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Distribution of microplastics in surface water of tropical urban lakes: A case study in Ha Noi, Vietnam

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ABSTRACT

Microplastics are nowadays considered ubiquitous pollutants since they have been found widespread in all environmental compartments, particularly in aquatic systems. In urban water bodies, municipal wastewater discharges and overflows of combined storm and wastewater drains are the sources of microplastic pollution. The investigation was performed on the distribution of microplastics in the surface water of three urban lakes: West Lake, Yen So Lake, and Bay Mau Lake, from February 2020 to January 2021. Results show that microplastics were widely and unevenly distributed in all three lakes in Ha Noi and reached a high abundance on the site of West Lake, which is most intensively surrounded by population density, restaurants/bars, and aquaculture activities. Microplastic abundance was highest in February 2020 for all three urban lakes, with 154.92 items m^{-3} in Bay Mau, 589.46 items m^{-3} in West Lake, and 139.86 items m^{-3} in Yen So Lake. There was a decreasing trend in the following sampling times of July, October 2020, and January 2021 (range: Bay Mau: 16.02-59.04 items m^{-3}; West Lake: 36.51-201.08 items m^{-3}; Yen So: 14.07-67.27 items m^{-3}). The dominant microplastics in urban lakes were fibers with a size of 1-3 mm, while microplastic fragments were 0.045-0.3 mm^2. Analysis of the chemical composition of microplastics indicated dominance by rayon (13.5-58.5%) and polyethylene terephthalate (14.1-30.8%). This study is an essential reference for understanding the characteristics of the variation in microplastics in urban lakes to reduce local microplastic pollution effectively.

Keywords: microplastics, surface water, urban lake.

1. Introduction

Plastics are durable and inexpensive and are thus widely used in daily life and in industrial, scientific, and technological applications (Chen et al., 2015, Ren et al., 2018). Plastic production has increased sharply since the 1950s (Thompson et al., 2009). Lakes and rivers carry most plastic litter to the oceans (van Emmerik and Schwarz, 2020). Under the influence of several natural and artificial factors (e.g., UV light, water turbulence, or other physical or chemical degradation processes), fragmentation of macroplastics could break down into microplastics (MPs) with sizes from 0.1 mm to < 5 mm (Phuong et al., 2018). Compared to marine microplastics research,

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few studies have bio-monitored microplastics in inland waters, especially in urban water bodies. Recently, the contamination of freshwater systems by microplastics has become an area of increasing concern (Li et al., 2018a, Li et al., 2018b). Microplastics' occurrence and distribution were demonstrated on Lake Victoria's surface water (Egessa et al., 2020) or Wuliangsuhai Lake, northern China (Mao et al., 2020). Further information on microplastic pollution in freshwater systems comes from studies on urbanized rivers (Yan et al., 2021, Zhang et al., 2020, Oanh et al., 2022) and textile industrial areas (Deng et al., 2020). Although microplastic presence has been documented in urban water cycle compartments (Strady et al., 2021), the level of knowledge still needs to be due to less information available for urban lakes in developing countries.

Urban lakes are inland water bodies surrounded by an urban environment. These lakes are a landscape feature that significantly contributes to increasing the quality of life in urban centers by increasing amenities, providing recreational and educational activities, and even mitigating the urban climate (Martínez-Arroyo and Jáuregui, 2000). Urban lakes can suffer from significant cumulative impacts with urbanization in the cities. Because urban lakes tend to receive municipal wastewater discharges such as runoff from roads, pavements, rooftops, parking lots, and driveways; thus they tend to emphasize the environmental problems affecting the metropolitan areas by collecting and accumulating large amounts of pollutants, including plastic wastes (Naselli-Flores, 2008). Besides, receiving municipal wastewater discharges, septic tank effluent and runoff from failed septic tanks, runoff from construction sites, and overflows of combined storm and wastewater drains may create environmental problems for urban lakes (Naselli-Flores, 2008). According to the report of Nizzetto et al. (2016), urban areas and treated/untreated wastewater are significant sources of microplastic pollution in inland waters. Several studies showed that water bodies in urban areas have relatively high concentrations of microplastics (Vaughan et al., 2017, Wang et al., 2017a, Wang et al., 2017b). In Vietnam, microplastics are currently encountered in freshwater systems such as ponds (Le et al., 2022a), lakes and reservoirs (Strady et al., 2021), and rivers (Lahens et al., 2018, Oanh et al., 2022, Le et al., 2022b, Kieu-Le et al., 2023). However, those studies were mainly conducted on the surface water of the extensive water systems, while the study of urban lakes in densely populated areas has not been widely performed. Therefore, this study aimed to investigate microplastics' distribution, appearance characteristics, and polymer composition in tropical urban lakes. Hopefully, this research assists policy-making for inland MPs pollution management by providing preliminary data on MPs assessment.

2. Materials and Methods

2.1. Study site description

Hanoi (population: > 7.7 million), the capital of Vietnam, is crossed by major rivers such as the Red River (length through Ha Noi: 120 km) and the Nhue River (length through Ha Noi: 74 km), which shaped over centuries the urban and agricultural development of the city and formed several lakes, like the West Lake. The West Lake, located on the Northwest of Hanoi (21°3′18″N 105°49′12″E), is the largest in Ha Noi with a total area of 510 ha. Its shoreline length is about 17 km, and hotels, restaurants, and residential areas, which daily discharge large volumes of untreated wastewater, surround it. Currently, the water quality of West Lake is becoming a big problem for the local government and authority.

Being located in the southern gateway of Hanoi, the Yen So Lake (137 ha) (20°9′74″N

105°85′62″E) is a typical retention basin - an artificial lake to contribute to the Hanoi drainage system receiving untreated wastewater from Kim Nguu and Set canals and treated wastewater from Yen So Wastewater Treatment Plant since the last ten years. Nevertheless, Yen So Lake receives poor scientific interest (besides metal concentrations Le and Ngo (2013) and has minimal scientific data characterizing its environmental features.

