Environmental Pollution 323 (2023) 121303

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Spatio-temporal distribution of microplastics in water and sediment samples of the Plankenburg river, Western Cape, South Africa☆

Komlan Apetogbor[a], Omoniyi Pereao[a,*], Conrad Sparks[b], Beatrice Opeolu[a]

[a] Environmental and Toxicology Research Group, Faculty of Applied Sciences, Cape Peninsula University of Technology, Symphony way, PO Box 1906, Bellville, 7535, South Africa

[b] Department of Conservation and Marine Sciences, Cape Peninsula University of Technology District Six Campus, Cape Town, 8000, South Africa

ARTICLE INFO

Keywords:
Freshwater
Sediment
Microplastics
Plankenburg river
Water quality
South Africa

ABSTRACT

Microplastic (MPs) pollution has become a subject of environmental concern due to its wide ubiquity in the environment. Microplastics are possible sources of other hazardous chemicals to aquatic organisms due to their composition and sorption properties. In this study, MPs occurrence in water and sediment samples of the Plankenburg River, Western Cape, South Africa was investigated. The physicochemical characterization of the river water was done onsite. 30 L water samples were collected and filtered in 10 L triplicates through a 250 μm mesh onsite using a metal bucket. An additional 12 L sample was collected and filtered in 4 L triplicates through 20 μm mesh in the laboratory. The extraction of MPs from water in the laboratory was by density separation. Sediment samples were also collected at the selected sites, oven-dried and microplastics in the laboratory. Sampling was conducted over four seasons – spring, summer, autumn, and winter. Microplastics were classified by visual observation and Fourier Transform Infrared Spectroscopy (FTIR-ATR). The seasonal distribution of MPs in the surface water samples varied across all sites. However, spring samples had the highest MPs occurrence (5.13 ± 6.62 MP/L) and the least, in autumn (1.52 ± 2.54 MP/L). The MPs in sediment samples were observed in spring (1587.50 ± 599.32 MP/kg). Fibres were the most dominant microplastic particle type (shape), with a size range of 500–1000 μm at the different sites. The infrared spectroscopic analysis confirmed the dominant polymer type to be polyethylene. This study provides an understanding of the microplastic occurrence in the Plankenburg River system and gives a baseline for future monitoring and assessment of water and sediment in the South African freshwater systems.

1. Introduction

Plastic pollution has been reported to have adverse effects on the reproduction, behaviour, survival, growth, and metabolism of aquatic organisms. However, the estimated quantity of microplastics released into the aquatic environment is still being investigated (Critchell and Hoogenboom, 2018; Pereao et al., 2020). Microplastics are ubiquitous in the environment because they are widely used, relatively cheap and durable but persistent in the environment (Lin et al., 2020). They get into rivers through the wind, storm sewers and wastewater treatment plants. The most significant source of freshwater pollution is wastewater effluent from sewage treatment plants and runoff from road surfaces caused by the breakdown of road markings and tyre debris (Horton et al., 2017). Mani et al. (2015) identified the closeness of urbanisation to rivers as sources of microplastics from various activities such as effluent discharge, road runoff, littering and atmospheric deposition to aquatic ecosystems.

Microplastic studies in freshwater have increased rapidly signifying their importance to the water sector. The reported microplastic values in marine ecosystems are equivalent to the observed amounts in the freshwater environments (Ma et al., 2019) with a highly heterogeneous distribution in different areas (Wagner and Lambert, 2018). The study on Shanghai rivers by Peng et al. (2018) showed that river sediments are reservoirs for terrestrial-based microplastics with an average of 802 ± 594 items per kilogram of dry weight (items/kg^{-1} dw) microplastics in river sediment samples while the average microplastics found in Poyang Lake were 1134 (items/kg^{-1} dw) by (Liu et al., 2019). The presence of microplastic is therefore a worry due to the potential threats to the

☆ This paper has been recommended for acceptance by Eddy Y. Zeng.

* Corresponding author.
E-mail addresses: pereaokola@gmail.com, pereaoo@cput.ac.za (O. Pereao).

https://doi.org/10.1016/j.envpol.2023.121303
Received 20 September 2022; Received in revised form 13 February 2023; Accepted 14 February 2023
Available online 15 February 2023

suitability of water for human use (Amoatey and Baawain, 2019). Several studies have been conducted on MP pollution in both marine and freshwater ecosystems to understand the occurrence of microplastics in water bodies.

Most plastics are manufactured, used and deposited in the terrestrial environment, with rivers as a primary pathway (source) of microplastics to the ocean (Horton et al., 2017), but it is limited with no measurable information or data on the environmental fate of riverine microplastics which can hinder the development of regulatory activities and proper risk assessment (Yuan et al., 2022a). Some studies suggested that anthropogenic disturbances in the catchment, such as population density, land use, and point source pollution are closely related to the increased microplastic pollution in rivers (Barrows et al., 2018; Cao et al., 2021). It was also found that elevation and precipitation were closely associated with microplastic pollution in riparian soils (Zhou et al., 2021). Thus, microplastics may present an environmental risk to the inhabiting organisms and the quality of soil since soil properties, as well as biodiversity and function may be affected (Huerta Lwanga et al., 2016). These high loads of diverse microplastics in river ecosystems have increased research investigations to provide a better understanding of the major driving factors behind the geographical distribution and characteristics of the heterogenous MP. Microplastics are defined by their size, origin, shape, polymer composition, and colour (Jiang et al., 2018).

Large plastic waste items undergo fragmentation under physical action, ultraviolet radiation, oxidative properties of the atmosphere and hydrolytic properties of water bodies and are progressively broken down into smaller particles known as microplastics (Xu et al., 2021). The most identified microplastics in the environment are polyethylene (PE, low and high density), polystyrene (PS), Polyvinylchloride (PVC), polypropylene (PP), and polyethylene terephthalate (PET) (Sorolla-Rosario et al., 2022) as well as polyamide fibres (nylon) (Fan et al., 2021). Plastics have become the largest component of marine debris and a major threat to aquatic ecosystems (Green, 2016). MPs are subjected to mechanical, chemical, and biological interactions leading to their abiotic and biotic transformation, which can in turn influence the transport and bioavailability of MPs (Gao et al., 2022; Zhang et al., 2021). There is a higher possibility of the breakdown of microplastics to nanoplastics that may have higher environmental risks due to the nature of nano-sizes (Li et al., 2018).

In Africa and specifically South Africa, several research studies on microplastic pollution have been reported in the marine environment but there is still limited information on freshwater systems (Migwi et al., 2020; Weideman et al., 2020). The Plankenburg River in South Africa flows through different land use practices in Stellenbosch and receives agricultural pollutant inputs from its source through formal and informal residential neighbourhoods to industrial activities. Although the river is not used for potable activities, it is important for the ecological health of the system as well as possible urban agriculture and previous studies on the river already revealed organic contaminant pollution.

This present investigation studied the microplastic pollution characteristics and distribution in the surface water and sediments of the Plankenburg River in South Africa through laboratory and field investigations on the physicochemical parameters, distribution, abundance, shape, colour, size, and polymer composition of MPs. The sampling sites were chosen to assess the discharges from diffuse sources (transport by the river), and direct sources into the river from the industrial and recreational park. The analysis of shape, colour and plastic type in this study should show if the extent of MPs pollution in freshwater river systems is comparable to the sediments. The study will reduce the knowledge gaps on MP pollution status in the South Africa surface water and sediment and provide insight into the status of MP pollution in South Africa.

