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Characteristics of microplastics in shoreline sediments from a tropical and urbanized beach (Da Nang, Vietnam)



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ABSTRACT

Microplastics in shoreline sediments were investigated from Da Nang beach for the first time. Sediment samples at the two depth strata (0–5 cm and 5–10 cm) at eight sites along the entire coast were collected for identifying the characteristics of microplastics, including their concentration, size, shape, color, and nature. The synthetic fiber was the predominant type of microplastics, accounting for 99.2% of the total items. Blue (59.9%) and white (22.9%) were the most common colors of the fibers. Synthetic fibers showed a homogenous distribution at all sampling sites with a mean concentration of 9238 ± 2097 items kg^{-1} d.w. Meanwhile, the fibers tended to concentrate much more at the surface stratum than the deeper stratum. A large number of synthetic fibers (81.9%) were in the size range of 300–2600 μm , which might pose a threat to marine biota and human health.

1. Introduction

Microplastic pollution is an alarming problem that poses many threats to human health and to the ecosystem. With a size of between 1 μm and 5 mm (Frias and Nash, 2019), microplastics (MPs) are widely distributed in the environment and can enter the human body and organisms through ingestion and inhalation to cause adverse impacts (Thompson et al., 2009). MPs have been detected in a variety of organisms at all trophic levels from zooplankton (Cole et al., 2013; Sun et al., 2017) to invertebrates (Setälä et al., 2016; Van Cauwenberghe et al., 2015), fishes (Neves et al., 2015; Vendel et al., 2017; Pazos et al., 2017), birds (Amelineau et al., 2016; Provencher et al., 2018), and mammals (Nelms et al., 2018; Nelms et al., 2019). Moreover, toxicity associated with plastics such as plastic additives or adhered pollutants absorbed in plastic particles (e.g. trace metals, endocrine-disrupting chemicals, POPs) may potentially impact higher trophic level species and human health through bioaccumulation and biomagnification processes via the food webs (Andrady, 2011; Wang et al., 2018). Adverse effects of MPs in organisms have been evidenced at different levels such as causing oxidative stress and histological changes, altering feeding preferences and behaviors, inhibiting incubation time and hatching of eggs, decreasing growth rate and survival rate (Lo and Chan, 2018; Luan et al., 2019; Wang et al., 2019; Cole et al., 2015;

Lönstedt and Eklöv, 2016; Lee et al., 2013; Carson et al., 2011).

Shorelines all over the world concentrate a large number of macroplastics as well as microplastics, which came from both anthropogenic activities inland and the sea (Ryan et al., 2009). Shoreline areas, especially beaches, are environments presenting ideal conditions (e.g. high irradiation and temperature, abundant wind, and waves) for the degradation of macroplastics into microplastics (Browne et al., 2007). The widespread distribution of microplastics in the shoreline sediment has been reported in many areas all over the world such as the western Gulf of Lion, Northwestern Mediterranean Sea (Constant et al., 2019), Germany (Liebezeit and Dubaish, 2012), Canada (Mathalon and Hill, 2014), Brazil (Filho and Monteiro, 2019), Portugal (Martins and Sobral, 2011), Italy (Fischer et al., 2016), Orkney (Blumenröder et al., 2017), and China (Qiu et al., 2015). The abundance of MPs presents a wide range of concentrations from only a few particles (e.g. in Belgium; Claessens et al., 2011; Russia; Esiukova, 2017; Portugal; Martins and Sobral, 2011) to thousands of particles per kilogram of dry weight sediment (e.g. in Tunisia; Abidli et al., 2017; Beibu Gulf, China; Qiu et al., 2015; Canada; Mathalon and Hill, 2014).

While a huge amount of research on MPs in the shoreline sediment has been conducted in many countries in America and Europe, studies on MPs in South East Asia marine environment are still rare although MPs pollution in this region seems more serious. In fact, South East Asia

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Fig. 1. Map of Da Nang shorelines and sampling sites.

accounts for half of the countries in the list of top 10 countries that release plastic to the ocean (Jambeck et al., 2015). According to Shim et al. (2018), the microplastic concentrations in beaches in Asia, especially East Asia, were significantly higher than those in countries in Europe, North and South America, North and South Pacific, Atlantic, and the Mediterranean. Hong Kong was identified as hotspots of marine plastic pollution with the density of MPs in the sediment of 25 beaches along the coastline reaching 5595 items m^{-2} (Fok and Cheung, 2015). Some other Asia countries with a high level of microplastic concentrations were China (5000–8714 items kg^{-1} sediment at Beibu Gulf areas; Qiu et al., 2015), Japan (1900 items kg^{-1} sediment at Tokyo Bay; Matsuguma et al., 2017), and South Korea (large MPs (1–5 mm): 0–2088 items m^{-2} , and small MPs (0.02–1 mm): 1400–62,800 items m^{-2} at 20 sandy beaches; Eo et al., 2018). Meanwhile, Singapore was the country with the lowest concentrations of MPs in the region (0–16 items kg^{-1} sediment in 2006; Ng and Obbard, 2006; and 36.8 ± 23.6 items kg^{-1} sediment in 2014; Nor and Obbard, 2014).