Finally, the Bay Mau Lake (26 ha) is located inside Thong Nhat Park (21°00′41″N105°50′36″E). It is adjacent to Dong Da and Hai Ba Trung's district residential areas, which directly release untreated domestic wastewater into it. The total amount of wastewater discharged into Bay Mau Lake during the dry season ranges from 8,500 - 10,000 m^3 daily. During the rainy season, the wastewater is mixed with rainwater and flows into the lake (Fig. 1).

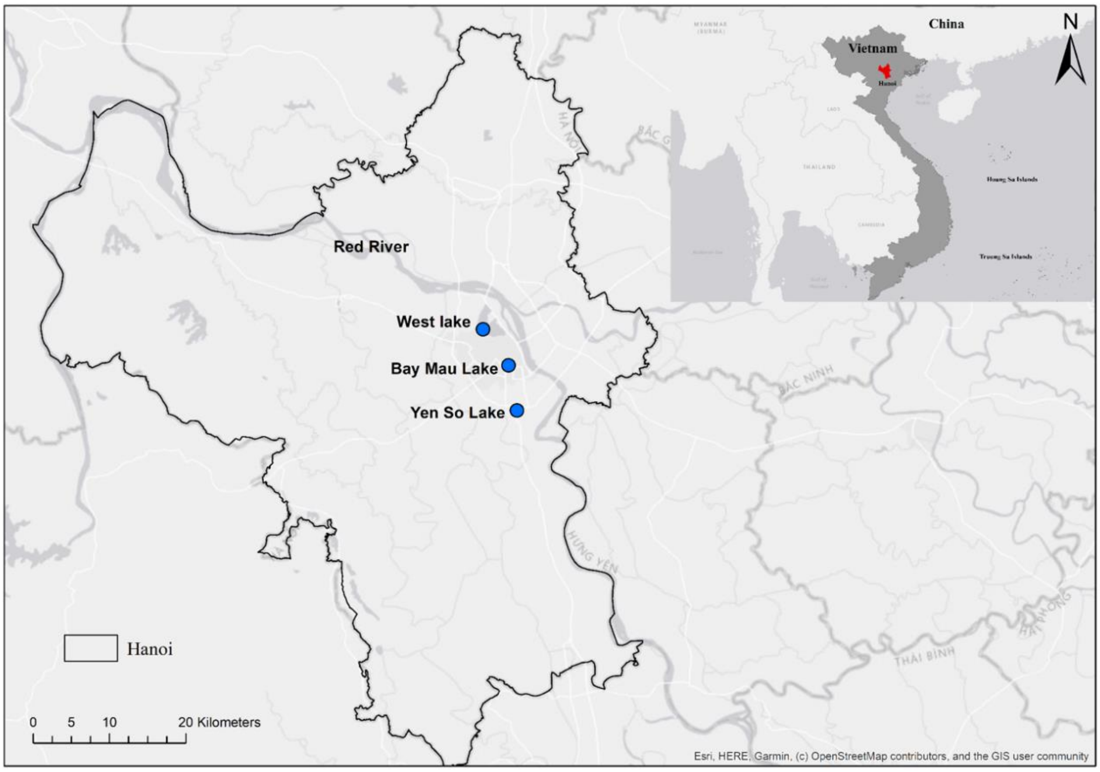

Figure 1. Locations of three urban lakes in Ha Noi: Bay Mau, West Lake and Yen So Lake

2.2. Collection of surface water samples

Field sampling in the three urban lakes was carried out in 4 sampling times, including February 2020 and July 2020, October 2020, and January 2021 (Table 1).

The microplastic sampling procedure for surface water was conducted according to the method reported by (Strady et al., 2021). Briefly, surface water samples were taken from a local boat using an 80 µm mesh size plankton net (diameter 50 cm) coupled to a flowmeter (General Oceanics®) to determine the sampled water volume. The number of flowmeter rotations at each sampling site was recorded to calculate the volume of filtered water. The net was exposed for less than 15 min, equivalent to 3.3 to 16.1 m^3 according to sites and sampling times. The exposure time was adapted to the microplastic concentrations measured at each sampling site during pre-campaigns. The net was then rinsed from the outside, and the collected fraction was recovered from a stainless-steel bucket into a 500 mL glass container and kept in the dark at 4°C in the laboratory until analysis. This study collected 300-500 mL water samples at each sampling site. Because the target contaminants detected by this study were various types of tiny plastic particles or fibers, the sampler (plankton net, stainless-steel bucket) and glass containers were cleaned to avoid any contaminants that could affect the result of the study. Three replicates were taken per lake and per sampling time.

Table 1. Location and characteristics of three lakes in this study

Lake	Latitude (N)	Longitude (E)	Water volume (m^3)	Area (ha)	Depth (m)	Type of waterbody	Description and observations
West lake	21 047838	105 815903	10,000,000	510	1.0-5.0	Natural lake	West Lake is the biggest natural freshwater lake of Hanoi, Vietnam, located northwest of this city and a popular place for recreation with many surrounding gardens, hotels, restaurant and other entertainment centers
Bay Mau	21 011198	105 841955	-	28	0.5-2	Natural lake	Bay Mau Lake is a freshwater lake located in Thong Nhat Park in Hanoi and is one of 26 lakes regulating rainwater and wastewater of Hanoi capital
Yen So	20 961782	105 850589	4,000,000	137	1.0-3.5	Artificial lake	Yen So is an artificial lake to receive treated wastewater from Yen So Wastewater Treatment Plant, where received discharge daily from Hanoi and treated about 50% of Ha Noi's wastewater

