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1      **Microplastics in sediments from urban and suburban rivers: influence of**  
 2      **sediment properties**

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## HIGHLIGHTS

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- Abundance and distribution microplastics in urban and suburban rivers were investigated
- Polypropylene and polyethylene were the dominant polymer types for fiber microplastics
- Sediment properties play role in microplastic accumulation and fate
- Human activities and urbanization increase microplastic pollution
- The potential ecological risk in urban and suburban river sediments was high

44 **Abstract:**

45 Although sediments are considered to be a major sink for microplastics (MP), there is still  
46 a relative lack of knowledge on the factors that influence the occurrence and abundance of  
47 MP in riverine sediments. The present study investigated the occurrence and distribution of  
48 MP in riverine sediments collected at twelve sites representative of different populated and  
49 urbanized rivers (To Lich, Nhue and Day Rivers) located in the Red River Delta (RRD, Vi-  
50 etnam, during dry and rainy seasons. MP concentrations ranged from 1,600 items  $\text{kg}^{-1}$  dw to  
51 94,300 items  $\text{kg}^{-1}$  dw. Fiber shape dominated and MP were made of polypropylene (PP) and  
52 polyethylene (PE) predominantly. An absence of seasonal effect was observed for both frag-  
53 ments and fibers for each rivers. Decreasing MP concentrations trend was evidenced from the  
54 To Lich River, to the Nhue River and to the Day River, coupled with a decreasing fiber length  
55 and an increasing fragment area in the surface sediment from upstream to downstream. Con-  
56 tent of organic matter was correlated to MP concentrations suggesting that, high levels of or-  
57 ganic matter could be MP hotspots in urban rivers. Also, high population density as well as in  
58 highly residential areas are related to higher MP concentrations in sediments. Finally, a MP  
59 high ecological risk (RI: 866 to 4711) was calculated in the RDD.

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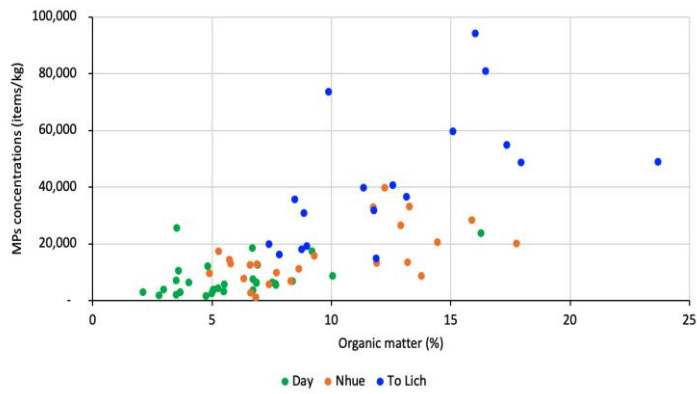
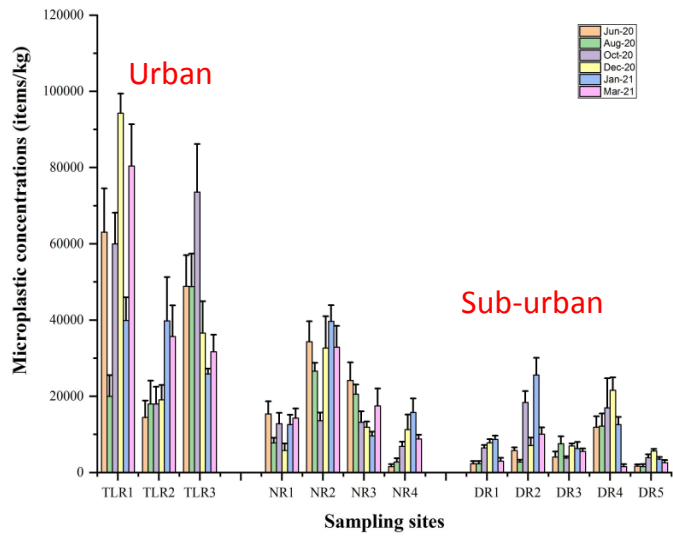
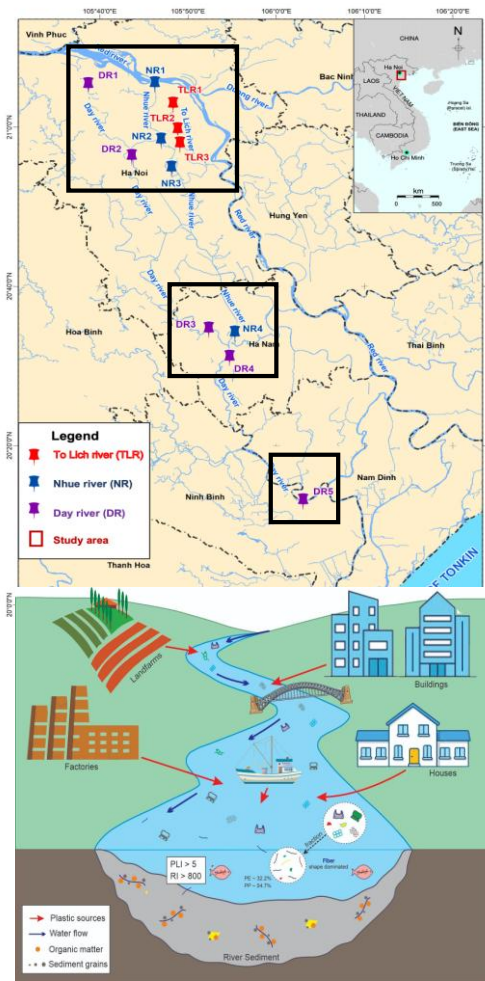
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64 **Keywords:** Microplastics, aquatic ecosystems, riverine sediment, urban and suburban rivers

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66 Graphical abstract:



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## 68 **Introduction**

69 Plastic production has increased rapidly since the start of large-scale plastic manufacturing  
70 in the 1950s due to its versatility, low cost, and durability (GESAMP, 2019). Global plastics  
71 production doubled from 2000 to 2019 to reach 460 million tons with only 9% recycled, 12%  
72 incinerated, and the remaining left in the environment or landfills (Geyer et al., 2017; OECD,  
73 2022). Global studies on plastic production and transportation estimated that the annual river-  
74 sourced contribution of plastic waste to oceans ranged from 0.41 to more than 8 million tons  
75 per year (Geyer et al., 2017; Lebreton et al., 2017; Meijer et al., 2021). Plastic waste is mostly  
76 non-degradable or very slow to degrade, resulting in accumulation in various environmental  
77 compartments (Abbasi et al., 2019; Wong et al., 2020; Bank, 2021; Dissanayake et al., 2022),  
78 in the form of microplastics (MP) -tiny particles smaller than 5 mm in size. Once in the envi-  
79 ronments, due to their specific physical properties, MP can become harmful as they can  
80 adsorb a wide range of toxic chemicals, and pathogens (Barletta et al., 2019; Guo and Wang,  
81 2019; He et al., 2020; Mao et al., 2020; Naqash et al., 2020) and be transferred to living or-  
82 ganisms through the food chain (Wootton et al., 2021). Since MP have small sizes, they are  
83 easily ingested by various organisms, leading to intestinal damage, reproductive dysfunction,  
84 lethality, developmental inhibition, reduction in lifespan, behavior and neural toxicity and  
85 oxidative damage (Lei et al., 2018 a, Song et al., 2019; Deng et al., 2020b; Li et al., 2020a).

86 MP pollution in freshwater ecosystems has been studied extensively since the last decade  
87 (Wagner et al., 2018 a), but a majority of research focused mainly on quantifying MP in sur-  
88 face waters, while less attention is given to their occurrence and migration in sediment.  
89 However, sediments have been considered to be the long-term sink for MP debris in aquatic  
90 ecosystems. MP can be entrapped and aggregated with other substances such as suspended  
91 matter, bacteria, fungi and algae to form a relatively large combination resulting in the rapid  
92 settlement of MP in the bottom of water bodies (Zhao et al., 2022). Recently, it has been

93 estimated that 70 - 90% of MP settled and accumulated into sediment environments world-  
94 wide (Yang et al., 2021). As a part of freshwater systems, rivers are one of the main pathways  
95 for transporting inland macro- and MP debris to the ocean (Lebreton et al. 2017). Although  
96 MP contamination in river systems has received attention, knowledge of MP distribution in  
97 riverine sediments still needs to be improved and clarified. Studies conducted in Asia, Eu-  
98 rope, America and Africa have shown that the abundance of MP in river sediments varied  
99 from almost none to several ten thousands of items per kilogram (Yang et al., 2021; Fan et al.,  
100 2022).

101 In Asia, urban rivers are crossing densely populated areas where people produce and use  
102 plastics. Therefore, urban rivers are a receptacle and a potential sink of plastic and MP, origi-  
103 nating from direct release of domestic and industrial wastewaters, treated and untreated (Peng  
104 et al., 2018; Cordova et al., 2022; Talbot and Chang, 2022) and from urban runoff (Yukioka  
105 et al., 2020; Le et al., 2023b). In riverine sediments, abundance of MP is often related to the  
106 proximity of dense population areas, land use and the intensity of anthropogenic activities  
107 (Rodrigues et al., 2018; Kumar et al., 2021). For example, a high concentration of MP in riv-  
108 erine sediments was recorded in most rivers crossing dense population areas such as in the  
109 Beijiang River, China (178 - 544 items kg<sup>-1</sup> (Wang et al., 2017); and the Nakdong River, South  
110 Korea (1,970 ± 62 items kg<sup>-1</sup>; observation size range [0.02 - 5 mm] (Eo et al., 2019). High  
111 levels of MP pollution were subjected to intense industrial activities (Lahens et al, 2018;  
112 Deng et al., 2020a) or recreational-tourism (Manbohi et al., 2023). Although studies on MP  
113 distribution in riverine sediments has increased lately (Phuong et al., 2022), the link between  
114 the occurrence of MP and the sediment properties still need to be better understood, despite  
115 past studies evidencing the role of grain size and organic matter content on MP fate and trap-  
116 ping (Mendes et al., 2021; Soltani et al., 2022). Since the understanding and identification of  
117 MP sources and sinks is important to effectively reduce the impact of plastic pollution on re-

118 ceiving ecosystems, the objective of this study is to characterize microplastic (MP) distribu-  
119 tion in riverine sediments from three contrasted river catchments in the Red River Delta  
120 (RRD) hydrosystem. More specifically, we aimed (i) assessing the level of MP concentrations  
121 in riverine sediments; (ii) evaluating sediment characteristics as a proxy of microplastic depo-  
122 sition in sediment; and discussing the correlation between MP abundance and sediment prop-  
123 erties, catchment characteristics; (iii) understanding the pollution status and ecological risk  
124 level of MP in urban and suburban rivers. The Red River Delta, localized in Northern Vi-  
125 etnam, is under the direct influence of the growing megacity of Hanoi, capital of Hanoi, and is  
126 subjected to a rapid change of urbanization that impacts its ecosystem. The three river catch-  
127 ments, e.g., To Lich River, Nhue River and Day River, located in the Red River Delta hydro-  
128 system, representing specific land use and urban pressure, were selected to monitor sediment  
129 characteristics and MP concentrations along each river and during both dry and rainy seasons.  
130 Therefore, the RRD can be considered as a representative model of Asian rivers crossing de-  
131 veloping megacities.

