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Optimization of Ferrofluid Based Microplastics Removal: A Case Study of Kibangu River, Tanzania

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ABSTRACT

Microplastics (MPs) pollution has become a major global environmental concern, significantly affecting aquatic ecosystems. This study assessed MP contamination in the Kibangu River and developed a novel ferrofluid-based method for MP removal. MP abundance in the river ranges from 9 to 21 particles/l, with an average of 15 particles/l. The highest abundance was recorded at the Riverside Interchange (21 particles/l), while Nida Textiles exhibited the lowest (9 particles/l). Optimization experiments identified 3.2 g/l ferrofluid concentration and a 25-minute contact time as the most effective conditions for removal, beyond which no significant improvement was observed. Removal efficiency varied with MP size and polymer type; smaller particles (38 µm) exhibited higher removal rates due to their larger surface area to volume ratio. Polyethylene (PE) achieved a 93% removal rate, while polypropylene (PP) reached 88%. Fresh vegetable and castor oils significantly enhanced ferrofluid performance at lower concentrations (1–1.5 ml), with fresh vegetable oil showing the highest efficiency. However, higher oil concentrations and used oils were less effective. These findings underscore the importance of optimizing oil selection and operational parameters to enhance MP removal. This study presents a scalable, environmentally friendly solution to mitigate MP pollution, providing a foundation for further research and potential applications in water treatment and environmental management.

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INTRODUCTION

Microplastics (MPs) have emerged as a significant environmental concern, infiltrating terrestrial, freshwater, and marine ecosystems (Wong et al., 2020; Campanale et al., 2020; Aragaw et al., 2020; De-la-Torre and Aragaw, 2021; Chiani et al., 2025). They are broadly categorized into two types: primary MPs, which are manufactured for industrial applications such as microbeads, microfibers, and plastic pellets; and secondary MPs, which are formed through the breakdown of larger plastic items into smaller fragments. Both types can absorb toxic organic pollutants and heavy metals due to their large surface areas and hydrophobic properties (Zhang et al., 2021; Park et al., 2020). MPs are commonly described as plastic particles measuring less than 5 mm in size (Nejat et al., 2024; Othman et al., 2021).

Global statistics highlight a growing trend of plastic waste being discarded into the

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environment each year, exacerbating the MP pollution problem. Africa consumed 16 kg of plastic per person annually in 2015 (Khan et al., 2020; Abdellatif et al., 2023), compared to 80 kg per person annually in the USA, with a total consumption of 84.3 million metric tons in 2019 (Allan et al., 2022). These chemicals can enter human biological systems through a variety of exposure pathways, including ingestion through fish, skin contact, and inhalation (Yang et al., 2021; Kundu et al., 2022). Cancer, negative inflammatory reactions, oxidative stress, reduced neurofunctional activity, reproductive problems, and mortality are health risks associated with exposure to these substances (Alimi et al., 2020; Lehel and Murphy, 2021).

MPs are often found in tap and bottled water, freshwater, wastewater, marine, and other types of water (Bellasi et al., 2020; Ding et al., 2020; Kankanige and Qi et al., 2020; Rasta et al., 2024). A significant source of MPs in the environment is human-generated waste; thus, state and local governments must make significant efforts to reduce waste volumes and ensure appropriate disposal. Still, poor nations remain far behind in managing plastic waste and the prevalence of MPs (Alimi et al., 2020). The size, fragmented nature, and potential sources of MPs influence global problems (Westphalen and Abdelrasoul, 2018).

Rainfall runoff can transport MPs from land to waterways, making rivers and oceans the primary reservoirs of these pollutants (Kuok &Tang, 2021, Choong et al., 2020). Water treatment is essential for removing MPs and preventing their contamination of water sources (Enfrin et al., 2019, Yang et al., 2019, Bucci and Rochman, 2020). MPs pose significant risks to marine environments and human health, with effective mitigation strategies, particularly for water and sediment treatment, still lacking.

