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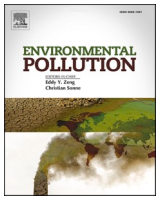



Assessing microplastic characteristics and abundance in the sediment and surface water of the Diep River, Western Cape, South Africa☆

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ABSTRACT

Rivers play a vital role in the water cycle and serve as habitats for numerous species and potentially contributing to microplastic pollution in the ocean. The Diep River is an important habitat for numerous species bordered by various ecological zones. However, it also presents a risk and pathway for microplastic pollution that can enter the ocean. This study investigated variations in microplastics particle concentrations in water and sediment samples from five locations in the Diep River. Water samples (100 L) were screened onsite using a 250 μm mesh, while an additional 20 L of water samples were filtered through a 20 μm mesh in the laboratory. Additionally, 20 g of sediment samples were collected for analysis at a depth of 5–10 cm from each site and characterised with a combination of visual and FTIR techniques. Fibres were found to be the most dominant shape at all the sites, DR-1 (95.80 %); DR-2 (88.2 %); DR-3 (75.0 %); DR-4 (72.0 %); and DR-5 (93.1 %). The black/grey (47 %) colour and 500–2000 μm (66 %) size categories were the most prevalent for all sites. FTIR analysis showed that polyethylene (52 %) and polystyrene (20 %) were the most abundant polymer types. The microplastic burden was higher in tourist and recreational areas than non-tourist areas. The MP Pollution Load Index (PLI) in the Diep River showed moderate contamination for all sites except DR 2, which has no water flow and therefore no values in autumn. This study offers new insights into microplastic contamination in South Africa's surface water.

1. Introduction

Water pollution is a significant global crisis that harms the environment and adversely affects living organisms and ecosystems. Human activities are recognized as the primary cause of poor water quality around the world, significantly impacting aquatic environments (Ighalo et al., 2021; Patidar et al., 2024). Water availability and quality are part of the most complicated issues of the 21st century due to urbanisation, population growth, drought, flooding, conflicts, and pollution (Dąbrowska et al., 2023). Population growth matches the added pressure on the environment, including waste, and water often serves as a basin for pollution, especially plastic pollution.

Plastics are highly versatile materials that can be used in many different applications including construction, healthcare, packaging, and electronics. They are discarded daily, leading to significant accumulation in the environment (Hofmann et al., 2023). This diverse use of plastics results in increased demand for plastic, which eventually ends up in the aquatic ecosystems (Zhao et al., 2024b), especially in places where they do not originate. Plastics enter freshwater systems from multiple sources and through various pathways, and through large number of plastic materials which are released into the environment which are not systematically contained but transferred between different environmental compartments (Miloloža et al., 2021). Plastic pollution represents an urgent environmental challenge due to its slow degradation and persistent presence in nature. Plastics break down into microscopic particles known as microplastics (MPs), synthetic polymers less than 5 mm in size (Pereao et al., 2020).

Microplastics' small size and large specific surface area make them easily accessible to aquatic organisms and can be ingested by various microorganisms. This ingestion can lead to the accumulation of MPs in marine food webs and organisms (Mia et al., 2024). Because of their strong hydrophobic properties, MP can readily adhere to pollutants (Wang et al., 2021) and consequently, they may act as carriers for harmful chemicals from those used in plastic manufacturing, and from

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other contaminants in the surrounding water (Pereao et al., 2020). They can magnify through the food chain, posing serious health risks to top predators, including humans (Jiang et al., 2018). Freshwater bodies serve multiple roles: they transport MPs from terrestrial to marine environments, act as repositories that hold MPs in sediment, and facilitate the formation of MPs through the breakdown of plastics in the water (Horton and Dixon, 2018). Given that these freshwater resources can accumulate numerous MP particles, it is crucial for environmental scientists, and researchers to intensify monitoring efforts to track MPs in freshwater bodies (Li et al., 2018).

South Africa is a water-scarce country (Oki and Quiocho, 2020), therefore, water resources must be preserved and protected from pollution, especially emerging MP pollution. South Africa's rich biodiversity may be at serious risk due to the pervasive threat of increasing microplastic pollution, which endangers its vital ecosystems and wildlife, making South African MP research very important (Naidoo and Rajkaran, 2020). The existing data on MP in South African aquatic environments is notably limited; however, efforts to enhance this knowledge are growing and showing promising developments (Dahms and Greenfield, 2024). The Orange-Vaal River (Saad et al., 2022), Mvudi River (Dalu et al., 2021), Crocodile River (Nkosi et al., 2023), and Plankenberg River (Apetogbor et al., 2023) are some of the major rivers that have been studied for microplastic pollution in South Africa.

This research aims to provide empirical data on the microplastic pollution status of the Diep River in South Africa and to enhance the understanding of microplastic pollution research in the country. The primary objectives of the study are to quantify and characterize the microplastic particles found in the surface water and sediments of the Diep River. The approach includes assessing the physico-chemical parameters of the river, examining the occurrence and distribution of MPs, and conducting a risk assessment related to their presence. The findings of this research provide more understanding about MP sources and transport, ultimately enhancing South Africa's effective microplastic monitoring and analysis.