2. Materials and methods

2.1. Study area

The Plankenburg River is approximately 10 km long and runs through Stellenbosch in the Western Cape Province of South Africa with a geographical location lying approximately on latitude and longitude coordinates of 33° 56′ 12″ S, 18° 51′ 41″E (Udebuani et al., 2021), and provides ecosystem services for residential, and industrial sectors. The sampling points were selected based on possible routes of microplastic entry, including human and industrial activities as shown in Fig. 1. The influence of the transport of MPs was monitored by sampling in the proximity of the Kayamandi Informal Settlement (PR 1) which lacks proper sanitation (Alegbeleye et al., 2016), and other areas of industrial activities (PR 2). A sampling at the Krom River (PR 3) and the confluence of the Plankenburg River mixed with the Krom River (PR 4) was to indicate the possible MP entry via anthropogenic activities in the area. Fig. 1 shows the four sampling sites while the GIS Coordinates are shown in Table S1.

2.2. Water and sediment sampling

Sampling was undertaken over four seasons (summer, spring, autumn, and winter). On each site, 30 L were sampled and filtered onsite in three replicates of 10 L through 250 μm stainless steel sieves for each of the selected sampling locations. The metal bucket was immersed below the surface water opposite the water flow direction. The residual particles on the sieve were transferred and stored in small glass jars and taken to the laboratory for further analysis. At each sampling site, the metal bucket and stainless sieve were cleaned carefully with Milli-Q water to reduce cross-contamination and rinsed thoroughly with water from the site before sampling. Contamination and disruption of MPs determination were avoided by cleaning plastic bags and nylon mesh with Milli- Q water when used. In addition to the onsite 30 L water samples, another 12 L sample of surface water were collected separately at each sampling site and transported to the laboratory and filtered through a 20 μm stainless steel sieve. The 12 L brought into the laboratory was filtered in three replicates of 4 L per site. 100 g sediment sample was collected using metal scoops at approximately 5 cm depth at each sampling site to achieve three replicates which were randomly collected 2 m apart and pooled as one sample per site. Sediment samples were individually stored in sealed plastic bags, placed in an ice chest, and transported to the Cape Peninsula University of Technology Microplastics Laboratory. Samples were oven-dried at 50 °C for 24 h and covered with aluminium foil to avoid contamination.

2.3. Microplastic extraction by density separation

The collected samples were processed to isolate the microplastics based on the adapted method from (GESAMP, 2019). MPs were extracted from the 12 L offsite sample and taken to the laboratory by filtration through a vacuum pump system with 20 μm mesh. Alkali digestion was used to degrade organic matter before the extraction process (Maes et al., 2017). The higher the density of the salt solution, the higher the floating of MPs, but as a drawback, high-density solutions could also float other small particles (such as organic matter), thus increasing the presence of interference species (Quinn et al., 2017). Based on previous studies (Cutroneo et al., 2021), an intermediate separation solution for the density extraction of microplastics was found in NaCl and the density separation was run at least 3 times. Residues of samples processed onsite were stored in glass jars and labelled appropriately. The residues were transferred into a 500 ml glass beaker with 10% Potassium hydroxide (KOH) and covered with aluminium foil for 24 h in the oven at a temperature of 50 °C. Hypersaline solutions (NaCl 360 $g \cdot \ell^{-1}$) were added to the digested sample, stirred vigorously for 2 min, allowed to settle for 15 min and then filtered through a vacuum

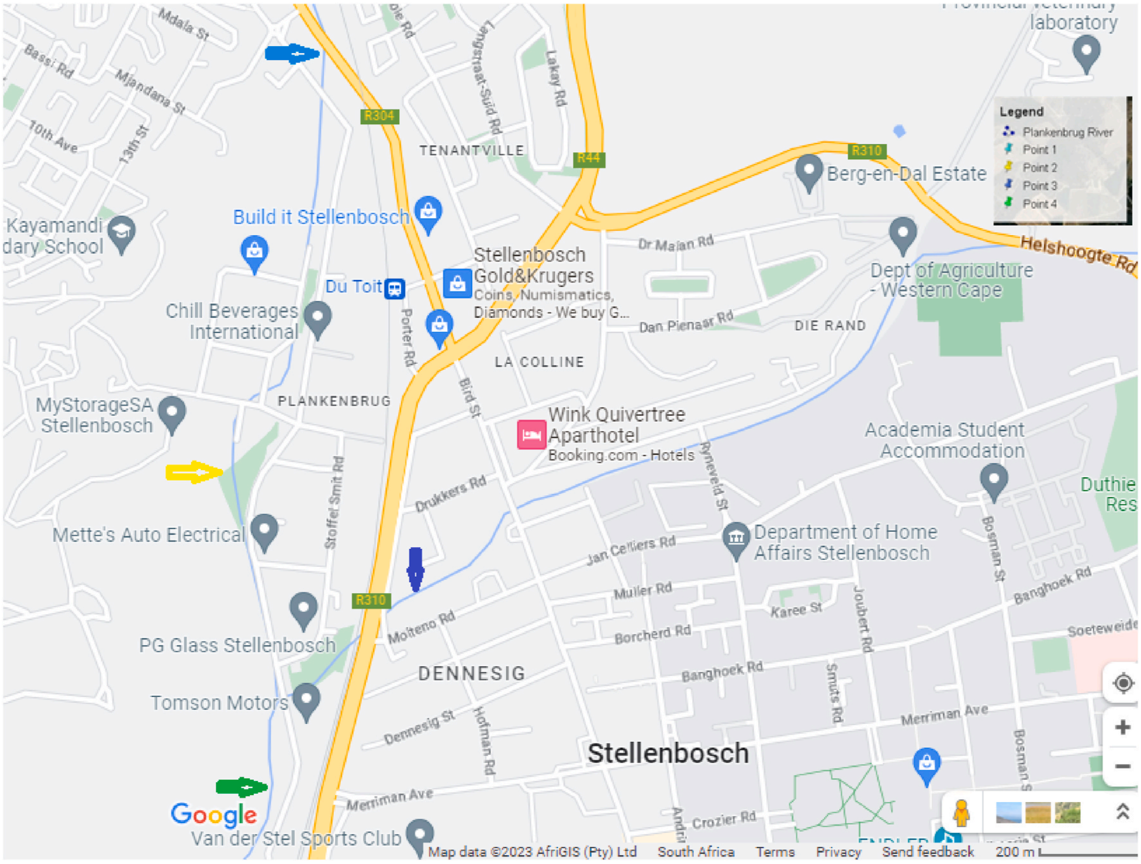

Fig. 1. Sampling sites on the Plankenburg River (Source: Google maps).

pump system with 20 μm mesh. This extraction process was repeated three times for each sample. The filters were then placed in clean petri dishes for further analysis. The extraction of microplastics from sediment samples was carried out with the density fractionation method as described by Di and Wang (2018) with minor modification. Sediment samples were dried in the oven at 50 °C for 48–72 h to constant weight, then 20 g of dry sediment from each replicate was transferred into a 500 ml glass beaker with 10% KOH and placed in the oven at 50 °C for 24 h. Saturated NaCl solution (360 g·ℓ^{-1}) were added to the digested sample, which was then stirred with a clean stainless spoon for 2 min and allowed to settle for 30 min. Dried sediment in the beaker was always covered with aluminium foil to avoid air-bone microplastic contamination. The supernatant of the solution containing floating particles was vacuum filtered through a 20 μm nylon mesh pre-washed with Milli-Q water, which was repeated three times for each sample. The mesh was placed in clean petri dishes for further analysis.