2.3. Sample processing and microplastic analysis

The protocol (Strady et al., 2021) aimed to ease the final observations of the filter. At first, each sample was sieved on a 01 mm mesh size sieve to remove litter > 01 mm (e.g., vegetable, wood, shell). In comparison, the plastic items > 01 mm were kept separately and put on a cellulose nitrate membrane for later observation under the Leica stereomicroscope. In a second step, the fraction <1000 µm was kept back in the 500 mL glassware bottle and was treated using three successive reagents addition : (i) 01 g of Sodium Dodecyl Sulfate (SDS, Merck®) at 50°C for 24 h; (ii) 01 mL of biozym SE (protease and amylase, Spinnrad®) and 01 mL of biozym F (lipase, Spinnrad®) at 40°C for 48 h; (iii) 15 mL of hydrogen peroxide (H_2O_2 30%, Merck®) at 40°C for 48 h. The bottle was closed and maintained in a laboratory oven during each step. Then, in a third step, the sample was transferred through a 250 µm mesh size sieve to remove all the mineral and organic particles lower than 250 µm and to obtain more evident filters for microplastic observations: the fraction < 250 µm was discarded while the fraction > 250 µm was transferred into a clean 250 mL glass beaker using filtered NaCl solution (density 1.18 g mL^{-1}). In the fourth step, the beaker was gently filled with NaCl solution to perform density separation by overflow. This step was repeated at least 05 times to ensure the retrieval of plastic items. Fifthly, the overflowed solution was filtered on cellulose nitrate membranes using a glassware filtration unit. Finally, the filters were kept separately in sterile petri dishes until observation under the stereomicroscope Leica S9i equipped with a high-resolution camera. Based on the GESAMP recommendation, when visual observation is performed without systematic analysis of the polymers, we set up for fiber measurement with the minimum length at 300 µm and the maximum length at 5,000 µm and for fragment measurement with a minimum area size of 45000 μm^2 and maximum size at 25,000,000 μm^2 (GESAMP, 2019).

2.4. µFTIR analysis

Given the number of samples and potential plastic particles, the associated analytical time, and the cost, the polymer identification by µFTIR was not done systematically but randomly. For each time sampling time and lake, 145 to 289 particles were randomly selected (Table 2) for polymer identification by µFTIR spectrometer (Nicolet In10Mx Dual Director microscope, Thermo Fisher Scientific). All identified spectra were compared to the library of Thermo Fisher (acceptance and validation for spectra matching higher than 70%) to identify their polymer nature; the verified non-plastic particles were excluded.

Table 2. Number of microplastic particles was chosen for identifying the polymer composition of each time sampling of three urban lakes

Sampling time	Bay Mau	Yen So	West lake
Feb. 20	130	242	202
Jul. 20	195	223	237
Oct. 20	137	243	277
Jan. 21	117	206	237

2.5. Quality control

Specific steps were set up based on the recommendations of (Strady et al., 2021) to ensure the control quality. All analysis processes were carried out under a fume hood, operators were fully equipped with cotton lab clothes and nitrile gloves, and all tools and glassware were washed three times with filtered distilled water to prevent sample contamination from the environment. The NaCl solution (density 1.18 g mL^{-1}) was filtered before use on cellulose nitrate membranes (porosity 0.45 µm) and kept in glass bottles. Due to tropical climate conditions, a fan was prohibited, and air conditioning was used to maintain a cool temperature in the room and avoid dust settling. Distilled water is treated as a blank during the entire treatment process. No microplastics were detected in the blank samples of any procedure, which indicated that the microplastic contamination during the experiment was negligible.

2.6. Statistical analysis

Statistical analyses were performed with GraphPad Prism 8 and SPSS 16.0. Data are indicated as mean ± standard error (SE). The normality of the data distribution was tested on data residues using the Shapiro-Wilk test ($p < 0.001$). Variance homogeneity was evaluated using the Levene test ($p < 0.05$). In homogenous variance and normalized data cases, one-way ANOVA was performed, followed by the Tukey Post hoc test at $p < 0.05$.

3. Results and Discussion

3.1. Microplastics abundance in three urban lakes

All lakes in Hanoi regulate a city's rainwater drainage system, improve the climate, air conditioning, and purification, and limit the effects of global warming. However, lakes in Ha Noi are under great pressure from encroachment and receiving wastewater from domestic and industrial production. Thus, urban lakes in Ha Noi might experience potential microplastic risk. As shown in Fig. 2 and Table 3, microplastics were detected in all water samples with variation concentrations. The abundance of microplastics on all lakes varied from 14.07 items m^{-3} to 589.46 items

m^{-3} and showed a declining trend in microplastic concentrations according to the sampling time within a lake. The highest microplastic abundances were found in February 2020 in any of the three studied urban lakes, with 154.92 items m^{-3} in Bay Mau, 589.46 items m^{-3} in West Lake, and 139.86 items m^{-3} in Yen So Lake, which is correspondingly higher ($p < 0.05$) than those observed in July 2020, in October 2020 and in January 2021 (Bay Mau: 16.02-59.04 items m^{-3}; West lake: 36.51-201.08 items m^{-3}; Yen So: 14.07-67.27 items m^{-3}). There was frequent anthropogenic activity, including many local festivals after the Lunar New Year around West Lake or many picnics/camping to be organized by people around three lakes in July, and humans were the primary source of microplastic pollution. Tourists leave their garbage behind, including mineral water bottles, food packaging bags, and straws (Xiong et al., 2018, Wang et al., 2021).

