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Profiling Microplastic Pollution in Surface Water Bodies in the Most Urbanized City of Sri Lanka and Its Suburbs to Understand the Underlying Factors

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Abstract This study investigated the microplastic pollution of surface waters in and around the most populated and urbanized city in Sri Lanka from 2019 to 2022. The sampling regime was designed to cover the rainfall-driven hydrology and varying levels of urbanization approximated by the built area fraction. Mass and particle concentrations of microplastics ranged from undetected to 0.01 g/L (average ± standard deviation: 0.00464 ± 0.00528 g/L) and from 2 to 36 particles/L (5.3 ± 6.9), respectively. The highest microplastic pollution was observed in the lake; however, in many cases it was without a statistically significant ($P < 0.05$) difference with canals. Concentrations in the dry state (i.e., at least 30 days after no rainfall) were about 1.5 times more than the wet state (i.e., at least 50 mm/day rainfall for 10 days) in the lake and in the semi-urban canal, but again, the differences were not significant; however, in urban canals, the concentrations were similar in both states. Over 80% of the microplastics were fibre and fragments. Mass concentrations of microplastics showed moderately positive (Pearson's $r > 0.6$) correlations with the built area fraction of the contributing catchment in both states but was significant ($P < 0.1$) only in the dry state. In the case of particle concentrations, none showed even a weak correlation. The independence of microplastic content against built area fraction and rainfall, as well as twice the concentrations found in point source inputs against the surface waters, gave the following insights. Microplastic content in our study area was governed mostly by the modified catchment hydrology spearheaded by stormwater drainages (some cases trans-catchment) and diffusion factors such as non-residential population.

Keywords Built areas · Microplastics · Point sources · Rainfall · Sri Lanka · Urban water bodies

1 Introduction

Plastic products are extensively manufactured and utilized by people in every corner of the world due to unique characteristics such as its lightweight, heat and electrical insulating properties, resistance to corrosion, ability to manufacture products of different shapes and colours, and low cost compared to products made of alternative materials (e.g. wood and metal) (Bujnicki et al., 2019; Deng et al., 2020). However, inappropriate disposal of plastic products has triggered severe environmental and health concerns (Wang et al., 2018; Bujnicki et al., 2019; Prata

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et al., 2021), and this is alarming when plastic pieces are small (diameter less than 5 mm are collectively identified as microplastics; Di and Deng et al., 2020). Both intentional (primary) and unintentional (secondary) production of microplastic over time have become a huge concern due to their ubiquitous occurrence in the atmosphere, lithosphere, as well as in the hydrosphere, posing a high possibility of entering the biosphere through food chains (Bujnicki et al., 2019; Prata et al., 2021). Microplastics tend to accumulate inside humans and animals causing long-term health impacts (Miller et al., 2020) and destructive changes in growth characteristics, reproduction, behavioural characteristics, and even mortality (Bujnicki et al., 2019; Prata et al., 2021). Microplastic pollution in the oceans has adversely affected the growth and photosynthetic performances of hermatypic corals (Reichert et al., 2019). Detection of microplastic in fish species (Miller et al., 2020), human faeces, plants, and consumable food products (Bujnicki et al., 2019) has urged further study of microplastic occurrence and the necessity of taking regulatory measures. Even though microplastic pollution has endangered all the spheres in the environment, pollution of the hydrosphere (water bodies) is more critical as it has the potential to spread the pollutant to other spheres easily due to its direct connectivity (Gomes et al., 2014).

As water is one of the most essential components for all living beings and is limited in both quantity and quality in many parts of the world, many researchers have investigated microplastic pollution in water bodies (Deng et al., 2020; Di & Wang, 2018). Early studies including one by Carpenter and Smith (1972) focused on the marine environment and coastal ecosystems (Ivar Do Sul & Costa, 2014; Luo et al., 2019; Zhang et al., 2020a, b; Zhang et al., 2021). Previous studies have repeatedly confirmed the occurrence of microplastics in ocean bottoms, shorelines, reefs, and aquatic life (Sharma & Chatterjee, 2017; Luo et al., 2019; Nie et al., 2019; Peixoto et al., 2019). Interestingly, pollution has been even propagated into regions with fewer inhabitants, for instance, the Arctic and Antarctic (Bujnicki et al., 2019), and also in inland surface water bodies (Di and Wang, 2018; Wang et al., 2018; Ding et al., 2019; Zhang et al., 2018; Deng et al., 2020).

With the increased attention to microplastic pollution on a global scale (Yu et al., 2018), several studies (e.g.Koongolla et al., 2018; Wijethunga et al., 2019; Ranatunga et al., 2021; Dharmadasa et al., 2021) have been undertaken to assess the degree of pollution in Sri Lanka as well. However, most of these studies are limited to the coastal waters or ecosystems. As an example, Koongolla et al. (2018) assessed microplastic pollution in water and sand along a 91-km coastal region of Southern Sri Lanka and were able to detect microplastic in the sand and water in 60% and 70% of the sites, respectively. Dharmadasa et al. (2021) observed water and sand of a protected marine area in Southern Sri Lanka to include polythene, polypropylene, and polystyrene as dominant polymers with the dominant shapes being fragments and filaments, and with over 40% of the microplastics being oxidized. Previous studies had also reported the occurrence of microplastic in planktivorous fish species depicting vulnerability and adverse health impacts on aquatic biota and marine biodiversity (Ranatunga et al., 2021; Wijethunga et al., 2019). In addition to the microplastic pollution in water and sand in coastal regions, researchers had reported the microplastic contamination of raw salt and commercial salt in Sri Lanka (Kapukotuwa et al., 2022).

The comprehensive literature review by us revealed that the research on microplastic pollution of inland water bodies, even in highly urbanized regions of developing countries where such pollution is possible, is limited and even the handful of studies that have been done have not reached international publications. Therefore, this study fills an important research gap by studying microplastic pollution of a developing/emerging lower middle-income country, which we consider would be analogous to countries with similar geo-political and climatic conditions. It should be noted that there are over 150 developing countries which has about 85% of the world population.

The first objective of this study was to investigate the microplastic pollution in terms of mass and particle concentrations and their composition referring characteristic surface waterbodies in and around the commercial capital (Colombo) of Sri Lanka. The second objective was to identify the hydrological impacts on microplastic pollution referring the rainfall and point source water inputs. The third and final objective was to investigate whether urbanization is correlated with the microplastic pollution.

2 Materials and Methods

2.1 Study Area

Samples were collected from three characteristic surface water bodies namely the Beira Lake network (one lake was sampled), the Dutch Canal network (five canals were sampled), and Talangama Canal. Beira lake and Dutch Canal networks are connected to the sea; therefore, in certain sections at certain points of time, the water can be brackish, whereas Talangama Canal is strictly freshwater (Fig. 1a–b). As per water quality observations (Table 1), it was conspicuous that all three water bodies, especially Dutch canal network and Beira Lake, are nutrient, and sediment polluted.