## 132 **2. Materials and methods**

### 133 **2.1. Study area**

134 The RRD, located in Northern Vietnam, is the country's second largest delta of the country  
135 (e.g., 169,000 km<sup>2</sup> RRD catchment area), and hosts Hanoi City, the capital (Figure 1). RRD is  
136 the most densely populated region with a population of more than 21 million inhabitants,  
137 growing annually by 1.14% (General Statistic Office 2018, 2021). The RRD has a tropical  
138 climate, characterized by two contrasted seasons: a rainy and warm season (May to October)  
139 and a dry and cooler season (November to April). There is an average annual rainfall of 1,700  
140 - 1,800 mm yr<sup>-1</sup> (Le et al., 2015). Over the past decade, anthropogenic activities have signifi-  
141 cantly altered the RRD hydrology, suspended sediment and associated nutrient load (Dang et



142 al., 2010; Le et al. 2015). Twelve sampling sites located upstream, midstream and down-  
143 stream sections of the To Lich, the Nhue and the Day Rivers were chosen (Figure 1; Table  
144 S1). Within the urban part of the RDD, the To Lich River (17 km length, mean annual dis-  
145 charge  $Q$ :  $30 \text{ m}^3 \text{ s}^{-1}$ ) flows through the Hanoi metropolitan area and receives untreated waste-  
146 water directly from urban areas, residential areas, and industrial zones, degrading the quality  
147 of its water badly (Duong et al., 2022). Along this river, three sampling sites were selected:  
148 upstream TLR-1 middle stream TLR-2 and downstream TLR-3. Then, the Nhue River (74 km  
149 length; mean annual discharge  $Q$ :  $70 \text{ m}^3 \text{ s}^{-1}$ ), a tributary of the Red River, flows through  
150 densely populated provinces and receives the waters directly from the To Lich River. Four  
151 sampling sites were selected along the Nhue River: NR-1 in the up-stream part at the conflu-  
152 ence with the Red River; NR-2 in the middle stream before the confluence with the To Lich  
153 River); NR-3, 7 km downstream of the confluence with the To Lich River and NR-4, 50 km  
154 downstream of the confluence. Finally, the Day River (mean annual discharge  $Q$ :  $252 \text{ m}^3 \text{ s}^{-1}$ )  
155 runs through highly urbanized provinces such as Hanoi, Hanam, Namdinh, and Ninhbinh,  
156 receiving waters from the Nhue River and flowing directly into the Gulf of Tonkin, dominat-  
157 ed by surrounding agriculture land use activities. Five sampling sites were selected along the  
158 longitudinal gradient of this river: DR-1, 9 km from the Day dam, Red river source; DR-2, 39  
159 km from the source; DR-3, 115 km from the source, situated before discharging from the pol-  
160 luted Nhue river; DR-4, 126 km from the source, located after receiving water from the Nhue  
161 River; and DR-5, 175 km from the source. The current ratio of the urban/rural population of  
162 the To Lich River (6.4) is 3.1 - 21.7-fold higher than in the Nhue River (2.01) and the Day  
163 River (0.3) (General Statistic Office, 2021).

## 164 **2.2. Sampling**

165 At each site, riverine sediment samples were collected during the rainy season, in June  
166 2020, August 2020, and October 2020 and during the dry season in November 2020, January

167 2021 and March 2021, for a total of 72 sediment samples. Riverine sediments (surface layer:  
168 0-5cm) were collected in triplicate in the middle, left, and right bank of the river, in the sub-  
169 merged zone (e.g., intertidal banks were avoided) using a Van-Veen grab sampler. Samples  
170 were directly pooled and homogenized before being wrapped in aluminium foil and trans-  
171 ported in an ice-box to the laboratory.

## 172 **2.3. Methods**

### 173 *Grain size distribution*

174 Grain size distribution was determined using laser diffraction with a Horiba LA 950 Grain  
175 Size Analyzer in triplicate. For this analysis, 2 g of sediment treated is required. Before ana-  
176 lyzing, organic matter was removed using 1 mL of 30 % H<sub>2</sub>O<sub>2</sub> overnight and sediment  
177 solutions were dispersed using 5.5 g L<sup>-1</sup> sodium hexametaphosphate (NaPO<sub>3</sub>)<sub>6</sub>. Grain size  
178 fractions were detected as volume percentages according to sediment grade based on a com-  
179 bination of sediment aggregated from Udden (1914) and Wentworth (1922) including: clay [<  
180 4 µm], silt [4 - 63 µm], sand [63-2,000 µm] and gravel [> 2,000 µm].

### 181 *Organic matter content*

182 Loss on ignition technique was measured to determine the organic matter (OM) content.  
183 Sediment sub-samples (1 g) were dried at 105 °C for 24 hours and then at 550 °C for 4 hours  
184 to estimate the pore water content and OM content, respectively, following the procedure of  
185 (Heiri et al., 2001).

### 186 *Microplastic extraction*

187 Sediment sub-samples were oven dried at 40 °C for 72 h to reach the constant weight, and  
188 were sieved (1 mm mesh size) to remove large particles (e.g., shells, leaves) prior to MP ex-  
189 traction and identification. MP extraction was performed using a density separation process  
190 (Strady et al., 2021; Duong et al., 2022) consisting of: (i) digesting the dried sediment with  
191 30% H<sub>2</sub>O<sub>2</sub> solution (Merck, Germany) at 40 °C for three hours to remove organic matter con-

192 tent; (ii) floatation of the fraction in a saturated NaCl solution ( $\rho = 1.2 \text{ g cm}^{-3}$ ) to separate MP  
193 particles; (iii) filtration of the supernatant solution through a GF/A glass microfiber filter  
194 (Whatman, diameter of 47 mm and pore size of  $1.6 \text{ }\mu\text{m}$ ) using a glassware filtration unit.

#### 195 *Microplastic observation*

196 MP collected on filters were analyzed using a Leica S9i stereomicroscope equipped with a  
197 camera. Based on their shapes, MP were categorised into fragments (including films and  
198 foams), fibers, and pellets. LAS software<sup>®</sup> was used to measure the color and size of the MP,  
199 with a defined size range of  $[300 - 5,000 \text{ }\mu\text{m}]$ , following the recommended protocol of  
200 GESAMP (2019).

#### 201 *Polymer identification by $\mu$ micro-Fourier Transform InfraRed ( $\mu$ -FTIR)*

202 Items suspected as MP from all sediment samples and in the range size of  $[300 - 5,000 \text{ }\mu\text{m}]$   
203 were randomly selected and analyzed for polymer compositions using a microscope coupled  
204 to a  $\mu$ FTIR spectrometer (NICOLET iN 10 MX infrared imaging microscope, Thermo Scien-  
205 tific). MP items were transferred onto Anodisc filters ( $0.2 \text{ }\mu\text{m}$  of porosity and 25 mm of di-  
206 ameter, Whatman, Germany). Measurement parameters and reference databases were de-  
207 scribed in the study of Dhivert et al. (2022). Among three detector types equipped on the in-  
208 strument, an imaging detector was used with 16 MCT detectors of  $25 \times 25 \text{ }\mu\text{m}$ . Each spec-  
209 trum was acquired in a transmission mode, wave numbers ranged from  $4,000$  to  $1,200 \text{ cm}^{-1}$   
210 with 1 accumulation and a resolution of  $8 \text{ cm}^{-1}$ . The background was performed on a clean  
211 Anodisc filter. Measured spectrums were automatically subtracted from the background dur-  
212 ing analyses. The whole filtered area was mapped and totaled more than 600,000 acquired  
213 spectrums for a filter. The obtained spectra were compared to reference spectra via the siMPle  
214 software (version 1.1.β). This free tool ([simple-plastics.eu](http://simple-plastics.eu)) was recently developed by  
215 Primpke et al. (2018). Reference databases include more than 30 polymer types and some

216 natural compositions, such as protein. An item is accepted as MP when the matching score is  
217 satisfied to the values set up by the default (*i.e.*  $\geq 75\%$  for PE;  $\geq 55\%$  for PP).

#### 218 *MP risk assessment*

219 The potential ecological risk of MP in sediments in the To Lich, Nhue and Day Rivers was  
220 calculated using a combination of Pollution load index (PLI), and ecological risk (RI) as pre-  
221 viously proposed by Li et al. (2020b). The calculation equations of the PLI and RI are given  
222 below:

$$223 \quad CF_i = C_i/C_o \quad (1)$$

$$224 \quad PLI = \sqrt{CF_i} \quad (2)$$

$$225 \quad RI = \sum_{n=1}^n (E_i) \quad (3)$$

$$226 \quad E_i = T_i \times (C_i/C_o) \quad (4)$$

227 Where:  $C_i$ : the concentration of MP (item per kg dry weigh) at the site  $i$ ;  $C_o$ : the minimum  
228 MP concentration. Instead of considering the minimum concentration observed during our  
229 study, as all sites are in urban zone and potentially contaminated, we used as  $C_o$  the MP con-  
230 centration determined at Ba Lat, Red river (rural area) ( $C_o=133$  items  $kg^{-1}$  dry weigh; Le et  
231 al., 2023a) as the reference background value.  $E_i$  and RI are the potential ecological risk fac-  
232 tor and the potential ecological risk, respectively;  $T_i$ : chemical toxicity of a specific polymer  
233 (Lithner et al., 2011). PLI is classified into four risk categories: I (PLI < 10); II (PLI: 10 - 20);  
234 III (PLI: 20 - 30); IV (PLI > 30). The potential ecological risk level is considered to be five  
235 categories: minor (RI < 150), medium (RI: 150 -300), high (RI: 300 - 600), danger (RI: 600 -  
236 1,200) and extreme danger (> 1200).

#### 237 **2.4. Quality control**

238 All sampling equipment and laboratory glassware were previously cleaned with filtered de-  
239 ionized water and wrapped in aluminum foil to avoid any cross-site contamination. Cotton  
240 laboratory coats and nitrile gloves were used and working surfaces were cleaned daily with  
241 ethanol. All reagents employed during the sample processing were previously filtered through  
242 a 1.6  $\mu\text{m}$  glass fiber filter (Whatman GF/A) and then stored in clean glass containers. Blank  
243 samples were run simultaneously with analysis samples to assess the background and cross-  
244 contamination during laboratory analysis. There were an average of two fibers per sample  
245 which is considered negligible compared to the number of MP detected in field sediment  
246 samples.

## 247 **2.5. Data treatments**

248 The MP concentration in sediments was expressed as particles per kilogram of dry  
249 sediment (items  $\text{kg}^{-1}\text{dw}$ ). Non-parametric Mann-Whitney and Kruskal-Wallis tests were used  
250 to compare the abundance MP among sites, rivers and sampling times. Correlations and  
251 Principal component analysis (PCA) using the R software - R version 4.0 (R Core Team,  
252 2018) were applied to investigate the covariance of the relationships between the occurrence  
253 of microplastics in river sediments, population characteristics and land uses of river  
254 catchments.

## 255 **3. Results and discussion**

### 256 ***3.1. Microplastic level, shape and size variations between rivers and seasons***

257 MP were identified in all three studied rivers, at all sampling sites and during both the dry  
258 and rainy seasons. Their concentrations ranged from 1,600 items  $\text{kg}^{-1}\text{dw}$  to 94,300 items  $\text{kg}^{-1}$   
259  $\text{dw}$  (Figure 2), which is higher than 60% of the reported MP concentrations in riverine sedi-  
260 ments from Asia (e.g., 100 - 1,000 items  $\text{kg}^{-1}\text{dw}$ ; Phuong et al., 2022). Fiber shape dominated  
261 over fragment shape in the three rivers (Figure 3), as reported worldwide in urbanized aquatic

262 environments (Alam et al. 2019; Murphy et al., 2022). MP colors observed in the three rivers  
263 were purple for 40% of the whole MP, black for 16%, green for 13%, red for 12%, blue for  
264 11% and the remaining was a mixture of grey, white and yellow (Figure 4).

265 The polymer compositions of analyzed MP were polyethylene (PE) and polypropylene  
266 (PP), which accounted for 87% of all identified MP, followed by polyester (5.78%), polysty-  
267 rene (PS) (4.1%), polyvinyl chloride (PVC) (1.5%), polyurethane (PU) (1.2%) and other  
268 (0.4%) (Table 1 and Figure 1S). The results are similar to previous studies conducted in rivers  
269 crossing areas subjected to high anthropogenic pressure, like in Shanghai, Haihe River basin  
270 and Wen-Rui Tang River, China (Peng et al., 2018; Liu et al., 2021a and b, Wang et al.,  
271 2018); in Indian Himalaya, India (Tsering et al., 2021) (Table 2).

