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Baseline

Baseline assessment of microplastic concentrations in marine and freshwater environments of a developing Southeast Asian country, Viet Nam

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ABSTRACT

In aquatic environments, assessment of microplastic concentrations is increasing worldwide but environments from developing countries remain under-evaluated. Due to disparities of facilities, financial resources and human resources between countries, protocols of sampling, analysis and observations used in developed countries cannot be fully adapted in developing ones, and required specific adaptations. In Viet Nam, an adapted methodology was developed and commonly adopted by local researchers to implement a microplastic monitoring in sediments and surface waters of 21 environments (rivers, lakes, bays, beaches) of eight cities or provinces. Microplastic concentrations in surface waters varied from 0.35 to 2522 items m-3, with the lowest concentrations recorded in the bays and the highest in the rivers. Fibers dominated over fragments in most environments (from 47% to 97%). The microplastic concentrations were related to the anthropogenic pressure on the environment, pointing out the necessity in a near future to identify the local sources of microplastics.

Microplastics, referring to plastic particles ranging from 1 to 5000 μm long (Frias and Nash, 2019), are polluting the terrestrial and aquatic environments and are becoming a threat to the health of ecosystems, biota and humans (Guzzetti et al., 2018; Prata et al., 2020; Rochman et al., 2013; Wang et al., 2019).

Microplastics can be specifically manufactured in the micrometer size to form pellets or microbeads for example, i.e. primary microplastics, or can result of plastic litter fragmentation, enhanced by UV radiation, temperature, turbulence (e.g. wave action, current), or of garment fragmentation during washing, i.e. secondary microplastics. Both primary and secondary microplastics are mainly released to the aquatic environment through wastewater effluents of domestic or

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industrial origins (Horton et al., 2017). The technologies used in wastewater treatment plants (e.g. primary sedimentation, dissolved air flotation, coagulation, filtration processes, activated sludge process, membrane bioreactor or ozonation) directly influence the removal of microplastic in the effluents and so their release in the environment (Bui et al., 2020). The sources of microplastics released to the aquatic environment are numerous. It can be from waste origin during solid waste collection, processing, land-filling or transportation, from tyre particles, vehicle-derived debris or from agricultural plastic (Galgani et al., 2015; Huang et al., 2020). Then, the runoff via storm drains or via drainage ditches, additionally to wind action and atmospheric fallouts (Dris et al., 2016), can transfer microplastics towards the aquatic environment.

Once in the environment, microplastics are subjected to transport, deposition, settling, resuspension, aggregation, biofouling (Li et al., 2018; Nguyen et al., 2020b; Waldschläger and Schüttrumpf, 2019). Their fate depends on several simultaneous factors, like particle characteristics such as density, shape, length, diameter and area (Khatmullina and Isachenko, 2017) and like environmental features such as hydrology, wind, tides, current, flooding, precipitations, river or lake depth, water physico-chemical characteristics (Choy et al., 2019; Hoellein et al., 2019; Hurley et al., 2018; Lenaker et al., 2019; Strady et al., 2020).

Assessment of microplastic concentrations in aquatic environments is increasing worldwide but some areas remain under-evaluated, especially the environments from or crossing the developing countries (Cera et al., 2020; Chae and An, 2017). Those areas were pointed out to emit large quantity of plastic litter to waterways and ocean (Jambeck et al., 2015; Lebreton et al., 2017) but little is known regarding their microplastic emission (e.g. (Alam et al., 2019; Cordova et al., 2019; Esquinas et al., 2020; Fu and Wang, 2019; Zhang et al., 2018, 2020).

Lately, most microplastic research papers or methodology reviews pointed out the need to homogenize the methodology, from the sampling, the laboratory analysis to the tools to observe and identify the nature of the polymers (e.g. Cowger et al., 2020; Dehaut et al., 2019; Prata et al., 2019). Many papers have indeed evidenced the influence of the equipments and protocols used on the measured concentrations (e.g. Barrows et al., 2017; Covernton et al., 2019). Nevertheless, establishing a common worldwide protocol is challenging and unrealistic. The disparities of facilities, financial and human resources between countries are the main barriers. In Viet Nam, for example, the absence of river, coastal and offshore oceanographic vessel is limiting the use of a Manta net trawl for sampling microplastics, and the absence of μFTIR or μRaman is restricting the possibility of determining the nature of the sampled microplastics locally. Thus, despite some methods are acclaimed by most organizations or group of experts (GESAMP, 2019), the impossibility of fully using them is not a choice but a reality which local researchers and technicians must face. Therefore, a common and adapted (i.e. to local facilities and resources) methodology for assessing microplastics in the aquatic environments have been developed in Viet Nam, following our first investigations in the Sai Gon River (Lahens et al., 2018; Strady et al., 2020) and based on existing scientific litterature. It aimed to face the local technical challenges, to follow as much