Separating MPs from environmental samples is crucial for impact assessment, but current methods lack standardization and effective removal approaches. This study aimed to address these challenges by measuring MPs levels in the Kibangu River, characterizing the polymers present, determining the best parameters for ferrofluid-based MPs removal, and evaluating the removal efficiency for polyethylene and polypropylene MPs.

Tanzania generated 315 thousand metric tons of plastic waste in 2018, with 96% poorly managed. Burning 60% of uncollected waste and 13% of dumpsite waste contributes to air pollution. (Kyara et al., 2021 and Sharma et al., 2021). Due to the growth of the plastics sector and international trade between China and Tanzania, MPs have grown more prevalent (Nchimbi et al., 2022; Mayoma et al., 2020). South Africa, Nigeria, and Egypt have the continent's largest economies. According to the study, which examined data from 2009 to 2015, these three countries were the leading producers and importers of plastic products and polymers (Babayemi et al., 2019).

Plastic production exceeds 300 million tons annually, with 50% used for disposable products. Improper management can significantly affect the environment and biodiversity. Around the world, plastic waste, which makes up 80% of marine debris, finds its way into the ocean, particularly near tourist sites and areas with high population density (International Union for Conservation of Nature, 2021). Plastic consumption trends and inadequate waste management could lead to 12 billion tons of plastic debris by 2050, accounting for 20% of global oil consumption (Uwaegbulam & Nwannekanma, 2018).

It has been demonstrated that water samples include a range of polymers, including PE and PP. Being one of the most widely used commercial polymers in the world, PE is especially noteworthy. This substance is made from ethylene monomers and has a specific gravity of 0.91 to 0.94 g/cm^3. It is distinguished by the absence of an aromatic benzene group. Numerous settings have been found to have PE, including freshwater rivers (Choong et al., 2021; Ma et al., 2022), sediments (Li et al., 2020), and marine ecosystems (Khalik et al., 2018).

Colloidal suspensions of magnetic nanoparticles in carrier liquids, such as mineral oil, silicone oil, vegetable oil, or synthetic oil, which can be chosen based on particular requirements, are known as oil-based ferrofluids. According to (Nabeel et al., 2014), mineral oils are often chosen for their wetting qualities and capacity to stop nanoparticle clumping, whereas vegetable oils are environmentally friendly but would need to be modified for increased stability. While there are still difficulties in maximizing these ferrofluids' qualities and guaranteeing stability, they have uses in engineering, biomedicine, and pollutant removal (Oehlsen et al., 2022). In MP removal systems, ferrofluids can be extracted using magnets by forming microplastic-oil-magnetite complexes (Henriques, 2022).

Recent studies have investigated advanced wastewater treatment methods. The electro-oxidation process effectively reduces organic pollutants, such as phenol and chemical oxygen demand (Habl et al., 2024), peroxi-coagulation and peroxi-electrocoagulation show high efficiency in removing methyl green, with peroxi-electrocoagulation proving to be more efficient under ideal conditions (Alalwan et al., 2023). Biofilm carriers have shown varying degrees of success in chemical oxygen demand removal, offering valuable insights into improving water treatment methods (Al-Amshawee et al., 2022).

The researcher suggests several synthesis methods for ferrofluids, such as co-precipitation, high-gradient magnetic separation (HGMS), electrophoresis, grinding, and thermal decomposition; co-precipitation is often employed because of its ease of usage. (Li & Li, 2021). Among the many benefits of ferrofluids are their high dispersibility, quick pollutant removal, and re-usability (Nayebi & Shemirani, 2021). They have proven effective in eliminating contaminants such as metals and MPs (Hamzah et al., 2021).

This research aims to identify the most cost-effective and efficient ferrofluid mixture for the prototype, various volumes of used and unused cooking oils, castor oil, and vegetable oil were tested. The goal was to evaluate the effectiveness of these ferrofluid mixes in magnetically removing two common types of MPs found in water bodies: PE and PP.