272 The three rivers presented specific MP concentrations over the whole sites and sampling  
273 periods (Kruskal-Wallis test,  $p < 0.0001$ , followed by the Conover-Iman test with  $p < 0.0001$   
274 for all). The To Lich River (TLR1, TLR2, TLR3) presented the highest concentrations with  
275 an average abundance of MP over the six sampling periods and sites of  $42,683 \pm 23,544$  items  
276  $\text{kg}^{-1}$  dw ( $n = 18$ ). No seasonal pattern was observed between the dry (corresponding Novem-  
277 ber, January, and March) and rainy (corresponding July, August, and October) seasons for  
278 MP in this river (Mann-Whitney test,  $p > 0.05$ ) pointing out the integrative aspect of the sed-  
279 iment through time in this riverine system. In comparison to other studies using the similar  
280 analytical procedure, notably for extraction, MP concentrations in the To Lich River sedi-  
281 ments were higher than those documented in other rivers in Europe, America, Africa and Asia  
282 (Table 2) and the same order of magnitude as sediments from the Phu Loc channel in Da  
283 Nang, receiving direct municipal untreated wastewater from densely populated areas (Nguyen  
284 et al., 2022). The Nhue River (NR1, NR2, NR3) presented an average abundance over the six-  
285 sampling periods and sites of  $16,350 \pm 10,359$  items  $\text{kg}^{-1}$  dw ( $n = 18$ ) while the lower average  
286 abundance of  $7,747 \pm 6,117$  items  $\text{kg}^{-1}$  dw ( $n = 18$ ) was measured in the Day River (DR1,

287 DR2, DR3) depicted in Figure 2. As for the To Lich River, no differences in MP concentra-  
288 tions were observed between the dry and the rainy seasons in both rivers (Mann-Whitney test,  
289  $p > 0.05$ ), which also points out the integrative aspect of this compartment.

290 Considering fiber only, fiber concentrations at each river evidenced an absence of seasonal  
291 effect (Mann-Whitney test,  $p > 0.05$ ) and concentrations were significantly different over the  
292 whole sampling period, with higher concentrations measured in the To Lich River, followed  
293 by the Day River and the Nhue River (Kruskal-Wallis test,  $p < 0.0001$ , followed by Conover-  
294 Iman test with  $p < 0.0001$  for all). Over the whole sampling period, the mean median fiber  
295 length was measured  $1,091 \mu\text{m}$  in the Day River,  $1,222 \mu\text{m}$  in the Nhue River, and  $1,291 \mu\text{m}$   
296 in the To Lich River (Figure 5), with a significant difference between the To Lich River and  
297 the Day River only (Kruskal-Wallis test,  $p < 0.027$ , followed by Conover-Iman test with  $p <$   
298  $0.009$  for the To Lich and Day Rivers). This decreasing fiber length from upstream to down-  
299 stream showed that longer fibers were sampled in the surface sediment of highly urbanized  
300 and still environments like the To Lich River (mean annual discharge  $Q: 30 \text{ m}^3\cdot\text{s}^{-1}$ ) and that  
301 shorter fibers were sampled in the surface sediment of the larger river, with higher water dis-  
302 charge, less direct urban pressure, and receiving waters from the whole basin, like the Day  
303 River (mean annual discharge  $Q: 252 \text{ m}^3\cdot\text{s}^{-1}$ ). The median fiber length, determined at each site  
304 and at each sampling time, presented an absence of seasonal effect for all rivers (Mann-  
305 Whitney test,  $p > 0.05$ ).

306 Considering fragment only, fragment concentrations at each river also evidenced an ab-  
307 sence of seasonal effect (Mann-Whitney test,  $p > 0.05$ ), with significantly higher concentra-  
308 tions measured in the To Lich River over the whole sampling period (Kruskal-Wallis test,  $p <$   
309  $0.0001$ , followed by Conover-Iman test with  $p < 0.0001$  for the To Lich River only. The mean  
310 median fragment area was  $210,016 \mu\text{m}^2$  in the Day River;  $163,408 \mu\text{m}^2$  in the Nhue River and  
311  $151,792 \mu\text{m}^2$  in the To Lich River, over the whole sampling period. Contrary to fiber shape,

312 we noticed an increasing fragment area size floating in the surface sediment, from upstream to  
313 downstream and a seasonal effect for fragment median area in the To Lich River only  
314 (Kruskal-Wallis test,  $p < 0.003$ , followed by Conover-Iman test with  $p < 0.003$  for the Day  
315 and To Lich Rivers and for the Nhue and To Lich Rivers) (Figure 5). To summarize, average  
316 concentrations over the six-sampling period and sites clearly evidenced a decreasing trend of  
317 MP concentrations, fibers and fragments, from the To Lich River, to the Nhue River and to  
318 the Day River, coupled with a decreasing fiber length and an increasing fragment area in the  
319 surface sediment from upstream to downstream.

### 320 ***3.2. Sediment characteristics***

321 Grain size trends are a natural result of sediment transport processes related to the effects  
322 of abrasion and selective sorting (Le Roux and Rojas 2007). The sediments sampled in the To  
323 Lich, Nhue and Day Rivers were categorized from silt to sandy silt. The mean grain size var-  
324 ied between the rivers from the To Lich River, to the Nhue River then to the Day River, and  
325 decreased from upstream to downstream (Table 3). The grain size of riverine sediments  
326 generally tends to decrease in the transport direction, from upstream to downstream (Le Roux  
327 and Rojas 2007). The sorting of the river sediment samples were divided into poorly sorted  
328 and very poorly sorted due to the average sorting values of all river sediments being higher  
329 than 2 mm. The sediments were categorized as very poorly sorted because the particle size  
330 either accumulated randomly (Ingmanson and Wallace, 1994) or was transported over a short  
331 distance (Folk and Ward, 1957). The poor sorting is also influenced by the current velocity  
332 which may be inhomogeneous most of the time (Li et al., 2022), so the accumulated sediment  
333 grains would be relatively various.

334 Conversely, this may also be because the sediments have possibly been deposited relative-  
335 ly close to the source areas. The skewness, a parameter of the asymmetry of frequency  
336 distribution concerning median value of sediment grain size, varied substantially and the



337 kurtosis, a measure of the “peakedness” of the distribution, changed slightly. The features of  
338 almost all riverine sediments define a symmetrical to fined skewed and platykurtic grain size  
339 distribution. This distribution indicates that positive skewness values generally find fine-sized  
340 substrate, i.e. silt to clay (Switzer and Pile, 2015) and low kurtosis value is produced with  
341 bimodal frequency (flat) curves equating to poorly sorted sediments.

342 The loss of ignition  $LOI_{550}$  is a standard method to determine the sediment's organic matter  
343 (OM) content. The level of OM varied significantly along the three studied rivers, with de-  
344 creasing values from upstream, e.g., 12.7 wt% in the To Lich River, to downstream with 9.7%  
345 in the Nhue River and 5.9% in the Day River (Kruskal-Wallis test,  $p < 0.0001$ , followed by  
346 Conover-Iman test with  $p < 0.0001$ ) (Table 3). The high OM values observed in the To Lich  
347 River, until 23.7% evidenced inputs of untreated wastewater, rich in organic matter, directly  
348 to the river. The decreasing trend from upstream to downstream is consistent with the de-  
349 creasing urban pressure observed in the water basins, the increasing river width and the in-  
350 creasing water discharge (see section 2.1).

### 351 ***3.3 Relationships between abundance of MP and sediment properties***

352 The accumulation of MP in river sediments depends on certain factors, including their  
353 sources, deposition rates, and environmental factors such as river morphology, fineness of  
354 sediments, amounts of organic debris, etc. (Corcoran et al., 2020; Mendes et al., 2021). The  
355 Pearson correlation analysis showed a significant and positive correlation between MP abun-  
356 dance and sediment properties such as OM ( $R = 0.7$ ;  $p < 0.001$ ) and sediment median grain  
357 size ( $R = 0.27$ ;  $p < 0.05$ ) (Table 4). High level of organic matter in sediment is probably due to  
358 the elevated total organic carbon found in the water column of the Tolich, the Nhue and the  
359 Day rivers ( $10.7 - 48.5 \text{ mg L}^{-1}$ ;  $3.7 - 18.3$  and  $12.5 - 26 \text{ mg L}^{-1}$ , respectively) (Kikuchi et al.,  
360 2009; Trinh et al., 2013). Increased OM, consequent eutrophication, and increased heavy  
361 metals from untreated wastewater input along the rivers are well documented in previous

362 studies (Trinh et al., 2013; Luu et al., 2020). As a transport agent in the aquatic system, OM  
363 could interact with and absorb on the surface of microplastic creating different forms of ag-  
364 gregations with a higher density that could be transported as distinct particles. A high concen-  
365 tration of OM in the water could make MP collide and speed up MP aggregation and  
366 biofouling (Li et al., 2020a; Luo et al., 2022). MP particles would probably incorporate and  
367 integrate into the aggregated matter, along with pieces of other OM, before accumulating in  
368 sediment (Rillig, 2018). Sediments with high total organic carbon (TOC) can absorb more MP  
369 from the environment than those with low TOC due to their high cohesive capacity of OM  
370 (Green and Johnson, 2020). The accumulation of MP at the organic rich sediment sites (the  
371 To Lich and the Nhue Rivers) was significantly higher than those at less organic rich sedi-  
372 ment sites (the Day River) ( $p < 0.001$ ) (Figure 2 and Table 3), suggesting that a high abun-  
373 dance of MP in sediment is mainly related to high organic content. This leads to the presump-  
374 tion that organic matter is an important factor in the accumulation of MP (Wang et al., 2021)  
375 and that high levels of organic matter could be the hotspots for MP in aquatic sediments.

376 The link between sediment grain size and MP has been previously identified in several  
377 field studies (e.g., Enders et al., 2019; Corcoran et al., 2020; Vermeiren et al., 2021; Dhivert  
378 et al., 2022). The current study observed a correlation between median grain size and the  
379 abundance of MP. The sediment types with the highest abundance across three rivers consist-  
380 ed of 85.9% silt (fine silt to coarse silt;  $< 63 \mu\text{m}$ ). Sediment samples from the three rivers  
381 exhibited a high level of MP (from 1,600 items  $\text{kg}^{-1}\text{dw}$  to 94,300 items  $\text{kg}^{-1}\text{dw}$ ), but the  
382 quantity of MP varied among different sediment grain sizes. The abundance of MP was posi-  
383 tively correlated with coarse silt ( $R = 0.25$ ,  $p < 0.05$ ) but negatively correlated with the pro-  
384 portion of fine silt and clay ( $R = -0.25$ ,  $p < 0.05$  and  $R = -0.32$ ,  $p < 0.01$ ) (Table 4). Although  
385 a clear correlation between sediment grain size and the abundance of MP was evident and  
386 noted in several studies, such relationships were not always consistent. For example, a num-

387 ber of studies reported that, in sediment samples with smaller grain sizes such as clay or silt  
388 fractions ( $< 63 \mu\text{m}$ ), a greater abundance of MP was observed (Corcoran et al., 2020; Enders  
389 et al., 2019; He et al., 2020). In contrast, it was found in both Peng et al. (2017) and Amrutha  
390 et al. (2023) that the sediment grain size was not significantly correlated with MP concentra-  
391 tions. This is likely due to a lack of comprehensive data sets on the interaction between trans-  
392 port and accumulation of MP and other multiple potential influence factors such as hydrody-  
393 namic conditions (He et al., 2020). Further studies are needed to provide a detailed under-  
394 standing of MP accumulation in sediments, combined with different potential factors such as  
395 sediment particle types, and flow conditions.

### 396 ***3.4 Relationships between abundance of MP and catchment***

397 In order to identify the relationship between the abundance of MP in sediment and influen-  
398 tial factors, a Principal Component Analysis (PCA) and Pearson correlation analyses were  
399 conducted (Figure 5 and Table 4). The variables in the data matrix for the PCA are based on  
400 the concentration of MP, sediment properties (grain size, OM) and catchment characteristics  
401 (area of catchment; population; population density; land use for agriculture; specially used;  
402 land use for residents). As defined by axes 1 and 2, representing around 70.9 % of the total  
403 variance, and two zones that are clearly individualized, the To Lich River and upstream of the  
404 Nhue River sites located in the right part of PCA and the Day and the Nhue downstream sites  
405 positioned in the left part of the PCA. A high abundance of microplastics, population, and  
406 resident areas can explain these sites. High agricultural land use explains the Day and Nhue  
407 downstream sites positioned in the right part of the PCA. Population density and urbanization  
408 are often associated with the intensity of human activities and socio-economic development,  
409 both supposedly linking MP occurrence in aquatic ecosystems. Based on the Pearson analysis,  
410 MP abundance has a significant positive correlation with population ( $R = 0.38$ ;  $p < 0.01$ );  
411 urban population/rural population ( $R = 0.72$ ;  $p < 0.001$ ); land use for resident and specially

412 used land, respectively ( $R = 0.53$ ;  $p < 0.001$ ); ( $R = 0.48$ ;  $p < 0.001$ ), which has a significant  
413 negative correlation with area ( $R = -0.52$ ;  $p < 0.01$ ); and land use for agriculture ( $R = 0.5$ ;  $p <$   
414  $0.001$  (Table 5). The results of the present study highlight that the abundance of MP increased  
415 in areas with higher population density as well as in highly residential areas.