Figure 2. The abundance of microplastics (items m^{-3}) in surface water of three urban lakes in Hanoi. Different letters denoted the significant differences between lakes at the same time of sampling and different numbers denoted the significant differences between sampling times of one lake. The significant level is at $p < 0.05$ (ANOVA, Tukey'test)

Table 3. Concentrations (mean ± SD) of microplastics of surface water samples collected from three urban lakes at different sampling times

Lake	Sampling time	Fiber (items m^3)	Fragment (items m^3)	Total (items m^3)
Bay Mau	Feb. 20	96.68 ± 3.2	62.24 ± 6.8	154.92 ± 9.3
	Jul. 20	17.55 ± 3.5	41.49 ± 4.6	59.04 ± 5.3
	Oct. 20	17.53 ± 3.6	9.97 ± 0.8	27.50 ± 4.2
	Jan. 21	12.66 ± 2.4	3.36 ± 1.3	16.02 ± 1.2
West lake	Feb. 20	395.31 ± 38.7	194.15 ± 6.0	589.46 ± 32.7
	Jul. 20	179.35 ± 8.8	21.73 ± 1.4	201.08 ± 9.6
	Oct. 20	61.08 ± 4.2	7.49 ± 1.2	68.56 ± 4.3
	Jan. 21	3.90 ± 0.3	32.61 ± 2.5	36.51 ± 2.7
Yen So	Feb. 20	106.41 ± 0.6	33.46 ± 2.9	139.86 ± 2.3
	Jul. 20	52.05 ± 4.5	15.22 ± 0.9	67.27 ± 4.3
	Oct. 20	66.42 ± 6.0	9.84 ± 0.3	76.25 ± 6.3
	Jan. 21	9.53 ± 1.0	4.54 ± 1.6	14.07 ± 1.1

Mainly, when comparing the concentrations of microplastics between the studied lakes, it is interesting that in February and July 2020, West Lake had significantly higher concentrations of microplastics in surface water than in Bay Mau and Yen So Lakes ($p < 0.05$). The results agree with studies that show high microplastic abundance in areas of highly intensive anthropogenic activities (Kataoka et al., 2019) or with a high density of local tourists (Egessa et al., 2020). Several factors may contribute to the observed microplastic distribution in urban lakes' surface water because the microplastic inputs can come from different sources. The domestic sewage and local trading markets could directly contribute as the primary sources of microplastic contamination in West Lake, especially without any strictly controlled wastewater discharge from the local government. Moreover, West Lake is surrounded by parks or lively restaurants and bars; thus, West Lake can receive extra plastic waste from many visitors to three famous local pagodas and temples, which are located around West Lake. Meanwhile, Yen So Lake is very close to the Yen So Wastewater Treatment Plant (WTP) and regularly receives effluent discharge from Yen So WTP. A previous study has reported a correlation between microplastic contamination and wastewater treatment plants (Baldwin et al., 2016) because the wastewater treatment plant has been pointed out as a source of microplastic contamination (Franco et al., 2021). In addition, Yen So Lake is recently considered a leisure location for Ha Noi people, with hundreds of people coming for picnics/camping on the weekend. However, the abundance of microplastics in surface water in Yen So Lake was not significantly higher than in Bay Mau Lake ($p > 0.05$). Bay Mau Lake is located in downtown Ha Noi and is strictly controlled by the waste discharge by the local government. However, Bay Mau Lake still receives runoff from roads, pavements, rooftops, parking lots, and driveways overflows of combined storm and wastewater drains, which may contribute to microplastic contamination for this lake. This study only focused on quantitative assessment and compositions (see section 3.3) of microplastic contamination in three urban lakes. Therefore, the sources, distribution pathways, and fates of microplastics should be considered for assessing the influence of wastewater from different anthropogenic activities of Ha Noi City on the microplastic pollution of urban lakes.

3.2. Distribution of microplastic shape, size, and color

In the microplastic samples collected from three studied lakes (Bay Mau, Yen So, and

West Lake), two types (fiber and fragment) were observed in the water samples (Fig. 3 and Table 3). Microplastic fibers were the primary type found in West Lake and Yen So Lake, ranging from 69 to 90%, followed by fragments with 10-31%. The results were in agreement with the previous studies, in which microplastic fibers were always dominant in surface water (Sighicelli et al., 2018, Deng et al., 2020, Jian et al., 2020, Mao et al., 2020, Zhang et al., 2020). Microplastic fibers in West Lake and Yen So Lake may be released from domestic sewage directly or indirectly, such as laundry, daily cleaning products, and effluent water from wastewater treatment plants (Wen et al., 2018). In addition, fishing activity in West Lake has also been regarded as a source of fiber (Wen et al., 2018, Di and Wang, 2018). Except for Bay Mau Lake, there was no significant difference between time samplings in each type of microplastics collected in West Lake and Yen So Lake ($p > 0.05$). Many microplastic fragments were found in February and July 2020 in Bay Mau Lake, with 42% and 64%, respectively, but dominant microplastic fibers were observed in October 2020 and January 2021, accounting for 71% and 88%, respectively. The dominant microplastic fibers or fragments may be due to the physical, chemical, and biological/biochemical decomposition of large plastic pieces into microplastic after entering water bodies. As Bay Mau Lake is located in Thong Nhat Park (downtown Hanoi) with a density of population, microplastic fragments might originate from the breakdown of many plastic products such as packaging materials of fast-food and takeaway, containers, cosmetics, and cleaning media used by people's leisure time in the park. The dominance of fragments over fibers in Bay Mau Lake on Feb. 20 and Jul. 20 agrees with the results in urbanized rivers (Yan et al., 2021).

