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Microplastic Pollution in Shoreline Sediments of the Vondo Reservoir Along the Mutshindudi River, South Africa

Thendo Mutshekwa [1,2,3,*], Samuel N. Motitsoe [3], Musa C. Mlambo [1,4], Lubabalo Mofu [4,5], Rabelani Mudzielwana [6] and Lutendo Phophi [6]

[1] Department of Freshwater Invertebrates, Albany Museum, Makhanda 6139, South Africa; musa.mlambo@gmail.com
[2] Institute of Water Research, Rhodes University, Makhanda (Grahamstown) 6140, South Africa
[3] School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, Johannesburg 2050, South Africa; samuel.motitsoe@wits.ac.za
[4] South African Institute for Aquatic Biodiversity (SAIAB), Makhanda 6140, South Africa; lubamofu@gmail.com
[5] Department of Ichthyology and Fisheries Science, Rhodes University, Makhanda 6139, South Africa
[6] Department of Geography and Environmental Sciences, University of Venda, Thohoyandou 0950, South Africa; rabelani.mudzielwana@univen.ac.za (R.M.); poppylutendo69@gmail.com (L.P.)
* Correspondence: thendomutshekwa@gmail.com

Abstract

Rivers are recognized as significant pathways and transportation for microplastics (MPs), an emerging contaminant, to aquatic environments. However, there is limited evidence on how riverine reservoirs influence MPs transport. To fill this gap and provide baseline empirical data and insights to South African context, the current study assessed the seasonal variation in MP densities from sediments collected upstream, within the reservoir, and downstream of the Vondo Reservoir along the Mutshindudi River. We hypothesised that MP densities would be highest within the reservoir, due to the lack of constant flow that would otherwise transport accumulated particles downriver. Additionally, we expected the cool–dry season to be associated with the highest MP densities. As expected, high MP densities were observed within the reservoir (117.38–277.46 particles kg^{-1} dwt) when compared to the downstream (72.63–141.50 particles kg^{-1} dwt) and upstream (28.81–91.63 particles kg^{-1} dwt) sites of the reservoir. The cool–dry season (91.63–277.46 particles kg^{-1} dwt) exhibited the highest MP densities compared to the hot–wet season (28.81–141.50 particles kg^{-1} dwt). However, MP densities downstream the reservoir were higher during the hot–wet season (141.50 $\pm$ 24.34 particles kg^{-1} dwt) compared to the cool–dry season (72.63 $\pm$ 48.85 particles kg^{-1} dwt). The most dominant MP particles identified were white, transparent, and black fibres/filaments composed primarily of polypropylene (PP) and polyethylene (PE). This suggests diverse sources of MP particles. No significant correlations were found between water parameters and MP densities across sampling sites and seasons, indicating a widespread and context-independent presence of MPs. These findings contribute to MP studies in freshwater environments and further reinforce the role of sediments as sink for MPs and suggest that riverine reservoirs similar to dams can trap MPs, which may then be remobilized downstream during high-flow periods. Importantly, the results of this study can support local municipalities in implementing targeted plastic pollution mitigation strategies and public awareness campaigns, particularly because the Vondo Reservoir serves as a critical water resource for surrounding communities.

Keywords: plastic debris; microplastic transport; impoundment; river continuum concept

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1. Introduction

Plastics are among the most flexible synthetic materials invented, and their production has grown exponentially [1,2]. An estimated 390.7 million tons of waste from plastic materials were produced in 2022 due to high demand for plastic across key sectors, including cosmetics and personal care, packaging, transportation and logistics [3]. Due to their affordability and durability, plastics are broadly utilised across almost every sector [4]. However, due to the improper discarding of plastic waste materials, some of the plastic materials end up in the aquatic environments via physical pollution, surface and stormwater runoff, sewage inputs, or domestic wastewater [1,5]. Larger plastic items discarded into the environment can subsequently break down slowly into small fragments through biological, chemical, and physical processes [6], subsequently resulting in MPs particles (smaller than 5 mm) [7].

Microplastic pollution in the world's oceans has been studied extensively [8]. However, due to the persistence and pervasiveness of MPs in the aquatic environment and the potential risk to aquatic ecosystems and human wellbeing [9], there is a growing interest in freshwater MPs [10–12]. After physical pollution, plastic degrades on land, and subsequently washed in rivers to be further transported down river, and this acts as major pathways for translocation from inland to dams and lakes and ultimately the ocean [8]. Additionally, aquatic organisms at various trophic levels can assimilate different types of MPs [13], making them available to higher-trophic-level organisms through predator-prey dynamics [14]. These organisms are exposed to MPs that have been free-floating and eventually settled onto sediments. According to Peng et al. [15], MPs with a 1.0 g/cm^3 density, sink and become deposited in the sediment.