MATERIALS AND METHODS

Sampling sites

The study was conducted in the Kibangu River since the river interacts with numerous cross-cutting points of potential sources of MPs like industries and human settlements. The direct or indirect contribution of MP abundance affects the concentration in the river which signifies the threats to the ecosystem near the river watershed. Four sampling points were chosen on the likelihood of contributing to MP pollution on the stream as point and non-point sources. The sampling points along the Kibangu River are Riverside Interchange (RI), Bonde la Mchicha (BM), NIDA Textile (NT), and lastly Kigogo Mbuyuni (KM). A handy GPS was used to record their geographical positions which later were plotted in ArcGIS 10.4 shown in Figure 1.

Materials used

Fluorescents green PE PP in 5g were purchased from Ecospheric LLC. The manufacturer certificate showed the particle size of MPs including 44 µm, 41 µm, and 38 µm. Materials and equipment during sampling: 12 plastic bottles of 1l were used for sample collection, pH meter (Hanna combo), Analytical Balance, Gloves for hand protection, Mobile phone for taking pictures, Tape, and mark pen. Material and reagents for sample preparation: Vacuum pump, Squirt bottle, Drying oven, 330 µm mesh, Acetic Acid, 2.0 M Iron (II) chloride solution, 1.0 M (III) chloride solution, 2.0M HCl solution, 0.7 M ammonia solution, Oil (vegetable oil, used vegetable oil, castor oil, used castor oil), Bar magnet, 0.1M KOH solution, Potassium Bromide (KBr). Equipment for Sample Analysis: Optimal microscope (SMZ-143) series (20´Microscope), MSE Bruker FTIR spectroscopy, Analytical Balance.

Analysis of Water Samples and Microplastics

A pH meter was used on-site to measure the salinity, pH, temperature, and electrical