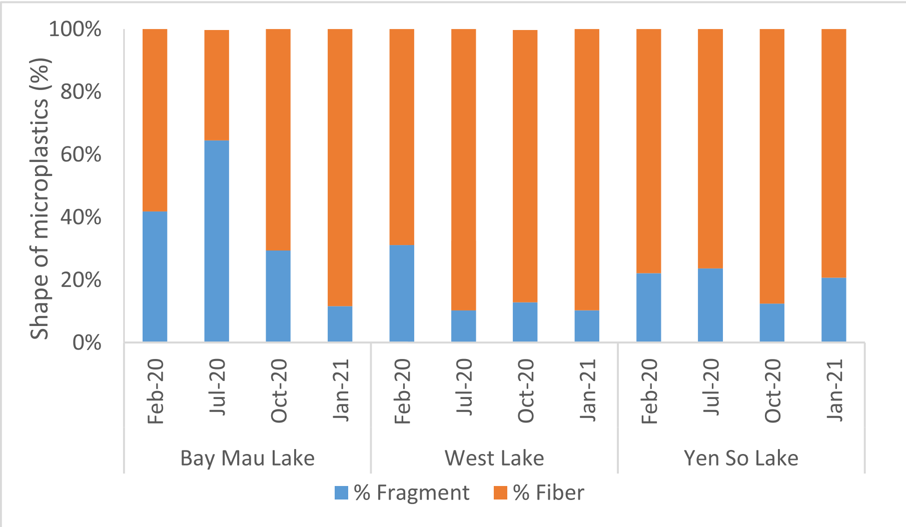

Figure 3. The distribution of shape in the water column of three urban lakes in Ha Noi

According to the microplastic sizes, the microplastics were divided into three categories for fiber type (i.e., 0.3-1.0 mm, 1.0-3.0 mm, and 3.0-5.0 mm) (Fig. 4a) and four categories for fragment type of microplastic (i.e., 0.045-0.3 mm^2, 0.3-0.5 mm^2, 0.5-1.0 mm^2, and 1.0-5.0 mm^2) (Fig. 4b). The fiber size length was mainly in the 1-3 mm range, accounting for the highest proportion (39-63%) among all water samples from three urban lakes in Ha Noi. About 7-56% of the detected microplastics with a size of

0.3-1.0 mm were found to be fiber shape, while the rest (6-30%) were within 1-5 mm. By interval data analysis, the size distribution of fiber microplastics was similar in three studied lakes during the period study (Figs. 5a, b, c). The highest size distribution of fiber microplastics was identified from 0.5 mm to 1.0 mm in February 2020, accounting for 51% in Bay Mau Lake, 56% in West Lake, and 44% in Yen So Lake (Fig. 4a). However, 1-3 mm microplastic size showed the highest size distribution in the following sampling times from July 2020 to January 2021. The high proportion of fiber microplastics with a size range of less than 3 mm was also certified in the previous studies (Lahens et al., 2018, Mao et al., 2020, Wu et al., 2020). For example, the dominant size detected of the Saigon River was less than 0.25 mm (Lahens et al., 2018), while Wu et al. (2020) found that 54-63% of the microplastic in Maozhou River was in the size range of 0.1-1.0 mm; 98.2% of the microplastics < 2 mm in Wuliangsuhai Lake in China (Mao et al. 2020). In the urban surface water of Wuhan, more than 80% of the microplastics were smaller than 02 mm (Wang et al., 2017b).

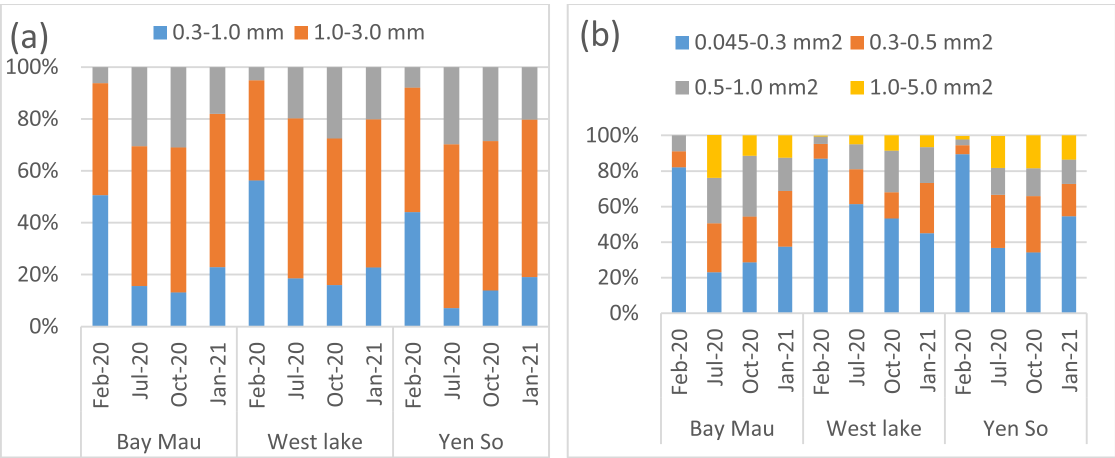

Figure 4. The size distributions of microplastics in water of three urban lakes in Ha Noi (a) fiber microplastics; (b) fragment microplastics

Different from the microplastic fibers, there was a similar size distribution of microplastic fragments in West Lake and Yen So Lake, except for water samples in Ban Mau Lake (Figs. 5d, e, f). The microplastic fragments with the size range of 0.045-0.3 mm^2 are predominant in the surface water of the studied lakes, occupying 23-89 % of the total amount of detected microplastics (Figure 4b), followed by the size of 0.3-0.5 mm^2 with 8-32 % of the total amount. Interestingly, Feb. 2020 had the highest percentage (82-89 %) of fragments with size 0.045-0.3 mm^2 in all three studied lakes. In the following months of sampling, the fragment with the size of 0.045-0.3 mm^2 decreased sharply, especially in Bay Mau Lake (23-38%). Several studies have indicated the dominance of small-sized microplastics in lakes such as mountain lake Mongolia (Free et al., 2014), the Laurentian Great Lake, Canada (Driedger et al., 2015), Taihu Lake and Poyang Lake, China (Su et al., 2016, Yuan et al., 2019). Little is known about the rate and mechanisms of plastic degradation and fragmentation in the freshwater environment. Environmental aging on large plastic debris can generate microplastic due to photochemical and biological processes (Andrady et al., 2011, Wu et al., 2020) significantly more quickly when dry and exposed on land than when in the water (Andrady et al., 1993). Further studies are required to distinguish the mechanisms of plastic degradation in freshwater and the role of the degradable processes in determining microplastic size range in urban lakes.