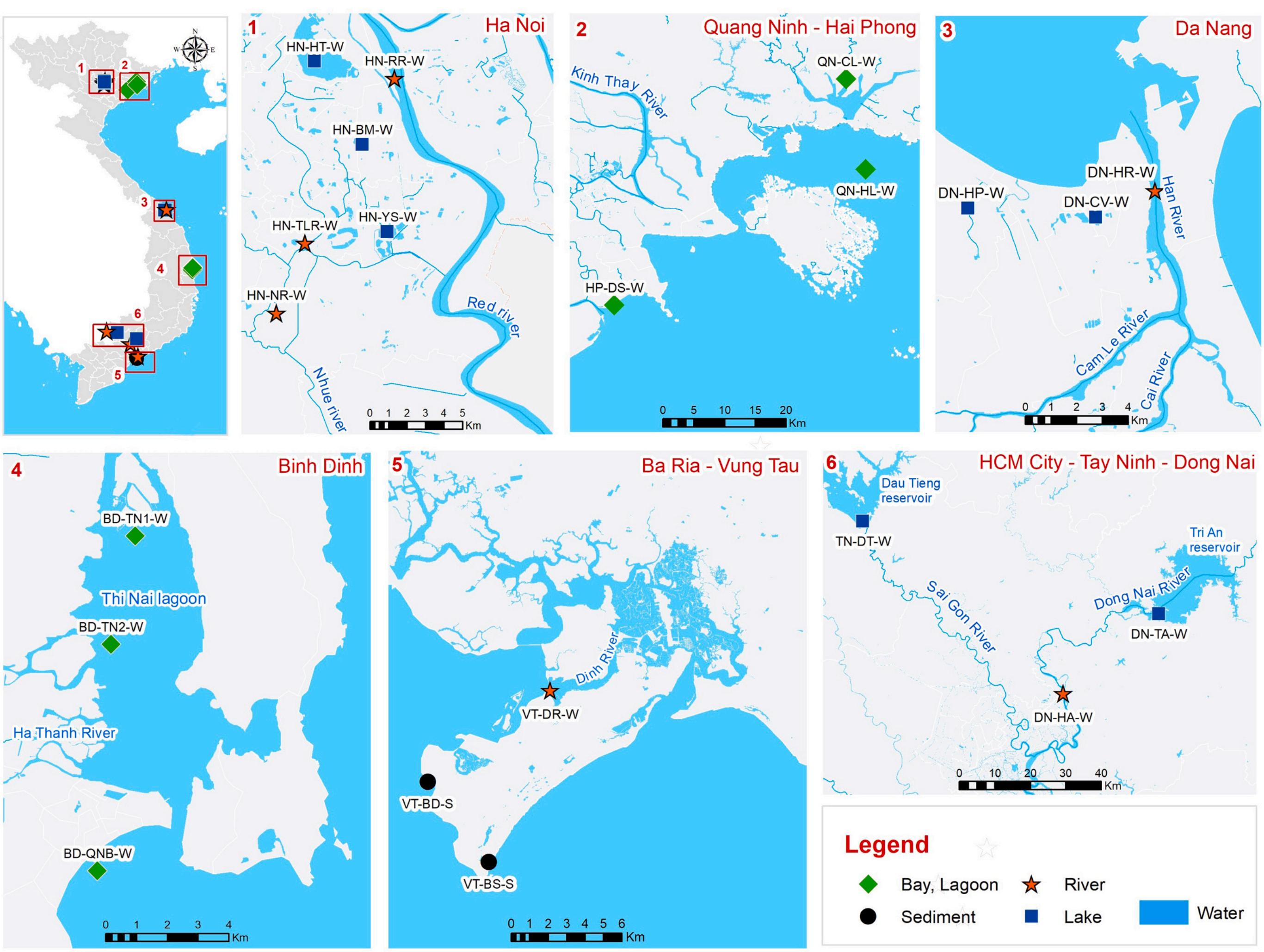

Fig. 1. Location of the 21 study sites.

as possible the recommendations of group of experts using effective alternatives and to provide robust assessment of microplastic concentrations in waters and sediments. The COMPOSE project (Creating an Observatory for Measuring Plastic Occurrence in the Society and Environment) was dedicated to set up common protocols, to train local researchers and technicians from various institutions across the country via a research network, to provide the basic tool and equipment, and to start a national monitoring assessment of microplastic contents in sediment and surface water of lakes, rivers, estuaries and bays.

Under this context, specific aquatic environments were studied in nine cities and provinces of Viet Nam, representing a total of 21 sampling sites (Fig. 1; Table 1), chosen for their particular environmental characteristics and their accessibility. Microplastics were measured in 19 surface waters and 2 beach sediments. In Northern Viet Nam, we focused on the Red River system (1140 km long; annual mean water discharge: 3495 $m^3 s^{-1}$ (Dang et al., 2010)) especially in its Delta, from Ha Noi, (7,520,000 inhabitants; GSO, 2019), the capital of Viet Nam, to the coastal zone of Quang Ninh province. Three riverine sites and three urban lakes were selected in Ha Noi: the site HN-RR-W on the Red River close to Ha Noi; the site HN-TL-W on the To Lich River (13.5 km long; mean water discharge: 30 $m^3 s^{-1}$), impacted by untreated wastewater release; the site HN-NR-W on the Nhue River (74 km long; mean water discharge: 70 $m^3 s^{-1}$), receiving waters from the To Lich River; the site HN-HT-W in the natural Ho Tay Lake (1.35 km^2 area; depth: 0.7–5.2 m) receiving domestic treated and untreated waters; the sites HN-BM-W and HN-YS-W in the artificial Yen So Lake (5.67 km^2 area; depth: 0.5–4.8 m) and Bay Mau Lake (0.28 km^2 area; depth: 0.5–2.5 m). In Hai Phong and Quang Ninh, three coastal sites were selected: the site HP-DS-W at the mouth of the Bach Dang estuary (a branch of the Red River Delta) in the Do Son Bay; the site QN-CL-W in the Cua Luc Bay nearby Ha Long City (300,000 inhabitants; GSO, 2019) and the site QN-HL-W in the Ha Long Bay well known for its intensive aquaculture farming and touristic activities. In Central Viet Nam, two urban lakes and one river were selected in Da Nang City (1284.9 km^2 area; 1,080,700 inhabitants; GSO, 2019): the site DN-CV-W in Cong Vien Lake (0.11 km^2 area; 2.2 m average depth), which is a closed system receiving wastewaters from domestic activities; the site DN-HP-W in Hoa Phu Lake (0.05 km^2 area; 3.2 m average depth) which is an opened system receiving mainly wastewaters from the city landfill; the site DN-HR-W on the downstream part of the Han River (204 km long; mean water discharge: 53 $m^3 s^{-1}$), in Da Nang City center. In the South Central coastal region, three sites were selected in Binh Dinh province (1,534,800 inhabitants; GSO, 2019): two sites in the Thi Nai lagoon (51 km^2 area), BD-TN1-W near the mouth of the Kon River (178 km long; mean water discharge: 59 $m^3 s^{-1}$) receiving untreated domestic and industrial wastewaters and BD-TN2-W near the mouth of the Ha Thanh River (58 km long; mean water discharge: 14 $m^3 s^{-1}$) receiving also untreated domestic and industrial wastewaters; the site BD-QNB-W located in Quy Nhon Bay. In Southern Viet Nam, in the Sai Gon- Dong Nai Rivers system, three sites were selected: the site DN-TA-W in the Tri An Reservoir (area: 75–324 km^2), located along the Dong Nai River; the site DN-HA-W on the Dong Nai River (586 km long; mean water discharge: 632 $m^3 s^{-1}$ (Nguyen et al., 2020a)), downstream the Tri An Reservoir and upstream the confluence with the Sai Gon River; the site TN-DT-W in the Dau Tieng Reservoir (area: 270 km^2) along the Sai Gon River, upstream Ho Chi Minh City (HCMC). Finally, in Ba Ria - Vung Tau province, on the coast zone, one site was selected at the mouth of the Dinh River estuary VT-DR-W nearby a fishery zone and two sites on shoreline, at two sandy beaches, the site VT-BS-S on Sau Beach, a 4 km long touristic and daily-cleaned beach and the site VT-BD-S on Dau Beach, an isolated narrow and 1 km long beach with many cliffs protruding into the sea. Surface water samples were taken from local boat in surface water of lake, river, estuary and bay, using a 80 μm mesh size plankton net (diameter 50 cm) coupled to a flowmeter (General Oceanics®) to determine the sampled water volume. The net was exposed from less than a minute to 10 min which was equivalent to 0.05 to 143 m^3 according to sites (Table 1). The time of exposure was adapted to the microplastic concentrations measured at each sampling sites during pre-campaigns. The net was then rinsed from the outside and the collected fraction was recovered in a 500 mL glass container, and kept at 4 °C in the laboratory until analysis. In rivers and estuaries influenced by tides, samples were taken at the end of the ebb tides.