Vietnam is the third highest consumer of plastic in South East Asia (after Malaysia and Thailand) with a plastic consumer per capita of 41 kg in 2015 (increased 10 times more than that in 1990) (Lahens et al., 2018). With more than 1.8 million tons of plastic waste generated per year and only 27% of them being recycled, plastic pollution has become a big problem that threatens the coastal area environment of the country. Vietnam has been identified as the 4th largest plastic emitting country in the world with an estimated 0.28–0.73 million metric tons per year of plastics discharged into the marine environment (Jambeck et al., 2015). A survey conducted by IUCN and Greenhub (IUCN, 2019) showed that plastic items accounted for 92% of the total debris collected on the beaches of Vietnam. However, up to now, there is no information on microplastics distribution along the shorelines, which may cause difficulty for the government to take a comprehensive view of the current situation of plastic pollution as well as to have an effective management strategy. In such context, the purpose of this study is to estimate the concentration of microplastics ($300 \mu m$ -

5000 μm) in the surface sediment of an urbanized shoreline in Vietnam and to characterize the parameters that may influence their distribution along the shorelines. To do so, we selected sandy beaches along the shorelines of the coastal megacity of Da Nang and investigated the characteristics of the microplastics (concentration, size, shape, color, and nature).

2. Materials and methods

1. Study sites and sample collection

Da Nang is one of the biggest and major coastal cities of Vietnam with a total area of 1284.88 km^2 ; a population of 1141130 people in 2019; and a density of 888.12 people km^{-2} (DSO (Danang Statistical Office), 2020). The city has a coastline of over 90 km (Thach and Nguyen, 2010) with many sandy beaches, which played an important role in the city's development. The shoreline area has an irregular semi-diurnal tidal regime with an average tidal range of around 1 m. The coastal water current is the predominantly southeast direction with an average speed of about 20–25 $cm s^{-1}$ (Le, 2009). Da Nang is characterized by a tropical monsoon climate with two seasons in a year, a wet season from September–December, and a dry season from January–August. The area receives a total of 2319 h of sunshine and 2150 mm of rainfall, obtains an annual mean temperature of 27.3 °C and humidity of 78.3% in 2019 (DSO (Danang Statistical Office), 2020). Rapid urbanization (urbanization rate: 87.2%) and the increase of economic development activities had put the coastal environment under many stresses. Every day, various kinds of solid waste and wastewater from the city and upstream areas are carried to the coastal areas and rushed along the shorelines. Tourism activities are important and contribute to waste emission with many resorts and bathing areas along the shoreline, as do fishery activities with waste emissions toward the coastal environment.

Eight sandy beach sites (B1 - B8) along the entire Da Nang coast

Table 1
Geographical information of sampling sites.

Sites code	Longitude	Latitude	Description
B1	15.98817	108.27746	Tan Tra beach - Resort area
B2		108.26330	Son Thuy beach - Public bathing area
B3	16.04755	108.25047	My Khe beach - Resort area
B4	16.07102	108.24661	Pham Van Dong beach - Public bathing area
B5	16.10054	108.25714	Tho Quang beach - Fishery activities
B6	16.07312	108.19404	Thanh Khe beach - Bathing, fishery activities
B7	16.08224	108.16564	Hoa Minh beach - Public bathing area
B8	16.12633	108.12457	Nam O beach - Abandoned area

were selected for sampling in November 2019 (Fig. 1, Table 1). At each beach, a transect was plotted from the water edge to the position in front of the vegetation or artificial structure. For one site, five subsamples were collected at five equidistant locations along the transect and mixed together to obtain a homogeneous composite sample. Sediment samples were collected with a clean stainless steel hard tube (diameter x height: 6 × 10 cm) and a flat metal spatula at two depth strata separately, from the surface to 5 cm and from 5 to 10 cm. The total volume of the sample at one site was about 700 cm³ for one depth stratum. Samples were then stored in closed clean glass bottles (Duran® bottle, 1000 mL) and transported to the laboratory.

2.2. Microplastics extraction, analysis, and observation

Sediment samples were homogenized and dried at 55 °C for 72 h in a drying oven. Then, the extraction was performed on subsamples of 10 g of dry sediment. The digestion step was conducted by adding H₂O₂ 30% to the samples and keeping at 40 °C for 3 h to remove natural organic matters (Masura et al., 2015). The oxidized sediments were subsequently sieved with filtered water using a 300 µm mesh size sieve. The fraction of the sample passed through the sieve (< 300 µm) was discarded because our target microplastic size was from 300 to 5000 µm. Meanwhile, the sample fraction greater than 300 µm retained on the sieve was kept for conducting the density separation step with filtered concentrated NaCl solution (1.18 g mL⁻¹) by overflow producing technique (Hidalgo-Ruz et al., 2012). The overflow was conducted three times for each sample to have a good recovery of microplastics. Then, the solution containing MPs was filtered through glass fiber filters (GF/A, pore sizes of 1.6 µm) using a vacuum pump. Filters with MPs attached were kept in covered glass Petri dishes for identification of MPs characteristics.

A Leica S9i stereo-microscope equipped with a camera was employed for observing, analyzing, and photographing particle samples on the filters. MPs particles were categorized into five types of geometric shapes following the recommendation of GESAMP (2019) and Free et al. (2014): fragment, fiber, pellet, film, and foam. The sizes of all particles were measured using the LASX software®. Since it is quite difficult to visually distinguish the nature of the particles when lower than 300 µm length size, the size range of MP observation in this study was limited to 300 µm to 5 mm for fibers and to 45,000 µm² (300 µm × 150 µm) to 25,000,000 µm² (5000 µm × 5000 µm) for fragments. The concentration of MPs was expressed as items per kilogram of dry sediment (items kg⁻¹ d.w.). Based on the recommendation of GESAMP (2019) for particles greater than 300 µm, we identified microplastic visually only using a stereomicroscope and we did not perform additional spectrometry analysis to identify systematically the nature of plastic. However, we isolated 10 items representing both the main types of fibers observed and for which their plastic nature needed to be validated. A XploRA™ PLUS Raman spectroscopy (Horiba®), with 785 nm laser wavelength to eliminate luminescence signals, coupled to Raman Spectra Database Collection KnowItAll® was used to determine

the polymer of the fibers selected. The fibers were Polyamides (PA, *n* = 3), Poly-ethylene vinyl alcohol copolymers (PVOH, *n* = 2), Polyester (*n* = 2), Polyethylene terephthalate (PET, *n* = 1), Polyacrylonitrile (PAN, *n* = 1), and Polyacrylate (*n* = 1), confirming our observation categorization as microplastics.