Beira Lake is situated at the centre of Colombo, Sri Lanka (Fig. 1c). Beira Lake occupies a 0.65 km^2 area and is surrounded by many commercial, industrial, and residential buildings, which may trigger uncontrolled pollution of the lake water and immense risk to aquatic species (Weerasinghe & Handapangoda, 2019). According to its geographic layout, the lake is divided into four main basins such as Southwest Lake, East Lake, Galle face Lake, and West Lake. In this study, sampling was done in Southwest Lake (6°55′03.4″N, 79°51′09.3″E). Beira Lake is connected to the Indian Ocean from Galle Face Lake and to Kelani River (one of major rivers in Sri Lanka) through the Saint Sebastian canal. Over 90% of the apparent catchment of Beira Lake is built.

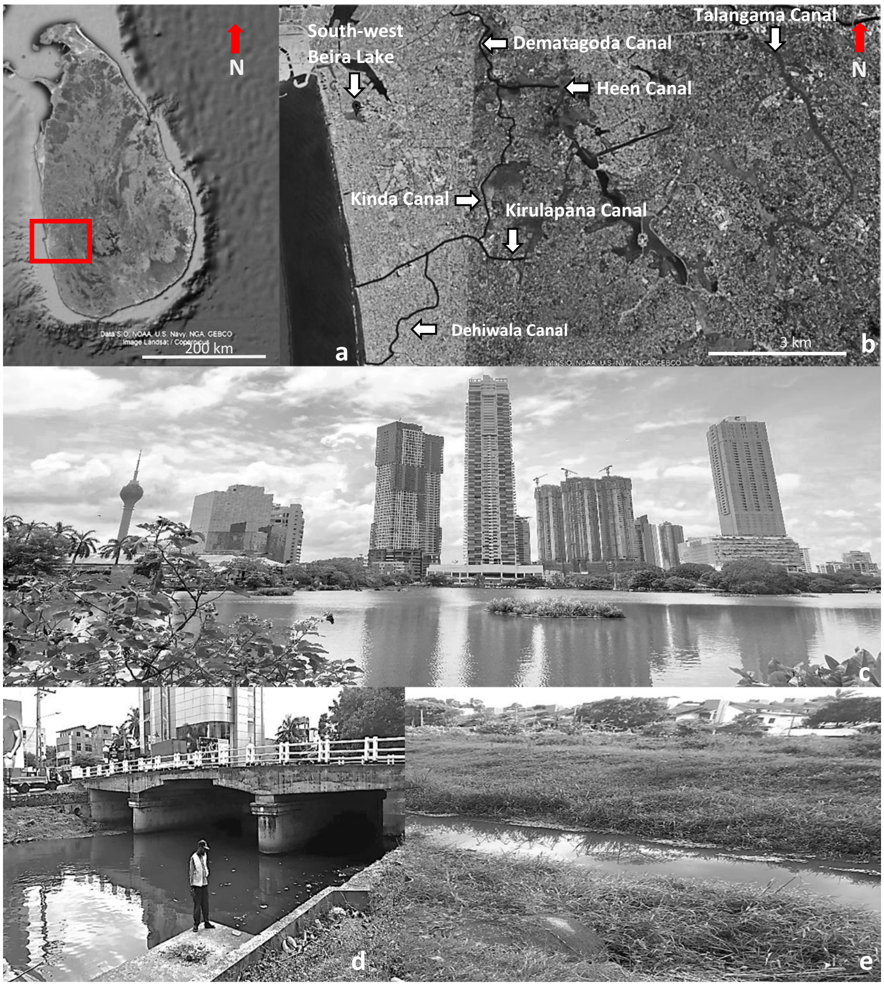

Fig. 1 Locations of sampled waterways (**a–b**) and photographs of Southwest Beira Lake (**c**), Kirulapana canal of Dutch canal network (**d**), and Talangama canal (**e**)

Table 1 Water quality of Dutch canal network, Talangama Canal, and Beira Lake

	Dutch Canal		Talangama Canal		Beira Lake	
	Wet	Dry	Wet	Dry	Wet	Dry
Dissolved oxygen (mg/L)	4.4 (2.7)	5.1 (1.2)	5.4 (1.3)	5.2 (0.9)	4.3 (1.1)	4.4 (0.8)
pH	7.0 (0.24)	6.7 (0.55)	6.7 (0.39)	6.5 (0.64)	9.2 (1.60)	8.65 (2.00)
Electrical conductivity (µS/cm)	259 (96)	261 (44)	131 (23)	150 (28)	302 (75)	550 (78)
Total solids (mg/L)	226 (106)	313 (47)	264 (136)	275 (110)	224 (125)	133 (79)
Total suspended solids (mg/L)	34 (13)	25 (12)	57 (57)	76 (71)	201 (50)	35 (29)
Temperature (°C)	21 (0.54)	24 (1.60)	23 (0.43)	24 (0.65)	22 (0.52)	26 (1.20)
Turbidity (NTU)	21 (9.3)	14 (5.1)	53 (52)	97 (80.8)	135 (50.0)	38 (45.0)
Nitrate-nitrogen (mg/L)	1.60 (1.00)	0.79 (0.37)	2.30 (0.85)	1.76 (2.20)	2.20 (0.60)	2.50 (1.10)
Ammoniacal-nitrogen (mg/L)	2.30 (2.60)	1.30 (0.93)	0.28 (0.19)	0.43 (0.19)	2.50 (0.50)	3.10 (0.90)
Soluble reactive phosphorus (mg/L)	0.75 (0.71)	0.28 (0.20)	0.49 (0.28)	0.29 (0.07)	0.90 (0.20)	0.70 (0.30)

The Dutch canal network was built by Dutch (1658–1796 AC, but with subsequent modifications up to date) covering Colombo city and its outskirts (Fig. 1d). It consists of five major sub-canals: Dehiwala, Kirulapana, Kinda, Heen, and Dematagoda. Dutch canal flows through the left bank of the lower valley of Kelani River and is a major flood detention zone of Colombo city (Gomes et al., 2019). Nearly 43.5% of the families in the vicinity dumped their household garbage into the canal and associated marshes about 25 years back and still to a lesser extent this seems to be the case (Dehini, 2020). The contributing catchment of Dutch canals is highly urbanized, and at certain sub-catchments, the built area fraction exceeds 90%.

Talangama Canal starts from Talangama tank (06° 88.71′N, 079°94.74′E) and finally connects to the Kelani River at Ambatale (06°93.80′N, 079°94.57′E) (Fig. 1e). The canal length is about 6 km and, in general, is straight. The purposes of the canal are to drain excess stormwater to Kelani River and for irrigation. As of now, nearly 100 acres of paddy fields are irrigated by Talangama Canal.

These water bodies are about 1 to 7 km apart and are subject to similar weather and climatic conditions. Table 2 shows the general hydrologic details of Kirulapana and Talangama canals. The study area has wet and dry seasons governed by rainfall. Dry seasons are from July to August and January to March (on average each month gets less than 5% of the total annual rainfall). Wet seasons are from April to June and September to December (on average each month gets more than 10% of the total annual rainfall). Figure 2 shows the monthly rainfall observed in Colombo from 2019 to 2022 (Department of Meteorology, Sri Lanka, 2022).