Studies have reported sediments as the main sink for MPs in aquatic environments, see Nel et al. [16] and Saarni et al. [17]. They can be caught and aggregated with various substances in waterbodies, for example, suspended matter, thereby resulting in the settlement of MPs at the bottom [18]. Recently, it has been estimated that 70% to 90% of MPs settle and accumulate in sediments worldwide [18]. Although MP pollution in river systems has received considerable attention, the occurrence and dynamics of MPs in the sediments for riverine reservoirs remain relatively understudied [19]. This is a critical oversight, as man-made reservoirs and dams can act as major sinks for MPs, influencing their accumulation, retention, and spatial distribution of MPs within aquatic systems [20]. Man-made riverine reservoirs are known to retain large amounts of suspended sediments and organic-rich matter [21], and are almost certainly trapping MPs at higher densities [20]. Studies have shown that MPs tend to settle behind reservoir walls [20,21], highlighting the significance of these structures in influencing the fate and transport of MPs in freshwater environments. These processes, driven by altered hydrological regimes and sedimentation patterns, underscore the need for more focused research on reservoirs as long-term reservoirs of MP pollution and their implications for vital ecosystem services such as water purification, sediment transport, and habitat quality [22].

According to the South African National Committee on Large Dams [23], South Africa is home to a significant number of man-made reservoirs, with over 4000 reservoirs, most of which are constructed as barriers across rivers to store water. Most of these rivers run through populated communities where physical pollution and plastics have been the major pollutants [24]. Thus, this leads to high levels of MPs pollution and eventually trapping, affecting the aquatic ecosystem, causing widespread human, wildlife, and aquatic ecosystem concerns [25]. To enhance our understanding of MP accumulation and their potential environmental risks in riverine ecosystems, this study investigated seasonal variations in MP densities in sediments collected upstream, downstream, and within the Vondo Reservoir along the Mutshindudi River in Limpopo province, South Africa. Vondo

Reservoir was chosen for this study because it is not subject to dredging or routine sediment flushing, making it a suitable site to investigate MPs pollution without human mitigation. Importantly, this study is the first of its kind to assess MP pollution in this reservoir.

We thus hypothesise that Vondo Reservoir will effectively reduce MP densities downstream of the reservoir by trapping plastic debris within the reservoir sediments. This hypothesis was based on findings from Watkins et al. [20], who reported the highest MP densities in sediments within reservoirs relative to both upstream and downstream reservoir sites. We also hypothesise that MP densities would vary across seasons (i.e., hot–wet and cool–dry), with the cool–dry season associated with high MP densities. This expectation is based on reduced rainfall, lower discharge, and slower flow velocities during the dry season, which favour the settling and accumulation of suspended particles, including MPs and this was seen in Xia et al. [26], Mutshekwa [27] and Nkosi [28].

2. Methods and Materials

The study was conducted in Vondo Reservoir (22°56′45″ S, 30°20′7″ E), an earth-fill reservoir standing 43 m high with a 294 m crest length, located along the Mutshindudi River near Thohoyandou in the Thulamela Municipality, Vhembe District, Limpopo Province. The Mutshindudi River, which feeds the reservoir, originates from the Soutpansberg Mountains [29] (Figure 1). The reservoir has a capacity of 30.5 million m^3, a depth of 43 m, and a surface area of 2.19 km^2 and serves as a water source for surrounding communities, including the Vondo Tea Estate and Tshilidzini Hospital [30]. However, the reservoir is exposed to multiple pollution sources, including agricultural runoff from tea and timber plantations, fishing activities, and domestic effluents from nearby residents, swimming, car washing, and laundry activities along the reservoir [31]. The upstream of the reservoir is influenced by small-scale agricultural practices, such as maize farming, as well as fishing activities. The reservoir itself is impacted by recreational activities, including swimming, fishing, laundry, and car washing, as well as the presence of nearby parks and human settlements [29]. In contrast, the downstream of the reservoir is primarily affected by recreational activities and runoff from surrounding residential areas. Climatic conditions within the Thulamela Local Municipality vary significantly, with mean air temperatures ranging between 18 °C and 28 °C, averaging around 23 °C. Mean annual rainfall varies from 450 mm to 750 mm, with an average of approximately 600 mm.

This study was carried out across two different seasons: the hot–wet season (March 2023) and the cool–dry season (June 2023). Sampling was conducted at three sites: (a) upstream of the reservoir, (b) within the reservoir near the dam wall, and (c) downstream of the dam wall along the Mutshindudi River. At each site, three replicates sediment samples were collected, resulting in a total of nine sampling units (3 sites × 3 replicates). All sediment samples were collected along the littoral zone (>1 meter depth). However, because sampling was limited to the shallow littoral zonessediments, seasonal comparisons may be biased. During the wet season, increased flow and runoff can lead to vertical and lateral redistribution of MPs within the sediment column, potentially burying or exposing different fractions of the MP load [26]. This means observed seasonal differences might partly reflect changes in sediment dynamics rather than actual differences in MP input or degradation.