416 Compared to the Day River, the To Lich and the Nhue Tivers have more urbanized area  
417 and populous catchments, the urbanized sites (TLR1, TLR2, TLR3) contaminated more MP  
418 than the suburban sites in the downstream course (DR1, DR2, DR3, DR4 and DR5) (Kruskal-  
419 Wallis test,  $p < 0.0001$ ), suggesting that high population and increased urbanization in an area  
420 could significantly strengthen the potential for MP outgassing. Our results are consistent with  
421 recent research showing that the MP level was 65% higher in the more urban sites compared  
422 to the more rural section of the Tame River, UK (Tibbetts et al., 2018). Similar studies have  
423 reported a general trend toward higher microplastic pollution levels in more urbanized and  
424 intensive anthropogenic activity zones (Townsend et al., 2019). Although agricultural input is  
425 an essential source of MP pollution, the lower level of MP observed in areas with high agri-  
426 cultural land use in the Day River (DR1 - DR5) suggested that agricultural land use may have  
427 less impact on MP distribution compared to urban areas (the To Lich and the Nhue River  
428 sites), which has also been discussed in other studies. Recent studies highlighted that signifi-  
429 cant differences in microplastic levels in sediment samples collected from different land uses  
430 of the Arvand River in Iran were found and the abundance of MP followed a decreasing or-  
431 der: urban > industrial > agricultural > and natural areas (Soltani et al., 2022). Using a multi-  
432 plicative linear regression and Bayesian Network modelling approach, MP were found to cor-  
433 relate significantly with land use and population (Tibbetts et al., 2018; He et al., 2020). How-  
434 ever, in their study on the distribution pattern of MP in Brisbane River sediment, He et al.  
435 (2020) implied that population and land use have a relatively greater impact on MP types  
436 rather than MP concentration.

### 437 *3.5 Potential ecological risk in urban and suburban rivers*

438 MP could cause multifaceted ecological risks in aquatic and terrestrial environments. To  
439 comprehensively reduce the risk of MP pollution and develop control measures, ecological  
440 risk assessment of MP is an important scientific basis. The Pollution load index (PLI) indi-  
441 cates the level of MP pollution in surface sediments, which is based on the ratio between the  
442 measured concentration of MP and the background value. The PLI values for MP determined  
443 at the To Lich - Nhue and Day Rivers were classified as hazard level II, meaning that the de-  
444 gree of MP contamination in sediment was at a moderate pollution load (Table 2S). The PLI  
445 results showed that the degree of pollution caused by MP was higher in the To Lich and Nhue  
446 Rivers compared to the Day River during the investigation. The main reason for this was the  
447 MP' sources and the significant anthropogenic activities in the studied area. Terrestrial input  
448 of microplastic particles into rivers may occur due to effluent discharge from municipal  
449 wastewater, runoff from urban, agricultural, recreational and industrial areas. Previous studies  
450 have indicated that the To Lich and Nhue rivers are strongly impacted by untreated wastewa-  
451 ter disposal waste and urban runoff from the country's capital of Hanoi (Nguyen et al., 2019;  
452 Duong et al., 2022). It has been noted that approximately 95% of untreated wastewater efflu-  
453 ents (approximately 450,000 m<sup>3</sup> per day) from many sources (domestic, hospital waste, and  
454 industrial waste) are discharged into urban rivers (Hoai et al., 2010), including the ones stud-  
455 ied (e.g., Nhue River, To Lich River). The entry of large amounts of untreated wastewater  
456 from urbanized, residential and recreational areas along the rivers which increased in OM,  
457 heavy metals, other pollutants, and the consequent eutrophication have been well documented  
458 in the studied sites. The fact that the number of MP in the three studied rivers presented high  
459 concentrations at all sampling sites confirms that the direct discharge of untreated wastewater  
460 from various sources from the city can be accredited as the potential primary origin of MP in  
461 these rivers. There are other MP sources of MP in the surrounding area of the rivers in this

462 study. According to Suzuki et al. (2022), generated MP are released into the aquatic environ-  
463 ment ( $2.4 \times 10^9$  -  $2.8 \times 10^{12}$  MP particulates per year and 0.014 to 5.8 tonnes per year) during  
464 mechanical recycling of plastic wastes from traditional villages located along the Nhue-Day  
465 basin. Furthermore, the results of  $\mu$ FTIR showed PE and PP were the most common polymer  
466 types found in all sediment samples. Such polymers most likely originate from single-use  
467 packaging materials (e.g., grocery bags, food packaging, bottles, straws, containers, cups,  
468 cutlery, etc.), textiles (e.g., clothes, carpets, rope and nets) and personal care products, and  
469 therefore may end up as discharge in sewage outlets. The PLI approach has been accepted and  
470 used in numerous studies to evaluate the pollution load of MP in sediments (Peng et al.,  
471 2018). However, the PLI risk level is usually incomparable among different studies due to the  
472 difference in background concentration values for calculation. In addition, the PLI is based  
473 only on the microplastic concentration without consideration of different MP characteristics  
474 (polymer types, colors, sizes and shapes). A high-risk degree of MP pollution in sediment  
475 would be highly dependent on the high toxicity of the polymer.

476 The potential ecological risk index (RI) is utilized to evaluate the level of MP contamina-  
477 tion in the sediment. This index has not only considered MP concentration but also the toxic-  
478 ity of polymer types. The toxicity level and toxic effects of different MP polymers vary ac-  
479 cording to their chemical properties and compositions. Regarding the risk levels based on RI  
480 values in sediments of the Day and To Lich and Nhue Rivers, they were categorized into two  
481 levels: danger (RI: 600 - 1200), and extreme danger (RI > 1200), respectively (Table 2S).  
482 Despite the preponderance of PP and PE polymers with low hazard scores, which were found  
483 in the sediment from the rivers in this study, the presence of strong toxic such as PS, PU or  
484 PVC had an impact on the risk assessment of MP. Overall, MP in freshwater sediments from  
485 the To Lich, Nhue and Day Rivers exhibited a medium pollution load and danger, reaching an  
486 extreme ecological risk level. Reducing, reusing, recycling, and treating plastic waste requires

487 a feasible solution in order to manage and prevent the increase of MP pollution loads in  
488 freshwater sediments from collected study areas. Finally, additionally to the MP concentration  
489 level, the potential ecological risk of MP should take into account their ability to act as a vec-  
490 tor of organic pollutants, metal contaminants, and microbial pathogens into organisms (He at  
491 al., 2020; Wootton et al., 2021). An ecological risk assessment indicator taking into account  
492 all those factors should be established to better characterize the impacts of MPs on riverine  
493 biodiversity.

#### 494 **Conclusion**

495 High MP abundance was observed in the surface sediments from the To Lich-Nhue-  
496 Day Rivers. The results clearly showed a decreasing trend of MP abundance from the dense  
497 urban areas toward the suburban zone areas. MP exhibited a significant positive and negative  
498 correlation with population and land use. MP and organic matter were positively correlated,  
499 suggesting that organic matter can play a significant role in MP trapping and retention in  
500 sediment. This finding can be relevant for urban rivers of developing cities or of developing  
501 countries from Vietnam and worldwide as the OM content is often higher due to direct  
502 wastewater released in the rivers. In the future, the effect of sediment characteristics on the  
503 fate and transport of MP should be further investigated especially on the point/non- point  
504 sources of MP, on particles interactions during their settling, and their impacts on ecosystems.

#### 505 **Conflict of interest statement**

506 The authors declare that the research was conducted in the absence of any commercial or fi-  
507 nancial relationships that could be construed as a potential conflict of interest.

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514

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523

#### 524 **References**

- 525 Abbasi, S., Keshavarzi, B., Moore, F., Turner, A., Kelly, F.J., Dominguez, A.O., Jaafarzadeh  
526 N., 2019. Distribution and potential health impacts of microplastics and microrubbers in air  
527 and street dusts from Asaluyeh County, Iran. *Environ. Pollut.* 244, 153-164.
- 528 Alam, F.C., Sembiring, E., Muntalif, B.S., Suendo, V., 2019. Microplastic distribution in  
529 surface water and sediment river around slum and industrial area (case study: Ciwalengke  
530 River, Majalaya district, Indonesia). *Chemosphere* 224, 637-645.
- 531 Amrutha, K., Shajikumar, S., Warriar, A., Sebastian J.G., Sali, Y.S., Chandran, T., Sivadas,  
532 S., Naik, R., Amrishi, V.N., Kumar, A., Unnikrishnan V., 2023. Assessment of pollution  
533 and risks associated with microplastics in the riverine sediments of the Western Ghats: a  
534 heritage site in southern India. *Environ. Sci. Pollut. Res.* 30, 32301-32319.
- 535 Bank, M.S., 2021. *Microplastic in the Environment: Pattern and Process*, first ed. Springer  
536 Cham.
- 537 Barletta, M., Lima, A.R.A., Costa M.F., 2019. Distribution, sources and consequences of  
538 nutrients, persistent organic pollutants, metals and microplastics in South American  
539 estuaries. *Sci. Total Environ.* 651 (1), 1199-1218.
- 540 Corcoran, P.L., Belontz, S.L., Ryan, K., Walzak, M.J., 2020. Factors controlling the distribu-  
541 tion of microplastic particles in benthic sediment of the thames river, Canada. *Environ. Sci.*  
542 *Technol.* 54 (2), 818-825.
- 543 Cordova, M.R., Nurhati, I.S., Shiimoto A., Hatanaka, K., Saville, R., Riani, E., 2022. Spatio-  
544 temporal macro debris and microplastic variations linked to domestic waste and textile in-  
545 dustry in the supercritical Citarum River, Indonesia. *Mar.Poll. Bull* 175, 113338.
- 546 Dang, T.H., Coynel, A., Orange, D., Blanc, G., Etcheber, H., Le, L.A., 2010. Long-term  
547 monitoring (1960-2008) of the river-sediment transport in the Red River Watershed (Viet-



548 nam): Temporal variability and dam-reservoir impact. *Sci. Total. Environ.* 408 (20), 4654-  
549 4664.

550 Deng, H., Wei, R., Luo, W., Hu, L., Li, B., Di, Y., Shi, H., 2020 a. Microplastic pollution in  
551 water and sediment in a textile industrial area. *Environ. Pollut.* 258, 113658.

552 Deng, Y., Yan, Z., Shen, R., Wang, M., Huang, Y., Ren, H., Zhang, Y., Lemos, B., 2020b.  
553 Microplastics release phthalate esters and cause aggravated adverse effects in the mouse  
554 gut. *Environ. Int.* 143, 105916.

555 Dhivert, E., Phuong, N.N., Mourier, B., Grosbois, C., Gasperi, J., 2022. Microplastic trapping  
556 in dam reservoirs driven by complex hydrosedimentary processes (Villerest Reservoir,  
557 Loire River, France). *Water Res.* 225, 119187.

558 Dissanayake, P.D., Kim, S., Sarkar, B., Oleszczuk, P., Sang, M.K., Haque, M.N, Ahn, J.H.,  
559 Bank, M.S., Ok, Y.S., 2022. Effects of microplastics on the terrestrial environment: A  
560 critical review. *Environ. Res.* 209, 112734.

561 Duong, T.T., Le, P.T., Nguyen, T.N.H., Hoang, T.Q., Ngo, H.M., Doan, T.O., Le, T.P.Q.,  
562 Bui, H.T., Bui, M.H., Trinh, V.T., Nguyen, T.L., Le, N.D., Vu, T.M., Tran, T.K.C., Ho,  
563 T.C., Phuong, N.N., Strady, E., 2022. Selection of a density separation solution to study  
564 microplastics in tropical riverine sediment. *Environ. Monit. Assess.* 194, 65.

565 Enders, K., K ppler, A., Biniash, O., Feldens, P., Stollberg, N., Lange, X., Fischer, D.,  
566 Eichhorn, K., Pollehne, F., Oberbeckmann, S., Labrenz, M., 2019. Tracing microplastics in  
567 aquatic environments based on sediment analogies. *Sci. Rep.* 9 (1), 15207.

568 Eo, S., Hong S.H., Song, Y.K., Han, G.M., Shim, W.J., 2019. Spatiotemporal distribution and  
569 annual load of microplastics in the Nakdong River, South Korea. *Water Res.* 160, 228-237.