3. Quality control

To avoid microplastic's contamination from the ambient environment, a variety of rules have been strictly followed during the sampling and analytical process (GESAMP, 2019; Dehaut et al., 2019): cleaning the working area with alcohol before carrying out the procedure, wearing of cotton lab clothes and gloves, using glass or metal equipment and containers for sampling and analyzing, previous rinsing with filtered water (tap water filtered through GF/A filters) of glassware, previous filtration of solution (using GF/A filters), checking filters and sieves under a microscope prior to use, covering samples with aluminum foil, ban of fans in the lab. Atmospheric control tests and blank samples (Dehaut et al., 2019) were conducted during the analytical process and evidenced only 2 microfibrils in the blank samples. The blank results were not retrieved from the sample concentrations measured.

4. Data analysis

All data analyses were performed using R software (R Core Team, 2018). One-way analysis of variance (ANOVA) was used to identify the variation in MPs concentrations, and *p*-values of less than 0.05 were regarded as significant. Data were presented as mean ± standard deviation (SD).

3. Results

1. Concentrations of microplastics

Microplastics were found in all sediment samples from Da Nang beaches with a total number of 745 items. Fibers were the predominant type of microplastic found at two depth strata and at all sampling sites, comprising up to 99.2% of the total identified items (Fig. 2). Fragments (*n* = 6 items) accounted for 0.8% of the total MPs, and all of them were only found at the surface stratum (0–5 cm). The other shapes (pellets, foam, and film) were not detected at all sampling sites. Accordingly, because of the quasi absence of fragments, we will consider later on that concentrations of microplastics are equal to the concentrations of fibers. The mean concentration of microfibrils at Da Nang beach was 9238 ± 2097 items kg⁻¹ d.w. Except for B6 site which exhibited the lowest concentrations (5100 items kg⁻¹ d.w.), the concentrations at the remaining sites (B1-B5, B7-B8) were rather similar and ranged from 9000 to 11,000 items kg⁻¹ d.w., indicating a homogenous distribution of microfibrils in the shorelines of Da Nang (Fig. 3).

However, considering the depth distribution, the concentration of microfibrils at the 0–5 cm depth stratum (5750 ± 1732 items kg⁻¹ d.w.) was higher than that at the 5–10 cm stratum (3488 ± 1585 items kg⁻¹ d.w.), and accounted for 62.2 ± 12.5% of the total microfibrils (Fig. 4). This trend was observed in most sites of Da Nang beach, demonstrating that the surface sediment was more concentrated in microplastics than the underlying sediment layer.

2. Colors

Microfibrils occurred in a variety of colors, including red, yellow, green, blue, purple, and white (Fig. 2). Blue was the most common color (59.9%), followed by white (22.9%). The other colors were only found with a small ratio (red - 8.2%, yellow - 6.8%, purple - 1.4%, and green - 0.7%). This color order of distribution was quite similar among sampling sites and also at both sediment layers (Fig. 3).

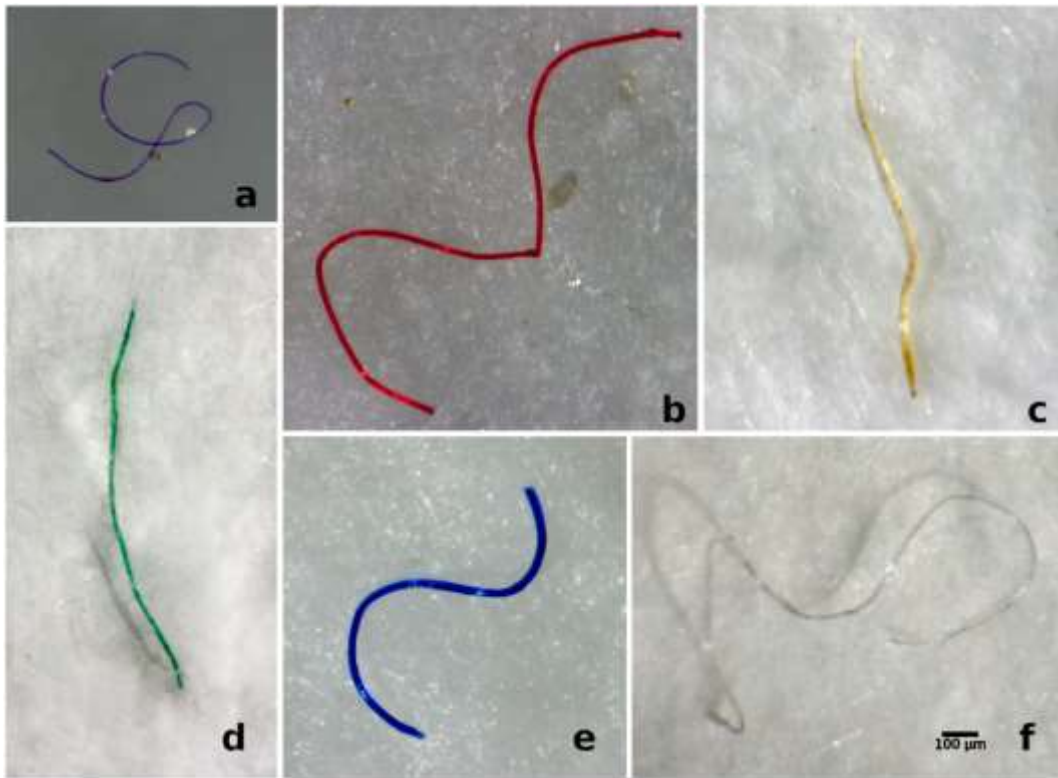


Fig. 2. Observed microplastics in Da Nang shoreline sediments (scale bar: 100 μm for all photos from a to f).