While sampling across the two seasons was aimed at providing insights into possible temporal variation in (MP) contamination, we acknowledge that the limited number of seasonal timepoints may not robustly capture seasonal trends but more about the hydrological changes. Therefore, observed differences between seasons should be interpreted with caution with hydrological difference in mind, as they may partly reflect sampling

variability rather than true temporal changes. More frequent and repeated sampling over time would be necessary to distinguish seasonal patterns with greater confidence.

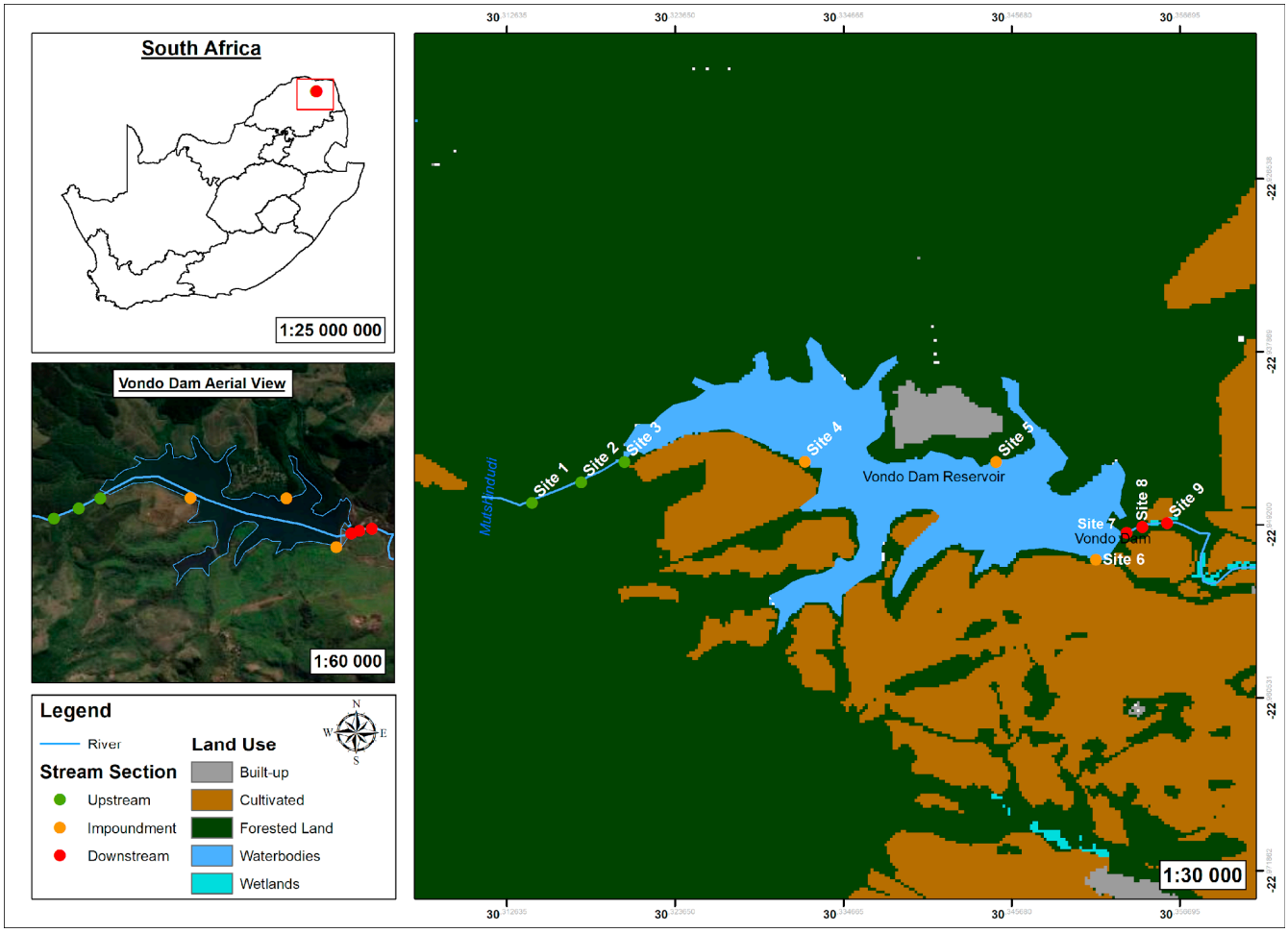


Figure 1. Location of sample collections (Site 1–Site 3 upstream; Site 4–Site 6 within the reservoir/impoundment: Site 7–Site 9 upstream) in the Vondo Reservoir located along the Mutshindudi River, Limpopo, South Africa.