2. Materials and methods

2.1. Description of the study area

Different land use types surround the Diep River catchment and pass through various activities and potential pollution sources. Samples were collected twice per season based on the pollution sources to the river at 5 different point location on the Diep River pathway. The map of the sampling sites was created using Google Earth as presented in Fig. 1. The Diep River has a total area of approximately 1495 km^2. It is surrounded by industrial and agricultural areas, municipal and informal communities, a wastewater treatment facility and four main towns border the Diep River catchment: Atlantis (West), Milnerton (South), Paarl (East), and Riebeek-West (North) (Gqomfa et al., 2022). The Geographic Information Systems (GIS) coordinates and descriptions of the sampling sites on the Diep River are presented in Table S1. Site 1 (DR-1) was located near farming areas and directly across from the Dunoon informal settlement. Site 2 (DR-2) was situated within the protected boundaries of the Table Bay Nature Reserve. Site 3 (DR-3) was positioned along a channel in a vibrant recreational area, providing direct access to the river. Site 4 (DR-4) was situated near a wastewater treatment plant in a



Fig. 1. Sampling sites on the Diep River (Google Earth).

mixed-use area that included both recreational and residential zones. Site 5 (DR-5) was about 1 km away from the popular Woodbridge Lagoon, a popular destination for recreational activities and closest to the ocean.

2.2. Freshwater sampling

Two procedures were used for the collection of water samples per site. First, a 100 L water sample was collected and filtered in five replicates of 20 L at each site via a 250 μm stainless steel sieve. In contrast, another 20 L metal bucket of water samples was collected per site and conveyed to the Microplastic Laboratory, Cape Peninsula University of Technology and filtered through a 20 μm mesh in replicates of 5 x 4 L. The 20 μm mesh was included to improve filtration process performance and to capture lower-sized MP (Cai et al., 2020; Ryan et al., 2020). The bucket was immersed 20 cm deep beneath the water and against the direction of water flow. The remaining particles from the 100 L were placed in a Falcon tube kept in a cooler box and transported to the Microplastic Laboratory for examination. The stainless-steel sieve and metal bucket were carefully cleaned to minimise cross-contamination using reverse osmosis (RO) filtered water. In situ measurements of temperature (°C), redox potential (ORP), dissolved oxygen (DO), total dissolved solids (TDS), pH, and electrical conductivity (EC) were conducted at each sampling site with the use of the multi-parameter device (SensoDirect 150, Lovibond and Tintometer, Germany). Additionally, physicochemical parameters such as chemical oxygen demand (COD) and biochemical oxygen demand (BOD) were analyzed in the laboratory. Samples were collected in September and November 2020 (spring), February 2021 (summer), March and May 2021 (autumn) and August 2021 (winter) and a total of 187 water samples were collected and processed from the Diep River.

2.3. Sediment sampling

At each sampling site along the Diep River, riverbed sediment samples were collected using a metal scoop at a depth of approximately 5–10 cm. Five replicates, each weighing 20 g, were obtained from each location. The sediment samples were placed into sealed pre-cleaned ziplock bags, stored in a cooler, and then transported to the laboratory for further analysis. In the laboratory, the wet samples were transferred to aluminium trays and covered with aluminium foil to prevent any contamination. They were then placed in an oven (model DHG 9070A) at 50 °C for 24 h to air-dry prior to further examination. In total, eighty-five sediment samples were collected from the river.

2.4. Microplastic extraction

The water samples underwent treatments to separate the microplastic particles, as Apetogbor et al. (2023) described. MPs from the 20 L sample were extracted by filtration via a 20 μm mesh using a vacuum pump system. The sample remains from the filtration through the 250 μm stainless-steel sieve processed onsite and previously stored was placed into 500 ml glass beakers with a 10 % Potassium hydroxide solution (KOH) in a ratio of 2:1 and covered with aluminium foil and placed in the oven an optimal temperature of 50 °C for 24 h. A Hypersaline solution (360 $g{\cdot}\ell^{-1}$of NaCl) was added to the digested sample, mixed briskly by stirring with a metal spoon for 2–3 min, set aside for 15 min to settle down, and the supernatant filtered with a vacuum pump set-up via a 20 μm mesh. For the separation, a suspension was created with salt solution isolation, to create two clear phases of upper and lower layers for the mixture when shaken together vigorously, and the MPs particles could be regained from the supernatant (Sadia et al., 2022). The microplastic extraction procedure was repeated thrice per sample and thereafter, mesh sieves were transferred into pre-cleaned sterile petri dishes to be further examined. Microplastic extraction from sediment samples were performed using the density fractionation method described by Sparks et al. (2021) with slight modifications. Sediment samples were dried thoroughly in the oven at 50 °C for 48–72 h and 20 g of dry sediment were weighed (Inoue et al., 2024) and transferred into a glass jar, thereafter, before adding 10 % KOH in a ratio of 2:1 and placed in the oven set to 50 °C for 24 h. A 360 $g{\cdot}\ell^{-1}$ super saturated NaCl solution was combined with the digested samples and subsequently stirred for 3 min with a cleansed stainless-steel spoon, covered with aluminium foil to prevent air-borne contamination and set aside for 30 min for settling. The supernatant formed from the solution was filtered through a 20 μm nylon mesh sieve that was cleaned using RO water with a 10 μm filter and repeated thrice per sample. Thereafter, the mesh sieves were added to sterile petri dishes for additional examination.