Surface beach sediments were sampled using a homemade PVC tube corer (6 cm diameter) over a depth of 5 cm. A sample is a composite of five-subsamples which were taken randomly in the intertidal zone in an area of 100 m^2. At each sites, the five subsamples were gathered in one PE plastic bag and each sample was kept in a cool place in the laboratory until analysis.

For surface water laboratory analysis, the protocol developed (Fig. 2) aimed to ease the final observations of the filter. At first, each sample was sieved on a 1 mm mesh size sieve to remove litter >1 mm (e.g. vegetal, wood, shell) while the plastic items >1 mm were kept separately and put on a GF/A filter for later observation. 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 (Lahens et al., 2018; Strady et al., 2020) (i) 1 g of Sodium Dodecyl Sulfate (SDS, Merck®) at 50 °C for 24 h; (ii) 1 mL of biozym SE (protease and amylase, Spinnrad®) and 1 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. During each step, the bottle was closed and maintained in a laboratory oven. Then, in a third step, the sample was transferred through a 250 μm mesh size sieve in order to remove all the mineral and organic particles lower than 250 μm and to obtain clearer filters for microplastics 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 5 times to ensure the retrieve of plastic items. Fifthly, the overflowed solution was filtered on GF/A filters 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.

For sediment laboratory analysis, the protocol developped followed the main steps of the protocol for surface waters and presented some specificities, mainly regarding the digestion steps (Fig. 3). To begin, 10 g of sediment was sieved on a 1 mm mesh size to remove the litter >1 mm and retrieve the plastic >1 mm. Then, the sieved fraction was put in a beaker and digested using 20 mL of H_2O_2 30% only. Laboratory tests evidenced that the use of SDS and bioenzymes do not have efficient effects on the organic phase removal in the sediments and did not improve the filter observation at the last step. The beaker covered with aluminium foil was put on a heating plate at 40 °C during 3 h for digestion. The oxidized sediment was then transferred in a 250 μm mesh size sieve using a spatula and rinsing with a squirt bottle containing filtered water. Then, the density separation, filtration and observations steps were similar to the ones for surface waters.

Microplastics observed were categorized under fragments (including films and foams), fibers and pellets. The morphology was measured using the LAS software® as followed: the area for fragments, the length and diameter for fibers, and the area and perimeter for pellets. The nature of microplastics was determined on ten subsamples from each sites using a FTIR-ATR iS50 Thermo Fisher Scientific®. On a total of 184 fragments and 43 fibers analyzed, the polymers were: 77 polyethylene, 62 polypropylene, 62 alkyd resin polyester, 13 polyolefins, 5 polyester, 2 polystyrene one polyamide and 5 additives. We note that only the largest fibers and fragments were analyzed by FTIR-ATR. The smallest size was very challenging to retrieve, and consequently, the determination of the nature of microplastic was not representative of the whole sample statistically. Thus, based on the GESAMP recommendation when visual observation is performed without systematic analysis of the polymers, we set up the minimum length at 300 μm (e.g. maximum 5000 μm) and minimum area size at 45000 $μm^2$ (e.g. maximum at 25,000,000 $μm^2$) (GESAMP, 2019). We defined fiber as elongated line being equally thick,

Table 1
characteristics of sampling sites.