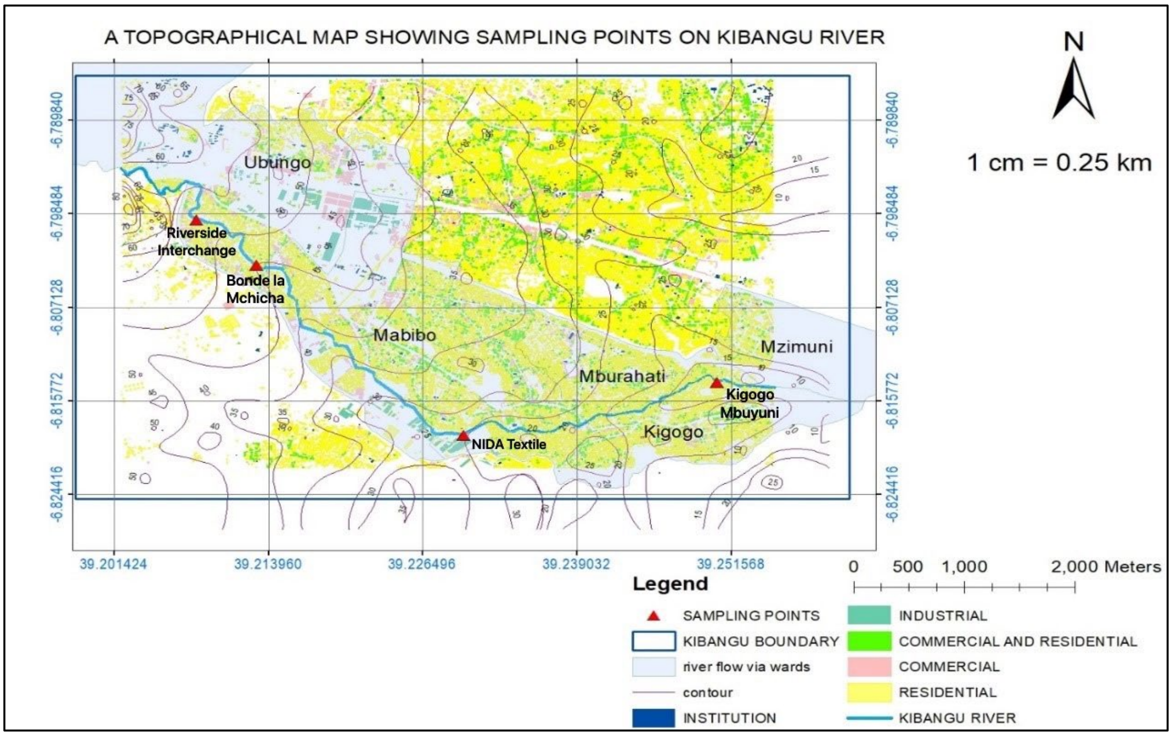

Fig. 1. Kibangu River showing sampling points (1°51'31"S, 29°41'28"E)

conductivity of water. Approximately 1000 mL of water samples were filtered (Li et al., 2020) through a 330 µm mesh (Figure 2a), with the filter paper transferred to Petri dishes for drying in an oven at 70°C for 15–20 minutes to preserve MP integrity (Figure 2b). MPs were analyzed and classified using a dissecting microscope (Figure 2c) based on shapes (fibers, fragments, beads, and films), with examination taking 25–30 minutes per sample (Abidli et al., 2017). FTIR spectroscopy was used for polymer identification, where samples were mixed, ground into a uniform mixture, and stored in vials for analysis (Figure 2d), with acetone used to clean equipment between preparations to avoid cross-contamination.

Ferrofluid Synthesis, Testing, and Optimization for Microplastic Removal

Ferrofluid was synthesized in the laboratory for its magnetic properties, facilitating MP removal. The synthesis process involved mixing 4.0 ml of 1M $FeCl_3$ and 1.0 ml of 2M $FeCl_2$ while stirring at 700 rpm. A 50 ml solution of 0.7M NH_3 was added dropwise, followed by introducing 1 ml of oil (vegetable oil, used vegetable oil, castor oil, used castor oil), and allowing the solution to settle for five minutes. The reaction after this period is shown below:

$$2FeCl_3\,(aq) + FeCl_2\,(aq) + 8NH_3\,(aq) + 4H_2O(l) \rightarrow Fe_3O_4(s) + 8NH_4Cl\,(aq) \quad (1)$$

The ferrofluid's strong magnetic responsiveness, verified in the presence of a magnet, confirmed successful synthesis (Figures 3a and b). MP removal experiments were conducted in four laboratory setups, optimizing parameters such as pH, ferrofluid concentration, contact time, and MP mass. Removal efficiency was determined by gravimetric analysis, comparing sample weights before and after extraction using an analytical balance (Figure 3c), with a precision of 0.0271g.

Determining the removal efficiency

A Beckman Coulter Z1 particle counter was used to measure MP concentration in the