2.1. Microplastic Collection and Extraction

Prior to sample collection, water quality variables, including water temperature (°C), pH, conductivity (µS cm^{-1}), and total dissolved solids (hereafter referred to as TDS) (mg L^{-1}) were measured in replicates ($n = 3$ per site) using a portable multi-parameter meter (EuTech Instruments Pte Ltd., Singapore, Republic of Singapore). To assess MP presence, a total of 54 sediment samples (weighing between 1.5 and 2.0 kg each) were collected across two seasons, with 27 samples collected per season. Sampling was conducted at a depth of 5–10 cm using a steel hand shovel following the procedure given in [27]. During collection, large debris such as plant material and stones were removed. The sediment samples were immediately wrapped in foil, labeled, stored in Ziplock bags, and transported to the University of Venda laboratory for analysis, in South Africa. Microplastic extraction followed the protocol outlined by Mbedzi et al. [32], which was selected for its high recovery efficiency, ranging from 88% to 95%. For detailed information on the recovery rate experiments, see Mbedzi et al. [32].

In the laboratory, sediment samples were firstly oven-dried at 50 °C until they reached a constant weight. Once dried, each sample was homogenised using a riffle splitter and sieved through a 500 µm stainless steel mesh to eliminate rocks and large organic debris.

The remaining sediment was weighed, allowing the concentration of microplastic particles kg^{-1} of dry weight (dwt) to be determined. Before extracting MPs, all instruments were rinsed with distilled water and then dried. To minimize airborne contamination, laboratory windows were kept closed, and the air conditioner was turned off throughout the experiment [33]. Cotton lab coats and polymer-free gloves were used throughout the laboratory procedures to maintain sterility and reduce the risk of MP contamination. The material retained on the sieve was examined for large MPs (500 µm to 5 mm) and included in the total MP count. The sieved sediments were then subjected to density separation using a 25 L stainless steel bucket filled with 100 mL of filtered NaCl solution (1400 g NaCl in 0.6 L water; density 1.22 g/cm^3), following the method described by Quinn et al. [34] and Cutroneo et al. [35,36]. To prevent contamination during the extraction process, three control steel buckets without sediment were processed alongside the samples and examined for potential contamination post-extraction. No contamination was found in blank samples [37] (Table S1). Each sample solution was stirred for six minutes and allowed to settle. The resulting suspended sample was filtered through a 63 µm mesh, and this process was repeated six times to ensure thorough separation. Deionised water was used to rinse the walls of the filtration apparatus and dislodge any remaining MP particles. Finally, the filter paper was placed in a covered Petri dish and oven-dried at 60 °C to constant weight before MP identification under a dissecting microscope. Filtration and identification were conducted under a laminar flow hood to limit exposure to airborne contaminants.

Preliminary observations of MPs were conducted using an Olympus dissecting microscope at 50X magnification to assess the shape (i.e., fibre/filament, film, foam, fragment) and colour (i.e., white, transparent, black, blue, red, green, and others such as yellow, orange, pink, brown, and grey) of the particles [38]. To monitor potential contamination during analysis, glass microfiber filter blanks were placed near the microscope and inside the drying oven as negative controls [33] (Table S1). No MP contamination was detected in these blanks. For polymer identification, 50–60% of the total MP particles found (smaller than 5 mm) were randomly selected and analysed using a vibrational Platinum-ATR Fourier transform infrared spectroscopy technique (FT-IR) (Bruker Alpha model; Ettlingen, Germany) with a spectral region of 400–3200 cm^{-1}, resolution of 8 cm^{-1}, and a rate of 16 scans per analysis. Prior to FT-IR analysis, the particles were treated with potassium hydroxide (KOH) for one hour to remove any adhering organic material, following the method described by Prata et al. [33]. This digestion step effectively eliminates organic matter while preserving the integrity of the MP particles. After treatment, the particles were thoroughly dried to remove moisture, which could otherwise interfere with FT-IR analysis. The MP particle spectra were compared to polymer databases, including the Hummel Polymer Sample Library, HR Polymer Additives and Plasticizers, HR Hummel Polymers and Additives, and Synthetic Fibres by Microscope, with a matching degree of >75% between sample and standard spectra considered acceptable.

2.2. Statistical Analysis

A non-parametric Wilcoxon signed-rank test was employed to assess variations on sediment MP densities between seasons (i.e., hot–wet and cool–dry) and sampling sites (i.e., upstream, reservoir, and downstream). This test was chosen because MPs density data was found not to be normally distributed, as indicated by the Shapiro–Wilk test ($p < 0.05$). Differences in environmental variables were analysed using two-way analysis of variance (ANOVA), followed by Tukey's HSD post hoc tests for multiple comparisons, where seasons and sites were factors. All statistical analyses were conducted using R version 3.4.2. Additionally, Pearson correlation analyses were performed using IBM SPSS

version 25 to examine the relationships between environmental variables and MPs densities. Statistical significance was determined at $p < 0.05$ for all tests.