570 Fan, J., Zou, L., Duan, T., Qin, L., Qi, Z., Sun, J., 2022. Occurrence and distribution of  
571 microplastics in surface water and sediments in China's inland water systems: A critical  
572 review. *J. Clean. Prod.* 331, 129968.

573 General Statistic Office (GSO), 2018. Statistical Yearbook of Vietnam 2018. Statistical  
574 Publishing House, Vietnam (in Vietnamese).

575 General Statistic Office (GSO), 2021. Statistical Yearbook of Vietnam 2021. Statistical  
576 Publishing House, Vietnam (in Vietnamese).

577 GESAMP, 2019. Guidelines for the Monitoring and Assessment of Plastic Litter in the Ocean,  
578 123 p.

579 Geyer, R., Jambeck, J.R., Law, K.L., 2017. Production, use, and fate of all plastics ever  
580 made. *Sci. Adv.* 3 (7).

581 Green, B.C., Johnson, C.L.E., 2020. Characterisation of microplastic contamination in sedi-  
582 ment of England's inshore waters. *Mar. Pollut. Bull.* 151, 110788.

583 Guo, X., Wang, J., 2019. Sorption of antibiotics onto aged microplastics in freshwater and  
584 seawater. *Mar. Pollut. Bull.* 149, 110511.

585 He, B., Goonetilleke, A., Ayoko, G.A., Rintoul, L., 2020. Abundance, distribution patterns,  
586 and identification of microplastics in Brisbane River sediments, Australia. *Sci. Total*  
587 *Environ.* 700, 134467.

588 Heiri, O., Lotter, A.F., Lemcke, G., 2001. Loss on ignition as a method for estimating organic  
589 and carbonate content in sediments: reproducibility and comparability of results. *J.*  
590 *Paleolimnol.* 25, 101-110.

591 Hoai, P.M., Ngoc, N.T., Minh, N.H., Viet, P.H., Berg, M., Alder, A.C., Giger, W., 2010.  
592 Recent levels of organochlorine pesticides and polychlorinated biphenyls in sediments of  
593 the sewer system in Hanoi, Vietnam. *Environ. Pollut.* 158 (3), 913-920.

594 Hosain, Md.J., AftabUddin, S., Akhter, F., Nusrt, N., Rahaman, A., Sikder, M.N.A., Monwar,  
595 Md.M., Chowdhury, M.S.N., Jiang S., Shi H., Zhang J., 2022. Surface water, sediment,  
596 and biota: The first multi-compartment analysis of microplastics in the Karnafully river,  
597 Bangladesh. *Mar. Poll. Pull*, 180: 113820

598 Ingmanson, D.E., Wallace, W.J., 1994. *Introduction to Oceanography*, fifth ed. Brooks/Cole  
599 Pub Co.

600 Kikuchi, T., Furuichi, T., Hai, H.T., Tanaka, S., 2009. Assessment of heavy Metal Pollution  
601 in River Water of Hanoi, Vietnam Using Multivariate Analyses. *Bull Environ Contam*  
602 *Toxicol.* 83 (4), 575-582.

603 Klein, S., Worch, E., Knepper, T.P., 2015. Occurrence and spatial distribution of microplastic  
604 s in river shore sediments of the rhine-main area in Germany. *Environ. Sci. Technol.* 49,  
605 6070–6076.

606 Kumar, R., Sharma, P., Manna, C., Jain M., 2021. Abundance, interaction, ingestion,  
607 ecological concerns, and mitigation policies of microplastic pollution in riverine  
608 ecosystem: A review. *Sci. Total Environ.* 782, 146695.

609 Lahens, L., Strady, E., Kieu-Le, T.-C., Dris, R., Boukerma, K., Rinnert, E., Gasperi, J., Tas-  
610 sin, B., 2018. Macroplastic and microplastic contamination assessment of a tropical river  
611 (Saigon River, Vietnam) transversed by a developing megacity. *Environ. Pollut.* 236, 661–  
612 671.

613 Le Roux, J.P., Rojas, E.M., 2007. Sediment transport patterns determined from grain size  
614 parameters: Overview and state of the art. *Sediment. Geol.* 202 (3), 473-488.

615 Le, T.P.Q., Billen, G., Garnier, J., Chau, V.M., 2015. Long-term biogeochemical functioning  
616 of the Red River (Vietnam): past and present situations. *Reg. Environ. Change* 15, 329-  
617 339.

618 Le, N. D, Hoang, T.T.H, Duong, T.T., Phuong, N.N., Le, P.T., Nguyen, T.D., Phung, T.X.B.,  
619 Le, T.M.H., Le, T.L., Vu, T.H., Le, T.P.Q, 2023a. Microplastics in the Surface Sediment of  
620 the main Red River Estuary. *Vietnam J. Earth Sci.* 45 (1), 19-32.

621 Le, T.M.T., Truong, T.N.S., Nguyen, P.D., Le, T.Q.D., Chan, Q.V., Le, T.T., Nguyen, Q, H.,  
622 Kieu-Le, T.C., Strady, E., 2023b. Evaluation of microplastic removal efficiency of waste-  
623 water-treatment plants in a developing country, Vietnam. *Environ. Technol. Innov.* 29,  
624 102994.

625 Lebreton, L.C.M., van der Zwet, J., Damsteeg, J.-W., Slat, B., Andrady, A., Reisser, J., 2017.  
626 River plastic emissions to the world's oceans. *Nat. Commun.* 8, 15611.

627 Lei, L., Liu, M., Song, Y., Lu, S., Hu, J., Cao, C., Xie, B., Shi, H., He, D., 2018. Polystyrene  
628 (nano)microplastics cause size-dependent neurotoxicity, oxidative damage and other  
629 adverse effects in *Caenorhabditis elegans*. *Environ. Sci. Nano.* 5 (8), 2009-2020.

630 Li, C., Busquets, R., Campos, L.C., 2020a. Assessment of microplastics in freshwater systems: a review. *Sci. Total Environ.* 707, 135578.  
631  
632 Li, R., Yu, L, Chai, M., Wu, H., Zhu, X., 2020b. The distribution, characteristics and ecological risks of microplastics in the mangroves of Southern China. *Sci. Total Environ.* 708,  
633 135025.  
634  
635 Li, T., Chen, X., Li, Z., 2022. Influence of the Lateral Heterogeneity of Shallow Sediments on Site Effects in the Yuxi Basin. *Pure Appl. Geophys.* 179, 2405-2421.  
636  
637 Lithner, D., Lason, Â., Dave, G., 2011. Environmental and health hazard ranking and assessment of plastic polymers based on chemical composition. *Sci. Total Environ.* 409, 3309-  
638 3324.  
639  
640 Liu, Y., Zhang, J., Tang, Y., He, Y., Li, Y., You, J., Breider, F., Tao, S., Liu, W., 2021a. Effects of anthropogenic discharge and hydraulic deposition on the distribution and  
641 accumulation of microplastics in surface sediments of a typical seagoing river: The Haihe River. *J. Hazard. Mater.* 404 (B), 124180.  
642  
643  
644 Liu Y., You J., Li Y.J., Zhang J.D., He Y., Breider F., Tao S., Liu W.X., 2021b. Insights into the horizontal and vertical profiles of microplastics in a river emptying into the sea  
645 affected by intensive anthropogenic activities in Northern China. *Sci.Total Environ.* 779,  
646 146589.  
647  
648 Luo, M., Wang, Z., Fang, S., Song, B., Cao, P., Liu, H., Yang, Y., 2022. Removal and toxic forecast of microplastics treated by electrocoagulation: Influence of dissolved organic matter. *Chemosphere* 308 (1), 136309.  
649  
650  
651 Luu, T.N.M., Do, T.N., Matiatos, I., Panizzo, V.N., Trinh, A.D., 2020. Stable isotopes as an effective tool for N nutrient source identification in a heavily urbanized and agriculturally  
652 intensive tropical lowland basin. *Biogeochemistry* 149, 17-35.  
653  
654 Manbohi, A., Mehdiinia, A., Rahnema, R., Hamzehpour, A., Reza Dehbandi., 2023. Sources and hotspots of microplastics of the rivers ending to the southern Caspian Sea. *Mar. Poll. Bull.* 188, 114562  
655  
656  
657 Mao, R., Lang, M., Yu, X., Wu, R., Yang, X., Guo, X., 2020. Aging mechanism of microplastics with UV irradiation and its effects on the adsorption of heavy metals. *J. Hazard. Mater.* 393, 122515.  
658  
659  
660 Meijer, L.J.J., van Emmerik, T., van der Ent, R., Schmidt, C., Lebreton, L., 2021. More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean. *Sci. Adv.* 7, eaaz5803.  
661  
662  
663 Mendes, A.M., Golden, N., Bermejo, R., Morrison, L., 2021. Distribution and abundance of microplastics in coastal sediments depends on grain size and distance from sources. *Mar. Pollut. Bull.* 172, 112802.  
664  
665  
666 Murphy, L., Germaine, K., Kakouli-Duarte, T., Cleary, J., 2022. Assessment of microplastics in Irish river sediment. *Heliyon* 8, e09853.  
667  
668 Naqash, N., Prakash, S., Kapoor, D., Singh, R., 2020. Interaction of freshwater microplastics with biota and heavy metals: a review. *Environ. Chem. Lett.* 18, 1813-1824.  
669

670 Nayal, R., Suthar, S., 2022. First report on microplastics in tributaries of the upper Ganga  
671 River along Dehradun, India: Quantitative estimation and characterizations. *J. Hazard. Ma-*  
672 *ter.* 8:100190.

673 Nel, H.A., Dalu, T., Wasserman, R.J., 2018 Sinks and sources: Assessing microplastic abun-  
674 dance in river sediment and deposit feeders in an Austral temperate urban river system. *Sci*  
675 *Total Environ.* 612: 950-956.

676 Nguyen, K.T., Nguyen, M.H., Truong, K.C., Ahmed, M.B., Huang, Y., Zhou, J.L., 2019.  
677 Chemical and microbiological risk assessment of urban river water quality in Vietnam.  
678 *Environ. Geochem. Health.* 41, 2559-2575.

679 Nguyen, T.Q.A., Vu, T.B.H., Nguyen, Q.T., Nguyen, H.N.Y., Le, T.M., Vo, V.M., Trinh, D.  
680 M., 2022. Urban drainage channels as microplastics pollution hotspots in developing areas:  
681 A case study in Da Nang, Vietnam. *Mar. Pollut. Bull.* 175, 113323.

682 Organization for Economic Co-operation and Development (OECD), 2022. Global Plastics  
683 Outlook: Economic Drivers, Environmental Impacts and Policy Options. OECD  
684 Publishing, Paris.

685 Peng, G., Zhu, B., Yang, D., Su, L., Shi, H., Li, D., 2017. Microplastics in sediments of the  
686 Changjiang Estuary, China. *Environ. Poll.* 225, 283-290

687 Peng, G., Xu, P., Zhu, B., Bai, M., Li, D., 2018. Microplastics in freshwater river sediments in  
688 Shanghai, China: a case study of risk assessment in mega-cities. *Environ. Pollut.*, 234, 448-  
689 456.

690 Primpke, S., Wirth, M., Lorenz, C., Gerdts, G., 2018. Reference database design for the  
691 automated analysis of microplastic samples based on Fourier transform infrared (FTIR)  
692 spectroscopy. *Anal. Bioanal. Chem.* 410 (21), 5131-5141.

693 Phuong, N.N., Duong, T.T., Le, T.P.Q., Hoang, T.K., Ngo, H.M., Phuong, N.A., Pham, Q.T.,  
694 Doan, T.O., Ho., T.C., Le, N.D., Nguyen, T.A.H., Strady, E., Fauvelle, V., Ourgaud.,  
695 Schmidt, N., Sempere, R., 2022. Microplastics in Asian freshwater ecosystems: Current  
696 knowledge and perspectives. *Sci. Total Environ.* 808, 151989.

697 R Core Team, 2018. R: A language and environment for statistical computing. R Foundation  
698 for Statistical Computing, Vienna, Austria.

699 Rillig, M.C., 2018. Microplastic Disguising As Soil Carbon Storage. *Environ. Sci. Technol.*  
700 52, 6079–6080.

701 Rodrigues, M.O., Abrantes, N., Gonçalves, F.J.M., Nogueira, H., Marques, J.C., Gonçalves  
702 A.M.M., 2018. Spatial and temporal distribution of microplastics in water and sediments of  
703 a freshwater system (Antuã River, Portugal). *Sci. Total Environ.* 633, 1549-1559.