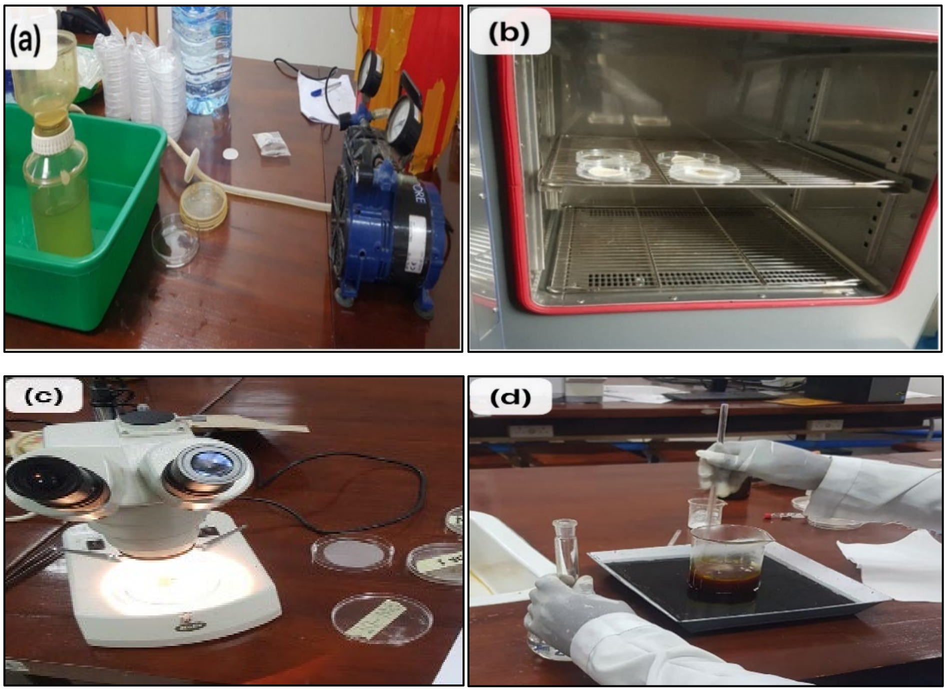

Fig. 2. (a) Sample filtration by vacuum pump, (b) Oven drying of filtered sample at 70 0C, (c) Microplastics examination using a dissecting microscope, and (d) Sample preparation for FTIR Spectroscopy reading

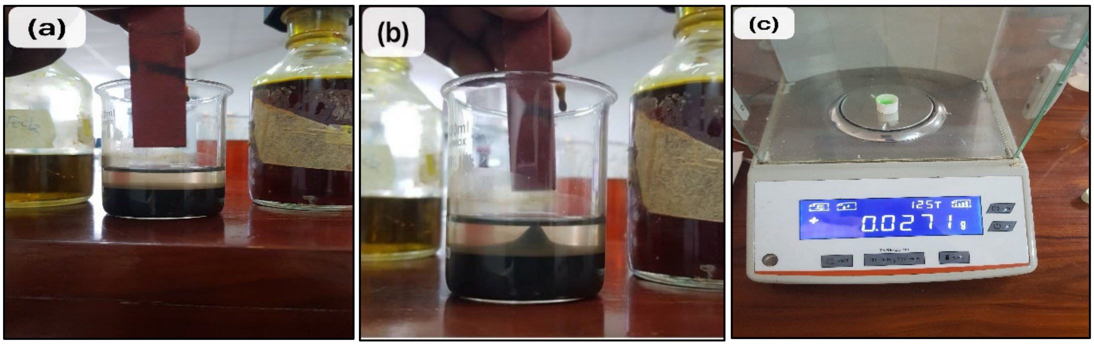

Fig. 3. (a) Testing of ferrofluid (No attraction is observed when a magnet is lowered in a beaker), (b) Testing of ferrofluid (when a magnet is lowered near the surface of the liquid, the attraction of magnetized ions is observed), and (c) Analytical balance for gravimetric analysis.

samples. To ensure accurate and reliable measurements, the instrument was meticulously calibrated before each set of analyses using manufacturer-supplied calibration standards. These standards, consisting of reference particles with known sizes and concentrations, enabled precise verification of the counter's accuracy. The calibration process involved fine-tuning the instrument's sensitivity and threshold settings to optimize detection efficiency while minimizing background noise and measurement drift.

To further validate the accuracy of the particle counter, a series of control tests were conducted using prepared solutions with known MP concentrations. These control measurements ensured that the instrument provided consistent and reproducible readings. Additionally, a blank sample (deionized water without microplastics) was analyzed to verify the absence of contamination and eliminate any risk of false-positive detections. Each sample was analysed three times to minimize potential errors in measurement. The particle counter provided consistent results across all trials, eliminating the need for a standard deviation calculation. The MP removal efficiency was then calculated using the following formula:

$$RE(\%) = \frac{C_i - C_f}{C_i} x100 \quad (2)$$

Where C_i and C_f represent the initial and final MP concentrations, respectively.

This calculation precisely assessed microplastic removal efficiency based on the measured data. By implementing rigorous calibration and validation procedures, we ensured the reliability of the particle counter, enhancing the accuracy of microplastic concentration measurements and the resulting efficiency calculations.