2.4. *Microplastic observation and identification*

The dried meshes in the pre-cleaned petri dishes were examined for microplastics based on physical appearance under a stereomicroscope (BS-3060CT, Bestscope, China). Particles were categorised based on their morphological characteristics (size, shape, and colour) as previously described by (Hidalgo-Ruz et al., 2012) and (Masura et al., 2015). Microplastics were classified and measured by their sizes using a microscope into six categories (Estahbanati and Fahrenfeld, 2016; Talbot et al., 2022): <63 μm, 63–500 μm, 500–1000 μm, 1000–2000 μm, 2000–5000 μm and >5000 μm. Particles were classified based on their shapes (fibre, fragment, Sphere and film) according to Baldwin et al. (2016), and Zhang et al. (2017). All suspected microplastic particles were photographed using a BestScope BHC3E-1080P HDMI Digital Camera (China) connected to the microscope. Microplastic abundance and mass were recorded in terms of MPs/L and MPs/Kg dry sediment. A minimum of 10% of randomly selected microplastic particles larger than 500 μm were analysed using Fourier Transform Infrared (FTIR-ATR). A spectroscopy Perkin Elmer Two FTIR-ATR Spectrometer system was used to analyse microplastic particles. With a resolution of 4 cm^{-1} and a data interval of 1 cm^{-1}, spectra in the wavenumber range of 5000 to 450 cm^{-1} were captured. Before each sample analysis, background scans were performed, and the ATR crystal was cleaned with 70% propanol before usage. Using a pair of fine tweezers and a force of at least 80 N, particles (Filaments and fragments) > 500 μm in size were squeezed against the diamond head. Polymer identification was done by comparing spectral scans with the ST Japan Library and a Perkin spectral library provided by the supplier (Perkin Elmer).

2.5. *Quality control and quality assurance*

Preventive measures were undertaken to minimise potential contamination of microplastic particles during sampling and laboratory processing using the method of Wang et al. (2017). Microplastic equipment was rinsed thoroughly with distilled water before use. Plastic items used were minimized, but when used, it was rinsed with Milli-Q ultra-pure water and blank experiments were conducted to account for possible contributions from the materials. Nitrile gloves were always worn during the whole process, and solutions were covered with aluminium foil for the duration of the process. Saturated NaCl solution and KOH were filtered through a 10 μm size mesh under vacuum. Airborne contamination control was conducted for the duration of laboratory sessions by putting Petri dishes containing a wet mesh on workbenches. If microplastics were detected on the control mesh and petri dishes placed at strategic points throughout the laboratory to determine if any air contamination occurred, the amount detected was subtracted from the values obtained. The wind direction was faced during sampling to avoid contamination. A total of nineteen fibres were recorded from the negative controls for the whole study and the data were adjusted accordingly. Extraction efficiencies were done by filtering known quantities of fibres to ensure the reliability of the data obtained in this study. The experimental process showed an efficiency rate of 95% fibres.

2.6. Data analysis

The microplastic abundance, in mean and standard deviation (SD) from water and sediment, was expressed as MPs/L and MPs/kg (dw), respectively. Based on the characteristics of the distributed data, non-parametric analyses were conducted on the data using the Kruskal–Wallis test for analysis between microplastic abundances in surface water and sediment, with the significance of differences between the groups, was determined by the Mann–Whitney *U* test with a <0.05 significance level. Post hoc analyses for significant differences between sites were conducted using pairwise comparisons of the Kruskal–Wallis analysis. The physicochemical parameters' data were analysed for means, and SD and correlated to MP's data parameters using the IBM Statistic Package for Social Science (SPSS) 28.

3. Results and discussions

The microplastic burden of the river was assessed spatially and temporally. A total of 1756 microplastics were recorded from water and sediment samples collected from the Plankenburg River. Two different environmental matrices (water and sediment) were collected and analysed. Six sampling events were conducted rather than eight due to the COVID-19 pandemic restrictions nationally and at Cape Peninsula University of Technology (CPUT). Two sampling events were carried out for spring and autumn but only one for each summer and winter season.

3.1. Spatial and temporal distribution of microplastics in water samples of the Plankenburg River

The distribution of microplastic particles in the river provides an understanding and information on MP occurrence in the freshwater ecosystem. Results of microplastic distribution over four seasons in the Plankenburg River are presented in Table S2. The spatial and temporal distributions of MPs using different mesh sizes showed a different recovery overview. The MPs from 20 μm to 250 μm were extracted and the results are presented in Fig. 2. The recovery efficiencies for two different mesh sizes during filtration were compared, and the results revealed that the 20 μm mesh had a better extraction efficiency than the 250 μm.

MPs abundances were calculated for each site and presented as the number of MPs/L (N = 72). For microplastics processed under 20 μm (Fig. 2a), there were no significant differences in microplastic occurrences between sampling points analysed (Kruskal-Wallis; $p > 0.05$). The highest mean occurrence of microplastics over the four sampling sites recorded in Fig. 2a PR2 (9.25 MP/L), and the lowest across the four sampling sites was recorded at PR4 (6.87 MP/L). There was no significant difference in the microplastic burden of samples processed through the 250 μm mesh across sampling points (Kruskal-Wallis; $p > 0.05$). The highest mean occurrence of microplastics was in summer and winter at PR1 (0.83 ± 0.96 and 0.77 ± 1.23 MP/L, respectively), in spring (PR2: 0.78 ± 1.27 MP/L) and autumn (PR4: 0.63 ± 1.03 MP/L), and the lowest across the four seasons were recorded in summer at PR2 (0.31 ± 0.47 MP/L) (Table S2). Seasonally, MPs were in abundance in winter at 0.63 ± 1.01 MP/L and lower in summer at 0.57 ± 0.85 MP/L (Table S2). The mean abundance in the 20 μm and 250 μm water samples were respectively 7.98 ± 4.61 MP/L and 1.72 ± 0.67 MP/L. The results of the occurrence of MP in this study are more than the observed abundance of 0.23 ± 0.27 items·L^{-1} obtained by Weideman et al. (2019) in the Orange–Vaal River system in South Africa. This study's findings are comparable to those reported by Alam et al. (2019), who found 5.85 ± 3.28 particles/litre of microplastics.

3.2. Spatial and temporal distribution of microplastics in sediment samples in the Plankenburg River

The results of microplastic distribution in sediment samples over four seasons in the Plankenburg River are presented in Table 1. A total of 72 sediment samples were collected for this study. Three replicates were collected per site over the four seasons in six sampling events.