Site code	Site name	Province/city	Latitude	Longitude	Environment	Surrounding anthropogenic activities	Compartment	Volume m^3	Mass kg	Sampling from
Riverine environments										
HN-NR-W	Nhue River	Ha Noi	N20°55′44.802″	E105°48′7.167″	River	Urban, dense population density, agricultural runoff, handcraft villages	Surface water	12.9		Bridge
HN-TL-W	To Lich River	Ha Noi	N20°57′47.372″	E105°49′4.947″	River	Urban, dense population density	Surface water	0.05		Bridge
HN-RR-W	Red River	Ha Noi	N21°2′34.872″	E105°51′39.146″	River	Urban, dense population density, agricultural runoff	Surface water	43.6		Local boat
DN-HR-W	Han River	Da Nang	N16°4′19.495″	E108°13′35.813″	River	Urban zone	Surface water	22.4		Bridge
DN-HA-W	Dong Nai River	Dong Nai	N10°54′1.947″	E106°50′20.446″	River	Urban zone, industrial environment	Surface water	46.6		Local boat
Lake and reservoir environments										
HN-BM-W	Bay Mau Lake	Ha Noi	N21°1′40.881″	E105°50′37.521″	Lake	Urban lake	Surface water	3.51		Local boat
HN-HT-W	Ho Tay Lake	Ha Noi	N21°3′6.537″	E105°49′13.738″	Lake	Urban lake, households	Surface water	11.7		Local boat
HN-YS-W	Yen So Lake	Ha Noi	N20°58′8.280″	E105°51′21.121″	Lake	Urban lake	Surface water	11.3		Local boat
DN-CV-W	Cong Vien Lake	Da Nang	N16°3′46.511″	E108°12′21.167″	Lake	Urban lake	Surface water	6.66		Local boat
DN-HP-W	Hoa Phu Lake	Da Nang	N16°3′57.851″	E108°9′39.671″	Lake	Urban lake	Surface water	3.26		Local boat
DN-TA-W	Tri An Reservoir	Dong Nai	N11°6′10.687″	E107°4′55.182″	Reservoir	Rural zone, aquaculture, agriculture	Surface water	143		Local boat
TN-DT-W	Dau Tieng Reservoir	Tay Ninh	N11°20′14.729″	E106°19′54.926″	Reservoir	Rural zone, aquaculture, agriculture	Surface water	132		Local boat
Estuarine, lagoon and beach environments										
HP-DS-W	Do Son Bay	Hai Phong	N20°39′46.738″	E106°43′40.713″	Bay	Fisheries	Surface water	44.2		Local boat
QN-CL-W	Cua Luc Bay	Quang Ninh	N20°58′56.247″	E107°3′48.628″	Bay	Industrial activities	Surface water	51.0		Local boat
QN-HL-W	Ha Long Bay	Quang Ninh	N20°55′35.79″	E107°4′45.01″	Bay	Aquaculture, touristic activities	Surface water	34.3		Local boat
BD-TN1-W	Thi Nai Lagoon 1	Binh Dinh	N13°50′24.3″	E109°13′22.6″	Lagoon	Aquaculture, fisheries	Surface water	21.0		Local boat
BD-TN2-W	Thi Nai Lagoon 2	Binh Dinh	N13°51′5.6″	E109°13′41.1″	Lagoon	Aquaculture, fisheries	Surface water	35.4		Local boat
BD-QN-W	Quy Nhon Bay	Binh Dinh	N13°45′36.9″	E109°13′21.8″	Bay	Recreational activities, fisheries	Surface water	4.56		Local boat
VT-DR-W	Dinh River-Estuary	Ba Ria -Vung Tau	N10°24′50.386″	E107°7′13.598	Estuary	Aquaculture, port, maritime traffic	Surface water	4.76		Local boat
VT-BS-S	Sau Beach	Ba Ria -Vung Tau	N10°19′48.576″	E107°5′25.659″	Beach	Touristic and cleaned beach	Sediment		0.01	Sediment core
VT-BD-S	Dau Beach	Ba Ria -Vung Tau	N10°22′8.947″	E107°3′38.48″	Beach	Local beach	Sediment		0.01	Sediment core

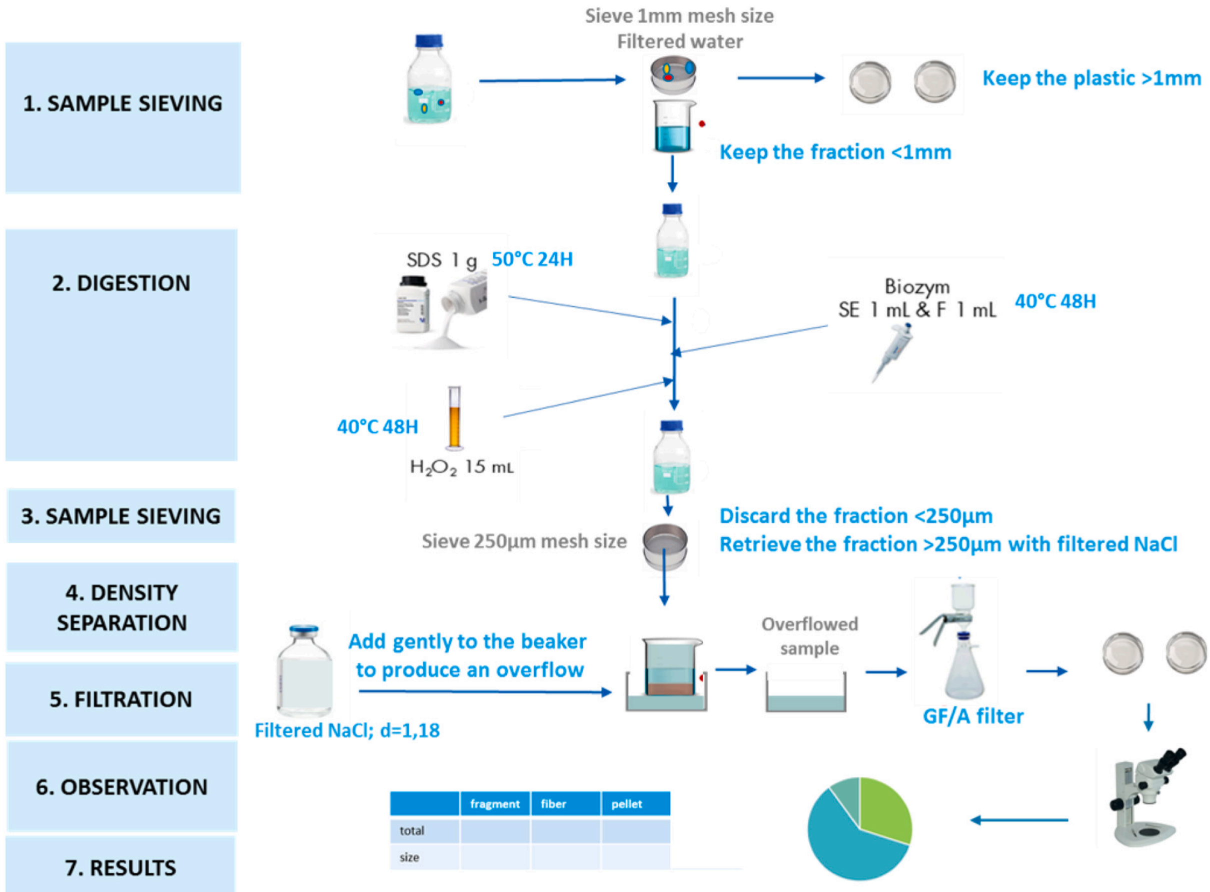

Fig. 2. Protocol for surface water analysis for microplastic observations (the volume of reagents are adapted for 300 mL of sample).

not tapered towards the ends, having a three-dimensional bending. Fragments were defined as irregular shaped hard particles having appearance of being broken down from a larger piece of litter, or flat flexible particle with smooth or angular edges, or near spherical or granular particle which deforms readily under pressure and can be partly elastic. All must have an absence of visible cellular or organic structures and being homogeneously colored. We excluded straight and transparent or whitish fibers in order to exclude biological or organic origin and we excluded particles from tyres.