Table 2 General hydraulic details of Kirulapana (part of Dutch canal) and Talangama Canal (parentheses show standard deviation)

Parameter	Kirulapana Canal		Talangama Canal	
	Wet season	Dry season	Wet season	Dry season
Velocity (m/s)	0.21 (0.02)	0.15 (0.03)	0.14 (0.11)	0.07 (0.04)
Depth (m)	0.88 (0.23)	0.87 (0.18)	0.58 (0.30)	0.45 (0.34)
Discharge (m^3/s)	8.3 (1.7)	5.0 (1.3)	0.61 (0.34)	0.29 (0.20)

2.2 Field Sampling Regime

The first author has been comprehensively studying Dutch and Talangama canals since 2014 under various study themes, ranging from water quality (Gomes et al., 2019), macroinvertebrate distribution, and ecological rehabilitation options (Dehini & Gomes, 2022). The studies related to solid waste pollution in canals were started in 2017, where microplastic pollution was part of it (Hiranya, 2019).

Sampling was conducted from 2019 to 2022 for the canals and in 2021 and 2022 for Beira Lake (Fig. 2). It was hypothesized that surface hydrology was an important factor in governing the microplastic concentrations; therefore, sampling dates were

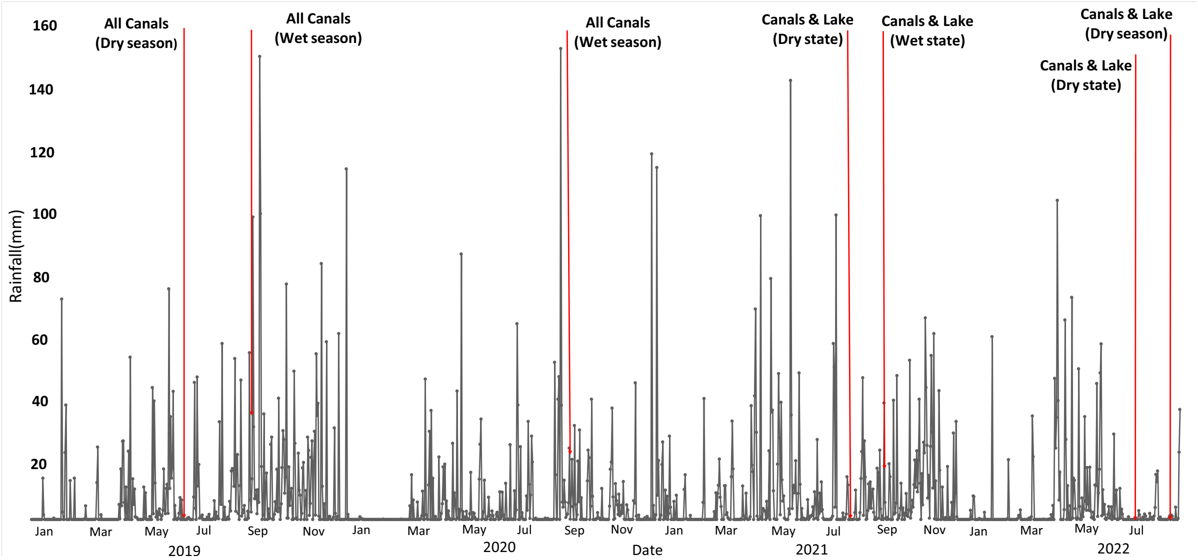

Fig. 2 Rainfall and sampling schedule

selected after observing the rainfall. Such sampling was done in the days after continuously high rainfalls (at least 50 mm/day rainfall for 10 days; herein after wet state) and in the days after prolonged no rainfall periods (at least 30 days without rainfall; herein after dry state). It should be noted that rainfall response sample regimes are used in water quality studies, especially in headwater catchments (Gomes & Wai, 2014) due to little or no lag in stream discharge in response to the rainfall. Even though our study area is not a headwater catchment, the response of canal flow (or lake water depth) to rainfall is fast, similar to that of a headwater catchment, due to anthropogenic disturbances such as impervious surfaces and stormwater drainage networks. Also, in many cases, the wet and dry states of the catchment coincided with the typical wet and dry seasons of the study area.

One sample for approximately every 100 m of canal length was obtained in each sampling session (thus one canal had at least three samples per session). From Beira Lake, samples were collected at locations about 50 m from the bank at every 200 m along the perimeter. All point sources (culverts and hume pipes, etc.) to these water bodies were classified into three size classes as low, medium, and high based on the maximum flow rate they could accommodate (first 1/3, middle 1/3, and last 1/3), and representative sampling was carried out for each group keeping the minimum number as two. In total in each sampling session (wet or dry), 10 samples were taken from Beira Lake. Such sampling for Dutch and Talangama canals was started only in 2022. The flow rates of point sources were calculated by two methods: the bucket method (dividing the bucket volume by the time taken to fill) and Manning's equation (Subramanya, 2019).

To mimic the non-point source inputs (i.e. surface runoff) 0.5 m × 0.5 m areas of the catchment were selected close to the Beira Lake banks (5–15 m from the water level), and water was sprinkled to mimic a rainfall (15 L over a 60 min period). This approximately corresponded to a 1-h annual maximum rainfall with an annual occurrence in Colombo (Suthakaran et al., 2014). In addition, samples were taken from ponded paddy fields close to the Talangama Canal.

Field blanks were also prepared during sampling for Dutch canal network, Talangama Canal, and Beira Lake in 2021 (wet state) and 2022 (dry state) sampling (one blank for each water body were prepared for a random site). In this regard, the same sampling bottles (reagent HDPE bottles) were filled with deionized water after washing the bottle twice with deionized water in the same area where field sampling was done. Similar procedure was followed to prepare the laboratory blanks, where three blanks were prepared in the laboratory a day before analysis in 2022. The field blanks gave 0.3 ± 0.5 particles/L and 0.06×10^{-3} g/L of microplastics, whereas in laboratory blanks, microplastics were undetectable.

2.3 Laboratory Analysis

National Oceanic and Atmospheric Administration (NOAA) guidelines and methods (Masura et al., 2015) were used to identify the amount of microplastic in water, and this is one of the most widely used microplastic extraction methods (Munno et al., 2018). However, this method may result in underestimation of microplastics due to chemical digestion and heating (Munno et al., 2018).

Water samples were wet sieved using 5-mm and 0.3-mm mesh-sized steel sieves. Then, sieves were washed with deionized water to remove any residual solid particles and salts. Dry weight of materials that passed through 5 mm mesh and retained on 0.3 mm were measured (after oven drying at 90 °C for 24 h). Subsequently, the dried material underwent wet peroxide oxidation by first mixing with 20 ml of aqueous 0.05 M Fe (II) solution and then with 20 ml of 30% hydrogen peroxide. After mixing with Fe (II) solution and peroxide, the mixture was kept for 5 min at room temperature and heated up to 75 °C on a hot plate fully covered with a watch glass. If the mixture contained residual natural material, another 20 ml of 30% hydrogen peroxide was added and repeated until all were dissolved. A 6 g of NaCl was added to 20 ml of the sample to increase the density of the solution and heated until all salts were dissolved, kept in a density separator overnight (i.e. at least 8–12 h). The bottom of the density separator was observed for settled solids and/or microplastics. Settled microplastics were collected by forceps from the bottom of the density separator, and the rest were discarded. Floating microplastics were separated using a glass microfiber filter paper and were subjected to air drying. The mass of the microplastics was then determined by weighing the separated and air-dried microplastics. Microplastics were observed via a 40 × Microscope (Zeiss primo star Binocular Microscope-Germany) to confirm their presence and counted using a colony counter (Galaxy 330 Colony counter, Rocker). It should be noted that in the first two sampling sessions in 2019, microscopic observations were solely to understand the composition, not to derive the particle concentrations.