From the results presented in Table 1, MPs ranged from 2133.33 ± 898.15 to 616.67 ± 160.73 MPs/kg in the sediment samples. The distribution suggests that in winter, there were more deposits of microplastics. The abundance of microplastics was calculated for each site and presented in microplastics per kilogram (N = 18). Results are reported as means (±SD) and significances set at $p < 0.05$. There were no significant differences in microplastic abundances across all sites for the six sampling events (Kruskal-Wallis; $p > 0.05$). The highest mean values of MPs were recorded in spring, summer, and autumn at PR1 (2133.33 ± 898.15, 1183.33 ± 301.39 and 1066.67 ± 415.53 MP/kg) and in winter at PR4 (1686.33 ± 860.72 MP/kg). The lowest across the four seasons were recorded in Summer (PR2; 616.67 ± 160.73 MP/kg) (Table 1). Reduced flow rate and large volumes of water in spring accounted for the high amount observed at different sites.

The seasonal distribution of microplastics in sediment from the

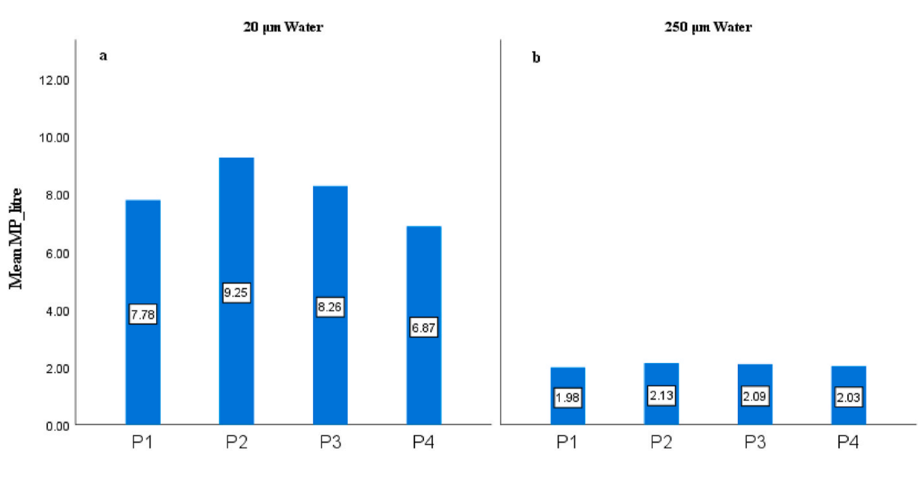

Fig. 2. Abundance and distribution of microplastic particles in the Plankenburg River water sample using 20 μm (a) and 250 μm (b) mesh sizes.

Table 1
Abundance and distribution of microplastic particles in the Plankenburg River sediment sample (mean ± SD).

Site	Season			
	Spring	Summer	Autumn	Winter
PR1	2133.33 ± 898.15	1183.33 ± 301.39	1066.67 ± 415.53	1666.67 ± 189.30
PR2	1358.33 ± 320.03	616.67 ± 160.73	1250 ± 370.14	1333.33 ± 275.38
PR3	1500 ± 251	783.33 ± 57.74	691.67 ± 159.43	983.33 ± 160.73
PR4	1358.33 ± 432.92	950 ± 86.60	866.67 ± 338.62	1686.33 ± 860.72
Seasonal mean	1587.50 ± 599.32	883.33 ± 266.57	968.75 ± 379.02	1416.67 ± 499.24

PR1: Kayamadi Informal Settlement/Commercial activities, PR2: Industrial and recreational park, PR3: Krom River, PR4: Plankenburg River mixed with Krom River.

Plankenburg River is summarized in Table 1. The spring samples had the highest MP abundance (1587.50 599.32 MP/kg). The mean abundance in the sediment samples of 1235.42 ± 552.23 MP/kg of dry sediment is higher than the MPs recorded by Maheswaran et al. (2022), who recorded an abundance of 699 ± 66.00 items/kg from the West Dongting Lake. This study result is lower than the one recorded by Xia et al. (2021), where the recorded abundances of MP were 33 200 items/kg of dry sediment. An assessment of the Bloukrans River, South Africa, showed microplastic contamination ranging from 6.3 ± 4.3 and 160.1 ± 139.5 kg^{-1} particles, respectively, in the summer and winter seasons (Nel et al., 2018), lower than the values recorded in the present study in summer and winter with a similar abundance trend. However, the lower burden of MPs in summer and autumn can be attributed to the low level of water in the river. The high concentrations of microplastics found at the PR1 sampling site may be suggested to runoff from informal settlements. The research by Huang et al. (2021) also showed how human activity affected river pollution.

3.3. Physical properties of microplastics in the Plankenburg River

3.3.1. Shape

Particles were categorised based on their morphological characteristics (size, shape, and colour) as described by Hidalgo-Ruz et al. (2012), and Masura et al. (2015). The shapes of MP's filtered from water and sediment are shown in Fig. 3. MP shapes were categorised into five: foam, fragment, Sphere, film, and fibre (Fig. S1). At all four sampling sites, fibres (PR4: 98.40%) and films (PR2: 2.71%) were recorded as the dominant forms of plastic particles in the Plankenburg River system. Because of the wide application of plastic fibres, they occupy a large proportion of many studies, especially in freshwater environments (Yin et al., 2022). As very close to human activities, the Plankenburg River received a large amount of fibre. According to Migwi et al. (2020), the high informal settlement population increases pressure on the waste disposal systems, posing a threat to the river's health. Thus, the dominance of fibres and films in the Plankenburg River could be an indication of household and industrial effluent discharge into the river breakdown of household fibres.

3.3.2. Colour

White, yellow/brown, black/grey, translucent, blue/green, and red/pink were among the colours of MPs that were found (Fig. 4). The amount of transparent MPs was highest in PR1 (80.62%) and lowest in PR2 (75.51%). According to previous research, transparent and blue/green MP was the dominant colour in the study of the freshwater system by Zhang et al. (2020). The colour of MPs is mainly due to the contamination of plastic materials from urban wastewater. Transparent and white MP may be caused by the discolouration of coloured MPs and weathering, while red/pink MP may be formed from coloured manufactured clothing (Maheswaran et al., 2022). Coloured MPs particles could easily be mistaken for food by freshwater biota, colour is a potential health hazard to the freshwater ecosystem, and its blocking effect of light can affect plant photosynthesis and animal activity (Silva et al., 2020). According to He et al. (2020), some colourless or transparent MPs particles could potentially be overlooked during extraction or identification processes.