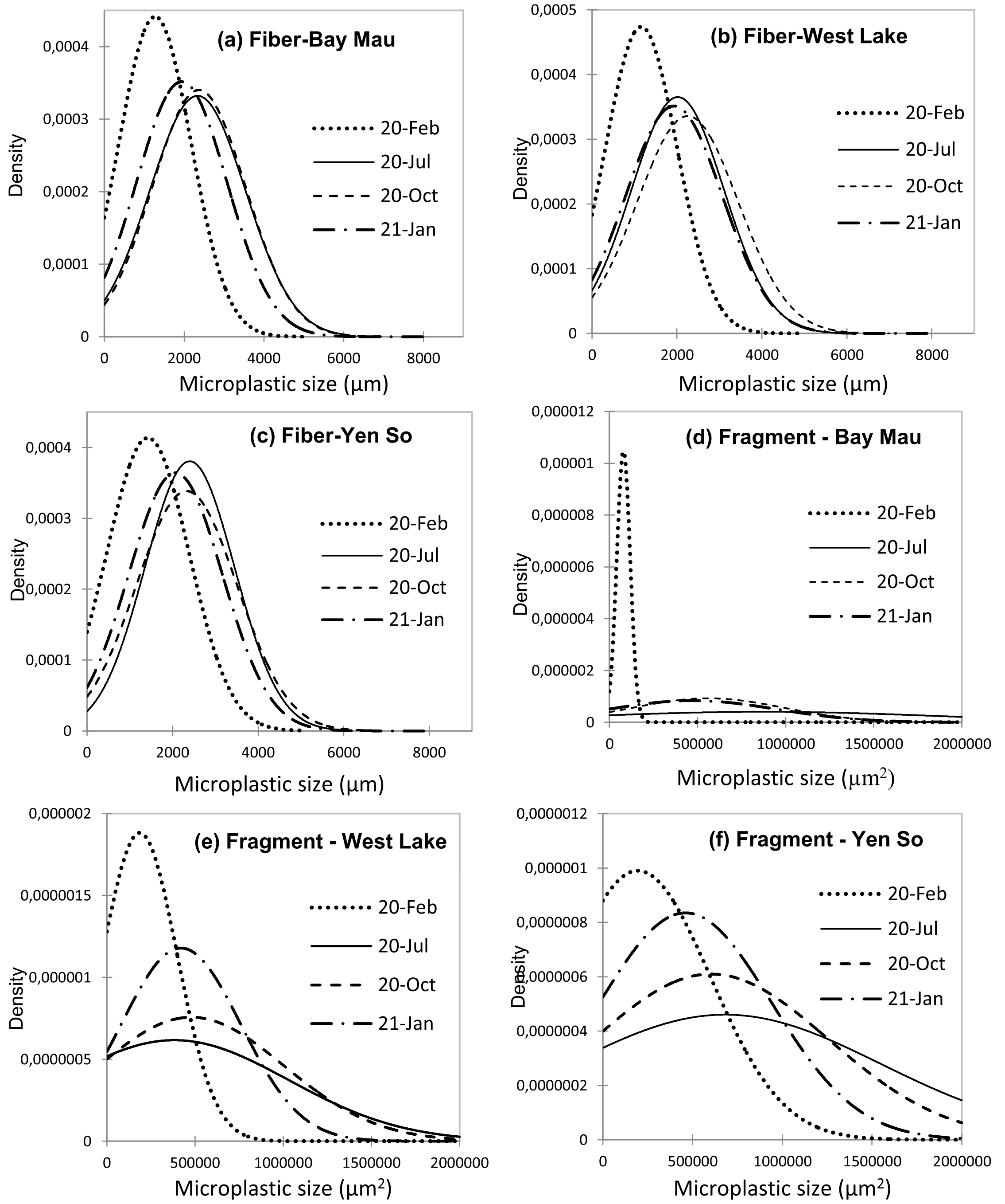

Figure 5. The density size distribution of microplastics size in water of three urban lakes in Hanoi. (a) fiber - Bay Mau Lake; (b) fiber - West Lake; (c) fiber - Yen So Lake; (d) fragment - Bay Mau Lake; (e) fragment - West Lake; (f) fragment - Yen So Lake

This study showed that microplastic fibers and fragments occurred in a variety of colors: including blue, white/transparent, black, yellow, green, pink, purple, orange, and brown (Figs. 6a and 6b). The most dominant colors were pink, purple, and white in microplastic fibers and fragments. Among fiber, the rarest colors were yellow, orange, and black, while fragments, brown, black, and orange, were the rarest. According to Thetford et al. (2003), plastic companies usually introduce tic products with various colors to consumers. Recently, the findings of Deng et al. (2020) also indicated that manufacturing and sale activities might be the main reasons leading to the colorful microplastic in the textile area. Moreover, microplastics that break down from large plastic products might show different colors from the original product because bleaching of the plastic debris in the environment may alter the original color of the plastic products (Scotle et al., 2015). Frankly, it is tough to explore the relationship between color distribution and microplastic occurrence in urban lakes; thus, a long-term survey is better for understanding microplastic color distribution in urban lakes.

