River Basin in dry season (a) and rainy season (b)

(b)

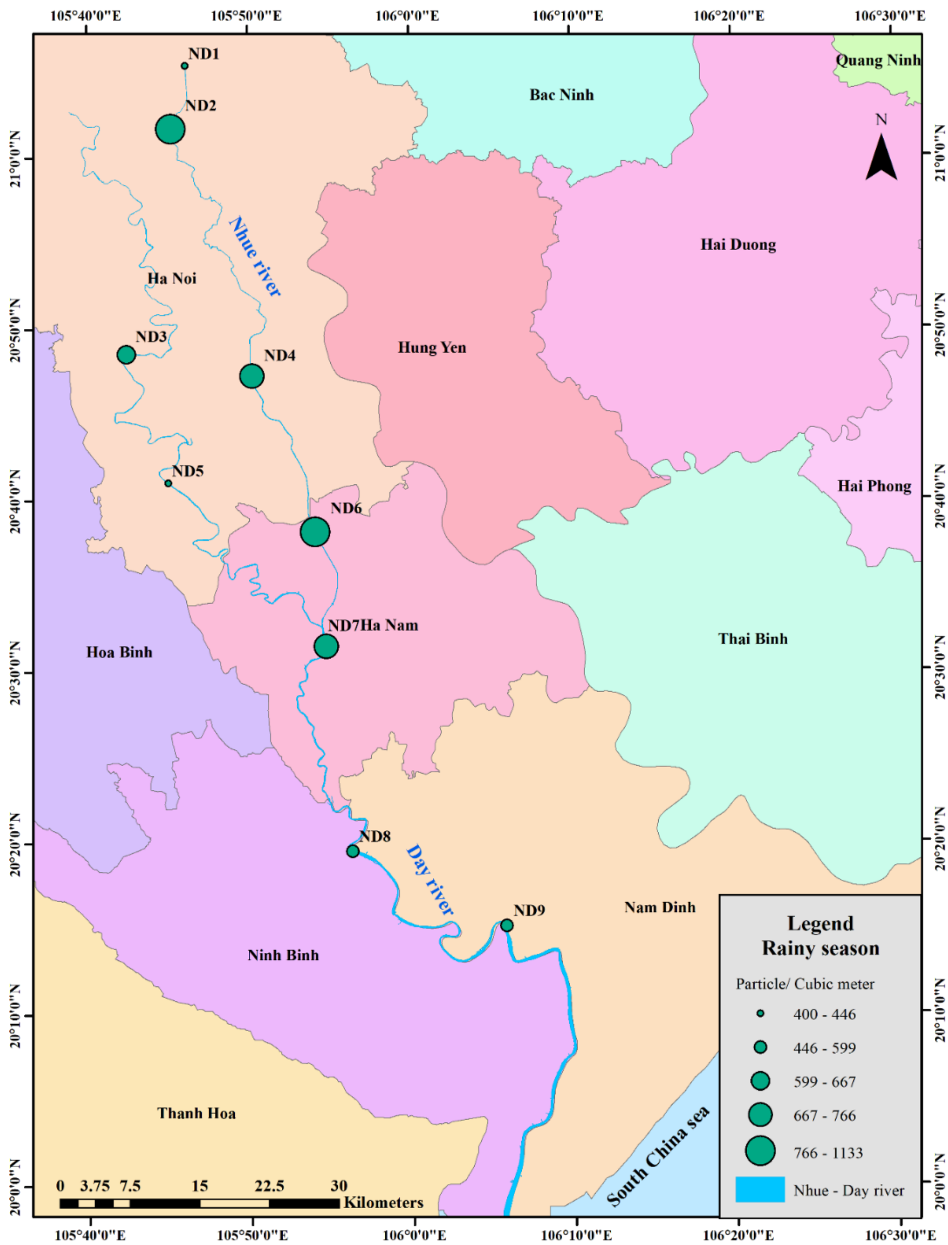

Figure 2. Distributions of MP contamination in surface water of Nhue - Day River Basin in dry season (a) and rainy season (b) (cont.)