3.3.3. Size

The identified MPs were classified into six categories according to their sizes: <63 μm, 63–500 μm, 500–1000 μm, 1000–2000 μm, 2000–5000 μm and >5000 μm. There is at present a technology and knowledge gap with respect to the detection of smaller sized microplastics (<150 μm) in sediments and freshwater samples (Yuan et al., 2022b), especially for those with similar smaller size to aquatic organisms ingested by prey organisms (Ory et al., 2017). Microplastic pellets detected in Riverbank sediments range in particle size from 63 to 200 μm, showing the source of the parent material to be from cosmetics and

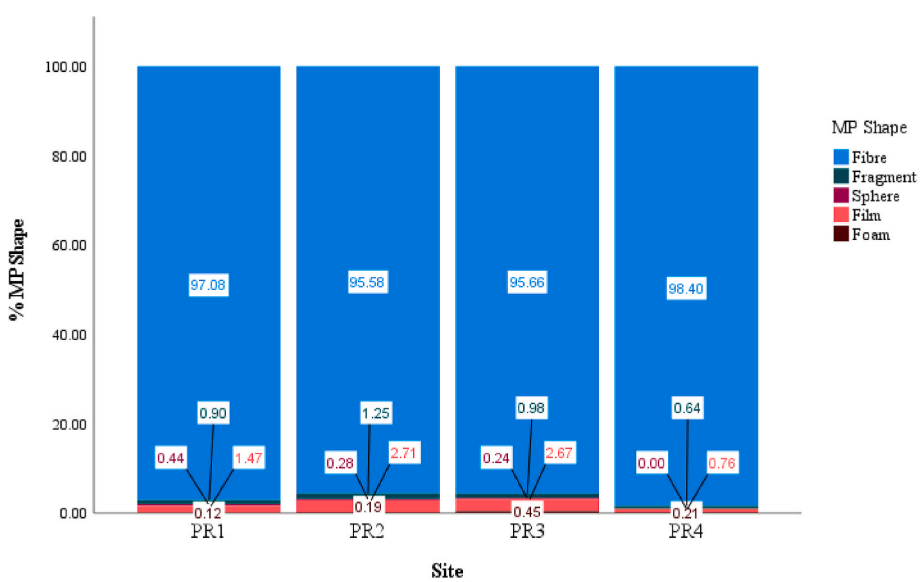

Fig. 3. The Plankenburg River microplastic particles distribution by shape.

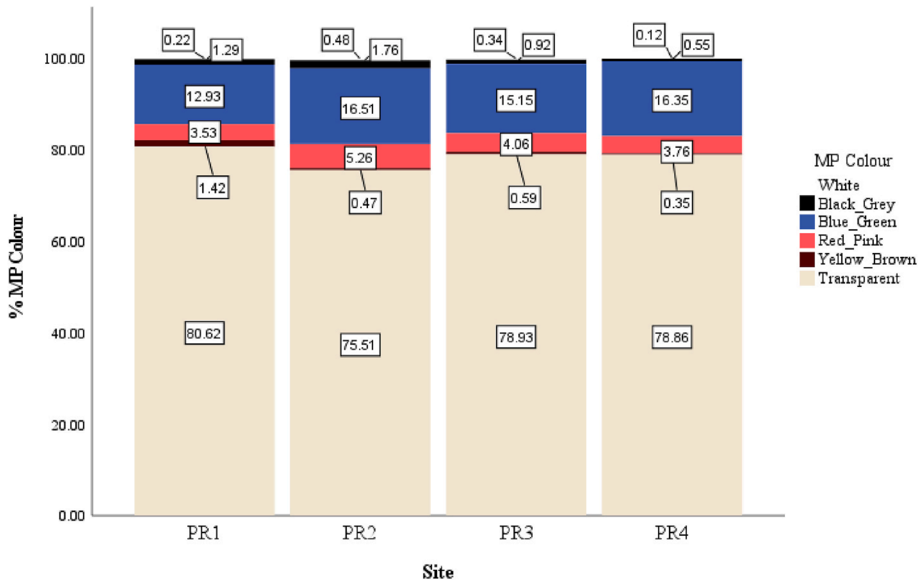

Fig. 4. Colour distribution of microplastic particles in the Plankenburg River. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

cleansers (Chen et al., 2021; Priya et al., 2022). Willis et al. (2017) observed high frequencies of 63 μm microplastics in sediments compared to the size distribution observed from net trawls of the ocean surface. Fig. 5 outlined a high proportion of MP particle size between 500 and 1000 μm at the different sites with 61.87% at PR4, similar to Yin et al. (2022) study on the Xiangjiang river. In the current study, MPs <63 μm particle size was substantially smaller than that reported by Maheswaran et al. (2022). Macro-plastic can break down into multiple small-size plastics that are considered to pose the most serious potential threats to both aquatic organisms and ecosystems. MPs with relatively lower density and smaller sizes have increased potential for transportation by wind and water. Consequently, MPs hazard impacts, compared to larger plastic debris, MP have more serious toxic effects and a higher probability of being mistakenly ingested by organisms (He et al., 2020; Yin et al., 2022). Additionally, pollutants, including heavy metals and organics, can adhere to the surface of MPs, and those with different particle sizes can have varying adsorption capacities for contaminants.

3.4. Chemical analyses of microplastics in the Plankenburg river

3.4.1. Polymer distribution of microplastics in the Plankenburg River

FTIR-ATR was used to conduct chemical analyses of plastic particles to identify the various polymer types detected in the freshwater system. The primary polymers found in the Plankenburg River were PE (57.86%), Cotton (29.84%), PP (6.68%%), and PET (5.62%) as shown in Fig. S2. Based on the proportion of the density of each type of MP, different percentages were recorded in water and sediment as shown in Fig. 6, and PE is the most predominant type of PM in water and sediment, followed by cotton. According to Xia et al. (2021), PE and PP are widely used due to their lightweight and stable characteristics as packaging bags in food, fishing and agricultural sectors. However, PE has been reported in the previous research literature as one of the most common polymer types with wide distribution in freshwater depending

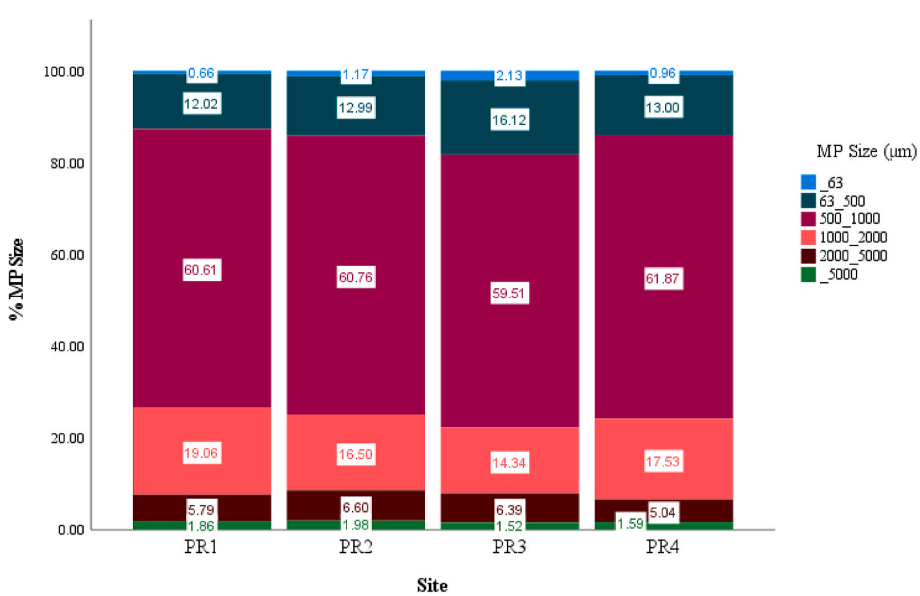

Fig. 5. The Plankenburg River microplastics occurrence by size.