2.4 Statistical Analysis

All data are presented as mean ± standard deviation, unless otherwise stated. The assumption of normal distribution and the homogeneity of variances were checked using Kolmogorov–Smirnov and Levene's tests, respectively. Significant differences between the two groups were realized by *t*-test, and for more than two groups, one-way ANOVA with Turkey's post hoc test was used. The bivariate correlations were realized via Pearson correlations. Significant differences were realized at $P < 0.05$ and $P < 0.1$. For statistical analyses, IBM SPSS V21 was used.

3 Results and Discussion

3.1 Mass Concentration of Microplastics in Beira Lake and Point Source Inputs

Beira Lake's dry state gave 1.5 times higher concentrations than the wet state, whereas in point source inputs, the wet state was 1.8 times higher than the dry; however, none of the differences were significant (*t*-test; $P > 0.3$) (Fig. 3). Same as the point source concentrations, point source loads showed twice as high loads for the wet state (0.002 vs 0.001 g/s in dry) with a better statistically significant difference than that for the concentrations (*t*-test; $P = 0.15$). Even though not statistically significant, these observations indicated the underlying gradients of microplastic pollution. High concentration in the dry state was an indication of the role played by the dilution and concentration processes of the lake (Plew et al., 2018; Perera and Gomes, 2022). High concentrations and almost double loads in the wet season in the point sources were an indication of their influence (which are the outlets of the manmade open channel drainage network) in shaping the concentrations of the lake. This was why the lake in the wet season was expected to have some dilution with freshwater inputs via runoff and/or point sources did not show a statistically significant improvement relative to the dry season.

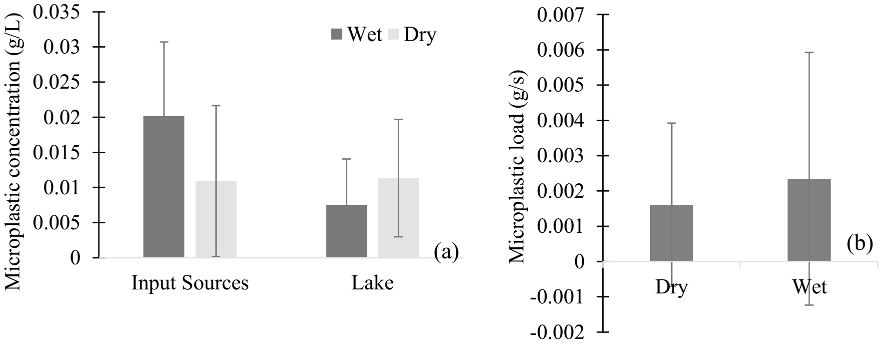

Fig. 3 **a** Microplastic mass concentration in Beira Lake surface and point sources in wet and dry states. **b** Loading rates in Beira Lake

3.2 *Mass Concentration of Microplastics in Canals*

Figure 4 compares the microplastic concentrations in each of the sub-canals of the Dutch canal network and Talangama Canal. In comparison with the concentration in the lake, the microplastic content in canals was in many cases less and in a few cases with a statistically significant difference (e.g. compared with dry state Kinda and Talangama canals, one-way ANOVA; $P = 0.002 < 0.05$). The highest microplastic concentration was observed in the Kirulapana and Kinda canals, in wet and dry states, respectively. However, the differences in concentrations amongst Dutch canals were not significant (one-way ANOVA; $P > 0.05$). Talangama Canal gave the lowest concentration, and it was significantly lower than all canals except for the Kirulapana canal in wet state (one-way ANOVA; $P < 0.05$). The variation of microplastic concentration amongst the sub-canals was random, and it was difficult to identify any trend with respect to canal hydraulics. This was the case along all Dutch canals as no trend (e.g. increase in concentrations due to cumulative effect in the longitudinal direction) was observed. It is typical to observe an accumulation trend of pollutants along the flow direction, especially in urban landscapes (Bowes et al., 2003), and no such trend in Dutch canals could be observed due to poor drainage, especially in the dry state where water was rather stagnated. However, drainage conditions were good in the wet state, yet no trend was able to be observed. The Talangama Canal, which showed good drainage throughout the year, too showed only a moderate and statistically insignificant increasing trend of microplastic concentrations (Pearson's $r = 0.6$; $P = 0.2 > 0.01$).

3.3 Microplastic Particle Concentrations and Compositions

Figures 5 and 6 show the microplastic particle concentrations and compositions respectively, and Fig. 7 shows representative photographs of plastics. Independent of the waterbody, over 80% of the particles were either fibre or fragments with almost an equal split between the two. However, Beira Lake gave a notable exception, where over 80% of the particles were fibre.

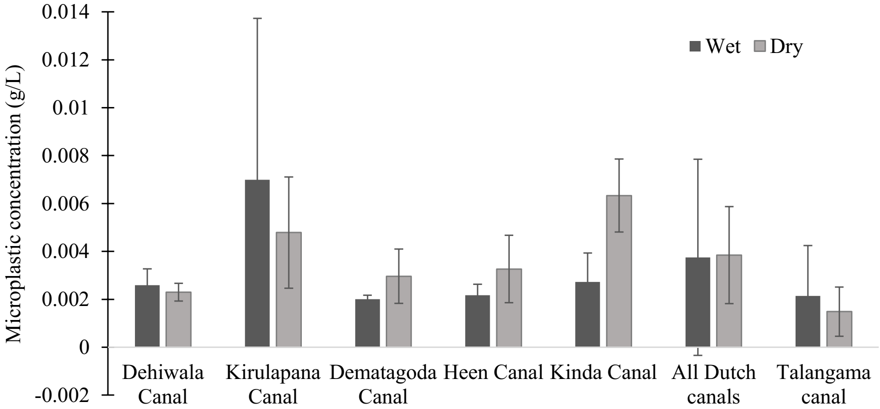

Fig. 4 Microplastic mass concentrations of canals in wet and dry states

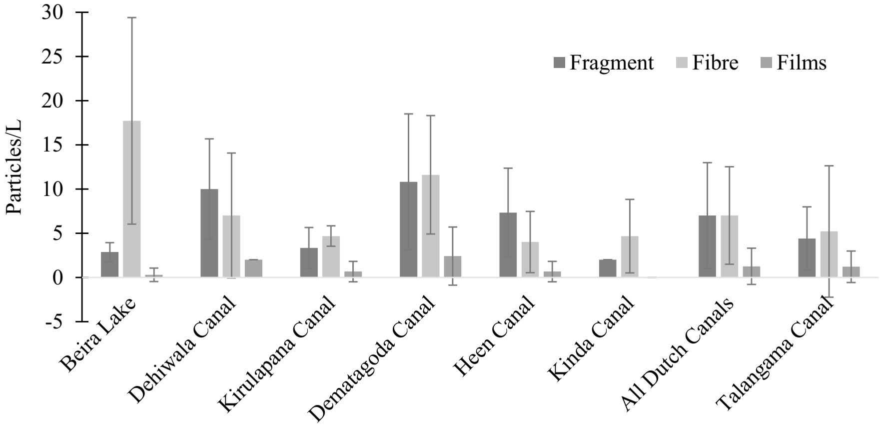

Fig. 5 Microplastic particle concentrations of Beira Lake and canals in dry state