2.5. Method development and recovery studies

To reduce water volume, samples were sieved through two mesh sizes (20 and 250 μm). Investigations on recovery efficiency and potential effects of microplastic methodologies, using different virgin polymers of different size ranges of 1000–2000 μm. Recovery rates were estimated as:

$$= \frac{Final\ number\ of\ particles}{Initial\ number\ of\ partcles} \quad x\,100$$

Results indicated no significant change in the polymer structural integrity and recovery efficiency using a 20 μm mesh size, achieving recovery rates of 95 ± 4 %.

2.6. Microplastic morphological and chemical characterisation

The dried-up mesh sieves that were in sterilised petri dishes were carefully analyzed for microplastics in terms of physical characteristics under a Stereo microscope (BestScope, China, BS-3060CT) attached to a BHC3E-1080P HDMI BestScope Digital Camera. Microplastic particles were categorized based on their morphological features, including size, shape, and color. The sizes were classified into four categories: C4 (less than 500 μm), C3 (500–2000 μm), C2 (2000–5000 μm), and C1 (greater than 5000 μm). Similarly, the colors of the MPs were divided into six categories: white, transparent, yellow/brown, red/pink, blue/green, and black/grey. The different shapes include fibre, fragment, foam, pellet, and film based on the method (GESAMP, 2019). The microplastic abundance and mass were documented as MP/L and MP/kg dry sediment. Microplastic particles greater than 500 μm were randomly selected for analysis using a PerkinElmer FT-IR Spectrometer Spectrum Two system with Attenuated Total Reflection (ATR) mode to identify suspected microplastic particle polymer types, and the chemical composition was compared with the ST Japan Library and a Perkin spectral library provided by PerkinElmer with a 70 % minimum match value (Peng et al., 2018). Spectral wave numbers were set to range from 4000 to 450 cm^{-1}, resolution set at 4 cm^{-1}, data interval set to 1 cm^{-1} and scans set to 10. Background scans were done before starting scans and the ATR crystal cleaned with propanol between scans. FTIR-ATR analysis was conducted for 10 % of MP particles larger than 500 μm due to handling difficulties, and non-microplastics were excluded from the statistics on size, shape and colour of particles.

2.7. Microplastic contamination factor and pollution load index

Microplastic river pollution load indices (MPPLI) and contamination factors (MPCfs) were projected as defined in prior studies (Kabir et al., 2021). The MPCf applies to the MPs contamination in the examined river relative to background standards. The Microplastic Pollution Load Index (MPPLI) is a crucial indicator in our study, calculated by taking the nth root of the sum of the microplastic pollution load indices and multiplying it accordingly. This structured approach allows for a clearer understanding of the impacts of microplastic pollution. This method is essential for assessing the severity of microplastic pollution. The

microplastic contamination factors (MPCfs) are categorized into risk levels, as outlined by Kabir et al. (2021) and Verla et al. (2019). According to this classification.

- MPCf <1 indicates minimal contamination
- 1 ≤ MPCf ≤3 indicates moderate contamination
- 3 ≤ MPCf ≤6 indicates significant contamination
- MPCf ≥6 indicates extremely high contamination

For the MPPLI, the levels of microplastic pollution are defined as follows.

- MPPLI <1 indicates low pollution
- 1 < MPPLI <3 indicates moderate pollution
- 3 < MPPLI <4 indicates high pollution
- 4 < MPPLI <5 indicates very high pollution
- MPPLI >5 indicates dangerous pollution

Equations (1) and (2) were used to perform the mathematical computation of the MPCf and MPPLI. MPb is the minimal baseline concentration derived from the lowest MPs abundance documented in the literature. MPi is the number of MPs in site I (Mason et al., 2018), which shares comparable settings and analytical frameworks as this research. Due to the analytical context of this study and the lack of background data in similar settings, the lowest MP abundance identified in this investigation was taken as the baseline concentration.

$$MPCf = MPi / MPb \quad (1)$$

$$MPPLI_{River} = (MPCf1 \times MPCf2 \times MPCf3 \ldots\ldots MPCfn)\ 1/n \quad (2)$$

2.8. Quality assurance and quality control

Throughout the process, cotton laboratory coats were worn with nitrile gloves. Filters and solutions used were covered with aluminium foil to prevent contamination. A 10 μm mesh was used to filter reverse osmosis (RO) water, saturated sodium chloride (NaCl) solution, and potassium hydroxide (KOH) using a vacuum pump. Before and after use, all microplastic equipment were carefully rinsed with filtered RO water, and wherever possible, plastic equipment was replaced with non-plastic alternatives. A control sample was always maintained in the laboratory, and blank control experiments were conducted to account for any potential contamination from materials used. A clean Petri dish was left open with a clean 20 μm mesh and microplastics discovered on the control petri dishes were recorded and subtracted from the final counts of identified MPs, ensuring the reliability of the results.