3. Results

3.1. Microplastic Densities

Mean (±standard deviation) MPs densities found in the current study are shown in Table 1, with a total mean of 121.57 particles kg^{-1} dwt across seasons and sites. Overall, MPs densities ranged from 28.81 to 277.46 particles kg^{-1} dwt, where MPs densities recorded within the reservoir were significantly greater (mean range 117.38–277.46 particles kg^{-1} dwt) than those recorded upstream (mean range 28.81–91.63 particles kg^{-1} dwt) and downstream (mean range 72.63–141.50 particles kg^{-1} dwt) of the reservoir (Wilcoxon signed-rank test: $p = 0.025$). Regarding seasons, high MPs densities were recorded during the cool–dry season (mean range 91.63–277.46 particles kg^{-1} dwt), whereas low MP densities were recorded during the hot–wet season (mean range 28.81–141.50 particles kg^{-1} dwt), with Wilcoxon signed-rank test indicating no significant difference between the season ($p > 0.05$). However, downstream had the highest MPs densities during the hot–wet season (117.38 ± 38.19 particles kg^{-1} dwt) compared to the cool–dry season (277.46 ± 90.61 particles kg^{-1} dwt) (Table 1).

Table 1. Mean (±standard deviation) MPs densities found upstream, within the reservoir, and downstream of the Vondo Reservoir along the Mutshindudi River, South Africa, across the hot–wet and cool–dry seasons.

Site	Hot–Wet Season (Mean ± SD)	Cool–Dry Season (Mean ± SD)
Upstream	28.81 ± 10.51	91.63 ± 29.07
Reservoir	117.38 ± 38.19	277.46 ± 90.61
Downstream	141.50 ± 24.34	72.63 ± 48.85

3.2. Microplastic Characteristics

A range of MPs colours was identified, including white, transparent, black, blue, green, red, and others (such as yellow, orange, pink, brown, and grey) (Figure 2A). Among these, white particles were the most prevalent (37.7%), followed by transparent (19.5%) and black (18.1%) MPs (Figure 2A). In terms of shape, fibres/filaments were the dominant form, accounting for 79.8% of all particles across different sites and seasons (Figure 2B). These were followed by fragments (17.8%), films (1.1%), pellets (0.9%), and foams (0.4%). Polymer identification using FT-IR was conducted on selected MP particles (2–5 mm), and classifications were made based on known polymer spectra [38]. In total, six distinct polymer types and one unidentified category (“others”) were detected. The most abundant polymer was polypropylene (40.3%), followed by polyethylene (29.8%), polyester (12.7%), polyethylene terephthalate (7.8%), high-density polyethylene (4.3%), and polyvinyl chloride (2.2%) (Figure 2C). Unidentified polymer types contributed less than 4% of the total.