704 Sekudewicz, I., Dąbrowska, A.M., Syczewski, M.D., 2021. Microplastic pollution in surface  
705 water and sediments in the urban section of the Vistula River (Poland). *Sci. Total Environ.*  
706 762, 143111.

707 Soltani, N., Keshavarzi, B., Moore, F., Busquets, R., Nematollahi, M.J., Javid, R., Gobert, S.,  
708 2022. Effect of land use on microplastic pollution in a major boundary waterway: The  
709 Arvand River. *Sci. Total Environ.* 830, 154728.

710 Song, Y., Cao, C., Qiu, R., Hu, J., Liu, M., Lu, S., Shi, H., Raley-Susman, K.M., He, D.,  
711 2019. Uptake and adverse effects of polyethylene terephthalate microplastics fibers on  
712 terrestrial snails (*Achatina fulica*) after soil exposure. *Environ. Pollut.* 250, 447-455.

713 Strady, E., Dang, T.H., Dao, T.D., Dinh, H.N., Do, T.T.D., Duong, T.N., Duong, T.T., Hoang,  
714 D.A., Kieu-Le, T.C., Le, T.P.Q., Mai, H., Trinh, D.M., Nguyen, Q.H., Tran- Nguyen, Q.A.,  
715 Tran, Q.V., Truong, T.N.S., Chu, V.H., Vo, V.C., 2021. Baseline assessment of  
716 microplastic concentrations in marine and freshwater environments of a developing  
717 Southeast Asian country, Viet Nam. *Mar. Pollut. Bull.* 162, 111870.

718 Suzuki, G., Uchida, N., Le, H.T., Tanaka, K., Matsukami, H., Kunisue, T., Takahashi, S.,  
719 Pham, H.V., Kuramochi, H., Osako, M., 2022. Mechanical recycling of plastic waste as a  
720 point source of microplastic pollution. *Environ. Pollut.* 303, 119114.

721 Switzer, A.D., Pile, J., 2015. Grain size analysis, in: Shennan, I., Long, A.J., Horton B.P.  
722 (Eds.), *Handbook of Sea-Level Research*, first Ed. John Wiley & Sons, Ltd.

723 Talbot, R., Chang, H., 2022. Microplastics in freshwater: a global review of factors affecting  
724 spatial and temporal variations. *Environ. Pollut.* 292, 118393.

725 Tsering, T., Sillanpää M., Sillanpää M., Viitala M., Reinikainen S.P., 2021. Microplastics  
726 pollution in the Brahmaputra River and the Indus River of the Indian Himalaya. *Sci Total*  
727 *Environ.* 789, 147968

728 Tibbetts, J., Krause, S., Lynch, I., Smith, G.H.S., 2018. Abundance, Distribution, and Drivers  
729 of Microplastic Contamination in Urban River Environments. *Water* 10 (11), 1597.

730 Townsend, K.R., Lu, H.C., Sharley, D.J., Pettigrove, V., 2019. Associations between  
731 microplastic pollution and land use in urban wetland sediments. *Environ. Sci. Pollut. Res.*  
732 26, 22551-22561.

733 Trinh, A.D., Vu, D.L., Ta, T.T., 2013. Partition of heavy metals in a tropical river system im-  
734 pacted by municipal waste. *Environ. Monit. Assess.* 185 (2), 1907-1925.

735 Udden, J.A., 1914. Mechanical composition of clastic sediments. *Bull. Geol. Soc. Amer.*  
736 XXV, 655-744.

737 Vermeiren, P., Lercari, D., Muñoz, C.C., Ikejima, K., Celentano, E., Jorge-Romero, G.,  
738 Defeo, O., 2021. Sediment grain size determines microplastic exposure landscapes for  
739 sandy beach macroinfauna. *Environ. Pollut.* 286, 117308.

740 Wang, J., Peng, J., Tan, Z., Gao, Y., Zhan, Z., Chen, Q., Cai, L., 2017. Microplastics in the  
741 surface sediments from the Beijiing River littoral zone: Composition, abundance, surface  
742 textures and interaction with heavy metals. *Chemosphere* 171, 248-258.

743 Wang, W., Wang, J., 2018a. Investigation of microplastics in aquatic environments: An  
744 overview of the methods used, from field sampling to laboratory analysis. *TrAC, Trends*  
745 *Anal. Chem.* 108, 195-202.

746 Wang, Z., Su, B., Xu, X., Di, D., Huang, H., Mei, K., Shang, X., 2018b. Preferential  
747 accumulation of small (<300 μm) microplastics in the sediments of a coastal plain river  
748 network in eastern China. *Water Res.* 144, 393–401.

749 Wang, C., Li, Y., Li, Y., Zhou, H., Stubbins, A., Dahlgren, R.A., Wang, Z., Guo W., 2021.  
750 Dissolved Organic Matter Dynamics in the Epipelagic Northwest Pacific Low-Latitude

751 Western Boundary Current System: Insights From Optical Analyses. *J. Geophys. Res.*  
752 *Oceans* 126 (9).

753 Wentworth, C.K., 1922. A scale of grade and class terms for clastic sediments. *JG* 30 (5),  
754 377–392.

755 Wong, J.K.H., Lee, K.K., Tang, K.H.D., Yap, P.S., 2020. Microplastics in the freshwater and  
756 terrestrial environments: Prevalence, fates, impacts and sustainable solutions. *Sci. Total*  
757 *Environ.* 719, 137512.

758 Wootton, N., Reis-Santos, P., Gillanders, B.M., 2021. Microplastic in fish-a global synthesis.  
759 *Rev. Fish. Biol. Fisheries.* 31, 753–771.

760 Xia, F., Yao, Q., Zhang, J., Wang, D., 2021. Effects of seasonal variation and resuspension on  
761 microplastics in river sediments. *Environ. Poll.* 286: 117403

762 Yang, L., Zhang, Y., Kang, S., Wang, Z., Wu, C., 2021. Microplastics in freshwater  
763 sediment: a review on methods, occurrence, and sources. *Sci. Total Environ.* 754, 141948.

764 Yukioka, S., Tanaka, S., Nabetani, Y., Suzuki, Y., Ushijima, T., Fujii, S., Takada, H., Van, T.  
765 Q., Singh, S., 2020. Occurrence and characteristics of microplastics in surface road dust in  
766 Kusatsu (Japan), Da Nang (Vietnam), and Kathmandu (Nepal). *Environ. Pollut.*  
767 256:113447.

768 Zhao, M., Cao, Y., Chen, T., Li, H., Tong, Y., Fan, W., Xie, Y., Tao, Y., Zhou, Z., 2022.  
769 Characteristics and source-pathway of microplastics in freshwater system of China: A  
770 review. *Chemosphere* 297, 134192.

771 Zhang, L., Liu, J., Xie, Y., Zhong, S., Yang, B., Yang, B., Lu, D., Zhong, Q., 2020. Distribu-  
772 tion of microplastics in surface water and sediments of Qin river in Beibu Gulf, China. *Sci.*  
773 *Total Environ.* 708:135176

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## TABLE CAPTIONS

778 **Table 1:** Polymer composition (MP numbe and percentage (%) of each polymer type) in sur-  
779 face sediment collected from the To Lich, Nhue, and the Day rivers

780 **Table 2:** Comparison of MPs concentration in sediment from different rivers worldwide

781 **Table 3:** Organic matter, grain size cumulative weight (%) and parameters (geometric mean -  
782 mm) in sediments collected from the urban and suburban rivers (the To Lich, the Nhue, and  
783 the Day rivers; n = 18, 24 and 30, respectively)

784 **Table 4:** Pearson correlations between Microplastic abundance, sediment properties (organic  
785 matter content - OM; medium grain size of sediment - Sed.size), weight percentage of sand,  
786 silt, clay and characteristics (Area; population - Popul; population density - Pop.Den; land use  
787 for agriculture - Agri; specially used land - Spec; land use for resident - Resid; Ur/ Rur- Ur-  
788 ban/Rural) in sediment collected from the To Lich, Nhue and Day rivers

789 **Table 1:** Polymer composition (MP numbe and percentage (%) of each polymer type) in sur-  
 790 face sediment collected from the To Lich, Nhue, and the Day rivers

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<b>Polymers</b>	<b>Number items</b>	<b>Proportion (%)</b>
Polyethylene (PE)	708	32.2
Polyester	127	5.78
Polypropylene (PP)	1,201	54.69
Polystyrene (PS)	90	4.10
Polyuethane (PU)	27	1.23
Polyvinyl acetat (PVAC)	1	0.05
Vinyl	1	0.05
Polyvinyl chloride (PCV)	34	1.55
Alkyd	3	0.14
Polyamide (PA)	3	0.14
Polyacrylonitrile (PAN)	1	0.05

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794 **Table 2:** Comparison of MPs concentration in sediment from different rivers worldwide

<b>Countries</b>	<b>Ecosystems</b>	<b>MP abundance (Items. Kg<sup>-1</sup> dry weight)</b>	<b>Size range dominant (mm)</b>	<b>Observation range (mm)</b>	<b>References</b>
South Africa	Bloukrans River	563	-	0.063 - 5	Nel et al., 2018
Poland	Vistula River	580	0.3 - 0.75	0.055 - 5	Sekudewicz et al., 2021
Gemany	Rhine	3,763	0.063 - 0.2	0.063 - 5	Klein et al. 2015
Indonesia	Ciwalengke River	30.3	1 - 2	0.05 - 2	Alam et al., 2019
India	Ganga River	12,325	Fragments	-	Nayal and Suthar., 2022
India	Brahmaputra River	3,485	0.02-0.15	0.15-5	Tsering et al., 2021
Bangladesh	Karnafully river	1,240	< 1	0.02 - 5	Hossain et al., 2022
China	Beijiang River	544	-	-	Wang et al., 2017
China	Urban rivers	802	0.1 - 0.5	-	Peng at al., 2018
China	Liangfeng river	33,200	0.050 - 0.5	0.050 - 5	Xia et al., 2021
China	Wen-Rui Tang River,	32,947	0.063-0.6	0.02-5	Wang et al., 2018b
China	Qin River	97	1 - 5	0.3 - 5	Zhang et al., 2020
China	Haihe River	11,917	0.1-1	0.05-5	Liu et al., 2021a
Vietnam	Phu Loc Chanel	6,120	0.3 - 2	0.3 - 5	Nguyen et al.,2022
Vietnam	To Lich	42,683	0.3 - 2	0.3 - 5	This study
Vietnam	Nhue	23,544	0.3 - 2	0.3 - 5	This study
Viet Nam	Day	16,350	0.3 - 2	0.3 - 5	This study

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796 **Table 3:** Organic matter, grain size cumulative weight (%) and parameters (geometric mean -  
 797 mm) in sediments collected from the urban and suburban rivers (the To Lich, the Nhue, and  
 798 the Day rivers; n = 18, 24 and 30, respectively)  
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	Organic Matter (wt %)	Cumulative weight (%)				Parameters (geometric mean - $\mu\text{m}$ )	
		Sand > 63 $\mu\text{m}$	Coarse Silt 15-63 $\mu\text{m}$	Fine Silt 4-15 $\mu\text{m}$	Clay < 4 $\mu\text{m}$	Mean	Sorting
<b>To Lich River</b>							
Average	12.63	21.18	36.90	48.28	1.76	18.47	2.51
Maximum	23.69	44.94	44.54	54.66	3.56	35.27	4.09
Minimum	7.39	5.05	19.44	35.91	0.57	12.65	1.79
SD	4.38	10.02	5.81	5.82	0.96	5.27	0.57
<b>Nhue river</b>							
Average	9.72	13.41	26.63	58.13	6.88	14.03	2.41
Maximum	17.74	41.91	47.22	73.64	17.64	38.70	4.36
Minimum	4.88	0.93	15.93	30.82	0.18	7.76	1.57
SD	3.76	9.88	10.57	10.73	5.51	6.90	0.64
<b>Day River</b>							
Average	5.93	12.76	29.21	58.05	6.41	12.88	2.26
Maximum	16.26	31.25	47.20	75.96	17.55	19.83	2.91
Minimum	2.09	0.45	8.84	35.84	1.33	6.90	1.68
SD	2.78	6.87	9.14	8.37	4.03	3.16	0.31