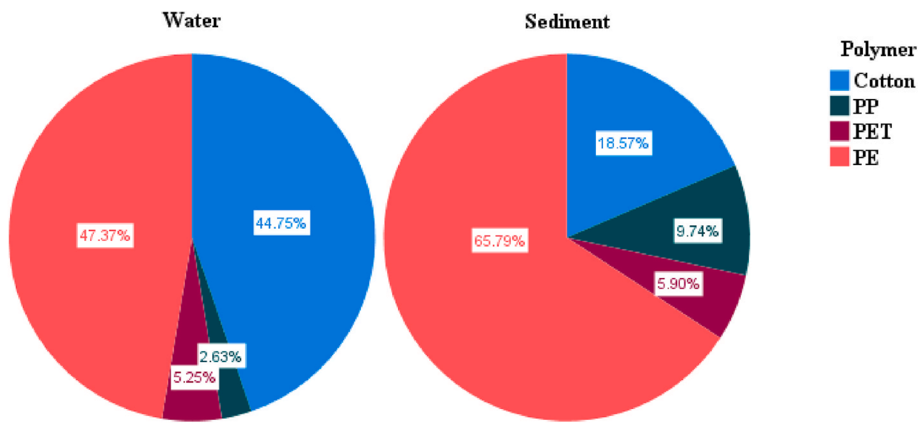

Fig. 6. Polymer-type distribution in water and sediment of the Plankenburg River.

on its quantity (He et al., 2020; Kukkola et al., 2021). Due to landfill operations by the people who live along the river, the Plankenburg River contains cotton, which is used in the production of fabrics, whereas PET is the most recycled thermoplastics and is mainly used for rigid and flexible packaging. In addition, the small amounts of PET may be more significant than large PE based on their differences in toxicity in aquatic systems.

Fibres were the most common shape of MP particles investigated in this study using FTIR-ATR. Fibres were categorised as Cotton (44,35%); PE (37,37%), PET (8,35%) and PP (9,93%) particles, whilst films were identified in PE particles only (Fig. S3a). Fibre polymer identification all over the four sites indicated that Cotton was the predominant polymer from site PR1 to PR 3 and PE at site PR4 (Fig. S3b), and this can be due to the various endeavours and activities within the vicinity of the river and the proximity to the informal settlement. Among the films analysed, PE was the only polymer identified at PR2 and PR4 (water and sediment). Based on the results obtained, MP observed in Plankenburg River might be due to the microplastics released from the daily life of the informal settlement, surface runoff, and discharge from the industrial and agricultural wastewater.

FTIR microplastic spectra found from Plankenburg River were compared with reference IR spectrums and were mainly composed of cotton, PE, PP and PET as shown in Fig. S4. PE characteristic spectra for the four sites display peaks around 717, 1472, 2916 and 2849 cm^{-1}. Cotton produces peaks around wave number regions 556, 1030, 2900 and 3327 cm^{-1}. PP spectra from the study river show peaks around 1376,1456 and 2917 cm^{-1}, and PET display peaks around 725, 1016,1238 and 1715 cm^{-1}. These results are consistent with those described by other authors (Maheswaran et al., 2022; Rodrigues et al., 2018).

4. Conclusion

Studies on microplastic pollution and its possible effects on aquatic ecosystems have increased recently, but there are still knowledge gaps on this topic, particularly concerning South African freshwater ecosystems. This study evaluated MP's distribution, abundance and characteristics in the surface water and sediments of the Plankenburg River in the Western Cape. Pre-treatment methods used to extract the microplastic included density separation, filtration, and alkaline digestion to ensure efficient extraction from water and sediment samples. MPs in the surface water were in abundance in spring at 5.13 $\pm$ 6.62 MP/L, while the occurrence of MPs in sediments was highest in spring at 1587.50 $\pm$ 599.32 MP/kg. Infrared spectroscopy analysis confirmed that the dominant polymer type was polyethylene (57.86%), and fibres (98.40%) were recorded as the dominant forms of microplastic particles, while the size range of 500–1000 μm (61.87%) was the dominant MPs at different sites. Spatial and temporal distributions showed differences based on anthropogenic activities. This study demonstrated that the microplastic pollution occurrence in the investigated freshwater systems was predominantly due to the accompanying surrounding intense anthropogenic activities within the vicinity of the freshwater resource. This study showed the need for further investigations on the effect of runoff, wind, and season on the occurrence of microplastics in freshwater ecosystems.

Credit author statement

Komlan Apetogbor: Material preparation, data collection and analysis, investigation, and writing the manuscript-original draft. Omoniyi Pereao: Material preparation, investigation, data collection and analysis, software and writing the manuscript-review & editing. Conrad Sparks: Supervision, analysis, and manuscript-review & editing. Beatrice O. Opeolu: Supervision, study conception and design, project administration; funding acquisition. All authors read and approved the final manuscript.

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.

Data availability

Data will be made available on request.

Acknowledgements

This research was supported by the Water Research Commission, South Africa (WRC Project No. C2020/2021-00087), CPUT Postgraduate Research Scholarship, and Environmental Chemistry and Toxicology Research Laboratory, Faculty of Applied Sciences, Cape Peninsula University of Technology, South Africa.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envpol.2023.121303.

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.

Alegbeleye, O.O., Opeolu, B.O., Jackson, V.A., 2016. Investigation into the bacterial pollution levels at various sites along the Diep and Plankenburg river systems, 3