3.3. Size

Microfibers in Da Nang beaches had a wide range of sizes with an average length of $1701 \pm 1029 \mu\text{m}$ (min-max: 303 μm - 4996 μm) and an average diameter of $19.58 \pm 9.27 \mu\text{m}$ (min-max: 4 μm–79 μm). The mean length and diameter of microfibers among the eight sampling sites were rather similar, whereas the mean length of microfibers in the shallow layer (0–5 cm) was significantly shorter than that in the deeper layer (5–10 cm) ($1596.3 \pm 982.7 \mu\text{m} < 1900 \pm 1046.1 \mu\text{m}$, $p = 1.47 \times 10^{-5} < 0.05$). In the 0–5 cm depth stratum, the most frequent size of fibers was in the range 300–2100 μm (accounted for 76.1% of total microfiber observed in the layer), and the highest ratio of fiber number was in the length of 1000–1100 μm (34 fibers, accounted for 7.4% of the total). Meanwhile, in the 5–10 cm depth stratum, 76.3%

of fiber was in the length from 500 to 2600 μm and the most dominant length was 1200–1300 μm (Fig. 5). Regarding fiber diameter distribution, there was no significant difference between the two depth strata (Fig. 6). The predominant fiber's diameter was from 5 to 30 μm (89.1%) in the surface stratum and from 5 to 35 μm (96.8%) in the deeper stratum. Moreover, the diameter group of 15–20 μm was the most common size in Da Nang beach sediment, which accounted for 25% and 29.4% of the total microfibers in stratum 0–5 cm and 5–10 cm, respectively.

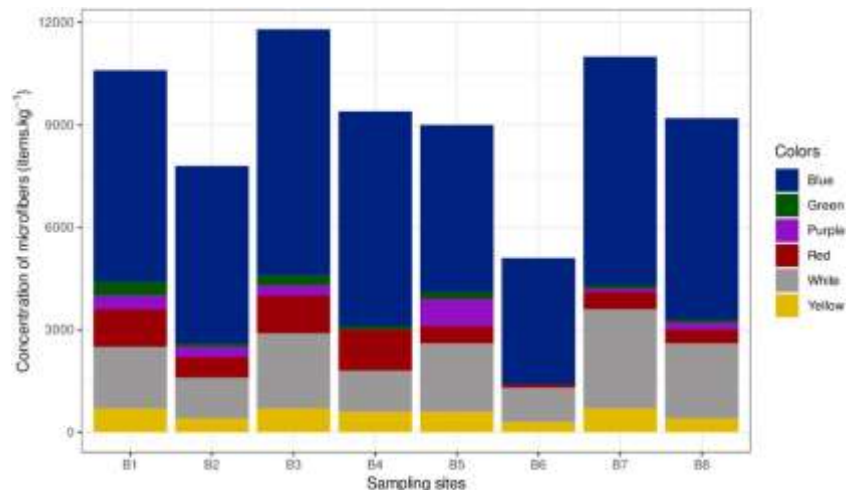


Fig. 3. Concentrations of microfibers (in items kg⁻¹ d.w.) and associated color distribution at the eight sampling sites along the Da Nang shorelines.

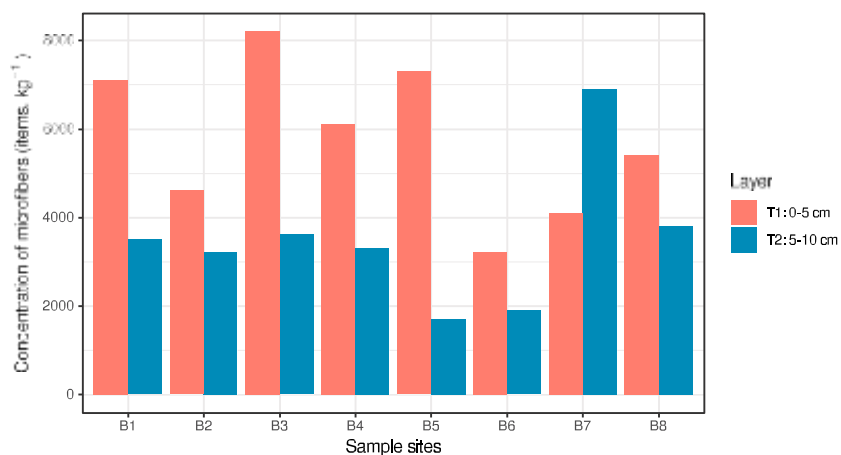


Fig. 4. Concentrations of microfibers measured at each sampling site for each sediment layer: T1: 0–5 cm and T2: 5–10 cm.