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801 **Table 4:** Pearson correlations between Microplastic abundance, sediment properties (organic matter content - OM; medium grain size of  
 802 sediment - Sed.size), weight percentage of sand, silt, clay and characteristics (Area; population - Popul; population density - Pop.Den; land use  
 803 for agriculture - Agri; specially used land - Spec; land use for resident - Resid; Ur/ Rur- Urban/Rural) in sediment collected from the To Lich,  
 804 Nhue and Day rivers

	TMPs	OM	Sed siz	Sand	Fine Silt	Coarse silt	Clay	Area	Pop Den	Agri	Spec	Resid	Ur/Rur
<b>TMPs</b>	1												
<b>OM</b>	<b>0.7***</b>	1											
<b>Sed Siz</b>	<b>0.27*</b>	0.02	1										
<b>Sand</b>	0.23	0.07	0.58	1									
<b>Fine silt</b>	-0.25*	0.01	0.93***	-0.87***	1								
<b>Coarse silt</b>	<b>0.25*</b>	-0.02	0.7***	0.34**	-0.71***	1							
<b>Clay</b>	-0.32	-0.12	-0.8***	-0.55***	0.66***	-0.78	1						
<b>Area</b>	-0.52	-0.3**	-0.38**	-0.25*	0.34	-0.36	0.39	1					
<b>Pop Den</b>	<b>0.49***</b>	0.28*	0.35*	0.21	-0.32	0.41	-0.4	-0.76	1				
<b>Agri</b>	-0.5***	-0.27*	-0.22	-0.12	0.20	-0.26	0.24	0.74	-0.86	1			
<b>Resid</b>	<b>0.53***</b>	0.3*	0.29*	0.17	-0.25	0.33	-0.36	-0.91	0.94	-0.88	0.85	1	
<b>Urb/Rur</b>	<b>0.72***</b>	0.58***	0.45***	0.37**	-0.42	0.34	-0.43	-0.64	0.74	-0.6	0.05	0.66	1

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806 Note: \*\*\* at the 0.01 level (2-tailed), correlation is significant; \*\*, at the 0.01 level (2-tailed), correlation is significant; \*, at the 0.05 level (2-  
 807 tailed), correlation is significant.

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## FIGURE CAPTIONS

809 **Figure 1:** Sampling locations along the To Lich, Nhue and Day Rivers

810 **Figure 2:** Spatial and seasonal distribution of microplastic concentrations in surface sediment  
811 collected in urban rivers (To Lich, Nhue Rivers) and suburban river (Day River) during dry  
812 and rainy seasons

813 **Figure 3:** Mean proportion of microplastics shapes (fragment and fiber) observed in surface  
814 sediment samples collected in the To Lich, Nhue and Day Rivers

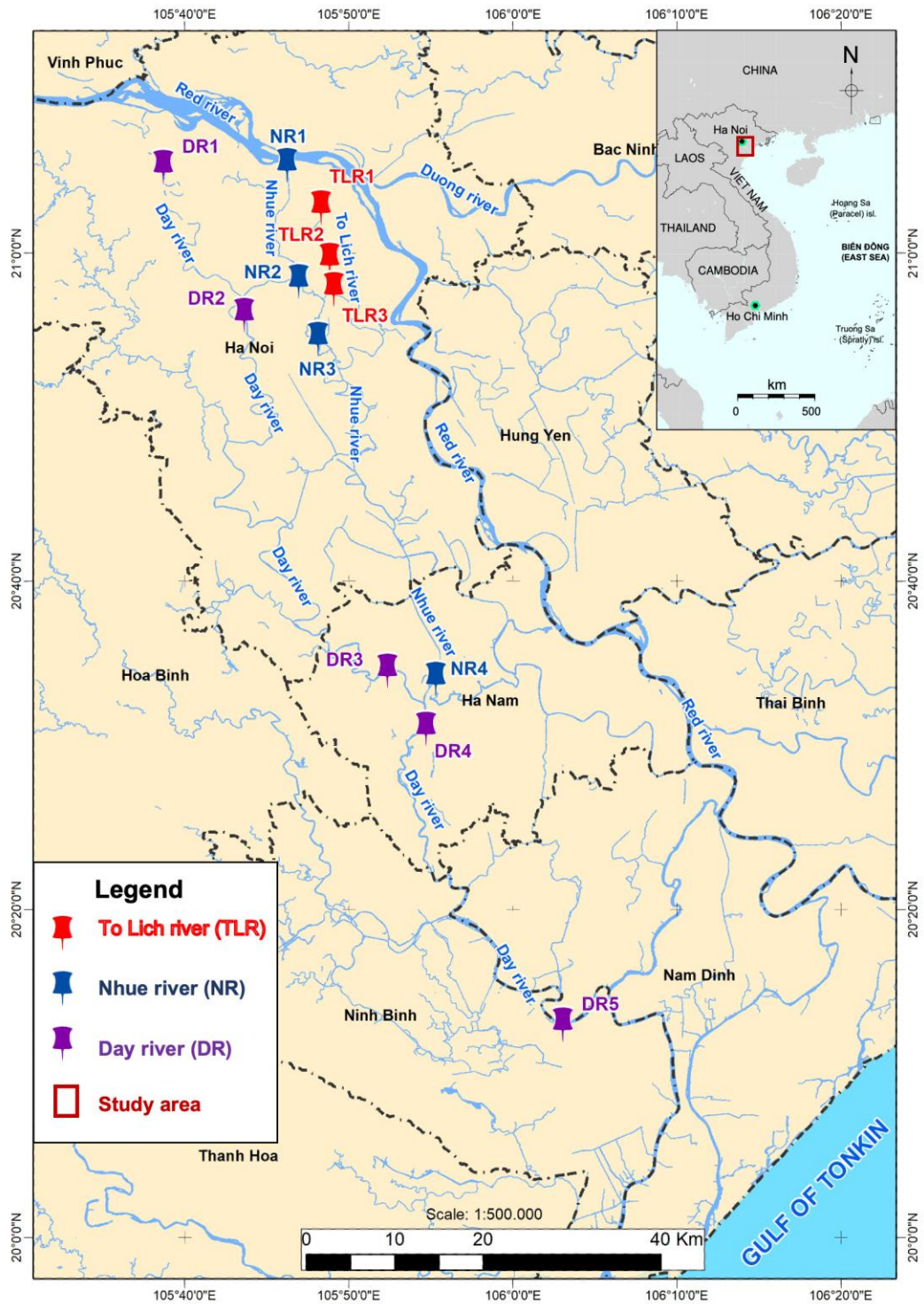
815 **Figure 4:** Occurrence of microplastic concentrations according to their size, area for fragment  
816 (a), length for fiber (b) in surface sediments collected from the To Lich River, Nhue and the  
817 Day Rivers.

818 **Figure 5:** Principal component analysis (PCA) based on microplastic abundance, sediment  
819 properties (organic matter content - OM; medium grain size of sediment - Sed.size), mass  
820 percentage of sand, silt, clay and characteristics (Area; population - Popul; population density  
821 - Pop.Den; land use for agriculture - Agri; specially used land - Spec; land use for resident -  
822 Resid) in sediment collected from the To Lich, Nhue and Day rivers

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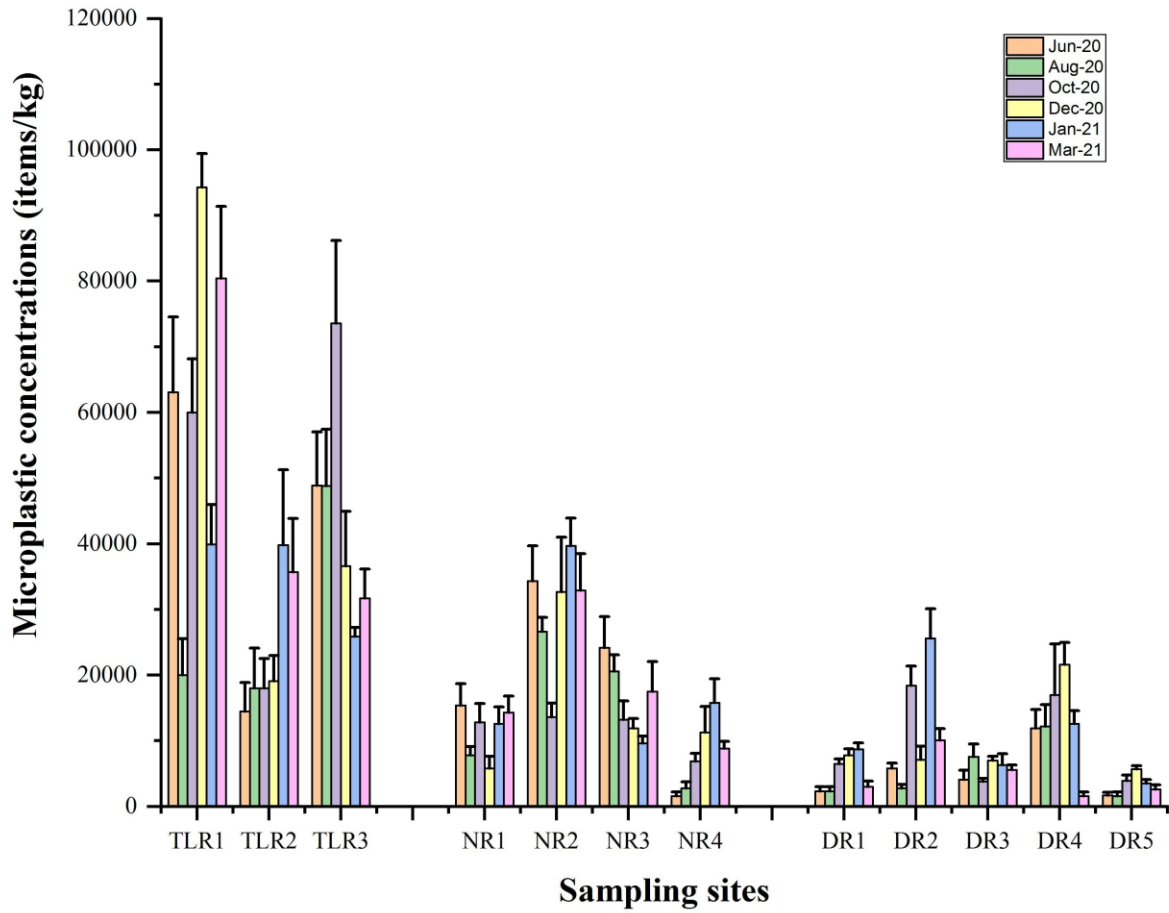
**Figure 1:** Sampling locations along the To Lich, Nhue and Day Rivers



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830 **Figure 2:** Spatial and seasonal distribution of microplastic concentrations in surface sediment  
831 collected in urban rivers (To Lich, Nhue Rivers) and suburban river (Day River) during dry  
832 and rainy seasons

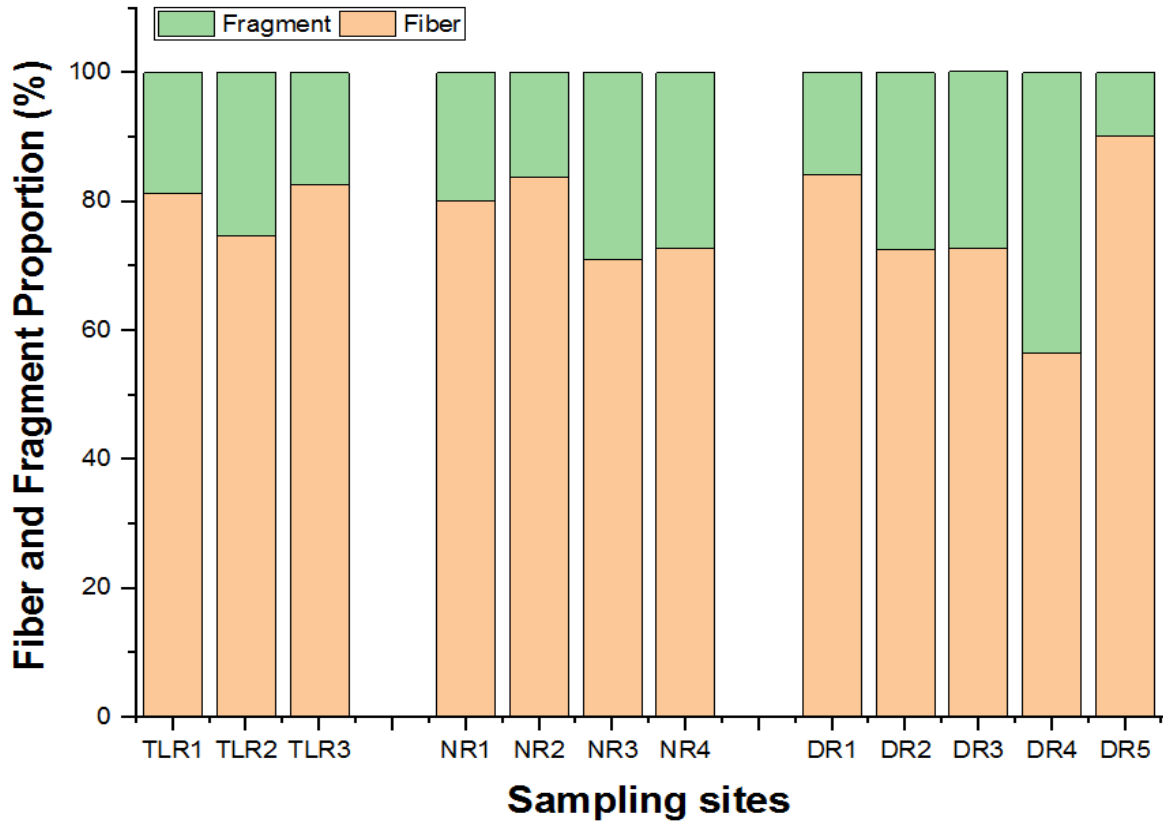
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838 **Figure 3:** Mean proportion of microplastics shapes (fragment and fiber) observed in surface  
839 sediment samples collected in the To Lich, Nhue and Day Rivers