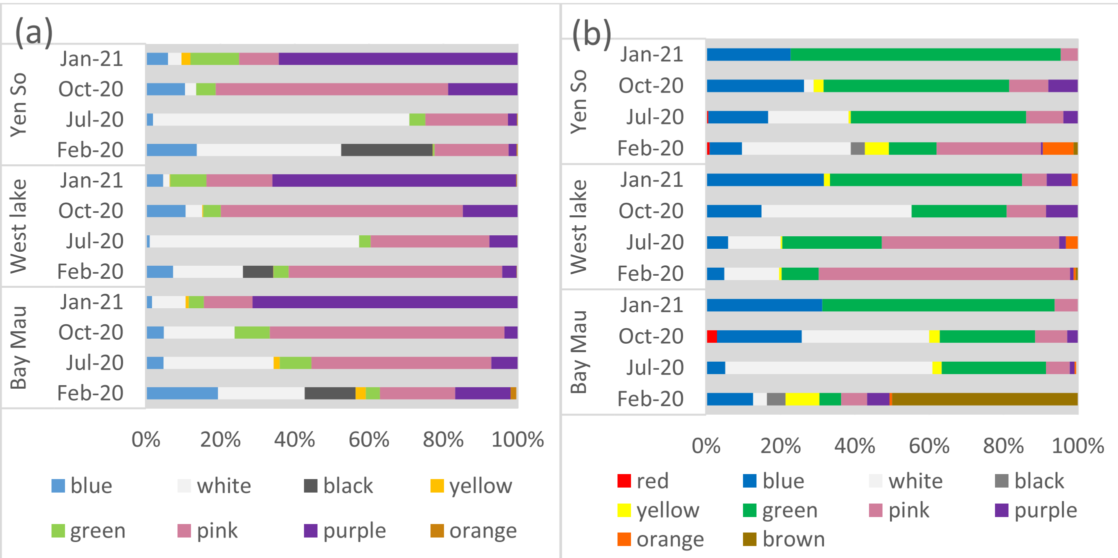

Figure 6. The color distribution of microplastics in water collected from three urban lakes in Ha Noi. (a) fiber microplastics, (b) fragment microplastics

3.3. Microplastic polymers

The identification of microplastic polymers in three urban lakes in Ha Noi showed in Table 4. Rayon, a semi-synthetic fiber, was detected in all samples, with high percentages from 13.5% to 58.5%. The Rayon fiber is used to make textiles for clothing and other purposes. Identifying microplastic polymers in lakes showed that polymer type, identified by μFTIR spectroscopy, ranged from 41.5-86.5% particles. Among polymer types, polyethylene terephthalate (PET) was the most dominant type of polymer found in all samples of three urban lakes, ranging from 14.1% to 54.7%, depending on seasonal sampling. The other components (12.8-56.5%) were a combination of nylon, polypropylene (PP), polyethylene (PE), polyester (PES), polyvinyl chloride (PVC), polystyrene (PS), and co-polymers such as poly (propylene: ethylene), poly (ethylene:vinyl chloride), poly (terephthaloyloxamidrazone), poly (oxothioxoquinazoline terephthalamide), poly (styrene:tetramethylene), polyether urethane, poly (tetrafluoroethylene, poly (styrene-4-sulfonate) and other polymers.

Table 4. Components of the selected items from the surface water samples collected from three urban lakes

Polymer	Bay Mau (%)				West lake (%)				Yen So (%)			
	Feb. 20	Jul. 20	Oct. 20	Jan. 21	Feb. 20	Jul. 20	Oct. 20	Jan. 21	Feb. 20	Jul. 20	Oct. 20	Jan. 21
Rayon	**46.2**	**37.9**	**29.9**	**32.5**	**49.5**	**13.5**	**30.3**	**41.8**	**30.2**	**22.0**	**58.5**	**35.0**
Nylon	10.0	1.0	0.7	0.9	6.9	1.5	6.5	1.7	2.5	3.1	2.9	-
Polypropylene (PP)	-	9.2	5.1	1.7	0.5	5.5	10.1	8.9	1.7	1.8	0.8	4.9
Polyethylene (PE)	0.8	-	8.0	2.6	-	0.8	-	0.4	0.8	-	-	6.8
Polyethylene terephthalate (PET)	**30.8**	**29.7**	**33.6**	**54.7**	**23.3**	**30.0**	**30.0**	**21.1**	**28.5**	**30.0**	**27.2**	**14.1**
Polyester	4.6	7.2	6.6	1.7	6.9	11.0	7.2	4.2	8.3	9.4	2.1	2.9
Polyvinyl chloride (PVC)	1.5	0.5		0.9	2.5	2.1	1.8	2.1	1.7	2.7	1.6	4.9
Poly (propylene:ethylene)	0.8	1.0	2.9	-	0.5	1.3	7.2	4.2	3.3	0.9	1.2	1.9
Poly (ethylene:vinyl chroride)	-	-	1.5	-	-	-	-	-	-	-	-	1.0
Poly (terephthaloyl oxamidrazone	-	-	-	-	-	-	-	2.1	-	-	-	0.5
Poly (oxothioxoquinazoline terephthalamide)	0.8	-	-	0.9	1.5	-	-	1.7	-	-	-	-
Polystyrene	-	-	1.5	-	-	-	-	0.8	-	-	-	-
Poly (styrene:tetramethylene)	-	-	-	-	0.5	-	-	0.4	-	-	-	-
Polyethylenimine (PEI)	0.8	9.2	-	-	-	26.6	5.8	1.3	18.6	24.2	0.8	1.5
Polyether urethane	-	-	-	-	-	-	-	-	-	0.9	0.8	-
Poly (tetrafluoroethylene)	0.8	-	1.5	-	-	-	-	-	-	0.9	0.4	-
Poly (styrene-4-sulfonate)	-	-	3.6	-	-	-	-	-	-	-	-	-
Others	3.1	4.1	5.1	4.3	7.9	8.0	1.1	9.3	4.5	4.0	3.3	26.7
Total (%)	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Number of MP particles	**(130)**	**(195)**	**(137)**	**(117)**	**(202)**	**(237)**	**(277)**	**(237)**	**(242)**	**(223)**	**(243)**	**(206)**