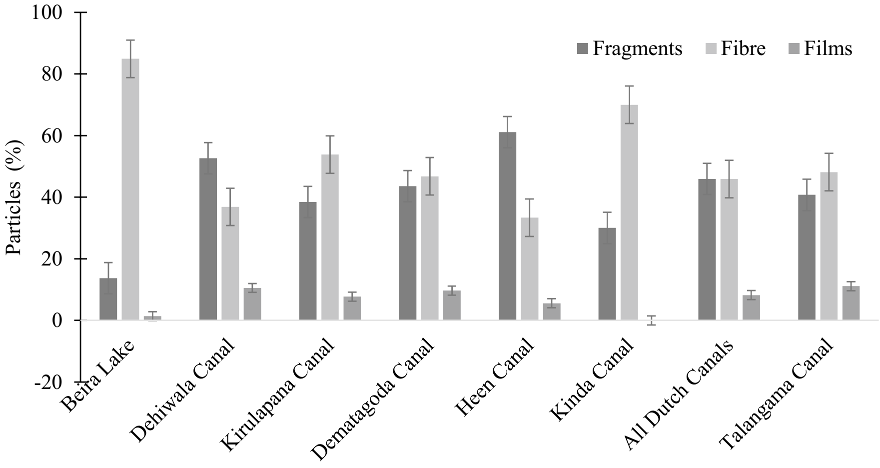

Fig. 6 Microplastic composition percentages of Beira Lake and canals in dry state

Sources of fibre include synthetic textiles, ropes, fishing nets, and plastic straws (Ivar Do Sul & Costa, 2014). The proximity to fisheries fields in Colombo and the fact that many water bodies are connected to the sea may have contributed. Furthermore, fibres are produced by household and textile laundering (Ivar Do Sul & Costa, 2014), which are common in areas that are populated. Fragments are one of the well-documented and observed microplastic types, generated because of plastic wastes such as bottles and plastic containers (Derraik, 2002). These were somewhat common in the canals, with intentional dumping and mobilization due to non-human vectors such as scavenger animals and wind. As per field observations, it was found that government agencies collect one boat full (about 3.5 m^3) of plastic waste daily from a two–three km Dutch canal stretch. Films are made from plastic wrapping bags and packing materials (Zhang et al., 2015). Microplastic films have a lower density than fibre, are easily transported and therefore, are quite difficult to find (Hastuti et al., 2014). The vicinities of the study areas lacked such plastic factories, and this could be the reason almost all samples were free from pellets. In addition, due to their high density, pellets may mostly be found with sediments (Turner and Holmes, 2011).

The microplastic particle concentrations (Fig. 5) were not analogous to the microplastic mass concentrations nor was there a correlation between these two. As an example, Dematagoda canal with the highest number of particles showed the lowest mass concentration, and an exact opposite observation was noted for the Kinda canal. This proved the necessity to observe the microplastics not only as particles/L, the most widely used unit of observation but also as g/L. Particles/L is important as a unit of occurrence,

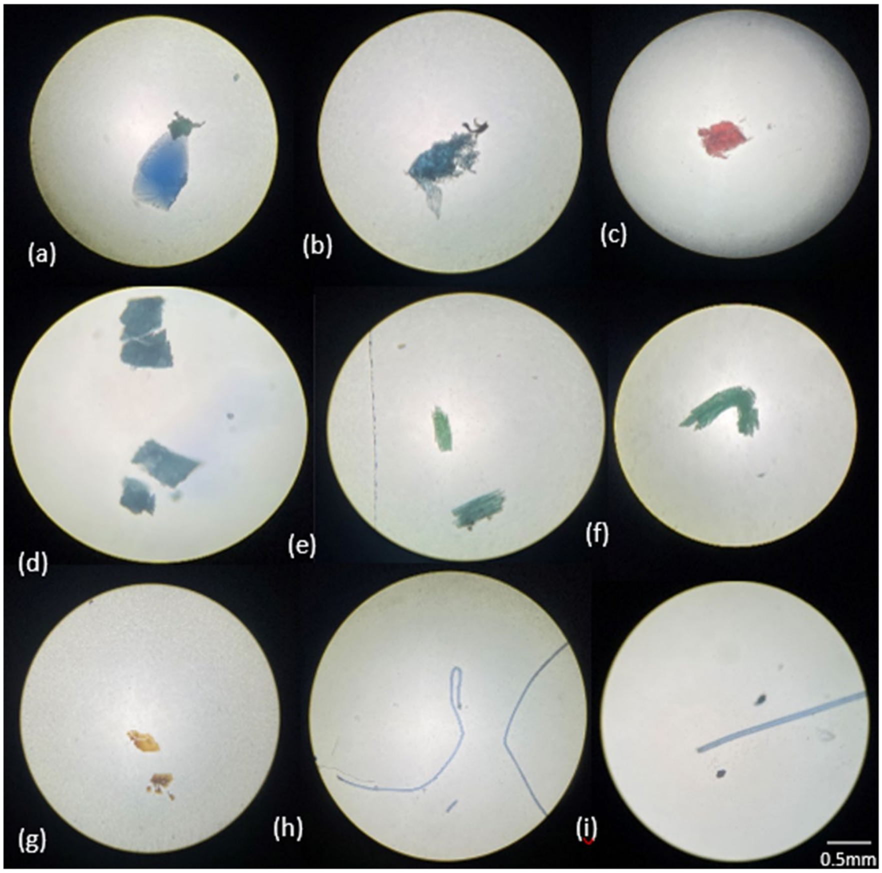

Fig. 7 Representative photos of different types of microplastics. **a**, **b**, and **c** films; **d**, **e**, **f**, and **g** fragments; **h** and **i** fibre

but g/L is important as a surrogate of toxicity (Leusch & Ziajahromi, 2021). Also, the method proposed by Leusch and Ziajahromi (2021) for the conversion of these two units seemed to be appropriate only for 50–60% of the cases. However, in many cases, the estimations were lower (with a maximum of 20%) for g/L when converted from particles/L.