To assure the control quality, control quality steps were set up based on the recommendations of Dehaut et al. (2019). To prevent microplastic contamination, operators were always using cotton lab clothes and gloves, the water and NaCl solution were filtered before use on GF/A filters (porosity 1.6 μm) and kept in glass bottles, and all glassware were rinsed with filtered water before being used. Due to tropical climate conditions, fan was prohibited and air conditioning was used to maintain cool temperature in the room and avoid dust settling. Specific control samples were established: (i) sieving atmospheric control (SAC) consisting on a filter places on the benchmarked and exposed to airborne contamination during digestion and sieving steps, (ii) observation atmospheric control (OAC) consisting on a filter places on the benchmark and exposed to airborne contamination during stereomicroscope observation, (iii) positive extraction control (PEC) consisting on spiked PE grinded beached yellow fish box (CRT 171, Carat GmbH) in the original sample.

Observation of microplastics on controls evidenced that: SAC had a mean value of 0.08 item (n = 12), and ranged from 0 to 1 item observed; OAC had a mean value of 0.5 item (n = 15), and ranged from 0 to 3 items observed; PEC had a mean value of 96% and ranged from 70% to 100%. Because of the low SAC and OAC values and the high PEC, no corrections related to controls have been applied on the measured microplastic concentrations in the environment presented hereafter.

Microplastic concentrations in surface waters varied from 0.35 to 2522 items m^{-3} showing a wide range of variation up to four orders of magnitude among the different environments (Fig. 4). Microplastic concentrations in sediments were in the same range, 1542 items m^{-3} in Sau Beach (VT-BS-W) with 7% of fragments and 2024 items m^{-3} in Dau Beach (VT-BD-W) without fragments observed.

Globally, lower range of microplastic concentrations was observed in bays while higher range of concentrations was recorded in rivers (Fig. 5). Those surface freshwater environments tend to be more polluted by microplastic than the surface marine environments. Compared to environments from countries listed as emitting the most plastic to the ocean (Jambeck et al., 2015), the level of microplastic concentrations measured in Viet Nam are in the low range of the ones measured in China, Philippines and Indonesia (Alam et al., 2019; Cordova et al., 2019; Esquinas et al., 2020; Fu and Wang, 2019; Zhang et al., 2018). In China, an important research effort on microplastic have been made the past five years (Xu et al., 2020) but the lack of homogenized protocols for sampling, analyzing and observations induced difficulty to compare the data, in term of size range and units. When focusing on studies with similar protocol and observation range as the present study, the level of concentrations measured in Chinese lakes (e.g. Di and Wang, 2018; Wang et al., 2017), rivers (e.g. Lin et al., 2018; Zhao et al., 2014) and bays (e.g. Chen et al., 2018; Zhu et al., 2019) were mostly higher than those measured in Viet Nam.

Microplastics exhibited a wide variation of concentrations from 2.3 items m^{-3} (Red River; HN-RR-W) to 2522 items m^{-3} (To Lich River; HN-TL-W), in which fibers were dominant over the other forms (Fig. 4). The main Vietnamese rivers exhibited the lowest concentrations: 2.3 items

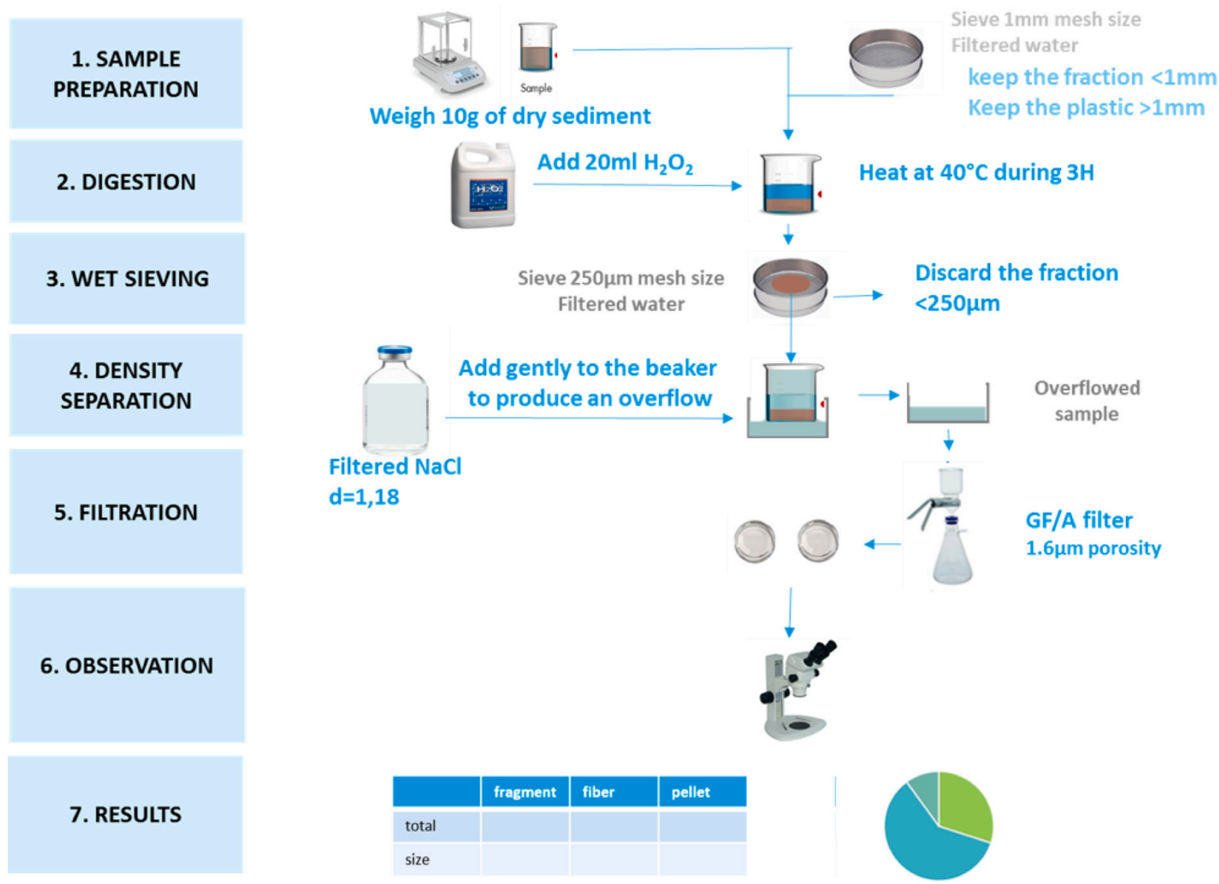

Fig. 3. Protocol for sediment analysis for microplastic observations (the volume of reagents are adapted for 10 g of sample).