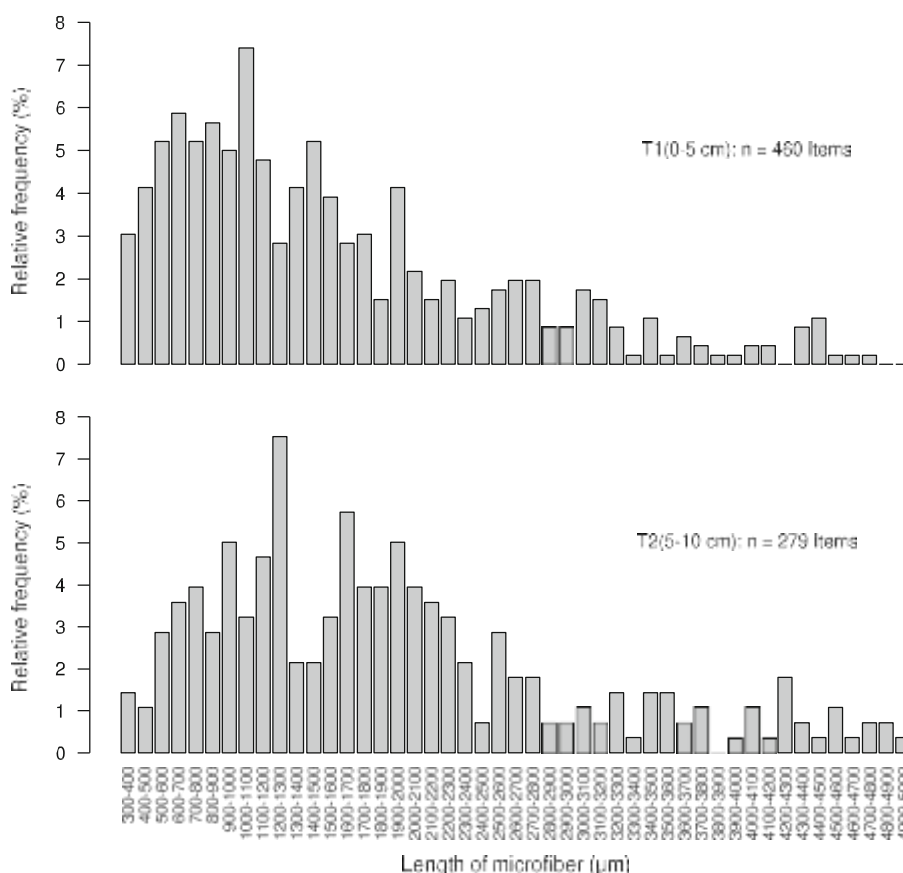


Fig. 5. Relative frequency of fibers length by size class cumulated for all samples on the two distinct strata (T1: 0–5 cm and T2: 5–10 cm).

4. Discussion

1. Dominance of synthetic fibers among the microplastics observed

Microplastics in Da Nang shoreline were mainly composed of fibers while the other shapes did not or occurred at a percentage lower than 1%. This pattern of shape's distribution is similar to microplastics observed in the tropical Corvina beach, northern Brazilian coast, where microfibers accounted for 95% of the total MPs particles, followed by fragments (~ 5%), and pellets (< 0.01%) (Filho and Monteiro, 2019) and in temperate European beach sediments composed of 98.7% of fibers, 0.4% of films, and 0.9% of fragments (Lots et al., 2017). Synthetic fibers (i.e. from petrochemical origin: polyester, polyamide,

polypropylene, etc.) are considered with artificial fibers (i.e. from artificial cellulose or silk e.g. viscose, rayon) and with the natural fibers (e.g. cotton, wool) as anthropogenic fibers (Strady et al., 2020). Anthropogenic fibers, and so synthetic fibers, are all used in the textile and apparel industries. The predominance of synthetic fibers in a lesser extent in comparison to the other shapes was reported at many beach sediment from countries worldwide such as Tunisia (71–99%; Abidli et al., 2018), Slovenia (75–96%; Laglbauer et al., 2014), Mexico (91%; Piñon-Colin et al., 2018), South Africa (more than 90%; Nel and Froneman, 2015), France (59–77%; Constant et al., 2019), and the southeastern United States (Yu et al., 2018). In Asia, synthetic fibers were also the common type of MPs found in beach sediments in Singapore (72%; Nor and Obbard, 2014), China (Qiu et al., 2015), India

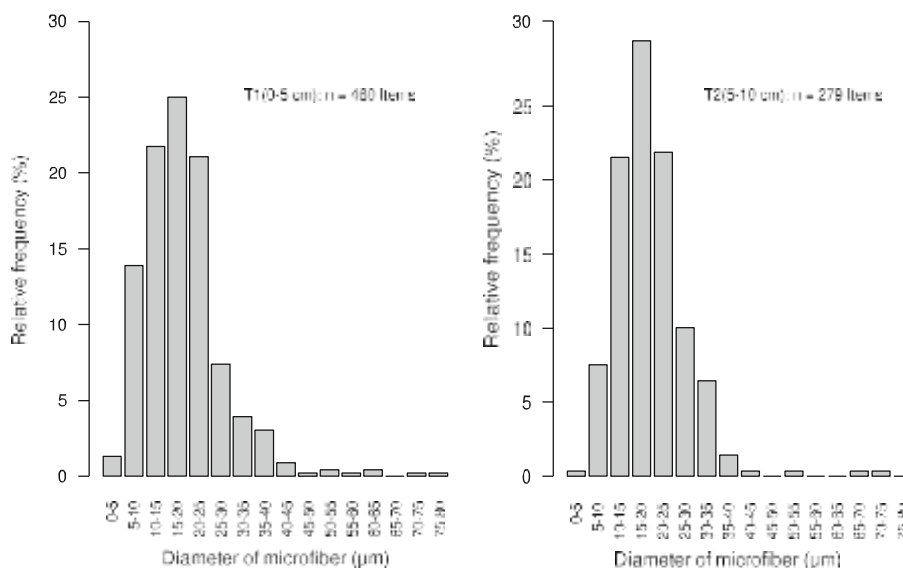


Fig. 6. Relative frequency of fibers diameter by size class cumulated for all samples on the two distinct strata (T1: 0–5 cm and T2: 5–10 cm).