3.4 Relationship with Urbanization

Microplastic mass concentrations showed a weak correlation with the built area fraction for both seasons, but only dry state showed a statistically significant difference at $P<0.1$ (wet state Pearson $r=0.6$; $P=0.14$ and dry state $r=0.7$; $P=0.08$). This was an indication that urbanization may have an impact on microplastic pollution from a toxicity perspective. However, from an occurrence perspective (i.e. particles/L), only fibre showed a correlation with urbanization, but that also has a weak statistically insignificant relationship (Pearson's $r=0.5$, $P=0.2>0.01$). In all other cases (total particles, fragments, and films), no correlation was observed between microplastic occurrence and urbanization. This also showed the importance of measuring microplastics as mass concentrations in addition to particle concentrations, as correlations depended on the unit of measurement.

The weak to no correlation between urbanization and microplastic was surprising since many past studies had endorsed a positive correlation between these variables (Peters & Bratton, 2016). Our results suggested that microplastic distribution was governed by factors beyond the contributing catchment defined by the surface topography. Water bodies can receive microplastic via point and non-point sources, and if point sources convey more microplastic, the role of the apparent catchment and its surrogates' could be marginal. Irrespective of the urbanization (or the built area fraction, the surrogate we used for urbanization), covered and uncovered manmade open channels (drains) were a key feature of the study area. These transport storm water to lakes, canals, rivers,

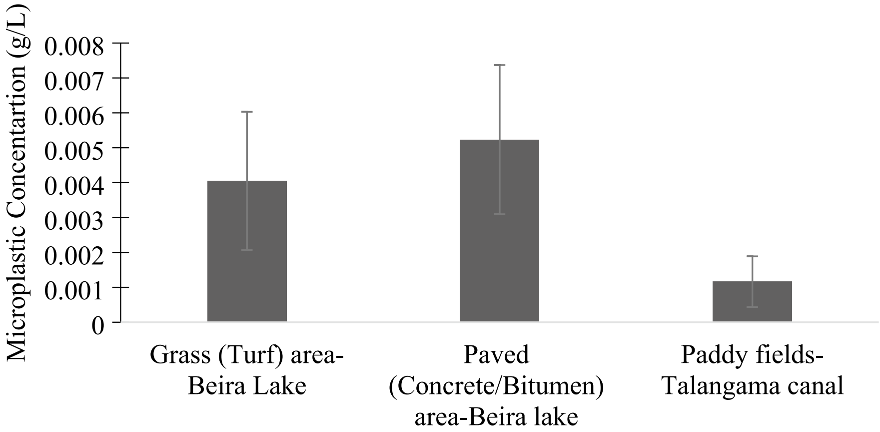

Fig. 8 Microplastic concentration (g/l) of catchment landscapes of Beira Lake and Talangama Canal

and sea. Even though these drains are meant to serve storm water, they are also used as expedient discharge points for domestic wastewater. These drains in certain cases are laid across sub-catchments and may drain against the surface drainage direction of sub-catchments. It should be noted that Colombo has an underground well maintained sewer network. Therefore, contamination by sewage is a remote possibility.

Our study was not comprehensive in studying the relative contribution of point and non-point sources on microplastic contamination, but by observing the microplastic load of point sources and non-point sources (i.e. the catchment runoff) (Figs. 3 and 8), we are of the opinion that the point sources were the main contributors. Also, built area fraction as a surrogate of urbanization may be too simplistic, and other composite variables of urbanization (e.g. the product of built area and population) may be better candidates (Gomes & Karunatilaka, 2022). Therefore, until such comprehensive analyses are made, we do not want to rule out the contribution of urbanization.

3.5 How Alarming Is Microplastic Pollution in Colombo and Its Suburbs?

Past studies have reported a wide range of concentrations of microplastics in other countries. As an example, the Pearl River and its tributaries in China (the second largest economy of the world and with a GDP per capita of about 8200 USD) showed 0.015–53 particles/L (D'Avignon et al., 2022). Another study in China (Xu et al., 2021) observed 6.33 ± 2.67 particles/L in Gehu Lake and 0.53–25.8 particles/L in Taihu Lake. In Klang River estuary in Malaysia (one of the Asian tiger club economies with a GDP per capita of about 10,000 USD), the abundance of microplastics ranged from 0.5 to 4.5 particles/L (Zaki et al., 2021). In Ciwalengke river in Indonesia (a GDP per capita of about 3800 USD which is close to that of Sri Lanka at 4200 USD), 5.85 ± 3.28 particles/L were observed (Alam et al., 2019). Liong et al. (2021) observed 10.7 to 14.3 particles/L in Miri River Estuary, again in Indonesia. Obviously, randomly referred literature based microplastic concentrations without the context to factors such as urbanization, weather, and climate by no way is representative of the extent and depth of pollution, but those would reveal that the microplastic pollution in Colombo, Sri Lanka, is alarming. It should be noted that some concentrations were well above the observations made in developed and/or industrialized regions of other countries (e.g. Beira Lake 4.6–16.2 particles/L vs 4.7–12.6 particles/L (D'Avignon et al., 2022) in Three Gorges Reservoir, China) and also with some South Asian countries (e.g. Ravi River in Pakistan had 0.2 particles/L (Bayar et al., 2022)).

4 Conclusion and Recommendations

This study confirmed that inland water bodies in Sri Lanka are contaminated with microplastics at considerable levels. It is true that other than the Talangama Canal, none of the waterways are used for direct human consumption of its waters or goods on a large scale. However, fishing is done for consumption, especially by low-income families in Kirulapana Canal (close to the sea outfall) and Beira

Lake. Therefore, it is possible that consumers have already ingested microplastic particles in thousands or more. Our study did not cover Kelani River, one of the major rivers in Sri Lanka (also is the largest individual surface water intake source of drinking water in Sri Lanka). This is one water body we recommend studying with respect to microplastics. Also, it is vital for future studies to cover aquatic fauna and sediments and incorporation of a finer spatiotemporal regime and target point and non-point sources. Finally, it is essential for government agencies to take necessary action to cut off or remove microplastics in pathways such as point source inputs.

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Data Availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

All complied with the rules and regulations of the related jurisdiction.

Ethical Approval This article does not contain any studies with human participants performed by any of the authors.

Competing Interests The authors declare no competing interests.

References

Alam, F. C., Sembiring, E., Muntalif, B. S., & Suendo, V. (2019). Microplastic distribution in surface water and sediment river around slum and industrial area (case study: Ciwalengke River, Majalaya district, Indonesia). *Chemosphere, 224*, 637–645. https://doi.org/10.1016/j.chemosphere.2019.02.188

Bayar, J., Hashmi, M. Z., Khan, M. A., Pongpiachan, S., Su, X., & Chakaraborty, P. (2022). Emerging issue of microplastic in sediments and surface water in South Asia: A review of status, research needs, and data gaps (pp. 3–19). https://doi.org/10.1007/978-3-030-89220-3_1

Boucher, J., & Friot, D. (2017). International Union for conservation of nature a global evaluation of sources primary microplastics in the oceans. https://doi.org/10.2305/IUCN.CH.2017.01.en

Bowes, M. J., House, W. A., & Hodgkinson, R. A. (2003). Phosphorus dynamics along a river continuum. *Science of the Total Environment, 313*(1–3), 199–212. https://doi.org/10.1016/S0048-9697(03)00260-2

Bujnicki, J., Dykstra, P., Fortunato, E., Grobert, N., Heuer, R. D., Keskitalo, C., & Nurse, P. (2019). *Environmental and health risks of microplastic pollution* (Vol. 64). European Commission.