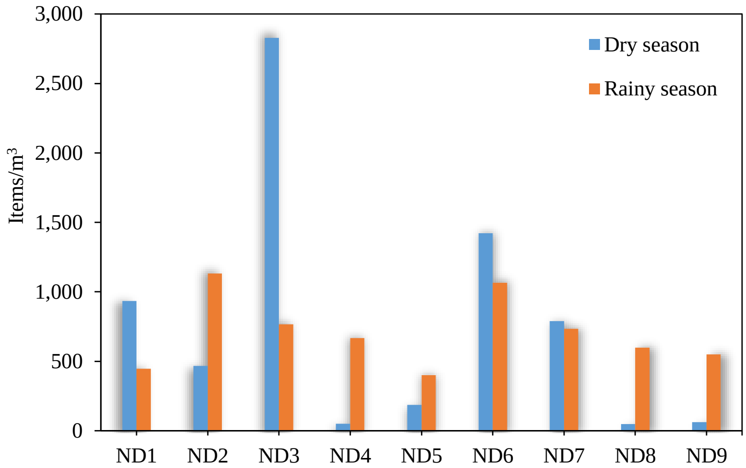

Figure 3. Microplastics abundance in surface water of Nhue - Day River Basin during dry and rainy season

The abundance of MPs in the surface water from urban areas in other parts of Vietnam and over the world is displayed in Table 2. The results in this study were compared with those in other rivers in Vietnam such as the Red River, Han River (which runs through Da Nang), and Dong Nai River. It is clear that, except for the To Lich River (2,522 items/m^3; (Strady et al., 2021)), the MPs concentration in the surface waters of the Nhue - Day River is in high levels. In particular, the average value of microplastics recorded in a m^3 of surface water in the study area is 327 times greater than the number of microplastics recorded in the Red River, nearly 280 times greater than the number of microplastics received from Han River water, and more than 193 times greater than the number of microplastics received from Dong Nai River. Especially, compared to Nhue - Day River itself in 2020, there is a significant increase in the microplastics abundance in 2021 (sample collected time of this study) alarming the polluted issue of this area.

The Nhue - Day River Basin has a greater MP concentration in waters than some rivers in Asian countries, such as Duong Tu River of China (8.6 items/m^3) and Surabaya River in Indonesia (1.47-43.11 items/m^3). The same situation happened when comparing with Rhine River in Europe, and Los Angeles River or San Gabriel River in the USA, where barely a few items per m^3 were found.

Table 2. Distribution of MPs in surface water in Vietnam and some countries in the world

Location	Size (mm)	Average abundance (items/m^3)	Abundant range (items/m^3)	References
Vietnam				
Nhue - Day River, rainy season	0.3-5.0	706	400-1,133	This study
Nhue - Day River, dry season	0.3-5.0	754	49-2,827	This study
Red River	0.3-5.0	2.3		Strady et al. (2021)
Han River	0.3-5.0	2.7		Strady et al. (2021)
Dong Nai River	0.3-5.0	3.9		Strady et al. (2021)
Nhue River (2020)	0.3-5.0	93.7		Strady et al. (2021)
To Lich River (2020)	0.3-5.0	2,522		Strady et al. (2021)
Saigon River	<5		22,812-251,000	Strady et al. (2020)
Other countries				
Hoang Ha River, China, dry season	<0.5	930	623-1,392	Han et al. (2020)
Maozhou River, China	0.001-5.000		4,000- 25,500	Wu et al. (2020)
Duong Tu River, China	0.3-5.0	8.6		Zhao et al. (2014)
Surabaya River, Indonesia	0.3-5.0		1.47-43.11	Lestari et al. (2020)
Han River, Korea	0.1-5.0		0-42.9	Park et al. (2020)
Danube River, Austia	0.5-5.0	17		Lechner et al. (2014)
Ravi River, Pakistan, rainy season	0.3-5.0	768		Aslam et al. (2022)
Ravi River, Pakistan, dry season	0.3-5.0	1,324		Aslam et al. (2022)
Rhine River, Europe	0.3-5.0	3.9		Mani et al. (2015)
Seine River, France	0.1-5.0	108		Dris et al. (2015)
Marne River, France	<5	398		Dris et al. (2018)
Los Angeles River, USA	0.3-5.0	13.7		Moore et al. (2005)
San Gabriel River, USA	0.3-5.0	0.6		Moore et al. (2005)
Hudson River, USA	0.1-5.0	0.98		Miller et al. (2017)
Ottawa River, Canada	0.1-5.0	0.2		Vermaire et al. (2017)