(51%; [Tiwari et al., 2019](#)), Hong Kong (57.2%; [Lo et al., 2018](#)), and Dubai, UAE (63.9%; [Aslam et al., 2020](#)). Sandy beaches from nine countries located around the Indian Ocean (including Australia, Bangladesh, India, Indonesia, Maldives, Myanmar, Pakistan, Sri Lanka, and Tanzania) were also reported to contain only synthetic fibers ([Balasubramaniam and Phillott, 2016](#)).

4.2. Comparison of microplastic concentrations to worldwide beach sediments

Measured microplastic concentrations can vary because of the sampling protocols (e.g. sediment depth, pooling of sediment, location on the shoreline), the methodologies used in the laboratory (e.g. separation technique used, sieving), and the size range of observation ([Table 2](#)). So far, most investigations targeted size range from 1 μm to 5000 μm ([Qiu et al., 2015](#); [Yu et al., 2016](#); [Lo et al., 2018](#); [Aslam et al., 2020](#)), while some targeted 1 μm to 1000 μm ([Claessens et al., 2011](#); [Dekiff et al., 2014](#); [Balasubramaniam and Phillott, 2016](#)) or 300 μm to 5000 μm ([Laglbauer et al., 2014](#); [Esiukova, 2017](#); [Matsuguma et al., 2017](#)). Those differences can thus induced a bias in the comparison of concentrations between sites. Therefore, some important parameters influencing the final concentrations were mentioned in the [Table 2](#) to make the comparison more accurate.

Concentrations of MPs in surface shoreline sediments from Asian countries are shown on [Table 2](#). A similar range of concentrations (6870 ± 6140 items kg^{-1} d.w.; min-max: 5014–8714 items kg^{-1} d.w.) to our study (9238 ± 2097 items kg^{-1} d.w.) was observed in beach sediments from the Beibu Gulf and the coast of the South China Sea ([Qiu et al., 2015](#)), located nearby human activities, despite that the range of MPs observation was broader than the one of our study ([Table 2](#)). In surface beach sediment from India, lower microplastic concentrations than in Da Nang were measured despite that the beaches were impacted by different anthropogenic activities like an urban area (Mumbai, 220 ± 50 items kg^{-1} d.w.), port and industrial areas (Tuticorin, 181 ± 60 items kg^{-1} d.w.), and tourism and fishing areas (Dhanushkodi, 45 ± 12 items kg^{-1} d.w.) ([Tiwari et al., 2019](#)) or Canacona city (520 items kg^{-1} d.w.; [Balasubramaniam and Phillott, 2016](#)). The MPs concentrations measured in other Asian beaches from Indonesia, Myanmar, Pakistan, Sri Lanka, Singapore, Japan, and Dubai were also one order of magnitude lower than the ones in Da Nang, despite again that the range of MPs observation was broader than our ([Balasubramaniam and Phillott, 2016](#); [Nor and Obbard, 2014](#); [Ng and Obbard, 2006](#); [Matsuguma et al., 2017](#)) ([Table 2](#)). The same

observations were made in other beaches from other continents like in Argentina (46.0 ± 34.8 to 86.2 ± 66.1 items kg^{-1} d.w.; [Reis, 2019](#)), in Belgium (52.8 – 213.4 items kg^{-1} d.w.; [Claessens et al., 2011](#)), Slovenia (213.2 items kg^{-1} d.w.; [Laglbauer et al., 2014](#)), Germany (13 – 532 items kg^{-1} d.w.; [Stolte et al., 2015](#)), Russia (1.3 – 36.3 items kg^{-1} d.w.; [Esiukova, 2017](#)), Romania (193.2 – 3606.8 items kg^{-1} d.w.; [Popa et al., 2014](#)), in Mexico (min-max: 16 ± 4 – 312 ± 145 items kg^{-1} d.w., mean: 162 ± 150 items kg^{-1} d.w.; [Piñon-Colin et al., 2018](#)). We note that the inhabitant population in touristic beaches of Mexico was lower than in Da Nang (until 251,871 inhabitants compared to 1,141,130 in Da Nang), pointing out the possible influence of population density on the observed concentrations. Same range of fiber concentrations than in Da Nang were recorded only in the Halifax Harbor in Canada (8000 items kg^{-1} d.w.; [Mathalon and Hill, 2014](#)).

4.3. Sources of microplastic in Da Nang shoreline beaches

The occurrence of synthetic fibers at Da Nang shoreline might be attributed to the discharge of domestic wastewaters to the beach ([Horton et al., 2017](#)). The effluents from clothes washing processes were identified as an important emission source of synthetic fibers ([Browne et al., 2011](#); [Napper and Thompson, 2016](#); [De Falco et al., 2018](#)), and since the wastewater treatment plants in Da Nang are applying basic treatment, they cannot remove all the MPs from the wastewater ([Gogina and Quan, 2018](#); [Filgueiras et al., 2019](#); [Browne et al., 2011](#)). Currently, Da Nang has 16 coastal wards with more than 30,570 households with many tourist accommodation establishments, which are partially connected to the city sewer system and which directly discharged domestic wastewaters (both treated and untreated) to the shorelines via 44 sewer outlets ([Fig. 1](#)) ([Da Nang DONRE \(Department of Natural Resources and Environment Da Nang\), 2018](#)). During the rainy season and the high tourist season, the overflow of wastewaters often occurs at the shorelines, adding more MPs to the beach. Moreover, industrial wastewaters from the textile and garment industry (~178 enterprises in 2019; [DSO \(Danang Statistical Office\), 2020](#)) are possibly another source of synthetic microfibers in Da Nang beach. The industrial wastewaters after treatment (and also without treatment) are discharged into the Han and Cu De Rivers and reach the bays and the beach ([Da Nang DONRE \(Department of Natural Resources and Environment Da Nang\), 2018](#)). The diameters of synthetic fibers measured in Da Nang beach (median: 18 μm, mean: 19.58 ± 9.27 μm; [Fig. 6](#)) were relatively similar to diameters of microfibers released in wastewaters from laundry activities (11.9 – 17.7 μm; [Napper and](#)

Table 2

Concentration of microplastics in surface shoreline sediments from Asia countries (n.a.: Not available).