m^{-3} in the Red River, 2.7 items m^{-3} in the Han River (DN-HR-W) and 3.9 items m^{-3} in the Dong Nai River (DN-HA-W) while the highest concentrations were measured in urban and smaller rivers: 93.7 items m^{-3} in the Nhue River (HN-NR-W) and 2522 items m^{-3} in the To Lich River (HN-TL-R) (Fig. 4). Indeed, the To Lich River is known to be a highly polluted river in Viet Nam receiving huge amount of untreated wastewaters (e.g. 1,200,000 m^3 d^{-1}), especially domestic ones (Duong et al., 2012; MONRE, 2019). Knowing that the population density of the neighborhood crossed by the river is of 2279 inhabitants km^{-2} and that a washing machine can release up to 728,000 fibers from a 6 kg wash load (Napper and Thompson, 2016), we can hypothesize that the direct release of domestic wastewaters coupled to the low water discharges of the river are responsible of the high concentration of microplastics (especially fibers) observed in this river.

Nevertheless, the microplastic concentrations measured in the studied riverine environments were all lower than the ones previously measured in the Sai Gon River and its urban canals, crossing Ho Chi Minh City, the economic capital of Viet Nam (Lahens et al., 2018; Strady et al., 2020). This river-estuarine system is largely impacted by textile and garment industry: tremendous concentrations of anthropogenic fibers were measured from 22,000 to 251,000 fiber m^{-3} for an observation range of 40–5000 μm in bulk water sampling, which is equivalent to 3960 to 45,180 fiber m^{-3} for an observation size range of 300–5000 μm (i.e., 82% of fiber length measured between 40 and 300 μm) (Strady et al., 2020). The fragment concentrations measured in the Sai Gon River and the main canals ranged from 7 to 94 fragments m^{-3} (e.g., for a minimal area observation range of 45,000 $μm^2$ (Lahens et al., 2018)) showing the extreme dominance of fibers over fragments in the system.

The morphology of microplastics was similar among the five studied riverine environments (Fig. 6). The fiber median size length ranged from 761 μm (DN-HA-W) to 1121 μm (DN-HR-W) and the fragment median area ranged from 76,487 $μm^2$ (HN-RR-W) to 125,935 $μm^2$ (DN-HR-W), except a higher median area observed in the To Lich River (i.e. 279,086 $μm^2$) (HN-TL-W), which may highlight a specific and localized source of microplastics to this highly contaminated river.

The microplastic concentrations in lake and reservoir environments varied from 1.5 items m^{-3} in Tri An Reservoir (HN-TA-W) to 611 items m^{-3} in Ho Tay Lake (HN-HT-W) (Fig. 4). The lowest concentrations were observed in the two sampled reservoirs, the Tri An reservoir, located on the Dong Nai River, and the Dau Tieng reservoir on the Sai Gon River upstream HCMC, which are respectively the second and third biggest reservoir in Viet Nam. Their water used for irrigation and domestic use, are thus of good quality (Ha et al., 2007; Strady et al., 2017), despite the occurrence of cyanobacteria in the Tri An Reservoir (Dao et al., 2016). Those reservoirs are few impacted by domestic, urban or industrial discharges, only fisheries or aquaculture can be observed. Similar to riverine environment, fibers were also the predominant form in these reservoirs, which accounted more than 95% (Fig. 4). The fiber median size lengths were in the same range than riverine environments with 846 and 760 μm in the Tri An and Dau Tieng Reservoirs respectively, while the fragment median area were slightly higher with 125,607 and 157,463 $μm^2$ respectively (Fig. 6).

The urban lakes showed elevated microplastic concentrations compared to reservoirs ranging from 70 items m^{-3} in Cong Vien Lake (DN-CV-W) to 611 items m^{-3} in Ho Tay Lake (HN-HT-W) (Fig. 4). The areas of the lakes do not seem to influence the microplastic concentrations in surface waters, the variables are not correlated (p value >0.1), which is contradictory to observations made in mountain lakes in more remote areas (Free et al., 2014). Those urban lakes are all characterized by high urban and domestic pressure on their ecosystems, with direct release of treated and untreated wastewaters. We rather suggest that the amount of wastewaters release, the quality of their treatment, and the