Western Cape, South Africa. Water Sci. Technol. 73, 2590–2599. https://doi.org/10.2166/wst.2016.054.
Amoatey, P., Baawain, M.S., 2019. Effects of pollution on freshwater aquatic organisms. Water Environ. Res. 91, 1272–1287. https://doi.org/10.1002/WER.1221.
Baldwin, A.K., Corsi, S.R., Mason, S.A., 2016. Plastic debris in 29 Great lakes tributaries: relations to watershed attributes and hydrology. Environ. Sci. Technol. 50, 10377–10385. https://doi.org/10.1021/acs.est.6b02917.
Barrows, A.P.W., Christiansen, K.S., Bode, E.T., Hoellein, T.J., 2018. A watershed-scale, citizen science approach to quantifying microplastic concentration in a mixed land-use river. Water Res. 147, 382–392. https://doi.org/10.1016/J.WATRES.2018.10.013.
Cao, L., Wu, D., Liu, P., Hu, W., Xu, L., Sun, Y., Wu, Q., Tian, K., Huang, B., Yoon, S.J., Kwon, B.O., Khim, J.S., 2021. Occurrence, distribution and affecting factors of microplastics in agricultural soils along the lower reaches of Yangtze River, China. Sci. Total Environ. 794, 148694 https://doi.org/10.1016/J.SCITOTENV.2021.148694.
Chen, X., Asce, A.M., Huang, G., Chair, C.R., 2021. Editorial overview: emissions of microplastics and their control in the environment. J. Environ. Eng. 147, 01821002 https://doi.org/10.1061/(ASCE)EE.1943-7870.0001897.
Critchell, K., Hoogenboom, M.O., 2018. Effects of microplastic exposure on the body condition and behaviour of planktivorous reef fish (Acanthochromis polyacanthus). PLoS One 13, e0193308. https://doi.org/10.1371/journal.pone.0193308.
Cutroneo, L., Reboa, A., Geneselli, I., Capello, M., 2021. Considerations on salts used for density separation in the extraction of microplastics from sediments. Mar. Pollut. Bull. 166, 112216 https://doi.org/10.1016/J.MARPOLBUL.2021.112216.
Di, M., Wang, J., 2018. Microplastics in surface waters and sediments of the three Gorges reservoir, China. Sci. Total Environ. 616–617, 1620–1627. https://doi.org/10.1016/j.scitotenv.2017.10.150.
Estahbanati, S., Fahrenfeld, N.L., 2016. Influence of wastewater treatment plant discharges on microplastic concentrations in surface water. Chemosphere 162, 277–284. https://doi.org/10.1016/j.chemosphere.2016.07.083.
Fan, C., Huang, Y.Z., Lin, J.N., Li, J., 2021. Microplastic constituent identification from admixtures by Fourier-transform infrared (FTIR) spectroscopy: the use of polyethylene terephthalate (PET), polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC) and nylon (NY) as the model constituent. Environ. Technol. Innovat. 23, 101798 https://doi.org/10.1016/j.eti.2021.101798.
Gao, P., Ju, C., Tang, Z., Qin, Y., 2022. Enhanced adsorption of tetracycline on polypropylene and polyethylene microplastics after anaerobically microbial-mediated aging process. J. Hazard. Mater. Adv. 6, 100075 https://doi.org/10.1016/J.HAZADV.2022.100075.
GESAMP, 2019. Guidelines for the Monitoring and Assessment of Plastic Litter and Microplastics in the Ocean. https://doi.org/10.25607/OBP-435. London, UK.
Green, D.S., 2016. Effects of microplastics on European flat oysters, Ostrea edulis and their associated benthic communities. Environ. Pollut. 216, 95–103. https://doi.org/10.1016/j.envpol.2016.05.043.
He, B., Goonetilleke, A., Ayoko, G.A., Rintoul, L., 2020. Abundance, distribution patterns, and identification of microplastics in Brisbane River sediments, Australia. Sci. Total Environ. 700, 134467 https://doi.org/10.1016/j.scitotenv.2019.134467.
Hidalgo-Ruz, V., Gutow, L., Thompson, R.C., Thiel, M., 2012. Microplastics in the marine environment: a review of the methods used for identification and quantification. Environ. Sci. Technol. 46, 3060–3075. https://doi.org/10.1021/es2031505.
Horton, A.A., Walton, A., Spurgeon, D.J., Lahive, E., Svendsen, C., 2017. Microplastics in freshwater and terrestrial environments: evaluating the current understanding to identify the knowledge gaps and future research priorities. Sci. Total Environ. https://doi.org/10.1016/j.scitotenv.2017.01.190.
Huang, D., Li, X., Ouyang, Z., Zhao, X., Wu, R., Zhang, C., Lin, C., Li, Y., Guo, X., 2021. The occurrence and abundance of microplastics in surface water and sediment of the West River downstream , in the south of China. Sci. Total Environ. 756, 143857 https://doi.org/10.1016/j.scitotenv.2020.143857.
Huerta Lwanga, E., Gertsen, H., Gooren, H., Peters, P., Salánki, T., Van Der Ploeg, M., Besseling, E., Koelmans, A.A., Geissen, V., 2016. Microplastics in the terrestrial ecosystem: implications for lumbricus terrestris (Oligochaeta, lumbricidae). Environ. Sci. Technol. 50, 2685–2691. https://doi.org/10.1021/ACS.EST.5B05478/ASSET/IMAGES/LARGE/ES-2015-05478X_0004 (JPEG).
Jiang, C., Yin, L., Wen, X., Du, C., Wu, L., Long, Y., Liu, Y., Ma, Y., Yin, Q., Zhou, Z., Pan, H., 2018. Microplastics in sediment and surface water of West Dongting lake and south dongting lake: abundance, source and composition. Int. J. Environ. Res. Publ. Health 15, 2164. https://doi.org/10.3390/IJERPH15102164, 2018.
Kukkola, A., Krause, S., Lynch, I., Sambrook Smith, G.H., Nel, H., 2021. Nano and microplastic interactions with freshwater biota – current knowledge, challenges and future solutions. Environ. Int. 152, 106504 https://doi.org/10.1016/J.ENVINT.2021.106504.
Li, J., Liu, H., Paul Chen, J., 2018. Microplastics in freshwater systems: a review on occurrence, environmental effects, and methods for microplastics detection. Water Res. 137, 362–374. https://doi.org/10.1016/J.WATRES.2017.12.056.
Lin, X.H., Li, J.P., Hu, X., 2020. Current situation and health harmful effects of microplastics in the environment. Zhonghua Lao Dong Wei Sheng Zhi Ye Bing Za Zhi 38, 153–156. https://doi.org/10.3760/cma.j.issn.1001-9391.2020.02.019.
Liu, S., Jian, M., Zhou, L., Li, W., 2019. Distribution and characteristics of microplastics in the sediments of Poyang Lake, China. Water Sci. Technol. 79, 1868–1877. https://doi.org/10.2166/WST.2019.185.
Ma, P., Wang, mu W., Liu, H., Chen, yu F., Xia, J., 2019. Research on ecotoxicology of microplastics on freshwater aquatic organisms. Environ. Pollut. Bioavailab. 31, 131–137. https://doi.org/10.1080/26395940.2019.1580151.
Maes, T., Jessop, R., Wellner, N., Haupt, K., Mayes, A.G., 2017. A rapid-screening approach to detect and quantify microplastics based on fluorescent tagging with Nile Red. Sci. Rep. 71 7, 1–10. https://doi.org/10.1038/srep44501, 2017.
Maheswaran, B., Karmegam, N., Al-Ansari, M., Subbaiya, R., Al-Humaid, L., Sebastin Raj, J., Govarthanan, M., 2022. Assessment, characterization, and quantification of microplastics from river sediments. Chemosphere 298, 134268. https://doi.org/10.1016/j.chemosphere.2022.134268.
Mani, T., Hauk, A., Walter, U., Burkhardt-Holm, P., 2015. Microplastics profile along the rhine river. Sci. Rep. 51 5, 1–7. https://doi.org/10.1038/srep17988, 2015.
Masura, J., Baker, J., Foster, G., Arthur, C., Herring, C., 2015. Laboratory Methods for the Analysis of Microplastics in the Marine Environment: Recommendations for Quantifying Synthetic Particles in Waters and Sediments. Marine Debris Program, Noaa.
Migwi, F.K., Ogunah, J.A., Kiratu, J.M., 2020. Occurrence and spatial distribution of microplastics in the surface waters of lake Naivasha, Kenya. Environ. Toxicol. Chem. 39, 765–774. https://doi.org/10.1002/ETC.4677.
Nel, H.A., Dalu, T., Wasserman, R.J., 2018. Sinks and sources: assessing microplastic abundance in river sediment and deposit feeders in an Austral temperate urban river system. Sci. Total Environ. 612, 950–956. https://doi.org/10.1016/J.SCITOTENV.2017.08.298.
Ory, N.C., Sobral, P., Ferreira, J.L., Thiel, M., 2017. Amberstripe scad Decapterus muroadsi (Carangidae) fish ingest blue microplastics resembling their copepod prey along the coast of Rapa Nui (Easter Island) in the South Pacific subtropical gyre. Sci. Total Environ. 586, 430–437. https://doi.org/10.1016/J.SCITOTENV.2017.01.175.
Peng, G., Xu, P., Zhu, B., Bai, M., Li, D., 2018. Microplastics in freshwater river sediments in Shanghai, China: a case study of risk assessment in mega-cities. Environ. Pollut. 234, 448–456. https://doi.org/10.1016/J.ENVPOL.2017.11.034.
Pereao, O., Opeolu, B., Fatoki, O., 2020. Microplastics in aquatic environment: characterization, ecotoxicological effect, implications for ecosystems and developments in South Africa. Environ. Sci. Pollut. Res. 27, 22271–22291. https://doi.org/10.1007/s11356-020-08688-2.
Priya, A.K., Jalil, A.A., Dutta, K., Rajendran, S., Vasseghian, Y., Qin, J., Soto-Moscoso, M., 2022. Microplastics in the environment: recent developments in characteristic, occurrence, identification and ecological risk. Chemosphere 298, 134161. https://doi.org/10.1016/J.CHEMOSPHERE.2022.134161.
Quinn, B., Murphy, F., Ewins, C., 2017. Validation of density separation for the rapid recovery of microplastics from sediment. Anal. Methods 9, 1491–1498. https://doi.org/10.1039/c6ay02542k.
Rodrigues, M.O., Abrantes, N., Gonçalves, F.J.M., Nogueira, H., Marques, J.C., Gonçalves, A.M.M., 2018. Spatial and temporal distribution of microplastics in water and sediments of a freshwater system (Antuã River, Portugal). Sci. Total Environ. 633, 1549–1559. https://doi.org/10.1016/J.SCITOTENV.2018.03.233.
Silva, M.S.S., Oliveira, M., Valente, P., Figueira, E., Martins, M., Pires, A., 2020. Behavior and biochemical responses of the polychaeta Hediste diversicolor to polystyrene nanoplastics. Sci. Total Environ. 707, 134434 https://doi.org/10.1016/j.scitotenv.2019.134434.
Sorolla-Rosario, D., Llorca-Porcel, J., Pérez-Martínez, M., Lozano-Castelló, D., Bueno-López, A., 2022. Study of microplastics with semicrystalline and amorphous structure identification by TGA and DSC. J. Environ. Chem. Eng. 10 https://doi.org/10.1016/j.jece.2021.106886.
Talbot, R., Granek, E., Chang, H., Wood, R., Brander, S., 2022. Spatial and temporal variations of microplastic concentrations in Portland's freshwater ecosystems. Sci. Total Environ. 833, 155143 https://doi.org/10.1016/J.SCITOTENV.2022.155143.
Udebuani, A.C., Pereao, O., Akharame, M.O., Fatoki, O.S., Opeolu, B.O., 2021. Acute toxicity of piggery effluent and veterinary pharmaceutical cocktail on freshwater organisms. Environ. Monit. Assess. 193, 293. https://doi.org/10.1007/s10661-021-09085-z.
Wagner, M., Lambert, S., 2018. Freshwater Microplastics - the Handbook of Environmental Chemistry, vol. 58, p. 302. https://doi.org/10.1007/978-3-319-61615-5.
Wang, W., Ndungu, A.W., Li, Z., Wang, J., 2017. Microplastics pollution in inland freshwaters of China: a case study in urban surface waters of Wuhan, China. Sci. Total Environ. 575, 1369–1374. https://doi.org/10.1016/j.scitotenv.2016.09.213.
Weideman, E.A., Perold, V., Arnold, G., Ryan, P.G., 2020. Quantifying changes in litter loads in urban stormwater run-off from Cape Town, South Africa, over the last two decades. Sci. Total Environ. 724 https://doi.org/10.1016/j.scitotenv.2020.138310.
Weideman, E.A., Perold, V., Ryan, P.G., 2019. Little evidence that dams in the Orange–Vaal River system trap floating microplastics or microfibres. Mar. Pollut. Bull. 149 https://doi.org/10.1016/j.marpolbul.2019.110664.
Willis, K.A., Eriksen, R., Wilcox, C., Hardesty, B.D., 2017. Microplastic distribution at different sediment depths in an urban estuary. Front. Mar. Sci. 4, 419. https://doi.org/10.3389/FMARS.2017.00419/BIBTEX.
Xia, F., Yao, Q., Zhang, J., Wang, D., 2021. Effects of seasonal variation and resuspension on microplastics in river sediments. Environ. Pollut. 286, 117403 https://doi.org/10.1016/j.envpol.2021.117403.
Xu, Z., Bai, X., Ye, Z., 2021. Removal and generation of microplastics in wastewater treatment plants: a review. J. Clean. Prod. 291, 125982 https://doi.org/10.1016/j.jclepro.2021.125982.
Yin, L., Wen, X., Huang, D., Zhou, Z., Xiao, R., Du, L., Su, H., Wang, K., Tian, Q., Tang, Z., Gao, L., 2022. Abundance, characteristics, and distribution of microplastics in the Xiangjiang river, China. Gondwana Res. 107, 123–133. https://doi.org/10.1016/j.gr.2022.01.019.
Yuan, W., Christie-Oleza, J.A., Xu, E.G., Li, J., Zhang, H., Wang, W., Lin, L., Zhang, W., Yang, Y., 2022a. Environmental fate of microplastics in the world's third-largest river: basin-wide investigation and microplastic community analysis. Water Res. 210, 118002 https://doi.org/10.1016/J.WATRES.2021.118002.