Rayon and polyethylene terephthalate were the most obtained because these polymers were widely used in everyday life. For example, rayon was widely used in the textile industry for clothing and other purposes. In contrast, polyethylene teraphthalate has widely used bottles, textiles, rigid packaging, flexible packaging, and other applications (Polygalov et al., 2021). The presence of rayon and polyethylene teraphthalate in Ha Noi urban lakes indicates that the wastes originate from population activities and can be classified as secondary microplastics. The indication of waste from population activities is strengthened by fiber dominance compared to fragments. This study found that PET MPs, though not as dominant use and load in river systems in Viet Nam as the polymer materials PE and polypropylene (PP) (Oanh et al., 2022), made up an essential part of the overall MPs load in urban lakes in Ha Noi. The results of this study were in line with previous studies that found that microplastics have been detected in several lake systems worldwide PET MPs (Corcoran et al., 2015, Imhof et al., 2016, Zbyszewski and Corcoran, 2011, Zhang et al., 2016). The opposite results were found in surface water of Sai Gon rivers, which observed that polyolefins and polystyrene, dominated microplastic particles (van Emmerik et al., 2019). Those authors found that PET was the least found plastic type (4.6%) in the Saigon River, while soft polyolefins were most abundant (30.6%), followed by expandable polystyrene (25.5%) and hard polyolefins (20.6%). The predominance of polyethylene microplastics was found on surface water in the Changjiang River (Xu et al., 2018), with large quantities (82%). Polyethylene and polypropylene microplastics were mainly found in the Antua River's water in Portugal (Rodrigues et al., 2018). The variations of microplastic polymers found in water are strongly related to plastic use in population activities. According to the report of Plastic Europe (2022), PET is predominantly used as packaging material and make up 8.4% of the total plastic consumption. In Vietnam, PET is the top contributor in absolute leakage (112 thousand tons), with a leakage rate of 11%, and more than a tenth of PET put on the market leaks to the environment (IUCN, 2022). Therefore, PET could make up an essential part of MP load in the water systems and is also one of the polymers most likely to be littered and leaked (high release rate) in the environment.

Besides PET detection in the surface water of Ha Noi urban lakes, polyethyleneimine (PEI) was found in West Lake (with 26.6% in Jul. 2020, 5.8 % in Oct. 2020, and 1.3% in Jan. 2021) and Yen So Lake (with 18.6% in Feb. 2020, 24.2% in Jul. 2020, 0.8% in Oct. 2020 and 1.5% in Jan. 2021) and in July 2020 in Bay Mau Lake (9.2%). A previous study indicated that PEI had been applied in medical chemistry, such as the delivery of small drugs (enzyme immobilization), photodynamic therapy (PDT), antimicrobial coating, the preparation of nanosized delivery vectors, and non-invasive optical imaging devices (Vicennati et al., 2008). According to the Ha Noi Statistics Office (2021), Ha Noi has more than 43 public and many private hospitals. These hospitals have thousands of patients from Ha Noi and neighboring provinces for daily medical examination and treatment, especially in the rainy season. Therefore, the daily use of medical products containing PEI can contribute as a source of PEI microplastics for urban lakes in Ha Noi city. Furthermore, PEI also finds many applications in personal care products (detergents, cosmetics adhesives, and water treatment agents) and food packaging materials (e.g., PEI on polyolefin in contact with food, PEI in paper in contact with aqueous and fatty food, PEI in paper in contact with dry food and PEI on cellophane in contact with food) (Steuerle and Feuerhake, 2006). Consequently, with the high population density in Hanoi, waste originates from personal care products and food packaging that can contain high PEI microplastics.

Traditional polymers such as nylon, polypropylene, polyethylene, polyester, and polyvinyl chloride were found on the surface water of all three urban lakes in this study, with a percentage of less than 10% and a seasonal variable percentage for each lake. This opposite result was found in Benoa Bay, Bali, Indonesia, which observed that polypropylene and polyethylene dominated microplastic particles (Suteja et al., 2021). Polypropylene was widely used in the textile industry and product packaging, while polyethylene was widely used as a bottle or bottle cap (Avio et al., 2017). The lower presence of polypropylene and polyethylene in West Lake, Yen So Lake, and Bay Mau Lake indicated that waste originating from population activities was collected for recycling and reuse. According to social studies by NGOs in Vietnam, such as Green Hub and IUCN, a large proportion of plastic waste is collected by waste collectors (the informal sector) for recycling or reuse because of its value for waste pickers (IUCN, 2022, GreenHub, 2020). The variation of microplastic polymers found in water is strongly related to plastics' uses on land or population activities.

4. Conclusions

This study reveals that microplastics pollute the urban lakes in Hanoi. A significantly higher microplastic pollution level was found on Feb. 20 and July 20 compared with Oct. 20 and Jan. 21. The microplastics in surface water of urban lakes were dominated by fibers with dark colors and size in the range of 1-3 mm. Among microplastic fragments, small-sized of 0.045-0.3 mm^2 was dominant in all water samples of three lakes. Rayon and PET were the most abundant microplastics, followed by nylon, polyester, polypropylene, and polyethylene. Due to microplastic pollution, the ecosystem structure of urban lakes may significantly impair and represent a health risk for the urban population. Thus, a growing public awareness should be developed regarding the quality of urban lakes and unique management plans in several urban areas to restore and maintain the recreational value of these water bodies, enhance their educational power, and avoid sanitary problems arising from the deterioration of their water quality.

Credit authorship contribution statement

This manuscript was written through the contributions of all authors. *Huong Mai:* conceptualization, manuscript writing, methodology, μFTIR analysis, and statistical data analysis. Bui Van Hoi, Dao Thanh Duong, Tran Manh Quan, Chu Nguyen Hoang Anh: seasonal water sampling in three lakes. Nguyen Danh Thien, Vu Toan Khanh: conducting the extraction and digestion to get MiP from water. Nguyen Thanh Duong: microplastics lecturing using stereomicroscope for water samples. Emillie Stragy: Writing review and editing of the manuscript contents.

Declaration of competing interest

The authors declare no competing financial interest.

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