3.2 Morphology of MPs

3.2.1 Shape distribution

Figures 4 and 5 show the composition of MP pollution based on different types. In both seasons, fibers identified as the most dominant type of MPs collected from the sampling points was similar to those of other studies on freshwater MP (Koelmans et al., 2019). Fibers come from a variety of sources, such as washing clothes, using and wearing plastic objects, and the waste plastic produced during industrial production (Browne et al., 2011). Furthermore, fiber-like MPs are likely to be formed from huge blocks of plastic during migration, which are subject to wind, water flow, temperature, and abrasion by hard things

(Peters and Bratton, 2016). Indeed, in both seasons, this form of plastic produced much more fibrous MPs than other types of MPs. Fibers were 93.26% of all MP types, while fragments were 6.47% in dry season. In rainy season, there was a light increase in the number of fragmented MP. Fragment MPs have a higher density than fibers, some types of density can increase to 1.2 g/L. In the rainy season the river water discharge increases causing a high-water velocity which facilitated the transportation of fragment in the flow. Therefore, the concentration of MP in fragment shape in dry season was higher than that in rainy season.

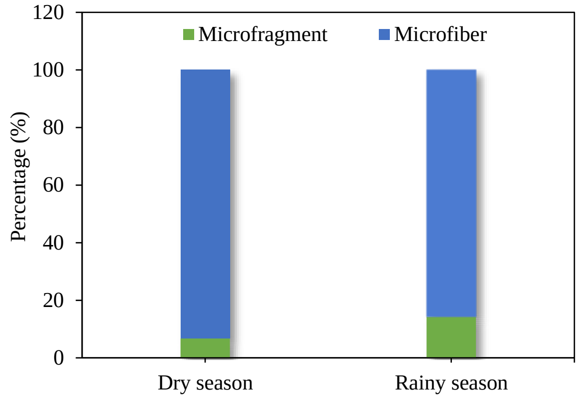

Figure 4. Shape distribution and pictures of MPs in surface water of Nhue - Day River Basin during dry and rainy season