Carpenter, E. J., & Smith, K. L. (1972). Plastics on the Sargasso Sea Surface. *Science, 175*(4027), 1240–1241. https://doi.org/10.1126/science.175.4027.1240

D'Avignon, G., Gregory-Eaves, I., & Ricciardi, A. (2022). Microplastics in lakes and rivers: An issue of emerging significance to limnology. *Environmental Reviews, 30*(2), 228–244. https://doi.org/10.1139/er-2021-0048

Dehini, G. K., & Gomes, P. I. A. (2022). Deriving optimal hydraulic, water quality and habitat quality criteria against a predefined reference state of urban canals via an analytical method: Implications on ecological rehabilitation. *Ecological Engineering, 182*, 106697. https://doi.org/10.1016/j.ecoleng.2022.106697

Dehini, G. K. (2020). Eco-hydraulic signature of Colombo Dutch Canals and implications for rehabilitation [M.Phil. Dissertation, Sri Lanka Institute of Information Technology, Malabe, Sri Lanka]

Deng, H., Wei, R., Luo, W., Hu, L., Li, B., Di, Y., & Shi, H. (2020). Microplastic pollution in water and sediment in a textile industrial area. *Environmental Pollution, 258*, 113658. https://doi.org/10.1016/j.envpol.2019.113658

Department of Meteorology, Sri Lanka. (2022). Weather and climate data. http://www.meteo.gov.lk/

Derraik, J. G. B. (2002). The pollution of the marine environment by plastic debris: A review. *Marine Pollution Bulletin, 44*(9), 842–852. https://doi.org/10.1016/S0025-326X(02)00220-5

Dharmadasa, W. S., Andrady, A. L., Kumara, P. T. P., Maes, T., & Gangabadage, C. S. (2021). Microplastic pollution in marine protected areas of Southern Sri Lanka. *Marine Pollution Bulletin, 168*, 112462. https://doi.org/10.1016/j.marpolbul.2021.112462

Di, M., & Wang, J. (2018). Microplastics in surface waters and sediments of the Three Gorges Reservoir, China. *Science of the Total Environment, 616–617*, 1620–1627. https://doi.org/10.1016/j.scitotenv.2017.10.150

Ding, L., Mao, R. F., Guo, X., Yang, X., Zhang, Q., & Yang, C. (2019). Microplastics in surface waters and sediments of the Wei River, in the northwest of China. *Science of The Total Environment, 667*, 427–434. https://doi.org/10.1016/j.scitotenv.2019.02.332

Do Sul, J. A. I., & Costa, M. F. (2014). The present and future of microplastic pollution in the marine environment. *Environmental Pollution, 185*, 352–364. https://doi.org/10.1016/j.envpol.2013.10.036

Gomes, P. I. A., & Karunatilaka, P. D. (2022). Investigation of long-term river water quality variations using different urbanization indices and assessment of common scientific perspectives of urbanization on water quality. *Environmental Quality Management*. https://doi.org/10.1002/tqem.21900

Gomes, P. I. A., & Wai, O. W. H. (2014). Sampling at mesoscale physical habitats to explain headwater stream water quality variations: Its comparison to equal-spaced sampling under seasonal and rainfall aided flushing states. *Journal of Hydrology, 519*, 3615–3633. https://doi.org/10.1016/j.jhydrol.2014.11.009

Gomes, P. I. A., Wai, O. W. H., Kularatne, R. K. A., Priyankara, T. D. P., Anojika, K. G. M. S., & Kumari, G. M. N. R. (2014). Relationships among anthropogenic disturbances representative riparian and non-riparian herbaceous indicators (biomass and diversity), land use, and lotic water quality: Implications on rehabilitation of lotic waters. *Water, Air, and Soil Pollution, 225*, 1–18.

Gomes, P. I. A., Fernando, B. A. V. W., & Dehini, G. K. (2019). Assessment of pollution sources, fate of pollutants, and potential instream interventions to mitigate pollution of earthen canals of urban to rural-urban fringe. *Water, Air, and Soil Pollution, 230*(11), 262. https://doi.org/10.1007/s11270-019-4314-7

Hastuti, A. R., Yulianda, F. R. E. D. I. N. A. N., & Wardiatno, Y. U. S. L. I. (2014). Distribusi spasial sampah laut di ekosistem mangrove Pantai Indah Kapuk, Jakarta. *Bonorowo Wetlands, 4*(2), 94–107.

Hiranya, A. P. O. (2019). Solid waste pollution of urban canals in Colombo [Undergraduate thesis, Sri Lanka Institute of Information Technology, Malabe, Sri Lanka].

Kapukotuwa, R. W. M. G. K., Jayasena, N., Weerakoon, K. C., Abayasekara, C. L., & Rajakaruna, R. S. (2022). High levels of microplastics in commercial salt and industrial salterns in Sri Lanka. *Marine Pollution Bulletin, 174*, 113239. https://doi.org/10.1016/j.marpolbul.2021.113239

Koongolla, J. B., Andrady, A. L., Kumara, P. T. P., & Gangabadage, C. S. (2018). Evidence of microplastics pollution in coastal beaches and waters in southern Sri Lanka. *Marine Pollution Bulletin, 137*, 277–284. https://doi.org/10.1016/j.marpolbul.2018.10.031

Leusch, F. D. L., & Ziajahromi, S. (2021). Converting mg/L to particles/L: Reconciling the occurrence and toxicity literature on microplastics. *Environmental Science and Technology, 55*(17), 11470–11472. https://doi.org/10.1021/acs.est.1c04093

Liong, R. M. Y., Hadibarata, T., Yuniarto, A., Tang, K. H. D., & Khamidun, M. H. (2021). Microplastic occurrence in the water and sediment of Miri River Estuary, Borneo Island. *Water, Air, and Soil Pollution, 232*(8), 342. https://doi.org/10.1007/s11270-021-05297-8

Luo, W., Su, L., Craig, N. J., Du, F., Wu, C., & Shi, H. (2019). Comparison of microplastic pollution in different water bodies from urban creeks to coastal waters. *Environmental Pollution, 246*, 174–182. https://doi.org/10.1016/j.envpol.2018.11.081

Masura, J., Baker, J., Foster, G., & Arthur, C. (2015). Laboratory methods for the analysis of microplastics in the marine environment: Recommendations for quantifying synthetic particles in waters and sediments

Miller, M. E., Hamann, M., & Kroon, F. J. (2020). Bioaccumulation and biomagnification of microplastics in marine organisms: A review and meta-analysis of current data. *PloS One, 15*(10), e0240792. https://doi.org/10.1371/journal.pone.0240792

Munno, K., Helm, P. A., Jackson, D. A., Rochman, C., & Sims, A. (2018). Impacts of temperature and selected chemical digestion methods on microplastic particles. *Environmental Toxicology and Chemistry, 37*(1), 91–98.