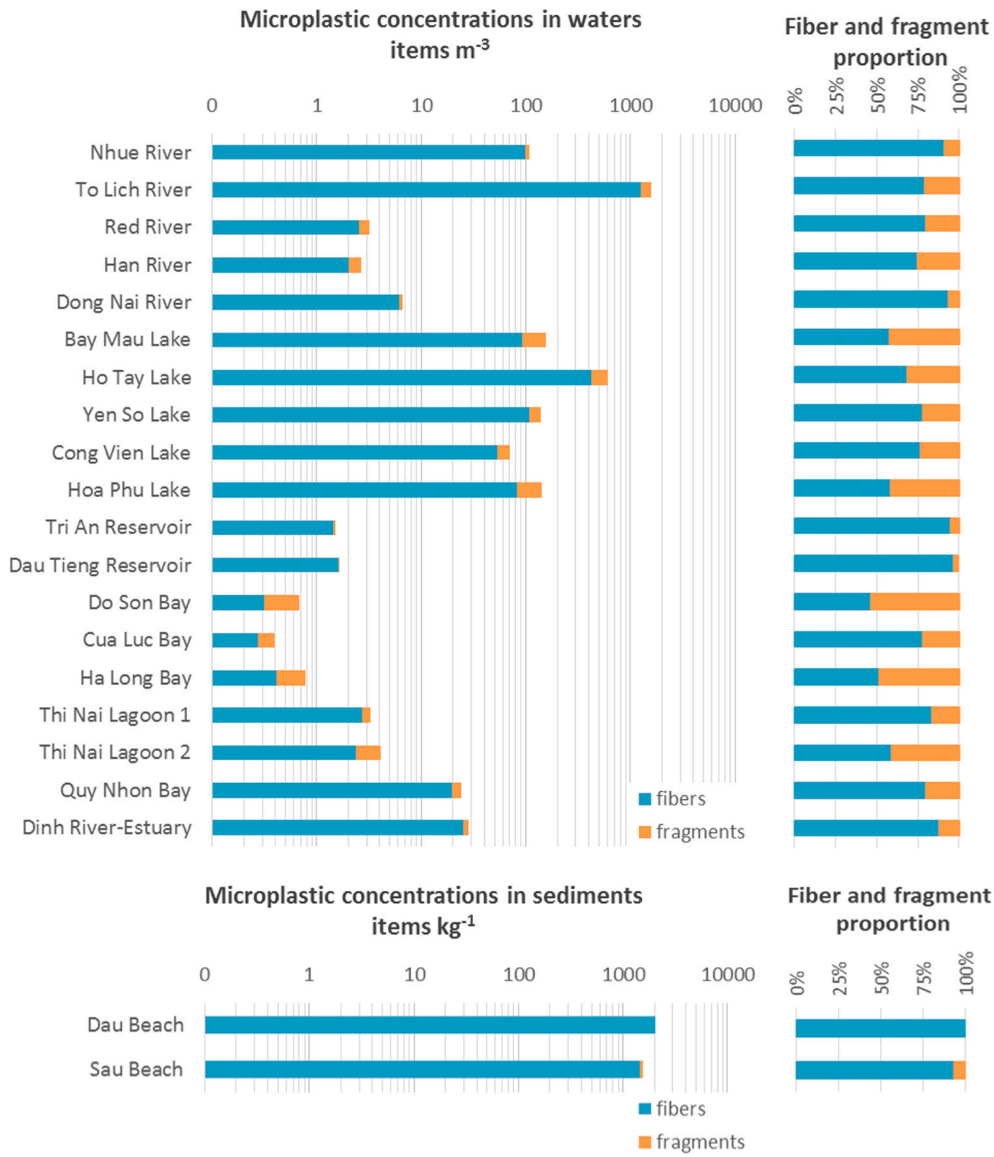

Fig. 4. Concentrations of microplastics, fibers and fragments in surface waters and sediments. Proportion of fibers relative to fragments in surface waters and sediments.

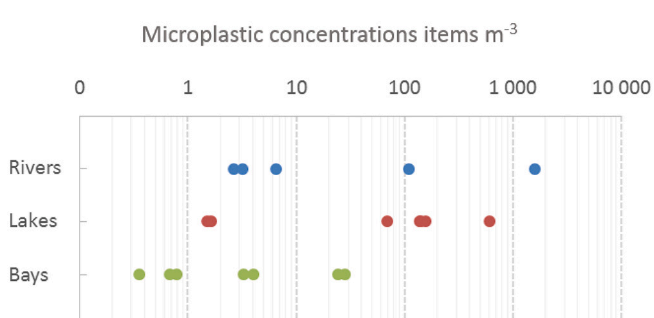

Fig. 5. Range of microplastic concentrations measured in river (blue), lake (red) and bay (green) environments. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

population density surrounding the lakes may affect the microplastic concentrations in lakes surface waters. Differences of plastic morphology were also observed between the lakes: the median fiber length ranged from 908 to 1894 μm and the median fragment area from 67,806 to 138,020 μm^2 area (Fig. 6). At Hoa Phu Lake, the release of leachate from the city landfill site might be responsible for microplastics release in the lake's water. The higher proportion of fragments relative to fibers (42%, Fig. 4) associated to tall fibers and large fragments (1393 μm length and 138,020 μm^2; Fig. 6), support the hypothesis of fragmentation processes of larger plastic items at the landfill station, followed by fragment release in the leachates and wastewaters and by fragment transport towards the lake (Horton et al., 2017).

In bays, microplastic concentrations varied from 0.4 items m^{-3} in Cua Luc bay (QN-CL-W) in Quang Ninh province to 28.4 items m^{-3} in the Dinh River estuary mouth (VT-DR-W) (Fig. 4). Fibers were also dominating in lagoons and bays, excepting for Do Son Bay, Ha Long Bay, and Thi Nai Lagoon area near the Ha Thanh river mouth where the ratio of fibers and fragments were rather similar (Fig. 4). At the mouth of the Dinh River estuary, the high microplastic concentration was associated to high percentage of fibers with short median fiber length (e.g., 502 μm; Fig. 6). This river is impacted by both untreated wastewaters release and fisheries activities. In Quang Ninh and Hai Phong provinces, the low measured microplastic concentrations (e.g. 0.4, 0.7 and 0.8 items m^{-3} in