2.9. Statistical analysis of experimental data

IBM SPSS Statistics v 25 was used for the statistical analysis. Prior statistical analysis data were tested by applying Levene's test for variance and the Kolmogorov-Smirnov test for normality. The relationship between the abundance of MPs in sediment and water samples was examined using the Kruskal-Wallis test. Samples and variations among groups were concluded by the Mann–Whitney *U* test with a significance threshold of less than 0.05. The Kruskal–Wallis's Pairwise analysis was used to compare significant differences between sampling sites. Pearson's correlation coefficient (r) was computed between different parameters in order to determine the extent to which values of both parameters were linearly correlated with the physicochemical parameters.

3. Results and discussion

3.1. Microplastics spatio-temporal distribution in Diep River water samples

The average concentration of microplastics from the two extraction processes in water samples collected over four seasons is presented in Table 1. The samples with smaller and larger mesh sizes are referred to as 20 μm and 250 μm, respectively. Microplastics were detected in all water samples, with the exception of samples from site DR-2, which was located near the Table Bay Nature Reserve.

Higher mean microplastics concentrations per litre were found in Water20 and Water250 for DR-1 (5.1 and 0.54), DR-4 (4.88 and 1.16), and DR-5 (5.25 and 0.68) during spring. For DR-1, informal settlements often lack proper disposal systems and limited recycling and waste management, while farming practices contribute to microplastic pollution by disposing of plastic packaging from agricultural products (Matavos-Aramyan, 2024). The release of MPs from personal care products, the loss of microfibres during laundry from synthetic clothing, and the degradation of plastic items on beaches (Islam et al., 2024) contribute to MP pollution in DR-4 and DR-5.

The 20-μm mesh size was more effective at extracting MPs, capturing them by multiple orders of magnitude. This observation highlights the loss of MPs during onsite filtration when using larger mesh sizes. Anthropogenic activities near the sampling sites, as well as seasonal factors like rainfall and wind conditions, played a significant role in the distribution of MPs within the aquatic ecosystem, particularly in areas close to a wastewater treatment plant. No samples were collected at DR-1, DR-2, DR-3, and DR-4 during the summer because the surface water at DR-2 dried up in autumn and due to excessive vegetation growth in winter. This reflects the environmental factors that influence microplastic transport. Except for DR-3, the results show a similar trend to the study by Schell et al. (2021), where the spring season recorded the highest concentrations of microplastics.

3.2. Microplastics spatio-temporal dispersion in Diep River sediment samples

Microplastics were found in all sediment samples, except for one collected from site DR-2. The data for the sediment samples were converted to reflect the number of MP/Kg of sediment. Fig. 2 illustrates the abundance and distribution of MPs in the sediment samples collected during autumn, spring, summer, and winter. The results indicated that the sediment samples contained between 110 and 450 mean MP/Kg.

Microplastic concentrations varied by season, with abundances ranging from 180 to 340 MP/kg in autumn, 130 to 450 MP/kg in spring, 210 MP/kg in summer, and 110 to 170 MP/kg in winter. In spring, the sites DR-1 (310 ± 250), DR-4 (245 ± 170), and DR-5 (450 ± 150) recorded the highest MP concentrations across all seasons, except for DR-3, which had a concentration of 130 ± 60.

3.3. Morphological distribution of microplastic in the Diep River

3.3.1. Shape

The Diep River is impacted by microplastics originating from a variety of sources, including a wastewater treatment plant, informal settlements, human activities, and industrial and recreational operations. To categorize the types of microplastic particles, specific criteria were applied according to (GESAMP, 2019). Fig. 3a illustrates the percentage distribution of microplastic shapes found in water and sediment samples collected from various sites. The highest concentration of MPs was observed at site DR-3, which is located near recreational, industrial and commercial activities. Site DR-4, situated close to a wastewater treatment plant, also showed a significant presence of microplastics.

Fig. 3a shows that DR-3 had the highest number of fragment proportion at 16.3 % compared to all other sites, indicating that the

Table 1
Microplastics prevalence and dispersion in the Diep River water samples (mean microplastic per litre ± SD).