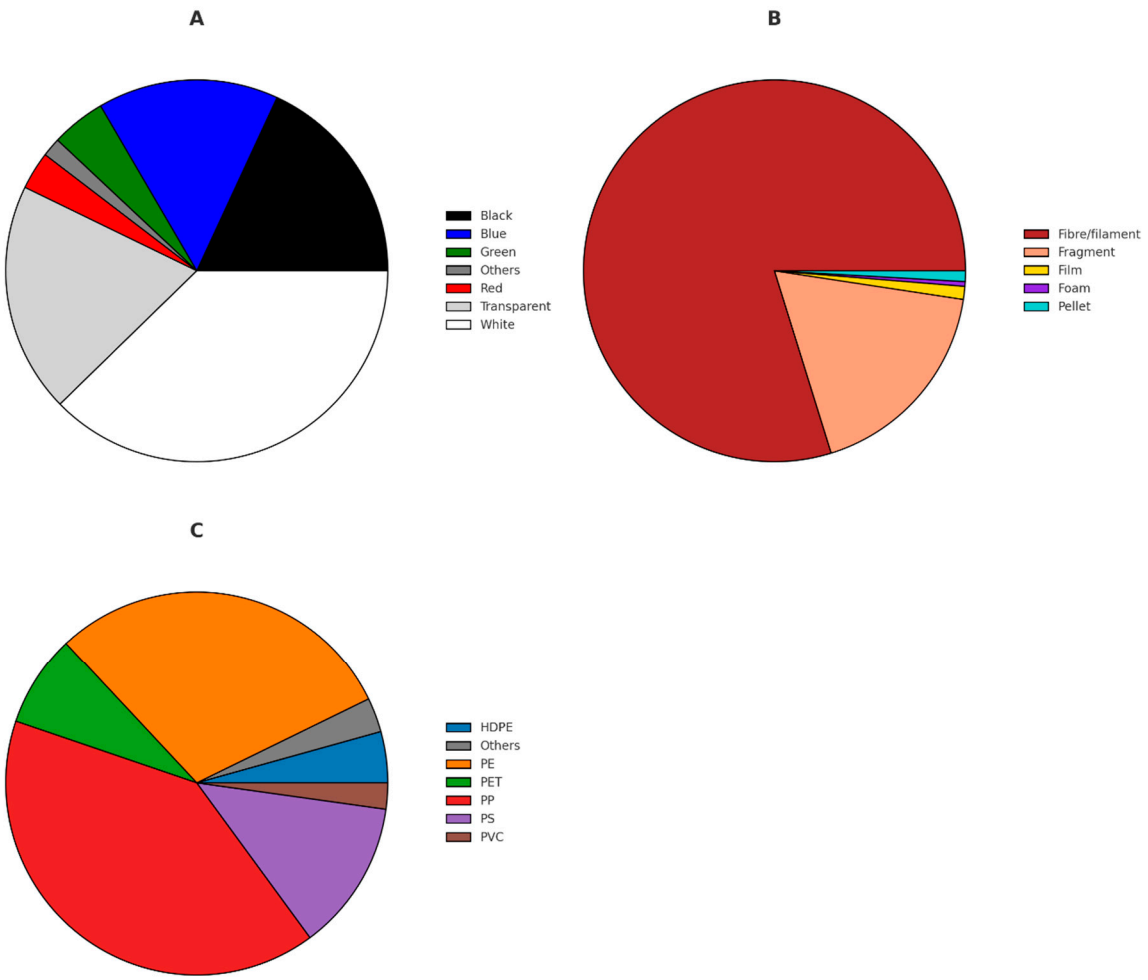


Figure 2. Overall (%) (**A**) colour, (**B**) shape, (**C**) polymer type found across sampling sites and two seasons in Vondo Reservoir along the Mutshindudi River, Limpopo, South Africa. Abbreviations: PP—polypropylene, PE—polyethylene, PS—polystyrene, PET—polyethylene terephthalate, PVC—polyvinyl chloride, HDPE—high-density polyethylene.

3.3. Water Quality Variables

During the cool–dry season, high mean values were recorded for water temperature (28.3 ± 0.7 °C; upstream), pH (8.3 ± 1.0; reservoir), and conductivity (335.3 ± 24.4 µS cm^{-1}; reservoir). In contrast, the highest mean total dissolved solids (TDS) concentration (204.7 ± 25.2 mg L^{-1}) was observed downstream during the hot–wet season (Table 2). ANOVA results showed that water temperature and conductivity differed significantly between seasons ($p < 0.05$), while pH and TDS showed no significant seasonal variation ($p > 0.05$) (Table 2). Across sites, there were no significant differences in water temperature (mean range: 23.0–28.3 °C), pH (7.2–8.3), TDS (112.6–204.7 mg L^{-1}), and conductivity (177.3–335.3 µS cm^{-1}). Site × season interaction was significant for conductivity (Table 2). Pearson correlation analysis revealed no significant relationships ($p > 0.05$) between MPs densities and water quality variables, thus supporting the null hypothesis that these factors have no measurable effect on MPs densities.

Table 2. Mean range water variables measured across sites (i.e., upstream, reservoir, downstream) and season along the Mutshindudi River, Limpopo. Abbreviations: TDS–total dissolved solids.

Variables	Unit	Upstream	Reservoir	Upstream
Water Temperature	°C	24.8–26.4	23.0–28.2	25.5–27.5
pH		8.1–8.2	7.2–7.9	7.7–8.3
Conductivity	$\mu S\ cm^{-1}$	177.3–326.1	202.5–321.0	149.7–281.7
TDS	$mg\ L^{-1}$	122.4–169.0	121.7–184.0	147.7–204.7

4. Discussion

The study aimed to assess seasonal variations in sediment MPs upstream, within the reservoir, and downstream sites of Vondo Reservoir along the Mutshindudi River. We found the highest MPs densities within the reservoir compared to upstream and downstream, indicating that the reservoir walls act as a barrier for MPs transportation and thus a sink [20,22], facilitating their accumulation due to reduced flow velocity and sedimentation processes [39]. Although only two seasonal sampling events were conducted, seasonal variation appeared evident, with the cool–dry season exhibiting the highest MPs densities. However, due to the limited temporal sampling resolution, these seasonal differences should be interpreted cautiously, as they may partially reflect short-term variability but more so representing two hydrological changes which has a clear effect on MPs densities. These findings suggest that seasonal context plays a critical role in shaping MPs presence and distribution, with the cool–dry season particularly conducive to MPs accumulation within the aquatic system [40]. We also found no significant correlations between water quality variables and MPs densities, suggesting that MPs pollution may occur independently of local physicochemical conditions and is influenced by broader, site-specific, or anthropogenic factors.