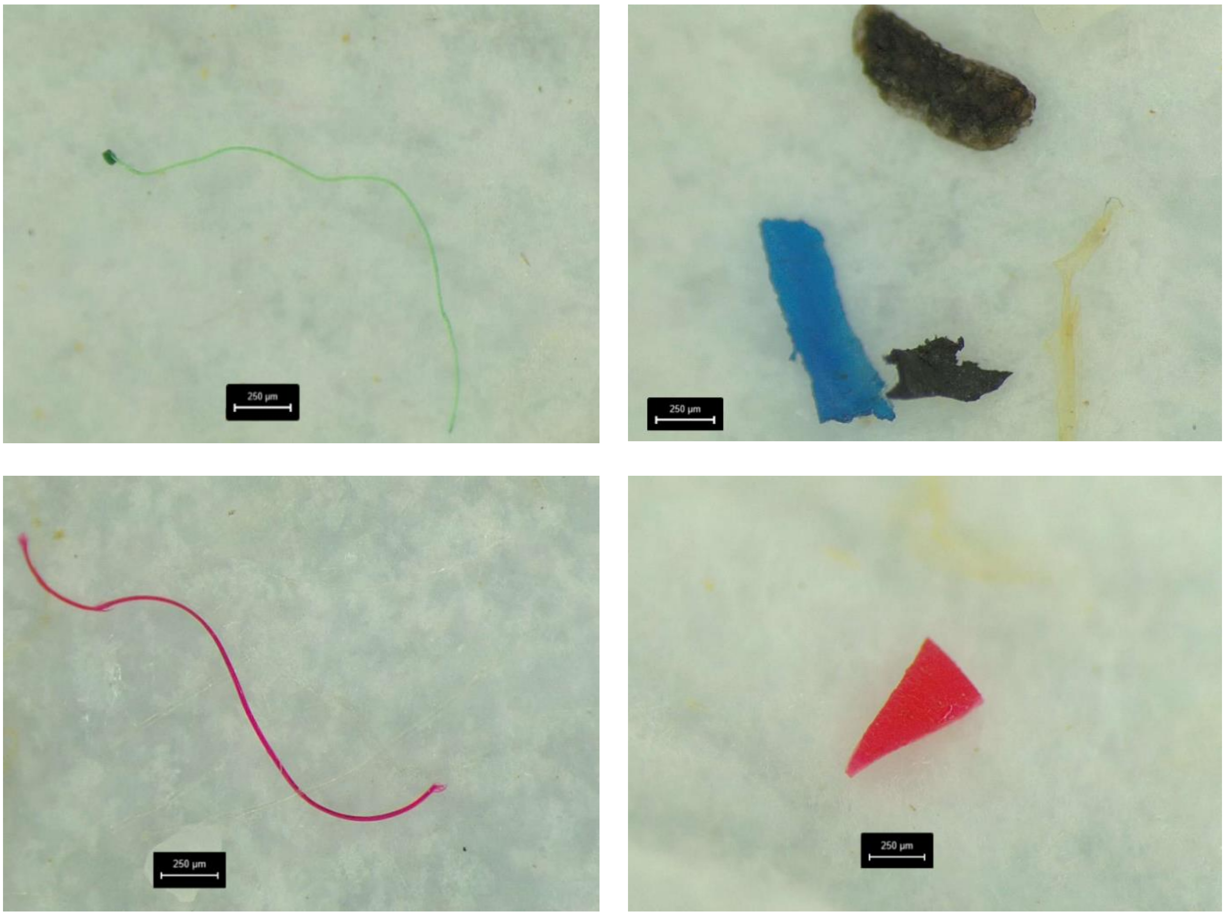

Figure 5. Photomicrographs of the MPs found in Nhue - Day River water

3.2.2 Colors distribution

Microplastics with different colors are presented in Figure 6. In dry season, black was seen to be the dominant color (33.6%), followed by blue (31.6%) and red (18.5%). Other pigmented particles, such as green (4.46%), yellow (1.53%), grey (0.03%), occurred only at low proportions. The colored particles are more likely to be mistaken for food by aquatic biota because they resemble low-trophic-level organisms (Browne et al., 2008). Furthermore, green MPs with irregular forms may be formed because of the breakdown of single-use plastic products containing colorants (Wang et al., 2018b). In contrast, in rainy season, white was the most common MP color with a percentage reaching 49.6%, followed by blue (31.6%). In both seasons, grey is the least common one. This result agreed with number of previous studies which high proportion of colorless MPs (transparent and white) was found (Phuong et al., 2018; Lestari et al., 2020; Wu et al., 2020). In addition, it was reported that the reason may be caused by the overflow of plastic manufacture from nearby companies, as well as fading during significant weathering processes such as wave action by tidal currents.

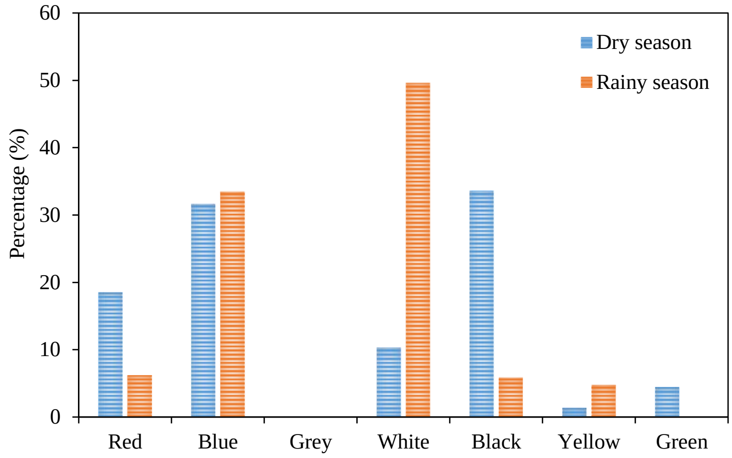

Figure 6. Colors distribution of MPs in surface water of Nhue - Day River Basin during dry and rainy season

3.2.3 Size distribution

Figure 7 shows the size distribution of MPs in both dry season (a) and rainy season (b). The microplastics tend to be unevenly concentrated in sizes as MPs with the size of 0.5-2.0 mm accounted for 71% to 100% in both seasons. In the dry season, the recorded MPs size values ranged from 0.301 mm to 4.71 mm. While in the rainy season, those numbers were 0.306 mm and 4.453 mm.

Even though there were no significant differences in the size range and the size majority of the MPs between two seasons, the sum of the percentage of MPs size 0.3-0.5 mm from all nine points in the dry season is smaller than in the rainy season, 56.97% compared to 119.85%, respectively. This can be explained by the fact that MPs in the dry season are subjected to adverse weather conditions with prolonged high temperatures, as well as the influence of UV, causing these MPs to break into smaller pieces. In the rainy season, these particles are transported everywhere by the water flow, so the encountering of small-sized pieces of MPs is more frequent.