Location	Habitat	MPs size range (μm)	Sampling depth (cm)	Type of MPs	Microplastics (mean \pm SD, min -max) (items kg^{-1} d.w.)	References
Vietnam, Da Nang	Sandy beach	300–5000	0–5 & 0–10	Fibers	9238 \pm 2097 (5100–11,000)	This study
China, Beibu Gulf and coast of the South Sea	Beach	1–5000	0–1	Fibers, granules, films	6870 \pm 6140 (5014–8714)	Qiu et al., 2015
China, Bohai Sea	Sandy beach	1–5000	0–2 & 0–20	Fragments, sheets, fibers	102.9 \pm 39.9–163.3 \pm 37.7	Yu et al., 2016
China, Hong Kong	-Sandy beach -Mudflats	1–5000	2–3	Fibers (57.2%), fragments (37.6%), films (2.4%), foams (2.2%), pellets (0.3%).	16.8 \pm 5 (0.58–98.6)	Lo et al., 2018
India: -Mumbai -Tuticorin, -Dhanushkodi	Sandy beach	36–5000	3–4	Fibers (51%), granules (40%), films (9%)	268 \pm 44.5 220 \pm 50 181 \pm 60 45 \pm 12	Tiwari et al., 2019
India, Palolem Beach	Sandy beach	1–1000	0–1	Fibers	520	Balasubramaniam and Phillott, 2016
Indonesia, Ngebum Beach	Sandy beach	1–1000	0–1	Fibers	172	Balasubramaniam and Phillott, 2016
Myanmar, Napoli Beach	Sandy beach	1–1000	0–1	Fibers	132	Balasubramaniam and Phillott, 2016
Pakistan, Hawkesbay Beach	Sandy beach	1–1000	0–1	Fibers	480	Balasubramaniam and Phillott, 2016
Sri Lanka, Thumpalai Beach	Sandy beach	1–1000	0–1	Fibers	384	Balasubramaniam and Phillott, 2016
Singapore	Intertidal mangroves	1–5000	3–4	Fibers (72.0%), films (23.3%), granules (4.7%)	36.8 \pm 23.6 (12.0 \pm 8.0–62.7 \pm 27.2)	Nor and Obbard, 2014
Singapore	Beach	1.6–5000	0–1 & 10–11	n.a.	0–16	Ng and Obbard, 2006
Japan, Tokyo Bay	Canal	315–5000		Fragments (75%), fibers (15%), beads (4%)	1800	Matsuguma et al., 2017
Dubai, UAE	Sandy beach	1–5000	0–1	Fibers (63.9%), fragments (20.5%), string (14.1%), polystyrene spheres (1.5%)	59.71	Aslam et al., 2020

[Thompson, 2016](#); $14 \pm 3 \mu\text{m}$ to $20 \pm 6 \mu\text{m}$; [De Falco et al., 2018](#)). Small diameters support also fiber suspension in the water column and transportation through a long distance from generation sources to the beach ([Waldschlager and Schüttrumpf, 2019](#)). Therefore, we suggest that microfibrils sampled in the beach can originate from domestic and industrial wastewaters.

Aside from domestic and industrial wastewaters, solid waste and landfill leachate might also contribute to MPs release to the environment and then to the beach ([Horton et al., 2017](#)). The daily amount of plastic waste generated in Da Nang in 2019 was estimated from 172 to 189 tons per day (11% of the total domestic solid waste; [Da Nang URENCO \(Da Nang Urban Environment Company\), 2019, 2019](#); [Tran, 2019](#)), equivalent to $0.15\text{--}0.17 \text{ kg cap}^{-1} \text{ day}^{-1}$, which is pretty high in comparison to other Asian and African countries ([Ritchie and Roser, 2018](#)). Although the city has been conducting many programs to manage plastic waste, they have not been systematically efficient and a large amount of plastic waste is still emitted to the surrounding environment and can be broken down into microplastics. Most of the collected plastic waste are buried together with other types of domestic solid waste in the city's landfill (~5 km from Da Nang Bay, [Fig. 1](#)), where they might decompose into microplastics and leak into the landfill leachate ([He et al., 2019](#)). At present, the landfill leachates after being treated are conveyed to urban canals and discharged to the beaches ([Da Nang DONRE \(Department of Natural Resources and Environment Da Nang\), 2018](#)). Finally, ghost nets from fishery activities could be also a main contributor to the anthropogenic fibers pollution observed on the beach sites ([Horton et al., 2017](#); [Lusher et al., 2017](#)). They are omnipresent in Da Nang beaches despite punctual clean-up campaigns.

4.4. Spatial and vertical concentrations of microplastic in the sediments

MPs were measured in the eight sampling sites and were similar in terms of shape, color, and concentrations, demonstrating a homogenous distribution for the entire shorelines. Those observations are quite unexpected, as the sites are subjected to different land use and beach waste management (touristic zone versus abandoned area) as well as received unalike pollution sources ([Table 1](#)).