Season								
Site	Autumn		Spring		Summer		Winter	
	Water20	Water250	Water20	Water250	Water20	Water250	Water20	Water250
DR1	1.6 ± 0.29	0.23 ± 0.11	5.1 ± 2.20	0.54 ± 0.19	–	–	2.44 ± 0.83	0.19 ± 0.10
DR2	–	–	1.25 ± 0.99	0.61 ± 0.32	–	–	–	–
DR3	2.5 ± 0.59	0.52 ± 0.28	1.42 ± 0.52	0.53 ± 0.22	–	–	2.2 ± 0.78	0.46 ± 0.17
DR4	3.3 ± 0.96	0.44 ± 0.22	4.88 ± 3.99	1.16 ± 0.66	–	–	3.2 ± 1.16	0.92 ± 0.31
DR5	2.55 ± 1.11	0.59 ± 0.24	5.25 ± 2.27	0.68 ± 0.31	1.95 ± 0.74	0.24 ± 0.08	2.15 ± 1.10	0.28 ± 0.12

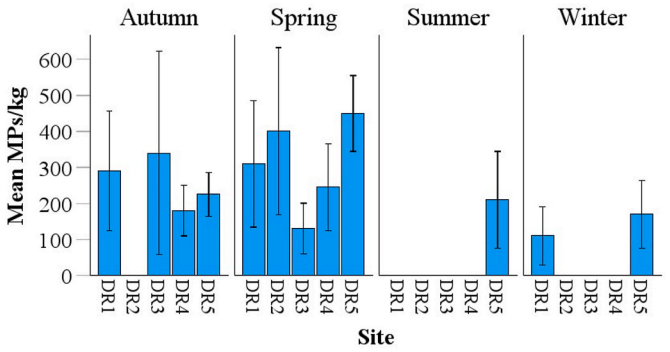

Fig. 2. Microplastics prevalence and dispersion in the Diep River sediment samples over 4 seasons.

combination of nearby activities may be a contributing factor. The predominant shape found across all sites was fibers, which comprised 95.80 % in DR-1, 88.2 % in DR-2, 75.0 % in DR-3, 72.0 % in DR-4, and 93.1 % in DR-5. Microplastic shapes like fragments and fibres accumulate and disperse more widely than others, impacting MP transport patterns and affecting how rapidly they settle out of water and air (Ward et al., 2024).

There were four sites examined, DR-1 (3.19 %), DR-2 (6.64 %), DR-3 (16.3 %), and DR-5 (3.57 %) that recorded fragments as the second most abundant shape types while only one site, DR-4 (13.2 %), recorded foam as the second most abundant MP type followed by fragments. Among all study sites, DR-4, near the wastewater treatment plant and along an industrial and recreational area, recorded the highest percentage of foam (13.20 %). This study is consistent with previous research indicating that fibers are the most dominant type of microplastic particles in freshwater ecosystems (Ghayebzadeh et al., 2021; Jiang et al., 2019; Strady et al., 2021).

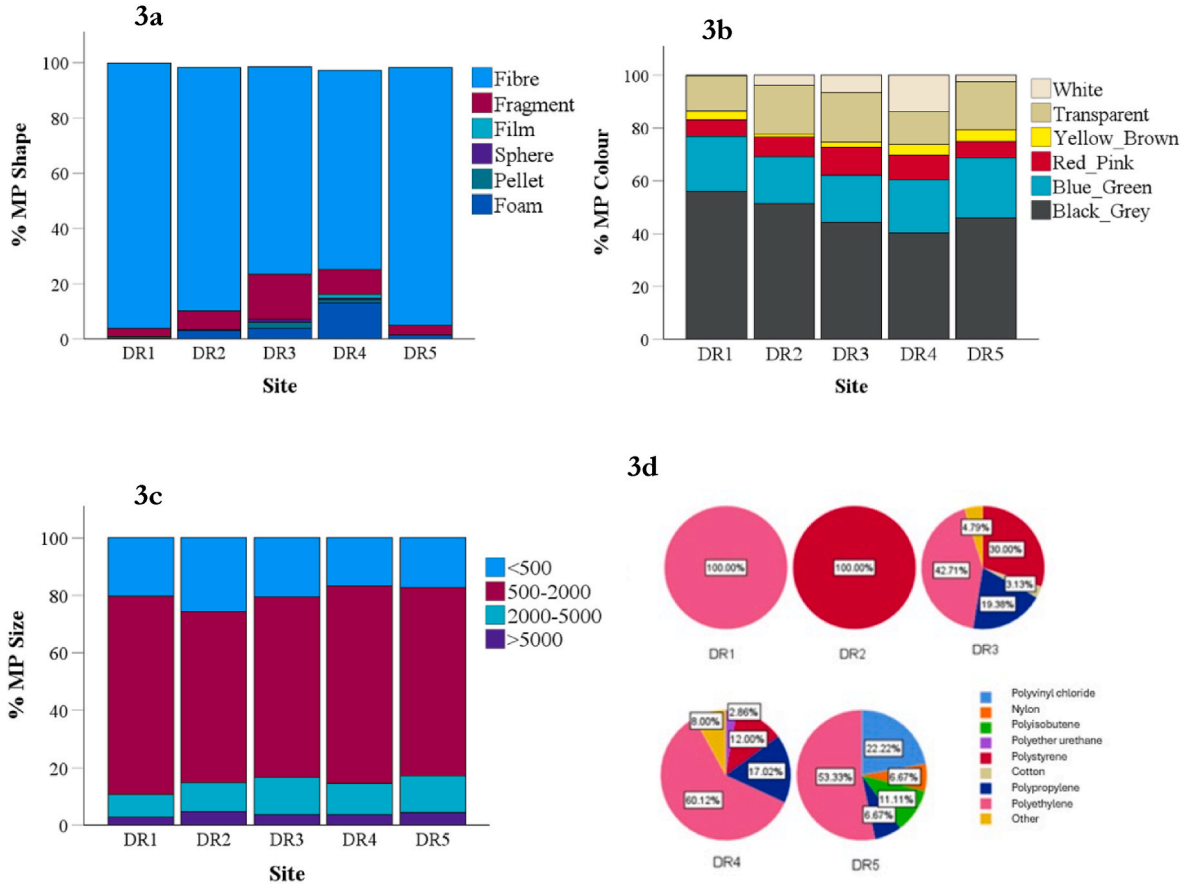

Fig. 3. MP Percentage distribution in water and sediment samples (a) shape, (b) colour, (c) size and (d) polymer types. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