Statistical Analysis

To count and describe microplastics, filtered samples were tested with a Motic SMZ-143 series microscope. Microplastic abundance was compared between sample stations using ANOVA. The polymer composition of each microplastic particle seen under a microscope was determined using Fourier Transform Infrared (FTIR) Spectroscopy. To visualize and analyze the data, Microsoft Excel was used. Significance was 0.05.

RESULTS AND DISCUSSIONS

The study at Kibangu River analyzed water quality, MP abundance, and polymer types in the samples. It assessed MP removal rates using varying ferrofluid concentrations and contact times, comparing the efficiency between PE and PP MPs based on size and comparing the mixing of ferrofluid with vegetable oil and castor oil. The findings highlight the effectiveness of ferrofluid in removing MPs and the impact of polymer type and particle size on removal efficiency.

Physicochemical characteristics of the Kibangu River

The study assessed Kibangu River's pH, temperature, conductivity, and salinity, essential for understanding water quality and optimizing ferrofluid-based microplastic removal under varying environmental conditions.

The pH levels of water from sampling points ranged from 7.25 to 8.88, with Bonde la Mchicha (BM) showing the lowest and Nida Textile (NT) the highest; pH fluctuations affect MP surface charge and interactions with contaminants, potentially affecting aggregation and removal efficiency (Dey et al., 2021; Wang et al., 2020). While most points were within the acceptable range, NT exceeded the recommended pH limit of 6.5-8.5 (Draft East African Standard, 2022), likely due to effluent discharge from the Nida Textile Industry and surrounding human activities. The temperature ranges from 26.4°C to 28.9°C which influence MP buoyancy, degradation rates, and adsorption capacity (Khan et al., 2023); with the highest recorded at Riverside Interchange (28.9^{0}C ± 0.53^{0}C) accelerate MP fragmentation and altering removal effectiveness. Variations in temperature may be due to the time or season of sample acquisition from sampling points, or human activities, with an increase at Nida Textile possibly caused by effluent discharge. Electrical conductivity ranges from 1788.83 to 2071.71 µs/cm, with Riverside interchange (RI) showing the lowest 1721.33 ±67.5 µs/cm and Nida Textile (NT) the highest 2055.67 ± 16.04 µs/cm. Nida Textile having the highest value, suggests the influence of man-made pollution, similar to findings along the Ng'ombe River catchment (Malale et al., 2018).

Quantification of Microplastics in Kibangu River

The quantification of MPs in the Kibangu River revealed an abundance ranging from 9 to 21 particles/l, with an average concentration of 15 particles/l (Figure 4). This level is notably higher compared to other rivers reported in previous studies. For example, MP concentrations