Our results supported our primary hypothesis. The highest MP densities were found within the reservoir, and this was consistent with Watkins et al. [20], who assessed MP densities across six reservoirs and found that MP densities were significantly higher within the reservoirs in five of the six dams in Ithaca, New York. Highest MP densities within the reservoir indicate that Vondo Reservoir may act as a major sink for MPs, likely due to reduced water flow and increased sedimentation [41], which is likely to promote the accumulation and retention of plastic particle as the reservoir in the current study does not undergo no regular dredging or flushing, similar to those assessed by Waktins et al. [20]. Conversely, Weideman et al. [42] suggested that riverine reservoirs have no effect on trapping MPs due to a non-significant difference in MP densities at sites above and below the Orange–Vaal River walls. However, our findings were also supported by Pojar et al. [43], who reported significant effects of riverine reservoirs on MP distribution. Similarly, Vayghan et al. [44] also reported the highest MP densities within a reservoir (528 items/kg dry weight) and lowest densities downstream (32 items/kg dry weight), which is consistent with our findings, which further supports that MPs can settling can occur behind a dam. The presence of MPs within the Vondo Reservoir could be attributed to various anthropogenic activities occurring around the reservoir, including illegal fishing, littering, nearby settlements that contribute raw and untreated sewage, storm water run-off directly into the reservoir, recreational parks, improper disposal of domestic waste, and runoff from the surrounding tea plantation industry [29,31]. Although MP densities were low both upstream and downstream, it is important to note that the upstream of the Vondo Reservoir is exposed to intensive agricultural activities, which may have contributed to the presence of MPs. Additionally, the downstream area is impacted by recreational activities and illegal dumping, which could also be sources of MP pollution [45].

Our findings also indicate that seasonal context was sensitive to MP densities, with the cool–dry season associated with the highest MP densities [27]. Previous studies also found seasonal variations, with sediment acting as a major sink of MPs [16,17,26]. Our findings align with those of Mbedzi et al. [32] and Themba et al. [46], who reported high MP densities in sediments during the dry season in the Nandoni Reservoir and subtropical Austral Reservoir, respectively. In the current study, the downstream during the hot–wet season was associated with high MP densities compared to the downstream during the cool–dry season, consistent with observations by Li et al. [47], who also reported increased MP concentrations during the wet season in Shanghai. As reported by An et al. [48], MPs may accumulate in surface sediments during the dry season and become resuspended during the wet season due to increased rainfall and runoff, potentially leading to their redistribution throughout the reservoir and downstream environments [49]. This was evident in our study, as the hot–wet season showed elevated MP densities downstream of the reservoir during rainy days. The increased MP presence in downstream sediments may be attributed to the overflow of the Vondo Reservoir during heavy rains, which likely facilitated the transport and deposition of MPs from the reservoir into downstream areas. While these results suggest seasonal temporal variation, more frequent and long-term sampling would be necessary to confirm this pattern and disentangle seasonal effects from sampling noise.

We found MPs with various colours and shapes, indicating that MP particles in the riverine reservoir along the Mutshindudi River may have come from multiple sources of pollutants [19]. Most MP particles found were dominated by white particles, followed by transparent, black, and blue particles, which helped identify the plastic origins. According to Mvovo [50], transparent and white fibre MP particles primarily originate from synthetic textiles (e.g., polyester and nylon), fishing gear (such as ropes and lines), and plastic packaging materials like bags and food wraps, which degrade and shed fibres into aquatic environments through washing, runoff, and environmental weathering. This was evident in our study since the Vondo Reservoir is prone to fishing activities and effluent from nearby settlements. Furthermore, fibres were the most dominant MP found, followed by fragments, films, and foams. A similar trend was observed by Queiroz et al. [51] in sediments from a tropical freshwater reservoir, where fibres were the most dominant, followed by fragments. Fibres found in our study may have originated from laundry effluent and degraded fishing gear, entering the dam through domestic wastewater discharge and recreational activities [19]. Conversely, fragments are likely derived from the breakdown of larger plastic items such as packaging materials and containers, introduced into the dam through surface runoff and environmental degradation [19]. MP particles were further confirmed using FT-IR, and PP was found to be the most dominant polymer, followed by PE, both of which are commonly used in household items, packaging materials, and fishing equipment. The predominance of PP and PE aligns with findings from other freshwater studies, where these polymers are frequently detected due to their widespread use, low density, and resistance to degradation [52]. We also detected denser polymers, such as PET and PVC, which are less likely to be efficiently recovered using the NaCl density separation method. Therefore, we acknowledge that the actual abundance of these polymers may be underestimated. Future studies should consider using higher-density solutions, such as zinc chloride or sodium iodide, to improve the recovery of heavier MPs.