However, regarding depth distribution, microplastic concentrations in the upper sediment layer (0–5 cm) were systematically higher than those in the lower layer (5–10 cm), which is in accordance with the observation by [Yu et al. \(2016\)](#) in Bohai beach sediments. In deeper beach sediments, the abundance of microplastic decreased significantly with depth in the Amazon macrotidal sandy beach (61.5%, 25.0%, and 13.5% from the surface to 20, 20–40, and 40–60 cm; [Filho and Monteiro, 2019](#)) and in sandy beaches of Brazil ([Turra et al., 2014](#)). The authors evidenced that this trend might be related to the combination of phenomena like the surface layer exchanges directly with the seawater or wastewater which might retain more microplastics, or the larger plastics in the top layer that could be ground to smaller particles by people's activities at the surface ([Yu et al., 2016](#)). This might also explain the reason why the length of microfibrils in our study site in the top 5 cm depth was shorter than that in the deeper layer (5–10 cm) ([Fig. 5](#)).

Synthetic fibers at Da Nang beaches had a median length size of $1456 \mu\text{m}$ and a mean length size of $1701 \pm 1029 \mu\text{m}$ ([Fig. 5](#)), which is rather similar to the size of microfibrils in the South Tunisia lagoon ($1390 \pm 270 \mu\text{m}$; [Abidli et al., 2017](#)). Besides, it should be noticed that 81.9% of fibers were in the range from 300 to 2600 μm , while the longer fibers (from 2600 to 5000 μm) only accounted for a low ratio.

This trend of size distribution was somewhat similar to that at the beach of Slovenia, where the highest frequency of size was 250–1000 µm and 2000–3000 µm (Laglbauer et al., 2014). However, in some other areas, shorter fibers were the more important fraction, for instance, in the Spanish Mediterranean continental shelf, 61% of fibers were 500–1000 µm (Filgueiras et al., 2019), or in the Venice lagoon of Italy, 93% of fibers was in the range 30–500 µm while longer fibers (about 2500 µm) were rarely observed (Vianello et al., 2013).

The diameter of the fibers in our study size was quite small, a median of 18 µm and a mean of 19.58 ± 9.27 µm (Fig. 6), in comparison to that reported in the other beach areas such as the northern coast of Taiwan (approximately 30 µm; Kunz et al., 2016), McCormack's Beach and Rainbow Haven Beach in Canada (several hundred micrometers; Mathalon and Hill, 2014) or the Germany beach (a few dozen micrometers; Dekiff et al., 2014).

4.5. Potential impact to the biota

The occurrence of a large number of synthetic fibers in the coastal environment is a danger to organisms in the marine ecosystems since they may accidentally or intentionally enter their body (Andrady, 2011). Especially, small-size synthetic fibers may pose more threat than large fibers to lower trophic organisms as these organisms capture any particles of appropriate size without selection. Meanwhile, higher trophic organisms could ingest microplastics by mistaking plastic for their prey (Wright et al., 2013; Moore et al., 2001). Synthetic fibers were reported to be the most dominant type of MPs in the body of many species such as zooplankton (70% of the total MPs; Sun et al., 2017), bivalves (> 50% - 84.1%; Li et al., 2015; Ding et al., 2018; Rochman et al., 2015); fishes (65.8% - 96%; Neves et al., 2015; Pazos et al., 2017). A study by Amelineau et al. (2016) stated that 100% of gular pouch samples contained plastic filaments, whereas fragments were only found in from 33% - 55% of the total gular pouches.

Fisheries and aquaculture in Da Nang also play an important role in the city's economy and is identified as one of six important marine economic sectors with total annual catches of seafood are from 33,909 tons (in 2015) - 37,530 tons (in 2019) (DSO (Danang Statistical Office), 2020). The presence of synthetic fibers in the Da Nang coastal sediment poses a threat to the accumulation of these microplastics in aquatic species, especially deposit and suspension feeders that are reared in Da Nang beaches sediments. Although there have been no studies on MPs accumulation in these species in Da Nang, other pollutants such as heavy metals (Pb and Cd) and organotin compounds were detected in some bivalves species from Da Nang coastal habitats (Midorikawa et al., 2004; Nguyen et al., 2015). Besides, the presence of MPs in many bivalve species of economic value living in beach sediment was also reported in many coastal areas, including Viet Nam. Mathalon and Hill (2014) detected an average of 178 microfibrils per farmed mussel and 126 microfibrils per wild mussel in the intertidal ecosystem surrounding Halifax Harbor, Nova Scotia, Canada. In Vietnam, the bivalves *Perna viridis* was reported by Phuong et al. (2019) to contain an average microplastic concentration of 2.60 items/individual and 0.29 items/g of wet tissue. The presence of MPs in seafood presents a hazard to food safety of humans, not only the local community but also tourists and people in seafood importing countries, as a calculation of Van Cauwenberghe and Janssen (2014), the annual dietary exposure for European shellfish consumers can amount to 11,000 microplastics per year.

5. Conclusions

Microplastic concentrations measured in Da Nang sediment beaches were rather high compared to those in worldwide beaches, even considering the bias induced by different methodologies. It demonstrated that Da Nang beaches are facing serious microplastic pollution. Synthetic fibers were identified as the most important shape (99.2%)

with a large majority of them (81.9%) ranging in the size range 300–2600 µm, which could potentially harm both marine and humans health. We assumed that the main sources of synthetic fibers are the domestic wastewaters from the inland population and resorts nearby as well as industrial wastewater discharges. Further investigations are required to better quantify and qualify the release of microplastics from those sources in order to have a robust baseline for effective management mitigation.

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CRedit authorship contribution statement

Tran Nguyen Quynh Anh: Writing - original draft, Writing - review & editing, Visualization. **Y. Nguyen Hoai Nhu:** Investigation. **Emilie Strady:** Methodology, Writing - review & editing. **Nguyen Quy Tuan:** Methodology, Investigation, Resources. **Trinh-Dang Mau:** Software, Validation, Formal analysis, Data curation, Project administration. **Vo Van Minh:** Conceptualization, Resources, Supervision.

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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