Nie, H., Wang, J., Xu, K., Huang, Y., & Yan, M. (2019). Microplastic pollution in water and fish samples around Nanxun Reef in Nansha Islands, South China Sea. *Science of The Total Environment, 696*, 134022. https://doi.org/10.1016/j.scitotenv.2019.134022

Peixoto, D., Pinheiro, C., Amorim, J., Oliva-Teles, L., Guilhermino, L., & Vieira, M. N. (2019). Microplastic pollution in commercial salt for human consumption: A review. *Estuarine, Coastal and Shelf Science, 219*, 161–168. https://doi.org/10.1016/j.ecss.2019.02.018

Perera, M. D. D., & Gomes, P. I. A. (2022). Do sediments of ephemeral and perennial streams show different impacts on water quality when subjected to the same drying conditions?. *Ecohydrology 15*(2). https://doi.org/10.1002/eco.2385

Peters, C. A., & Bratton, S. P. (2016). Urbanization is a major influence on microplastic ingestion by sunfish in the Brazos River Basin, Central Texas, USA. *Environmental Pollution, 210*, 380–387. https://doi.org/10.1016/j.envpol.2016.01.018

Plew, D. R., Zeldis, J. R., Shankar, U., & Elliott, A. H. (2018). Using simple dilution models to predict New Zealand estuarine water quality. *Estuaries and Coasts, 41*(6), 1643–1659. https://doi.org/10.1007/s12237-018-0387-6

Prata, J. C., da Costa, J. P., Lopes, I., Andrady, A. L., Duarte, A. C., & Rocha-Santos, T. (2021). A One Health perspective of the impacts of microplastics on animal, human and environmental health. *The Science of the Total Environment, 777*, 146094. https://doi.org/10.1016/j.scitotenv.2021.146094

Ranatunga, R. R. M. K. P., Wijetunge, D. S., & Karunarathna, K. P. R. (2021). Microplastics in beach sand and potential contamination of planktivorous fish Sardinella gibbosa inhabiting in coastal waters of Negombo, Sri Lanka. *Sri Lanka Journal of Aquatic Sciences, 26*(1), 37. https://doi.org/10.4038/sljas.v26i1.7587

Reichert, J., Arnold, A. L., Hoogenboom, M. O., Schubert, P., & Wilke, T. (2019). Impacts of microplastics on growth and health of hermatypic corals are species-specific. *Environmental Pollution, 254*, 113074. https://doi.org/10.1016/j.envpol.2019.113074

Sharma, S., & Chatterjee, S. (2017). Microplastic pollution, a threat to marine ecosystem and human health: A short review. *Environmental Science and Pollution Research, 24*(27), 21530–21547. https://doi.org/10.1007/s11356-017-9910-8

Subramanya, K. (2019). *Flow in open channels*. McGraw-Hill Education.

Suthakaran, R., Perera, K., & Wikramanayake, N. (2014). Rainfall intensity-duration-frequency relationship for Colombo Region in Sri Lanka. *In Proceedings of the SAITM Research Symposium on Engineering Advancements, Colombo, Sri Lanka*

Turner, A., & Holmes, L. (2011). Occurrence, distribution and characteristics of beached plastic production pellets on the island of Malta (central Mediterranean). *Marine Pollution Bulletin, 62*(2), 377–381. https://doi.org/10.1016/j.marpolbul.2010.09.027

Wang, W., Yuan, W., Chen, Y., & Wang, J. (2018). Microplastics in surface waters of Dongting Lake and Hong Lake, China. *Science of the Total Environment, 633*, 539–545. https://doi.org/10.1016/j.scitotenv.2018.03.211

Weerasinghe, V. P. A., & Handapangoda, K. (2019). Surface water quality analysis of an urban lake; East Beira, Colombo, Sri Lanka. *Environmental Nanotechnology, Monitoring and Management, 12*, 100249. https://doi.org/10.1016/j.enmm.2019.100249

Wijethunga, H. N. S., Athawuda, A. M. G. A. D., Dias, P. C. B., Abeygunawardana, A. P., Senevirathna, J. D. M., Thushari, G. G. N., Liyanage, N. P. P., & Jayamanne, S. C. (2019). Screening the effects of microplastics on selected invertebrates along Southern Coastal Belt in Sri Lanka: A preliminary approach to coastal pollution control

Xu, C., Zhang, B., Gu, C., Shen, C., Yin, S., Aamir, M., & Li, F. (2020). Are we underestimating the sources of microplastic pollution in terrestrial environment? *Journal of Hazardous Materials, 400*, 123228. https://doi.org/10.1016/j.jhazmat.2020.123228

Xu, X., Zhang, L., Xue, Y., Gao, Y., Wang, L., Peng, M., Jiang, S., & Zhang, Q. (2021). Microplastic pollution characteristic in surface water and freshwater fish of Gehu Lake, China. *Environmental Science and Pollution Research International, 28*(47), 67203–67213. https://doi.org/10.1007/s11356-021-15338-8

Yu, Y., Zhou, D., Li, Z., & Zhu, C. (2018). Advancement and challenges of microplastic pollution in the aquatic environment: A review. *Water, Air, and Soil Pollution, 229*(5), 140. https://doi.org/10.1007/s11270-018-3788-z

Zaki, M. R. M., Ying, P. X., Zainuddin, A. H., Razak, M. R., & Aris, A. Z. (2021). Occurrence, abundance, and distribution of microplastics pollution: An evidence in surface tropical water of Klang River estuary, Malaysia. *Environmental Geochemistry and Health, 43*(9), 3733–3748. https://doi.org/10.1007/s10653-021-00872-8

Zhang, K., Gong, W., Lv, J., Xiong, X., & Wu, C. (2015). Accumulation of floating microplastics behind the Three Gorges Dam. *Environmental Pollution, 204*, 117–123. https://doi.org/10.1016/j.envpol.2015.04.023

Zhang, K., Shi, H., Peng, J., Wang, Y., Xiong, X., Wu, C., & Lam, P. K. S. (2018). Microplastic pollution in China's inland water systems: A review of findings, methods, characteristics, effects, and management. *Science of the Total Environment, 630*, 1641–1653. https://doi.org/10.1016/j.scitotenv.2018.02.300

Zhang, D., Cui, Y., Zhou, H., Jin, C., Yu, X., Xu, Y., Li, Y., & Zhang, C. (2020). Microplastic pollution in water, sediment, and fish from artificial reefs around the Ma'an Archipelago, Shengsi, China. *Science of The Total Environment, 703*, 134768. https://doi.org/10.1016/j.scitotenv.2019.134768

Zhang, X., Leng, Y., Liu, X., Huang, K., & Wang, J. (2020). Microplastics' pollution and risk assessment in an urban river: A case study in the Yongjiang River, Nanning City, South China. *Exposure and Health, 12*(2), 141–151. https://doi.org/10.1007/s12403-018-00296-3

Zhang, D., Fraser, M. A., Huang, W., Ge, C., Wang, Y., Zhang, C., & Guo, P. (2021). Microplastic pollution in water, sediment, and specific tissues of crayfish (Procambarus clarkii) within two different breeding modes in Jianli, Hubei province, China. *Environmental Pollution, 272*, 115939. https://doi.org/10.1016/j.envpol.2020.115939