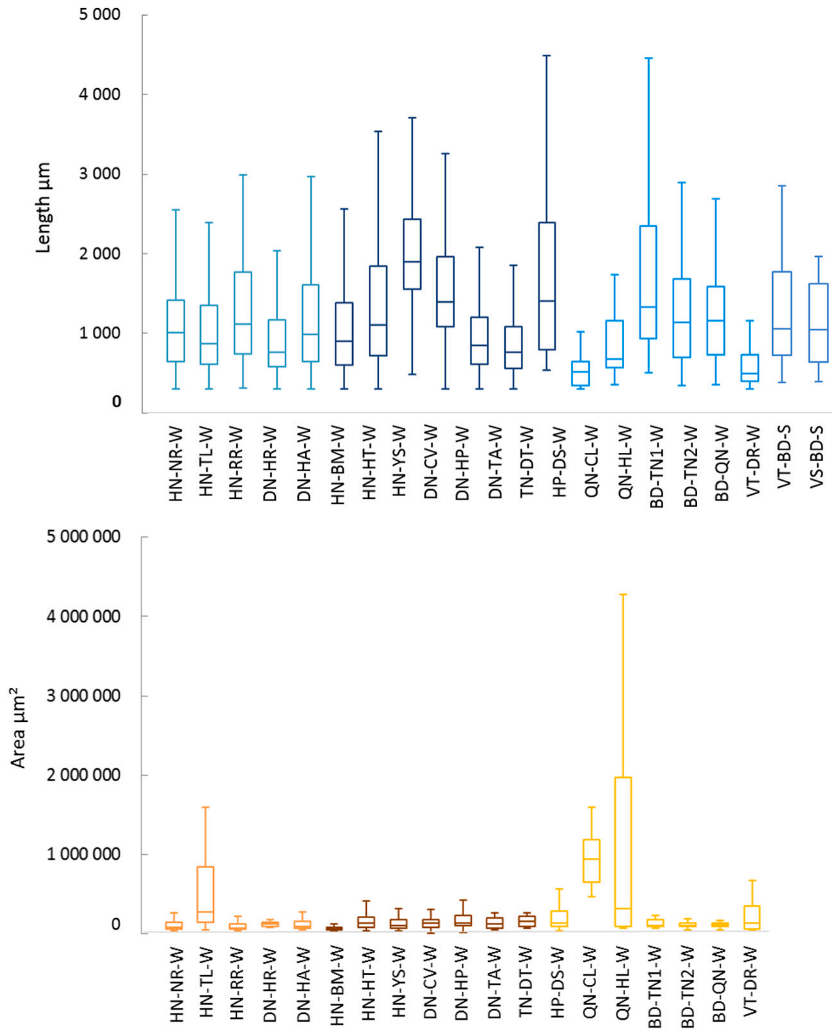

Fig. 6. Boxplot of length of fibers (in blue) and area of fragments (in orange) measured in surface waters and sediments. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Cua Luc (QN-CL-W), Do Son (HP-DS-W) and Ha Long Bays (QN-HL-W) respectively) were unexpected regarding the important aquaculture and touristic activity in this area. The touristic activity in the Ha Long Bay, a Unesco World Heritage Site, welcoming more than 10 million tourists per year, was often pointed out as an important source of marine plastic litter to the surface waters. In 2019, the total Pacific oyster farming area, consisting of hanging line system attached to a main line with EPS floating buoys, was estimated of about 3000 ha while the small-scale fish farming, consisting of bamboo or wood cages composed of net pen, mooring system and EPS buoys or HDPE barrel to lift the whole system, was estimated of 12,888 units (DARD, 2020). We expected that the wear and tear of the barrel, buoy and net by wave, currents, salt and UV irradiance action would have conducted to higher microplastic concentrations in the surface waters, as seen in China's bays characterized by intensive aquaculture activities (Chen et al., 2018; Zhu et al., 2019) where microplastic concentrations were one to three order of magnitude higher that in Quang Ninh and Hai Phong. The measured medians of fragments area were elevated, especially in the Cua Luc Bay (e.g., 941,885 µm^2; QN-CL-W; Fig. 6), and further investigations are thus required to identify the nature of those fragments and their possible sources. We also assume that the selection of the location of the sites was not adapted to evidence specifically the impact of aquaculture activities, as the samples were taken relatively far from the farms.

In Binh Dinh province, microplastic concentrations were 3.2, 4.1 and 24.3 items m^{-3} respectively in Thi Nai Lagoon (BD-TN1-W and BD-TN2-W), and Quy Nhon Bay (BD-QN-W). This province is also characterized by aquaculture activities, and reported 1221 small scale fish farming units in 2019 (DARD, 2020). Despite a lower aquaculture activity than in Quang Ninh, the microplastics concentrations were higher (Fig. 4). The Thi Nai lagoon is directly influenced by the Kon and Ha Thanh Rivers receiving untreated domestic and industrial waste waters from industrial zones, which could be responsible of main microplastic inputs to the lagoon and bay, additionally to the fishery activities.

This baseline study evidenced that the levels of microplastic concentrations fluctuated spatially and within a type of environment. Microplastic concentrations appeared to be related to the surrounding anthropogenic activities using plastic (fisheries, aquaculture, households, landfills, the urban pressure on the environment and the direct release of wastewaters, treated or untreated). As stressed by Cera et al. (2020), the setting up of an adapted and common methodology, performed by local researchers, is crucial for the understanding and the local remediation of microplastic pollution. This study pointed out the influence of the sources to each environment and so investigation should be emphasized in a near future to qualify and quantify those sources on the specific sites. The long term measurements of microplastic concentrations on those environments under a monitoring program will allow to address the temporal variability, linked to the sources and seasonal environmental change. Hydrological factors such as precipitation, water discharge, evaporation could be thus considered to better understand the temporal variability. In a policy perspective, this paper is the first baseline study on microplastic pollution in Viet Nam and will be of high interest for authorities that are currently amending the National Action Plan on the reduction of marine plastic pollution by 2030, and specifically designing a monitoring on microplastic concentrations. This baseline will also allow monitoring the effectiveness of actions of remediation that will be set up in the future by local authorities to reduce microplastic pollution from sources to sea.

CRediT authorship contribution statement

Emilie Strady: Conceptualization, Methodology, Validation, Supervision, Writing - original draft. **Thi Ha Dang:** Investigation, Writing - review & editing. **Thanh Duong Dao:** Investigation, Writing - review & editing. **Hai Ngoc Dinh:** Investigation, Writing - review & editing. **Thi Thanh Dung Do:** Investigation, Writing - review & editing. **Thanh Nghi Duong:** Investigation, Writing - review & editing. **Thi Thuy Duong:** Investigation, Writing - review & editing. **Duc An Hoang:** Investigation, Writing - review & editing. **Thuy Chung Kieu-Le:** Investigation, Writing - review & editing. **Thi Phuong Quynh Le:** Investigation, Writing - review & editing. **Huong Mai:** Investigation, Writing - review & editing. **Dang Mau Trinh:** Investigation, Writing - review & editing. **Quoc Hung Nguyen:** Investigation, Writing - review & editing. **Quynh Anh Tran-Nguyen:** Investigation, Writing - review & editing. **Quoc Viet Tran:** Investigation, Writing - review & editing. **Tran Nguyen Sang Truong:** Investigation, Writing - review & editing. **Van Hai Chu:** Investigation, Writing - review & editing. **Van Chi Vo:** Investigation, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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