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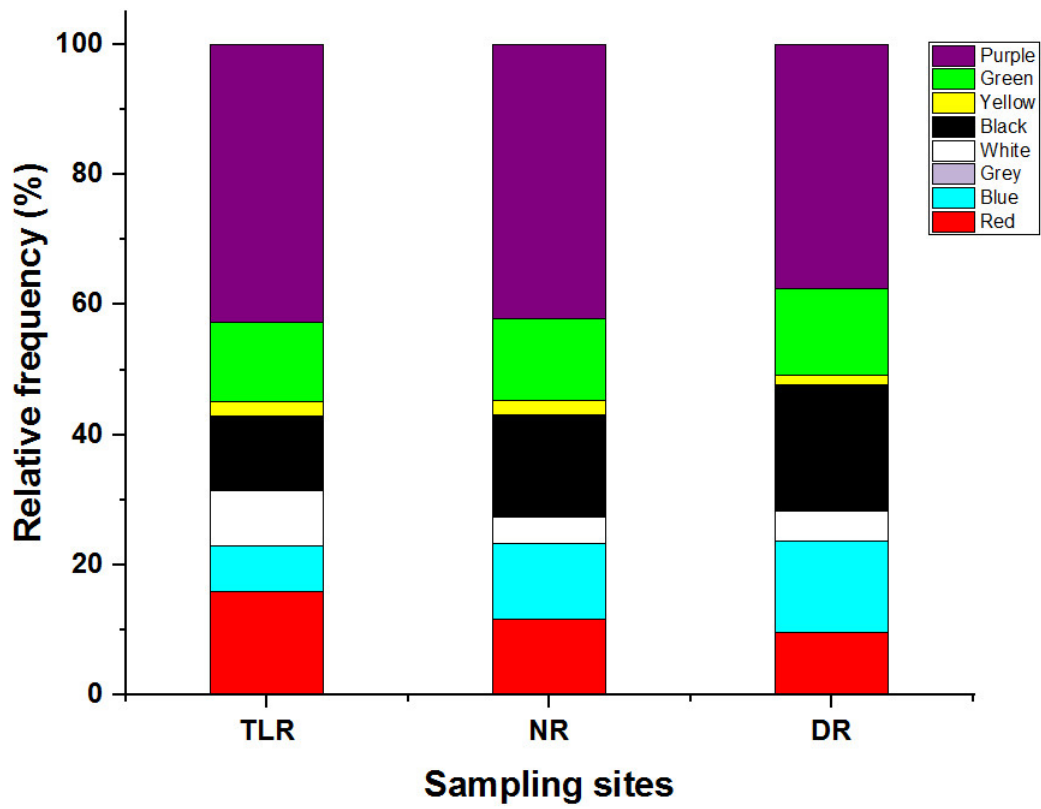
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**Figure 4:** Mean percentage of microplastic colors observed in surface sediment collected

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from the To Lich River, Nhue and Day River

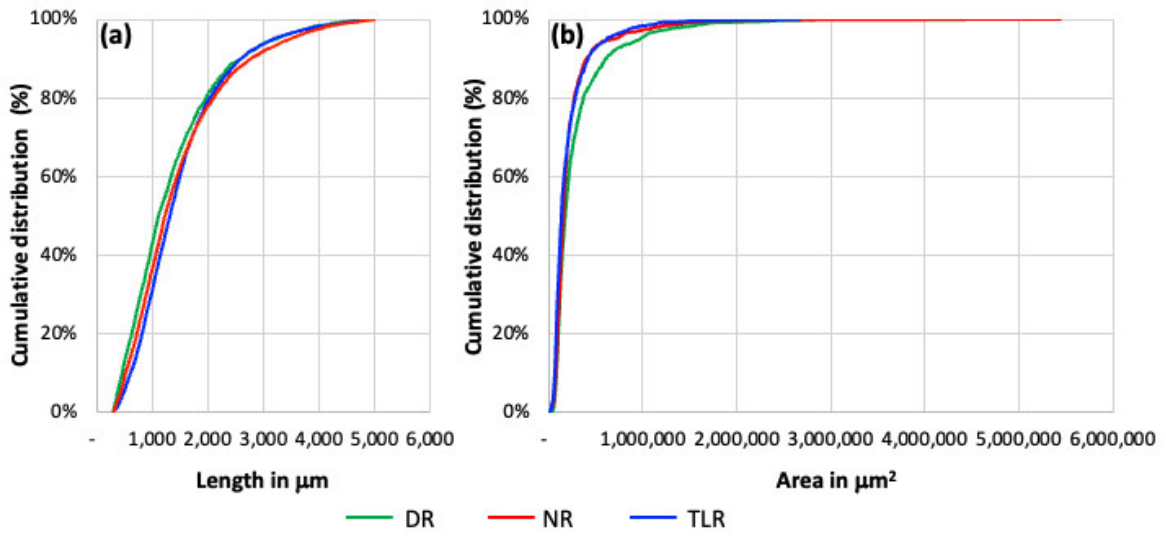


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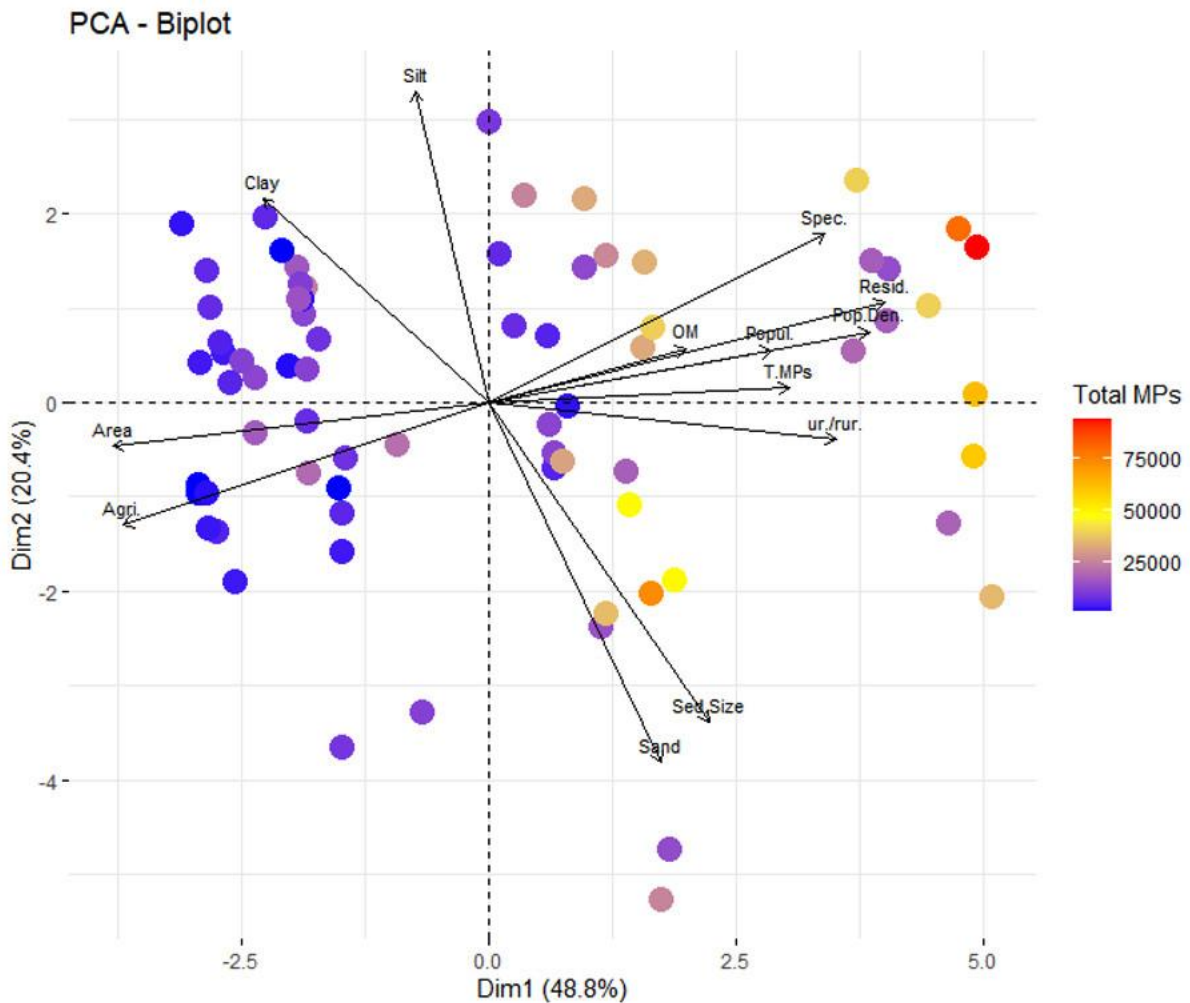


848 **Figure 5:** Occurrence of microplastic concentrations according to their size, length for fiber  
849 (a) area for fragment (b), in surface sediments collected from the To Lich, the Nhue and the  
850 Day Rivers



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857 **Figure 6:** Principal component analysis (PCA) based on microplastic abundance, sediment  
 858 properties (organic matter content - OM; medium grain size of sediment - Sed.size), mass  
 859 percentage of sand, silt, clay and characteristics (Area; population - Popul; population density  
 860 - Pop.Den; land use for agriculture - Agri; specially used land - Spec; land use for resident -  
 861 Resid) in sediment collected from the To Lich, Nhue and Day rivers  
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## Supplemental Tables and Figure

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877 **Table S 1:** Total area, total population density in area and land use types in the To Lich, Nhue  
878 and Day Rivers

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River	Total area (km <sup>2</sup> )	Total population in area (10 <sup>6</sup> inhabitants.km <sup>-2</sup> )	Sites	Depth (m)	Population density (inhabitants.km <sup>-2</sup> )	Land use types
<b>To Lich</b>	77.5	1.6	TLR1	0.55	24 078	Urban
			TLR2	0.5	32 268	Urban
			TLR3	0.7	4 497	Urban
<b>Nhue</b>	1,075	5.3	NR1	1.3	7 621	Urban
			NR2	1.2	8 423	Urban
			NR3	2.5	1 752	Urban
			NR4	0.5	1 841	suburban
			DR1	1.2	2 302	suburban
<b>Day</b>	7,665	22	DR2	1.3	8 423	Urban
			DR3	2.2	723	Rural
			DR4	2.3	1 841	Rural
			DR5	2.1	1 043	Rural

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882 **Table 2S:** Pollution load index (PLI) and Potential Ecological Risk Index (RI) the sediment  
883 samples collected from the To Lich, Nhue and Day Rivers

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	PLI	Hazard category	RI	Risk category
DR	6.52	I	866	Danger
NR	10.53	II	1,829	Extreme danger
TLR	17.3	II	4,771	Extreme danger

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888 **Figure 1S:** The spectra of microplastics PE, PP, and PS were obtained by micro-FTIR

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