3.3.2. Color

Fig. 3b illustrates the percentage distribution of microplastic colors across different sites along the Diep River. The black/grey category was the most prevalent in all sites: DR-1 (55.9 %), DR-2 (51.5 %), DR-3 (44.2 %), DR-4 (40.1 %), and DR-5 (46.0 %). The blue/green category was the second most abundant at DR-1 (20.9 %), DR-4 (20.2 %), and DR-5 (22.6 %). In contrast, the second most common color in DR-2 (18.6 %) and DR-3 (18.9 %) was transparent microplastics. White MPs were the least common, appearing at only 0.26 % in DR-1 and 2.50 % in DR-5. Yellow/brown MPs were least prevalent in DR-2 (1.17 %), DR-3 (1.81 %), and DR-4 (4.08 %). Black and white were following a similar pattern as fibres in color distribution across the different sites. Microplastics were found at all sites, likely due to their proximity to a wastewater treatment plant, a nature reserve, and an informal settlement, as well as being surrounded by residential, commercial, recreational, industrial, and agricultural zones. This suggests that anthropogenic activities contribute to the greater diversity of microplastic colors found in these areas (Edo et al., 2020). Fig. S1 displays selected images of MPs collected from various study sites.

3.3.3. Size

The percentage distribution of MP sizes in water and sediment samples is illustrated in Fig. 3c. The data reveals a trend among the sites regarding the most and least abundant MP sizes. The highest occurrence of MPs was found in the size category of 500–2000 μm, while the lowest was in the categories ≥5000 μm. Specifically, the percentages for each site were as follows: DR-1 (68.9 % for 500–2000 μm and 2.87 % for ≥5000 μm), DR-2 (59.6 % and 4.58 %), DR-3 (62.8 % and 3.71 %), DR-4 (68.8 % and 3.50 %), and DR-5 (65.6 % and 4.55 %). MPs measuring ≤500 μm occurred with the second highest frequency, while those in the range of 2000–5000 μm were the second least common. This study depicted a higher proportion of small-sized particle which may likely be due to the degradation of larger plastic debris into numerous smaller particles (Wang et al., 2017; Zhang et al., 2015).

3.4. Chemical properties of microplastics

Different types of polymers were identified, including polyvinyl chloride, nylon, polyisobutene, polyether urethane, polystyrene, polypropylene, polyethylene and the percentage distribution of these polymers is illustrated in Fig. 3d. The fiber polymers were primarily composed of polyamide bonds (nylon). The samples analyzed under FTIR in DR-1 consisted entirely of polyethylene polymers. In DR-2, all detected samples were polystyrene polymers. For DR-3, FTIR analysis indicated that polyethylene (42.7 %) was the most abundant polymer, followed by polystyrene (30.0 %), polypropylene (19.4 %), cotton (3.13 %), and other materials (4.79 %). In DR-4, the most prevalent polymer found was polyethylene (60.1 %), accompanied by polypropylene (17.0 %), polystyrene (12.0 %), polyether urethane (2.86 %), and other substances (8.00 %). Finally, the five polymers reported in DR-5 included polyethylene (53.3 %), polyvinyl chloride (22.2 %), polyisobutene (11.1 %), fiber (6.67 %), and polypropylene (6.67 %). Thus, there is greater variation in the types of polymers detected in the samples from DR-3, DR-4, and DR-5.

The polymers found at these sites are likely the result of human activities, particularly given that the surrounding areas include a wastewater treatment plant, as well as industrial and recreational zones. The channel at DR-3 feeds into this location and connects to the river, playing a role in the types of polymers detected at DR-4, in addition to the surrounding activities. In aquatic environments, polyethylene is commonly found in items like plastic bags and storage containers, which are known to float (Rossatto et al., 2023). These plastics are frequently used by humans, therefore, it is likely that anthropogenic activities are the primary cause of the various types of polymers identified at these sites, as plastic litter was observed nearby (see Fig. S2).