The findings of this study have significant implications for the health of riverine ecosystems and human populations reliant along the Mutshindudi River system. The Vondo Reservoir, a riverine reservoir situated along the Mutshindudi River in Limpopo Province, serves as a critical water supply source for numerous nearby communities. It forms part of the Vondo Regional Water Scheme, providing potable water to Thohoyandou

town, Tshilidzini Hospital, and several surrounding villages [53,54]. The presence of MPs in sediments in our current study poses a potential risk to both aquatic food webs and public health. MPs can be ingested by aquatic organisms, potentially bioaccumulating and biomagnifying through the food web, ultimately affecting fish and invertebrates that may be consumed by local communities [55]. In addition, individuals who engage in recreational activities such as swimming or fishing within the Vondo Reservoir may be at risk of direct or indirect MP exposure. Moreover, MPs from the Vondo Reservoir can be transported downstream along the Mutshindudi River, contributing to the contamination of the Luvuvhu River, into which it flows. This downstream transport could result in broader ecological impacts, further threatening aquatic life in connected river systems and affecting water quality in a larger catchment [25]. It is also important to acknowledge that atmospheric deposition may represent an additional and often overlooked pathway for microplastic input into freshwater systems. Airborne microplastics, transported via wind and precipitation, can be deposited directly into rivers and reservoirs. Although this source was not assessed in the present study, recent research by Mutshekwa et al. [56] has shown that MP deposition from the atmosphere occurs across seasons in South Africa and could contribute to sedimentary MP contamination, particularly in exposed open-water systems like Vondo Reservoir. Future studies should incorporate atmospheric sampling to better quantify this pathway and its role in freshwater MP pollution.

To the best of our knowledge, the current study is the first to investigate MP pollution in the Mutshindudi River and the Vondo Reservoir, thus providing essential baseline data for future monitoring and management efforts. The results highlight the urgent need for awareness campaigns targeting local communities to discourage littering and reduce recreational pressures on the reservoir. Furthermore, local municipalities must implement and enforce strict protocols and policies aimed at reducing plastic pollution, including improved waste management infrastructure and community education on the impacts of plastic waste. Future studies should aim to assess MP contamination in water, biota, and trophic transfer potential within the Mutshindudi River system to provide a more comprehensive understanding of ecological and human health risks. Investigations into the toxicity of MPs on aquatic organisms and their potential to adsorb and transport chemical pollutants are also crucial. By contributing to the growing body of research on MP pollution in South African freshwater systems, the findings of this study contribute to the development of effective mitigation strategies and highlight the need for integrated water resource management that incorporates MP monitoring and control at the catchment scale.

5. Conclusions

The current study assessed the temporal seasonal variation of MP pollution in the sediments of Vondo Reservoir, located along the Mutshindudi River. MPs were detected upstream of the reservoir, within the reservoir itself, and downstream, across both the hot–wet and cool–dry seasons. Sediment samples collected within the reservoir exhibited the highest MP densities, with the cool–dry season associated with the overall peak in MP densities, and this was supported by pollution indices values. However, due to the limited number of sampling events, these seasonal differences should be viewed as preliminary, and future research should involve more frequent sampling across multiple seasons to robustly identify temporal trends. Microplastics were found in various colours, shapes, and polymer types, suggesting that the MP particles found originated from multiple sources, such as recreational and domestic activities, such as washing and laundry, fishing, as well as illegal waste disposal. Given that the Vondo Reservoir serves as a major water supply for surrounding communities and towns, our findings highlight the importance of informing local municipalities about the presence and risks of plastic debris within the reservoir.

This information can support the development of mitigation strategies aimed at reducing the influx and accumulation of MPs in dammed freshwater systems. Furthermore, we recommend future studies to assess the ecological impacts of MPs on freshwater biota and habitats within the reservoir. It is also crucial to investigate the transport of MPs from the Mutshindudi River into larger river systems such as the Luvuvhu River, to better understand downstream contamination risks. Additional sampling at finer temporal resolutions will be vital to understand seasonal dynamics and better inform pollution management strategies. Importantly, comparative research on reservoirs that undergo regular flushing versus those that do not could offer valuable insights into the dynamics of MP retention and transport. Such studies will be essential to comprehensively understand the role of riverine reservoirs in modulating MP distribution in freshwater ecosystems.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w17131935/s1, Table S1: Results of Laboratory Blanks for MP Contamination Control (n = 3 per blank type).

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