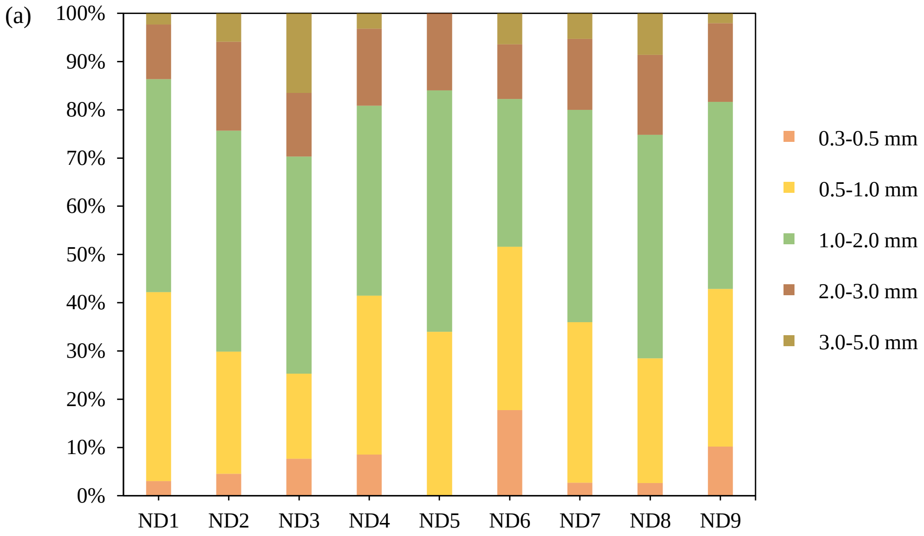

Figure 7. Size distribution of MPs in surface water of Nhue - Day River Basin during dry (a) and rainy (b) seasons

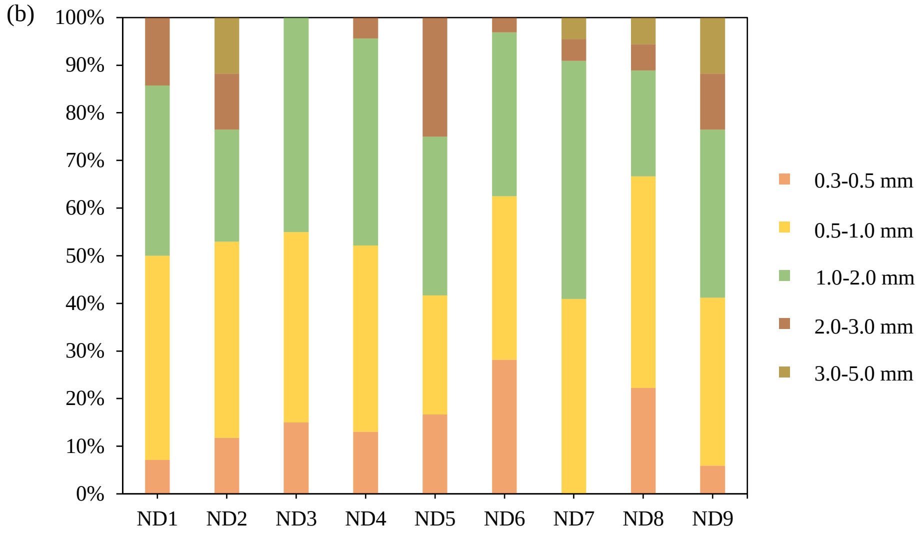

Figure 7. Size distribution of MPs in surface water of Nhue - Day River Basin during dry (a) and rainy (b) seasons (cont.)

4. CONCLUSION

In this study, the microplastic (MP) contamination, and MP characteristics in surface water along the Nhue - Day River Basin were investigated. The results showed the presence of MPs at different levels in water samples of all sampling points along the study area. Although there is no significant difference in abundance of MP between dry season and rainy season, the MPs were distributed more evenly along the river basin in the rainy season due to the influence of the river flow instead of concentrating at some specific points as in the dry season. In terms of shape, fiber was the dominant form of MP in both seasons.

The majority of the collected MPs were in the 0.5-2.0 mm size range, varying from 71% to 100% of the total MPs depending on the sampling point. The sum of the percentage of MPs size 0.3-0.5 mm from all nine sample points in the dry season was 56.97%, compared to 119.85% in the rainy season, indicating that the MPs were broken into smaller pieces due to UV exposing and weather condition. The results allow us to conclude that the Nhue - Day River is highly polluted with MPs compared to some other rivers in Vietnam, as well as in the world. It is of practical significance to understand the sources and sinks of MPs in inland freshwater environments.

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