The findings of this study are consistent with prior research on MPs in rivers, which consistently identify polyethylene, polystyrene, and polypropylene as prevalent materials, highlighting a significant environmental concern (Mao et al., 2020). FTIR spectra for polymers (polypropylene, polyethylene, polystyrene and cotton) at different sites in the Diep River are presented in Fig. 4 and polystyrene (PS) characteristic spectra peaks were displayed at around 3030, 2915, 1601, 1494, 1448, 1028, 877, 757, 716, 695 and 538 cm^{-1}, cotton produced characteristic spectra peaks at 1543 and 989 cm^{-1}; while polypropylene (PP) displayed characteristic spectra peaks at 2958, 2920, 2840, 1454 and 1377 cm^{-1}; and polyethylene (PE) showed characteristic spectra peaks at 2914, 2864, 2847, 1470 and 717 cm^{-1}.

3.5. Physico-chemical properties correlation with microplastics

Surface water physicochemical and microplastic sampling was conducted at the exact location to relate the role of physicochemical and environmental factors in the behaviour and characteristics of MP. The Spearman correlation coefficients, illustrating the relationship between the physicochemical properties of water samples and the prevalence of MPs in the Diep River, are presented in Table 2.

The negative correlation between pH and sediments, MPs in 250 μm, and 20 μm samples indicates that pH may not be playing a role in degrading the plastics to MPs. Zhao et al. (2024a) suggested that the pH of water can alter the surface charges of microplastics, potentially leading to their further degradation. In addition, a strong positive correlation existed between MPs and key indicators like electrical conductivity (EC), temperature (temp), oxidation-reduction potential (ORP), and total dissolved solids (TDS). This suggests that microplastics are more likely to be affected by TDS, temp and EC which may exacerbate MP degradation. Furthermore, anthropogenic activities and wastewater discharges contribute to elevated EC levels, intensifying these ecological challenges (Gqomfa et al., 2022). Microplastic

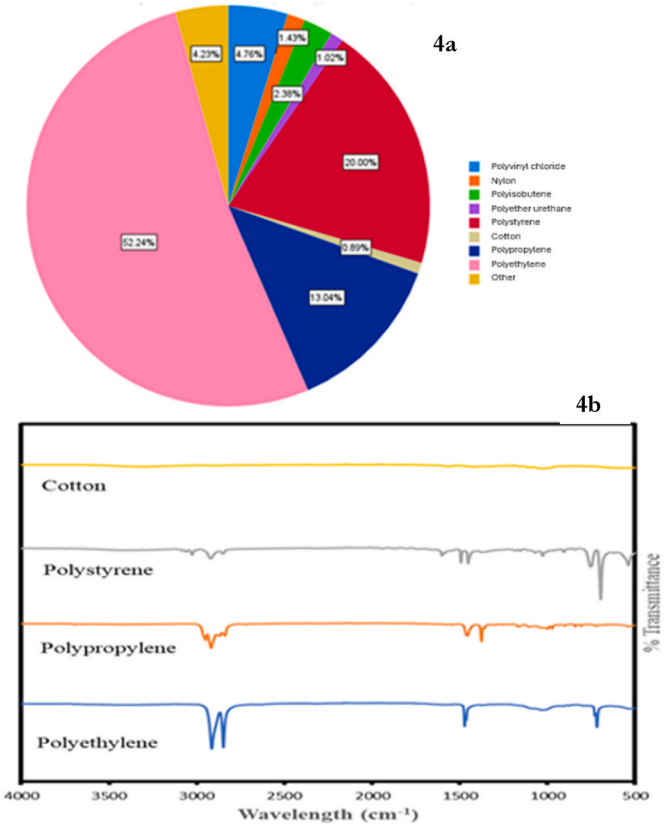

Fig. 4. (a) Percentage distribution of polymer types and (b) FTIR spectra of the different microplastics found at the Diep River.

Table 2
Spearman's correlation coefficient analysis of the physicochemical parameters and the occurrences of microplastics in the Diep River.

	pH	DO (mg/L)	EC (mS/m)	Temp (°C)	ORP (mV)	TDS (ppm)	COD	BOD	Water250	Water20	Sediment
pH	–										
DO (mg/L)	0.032	–									
EC (mS/m)	−0.011	−0.158	–								
Temp (°C)	−0.19	0.303	0.337	–							
ORP (mV)	−0.381	0.243	−0.221	0.266	–						
TDS (ppm)	−0.096	0.325	0.045	0.298	0.278	–					
COD (mg/L)	0.411	0.054	0.478[a]	−0.174	−0.348	0.044	–				
BOD (mg/L)	0.047	−0.097	0.042	−0.231	−0.075	−0.277	0.388	–			
Water250	−0.374	−0.327	0.018	0.092	0.488[a]	0.207	−0.182	0.046	–		
Water20	−0.181	0.042	0.092	0.022	0.129	0.06	−0.012	−0.056	0.356	–	
Sediment	−0.037	−0.028	0.389	0.406	0.126	0.103	0.118	0.219	0.356	0.274	–

[a] Correlation is significant at the 0.05 level (2-tailed).

abundances were found to be significantly influenced by EC, and TDS, indicating that microplastics attract solid particles, and higher total solids and conductivity levels indicate high microplastic pollution (Eamrat et al., 2022). A study conducted in the Fengshan River in Taiwan demonstrated strong correlations between microplastics in water and sediment samples and COD (Kye et al., 2023), though there were negative correlations between COD and microplastics in water samples in this study, but positive correlations were shown with microplastics in sediment samples. Zhao et al. (2024a) reported that COD displayed negative correlations with granulated and fibrous particles and implied that microplastic occurrence may be limited in high COD waters.