Yuan, Z., Nag, R., Cummins, E., 2022b. Human health concerns regarding microplastics in the aquatic environment - from marine to food systems. Sci. Total Environ. 823, 153730 https://doi.org/10.1016/J.SCITOTENV.2022.153730.

Zhang, L., Xie, Y., Zhong, S., Liu, J., Qin, Y., Gao, P., 2021. Microplastics in freshwater and wild fishes from lijiang River in Guangxi, southwest China. Sci. Total Environ. 755, 142428 https://doi.org/10.1016/J.SCITOTENV.2020.142428.

Zhang, W., Zhang, S., Wang, J., Wang, Y., Mu, J., Wang, P., Lin, X., Ma, D., 2017. Microplastic pollution in the surface waters of the Bohai Sea, China. Environ. Pollut. 231, 541–548. https://doi.org/10.1016/J.ENVPOL.2017.08.058.

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. Expo. Heal. 12, 141–151. https://doi.org/10.1007/S12403-018-00296-3/FIGURES/6.

Zhou, Y., He, G., Jiang, X., Yao, L., Ouyang, L., Liu, X., Liu, W., Liu, Y., 2021. Microplastic contamination is ubiquitous in riparian soils and strongly related to elevation, precipitation and population density. J. Hazard Mater. 411, 125178 https://doi.org/10.1016/J.JHAZMAT.2021.125178.