Several other conditions can influence microplastic size; a study conducted by Bayo et al. (2020) reported a notable reduction in microplastic size detected at lower pH levels. Furthermore, microplastics exposed to acidified marine water revealed effects such as disaggregation, structural modifications and plastic dissolution, and even short-term exposure to acidic conditions can lead to structural damage (Piccardo et al., 2020). A significant positive correlation ($r = 0.488$) was found between oxidation-reduction potential (ORP) and samples collected with a 250 μm mesh. This suggests that larger microplastics are more likely to degrade in waters with high ORP. A higher ORP indicates that the substances in the water can oxidize compounds and break down waste. Meanwhile, both the 250 μm mesh microplastics and sediment samples showed a positive correlation with BOD.

3.6. Microplastic contamination factor and pollution load index

Pollution Load Index (PLI) can be used to assess the level of microplastic contamination in the ecosystem and determine the environmental impact they cause to flora and fauna (Amrutha et al., 2023). The PLI is not influenced by chemical composition but depends on microplastic abundance since significant accumulation levels can lead to significant hazards (Ebere et al., 2021). The PLI results indicated that all the sites and rivers were polluted with MPs (PLI >1) and suggested some level of pollution at all sites. On this basis, we identified pollution hotspots for different seasons, which posed high MP pollution risks in all the sites except for the summer season, which had a low CF index probably due to the limited information obtained during the summer sampling.

As shown in Table 3, most sites' CF indicated moderately contaminated, except for DR 2, which has no values for the autumn season. However, most sites were considerably contaminated for spring except DR 2 and DR 3 for 20 μm and DR 1 and DR 3 for 250 μm, which were moderately contaminated. Generally, the Diep River exhibited moderate contamination PLI except for DR 4, which was adjacent to a wastewater treatment facility and recreational/industrial area and indicated a high PLI. Risk-zone classification and hotspot identification may facilitate further environmental pollution monitoring and management. This study shows that a higher pollution load resulted from increased MP abundance, as the PLI primarily measures MP abundance (Kabir et al., 2021). Increased PLI readings, indicative of a greater MP abundance, imply a substantial rise in anthropogenic activity in the area (Amrutha et al., 2023). The findings in this study indicate that different sources contribute to microplastic pollution as shown by the trends observed in their relative morphological contributions per site. Generally, sites downstream the river showed increasing microplastic load similar to findings from Luo et al. (2019), while microplastic distribution in rivers varied in urban areas due to multiple sources and environmental influences. The complexity of urban ecosystems presents distinct challenges in understanding microplastic pollution (Zhao et al., 2024a).

4. Conclusion

The effects of microplastic pollution on aquatic ecosystems have amplified worldwide, but there are knowledge gaps in South Africa, particularly in freshwater environments. Visual characterisation and FTIR technologies were utilised to analyse the chemical composition of MPs derived from water and sediment samples collected from the Diep River. Microplastic physical analysis showed that fibres were the predominant shape found in all the sites, with black/grey being the most dominant colour, and were mostly within the size category of 500–2000 μm. FTIR analysis showed that polyethylene and polystyrene were the most abundant polymers detected. The microplastic load increased at downstream sites along the river, indicating that higher pollution thresholds (PLI) correspond to elevated pollution risks. The correlation

Table 3
Diep River microplastics contamination factor and pollution load indices.

Season									
Site (MP per litre)	Autumn		Spring		Summer		Winter		MPPLI
	Water20_MPCF	Water250_MPCF	Water20_MPCF	Water250_MPCF	Water 20_MPCF	Water250_MPCF	Water20_MPCF	Water250_MPCF	
DR1	1.3	1.2	4.1	2.8	0	0	2	1	1.8
DR2	0	0	1	3.2	0	0	0	0	1.8
DR3	2	2.7	1.1	2.8	0	0	1.8	2.4	2.0
DR4	2.6	2.3	3.9	6.1	0	0	2.6	4.8	3.5
DR5	2	3.1	4.2	3.6	1.6	1.3	1.7	1.5	2.2

between water quality parameters and microplastic characteristics provided insights into factors influencing microplastic distribution, degradation and transport with a strong positive correlation existed between MPs and temperature (temp), and total dissolved solids (TDS). This study provided new perspectives in identifying potential sources and pathways while offering baseline data for future monitoring and management. Further research should be performed to ascertain the toxic potential effects of microplastics on aquatic life.

CRediT authorship contribution statement

Asmat Begum Khan: Writing – review & editing, Writing – original draft, Investigation, Formal analysis. **Omoniyi Pereao:** Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Formal analysis. **Conrad Sparks:** Writing – review & editing, Validation, Supervision, Methodology. **Beatrice Opeolu:** Writing – review & editing, Supervision, Software, Resources, Project administration, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

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Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envpol.2025.126555.

Data availability

Data will be made available on request.

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