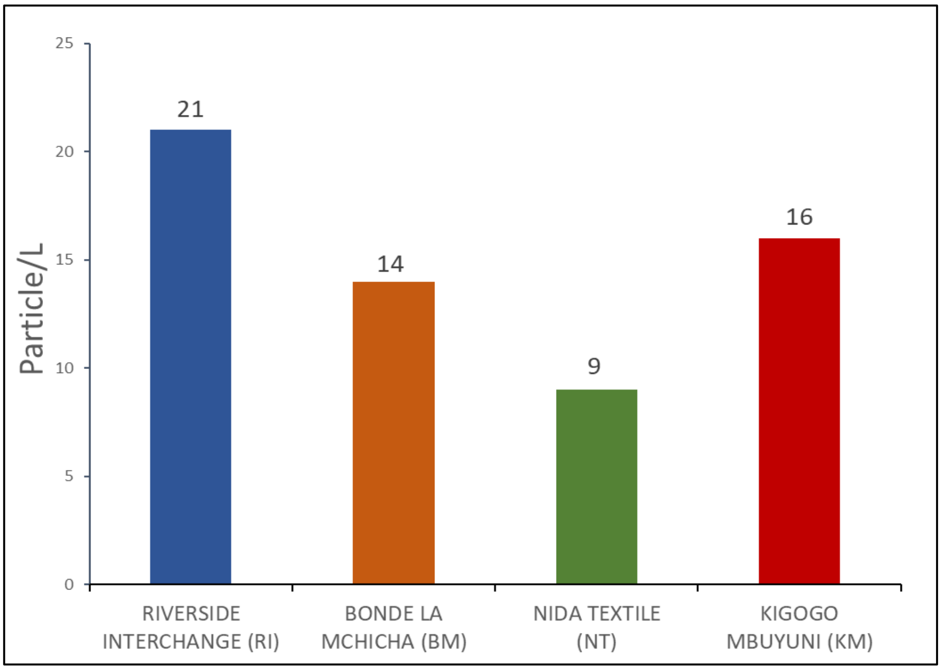

Fig. 4. Microplastics abundance in Kibangu River

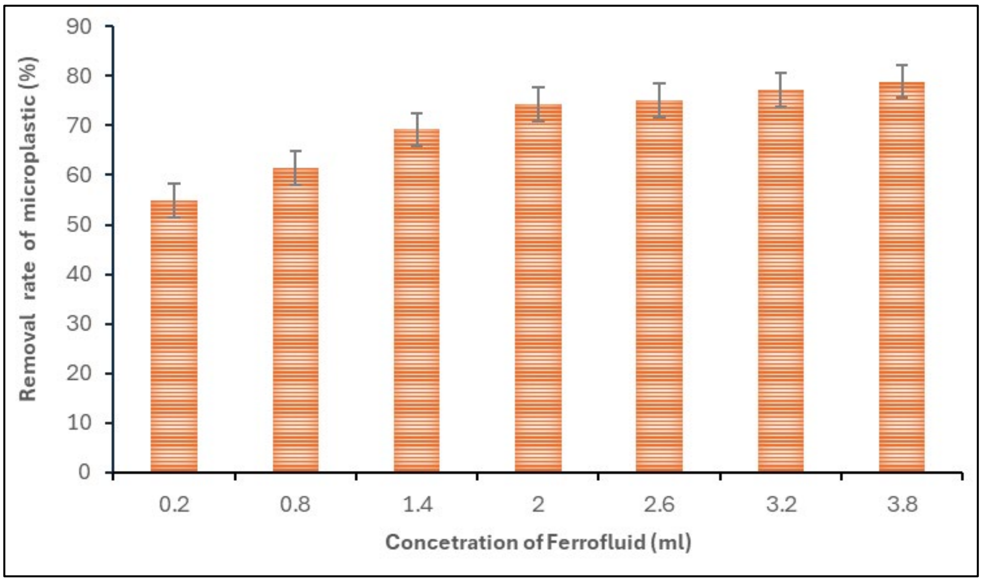

Fig. 5. Removal rates of microplastics after magnetization at different ferrofluid concentrations.

in the Wei River range from 3.67 to 10.7 particles/l (Ding et al., 2019), while the Pearl River and West River report values between 2.4–18.2 particles/l and 2.99–9.87 particles/l, respectively (Zhao et al., 2022). The levels in the Kibangu River are significantly elevated compared to the Yulin River (1.3×10^{-2} particles/l) (Mao et al., 2020), Tuojiang River (0.911 ± 0.199 to 3.395 ± 0.707 particles/l) (Zhuo et al., 2020), and Han River (2.32 ± 0.60 to 8.4 particles/l) (Chen et al., 2023). These findings indicate that the Kibangu River exhibits a remarkably high level of MP pollution, emphasizing the need for targeted mitigation strategies.

Microplastic Removal Rates Following Treatment with Varying Ferrofluid Concentrations and Contact Times

The removal efficiency of PE MPs significantly improved as the ferrofluid concentration increased from 0.2 to 3.2 g/l (Figure 5). The removal rates also increased steadily over time, reaching a plateau at approximately 25 minutes (Figure 6). Under ideal conditions of 3.2 g/l ferrofluid and a contact time of 25 minutes, the method achieved a maximum MP removal efficiency of 91.09% (Nizam, et al., 2023). These results suggest that the combination of 3.2 g/l ferrofluid and 25 minutes of treatment represents the best parameters for efficient MP removal. While the removal efficiency at 3.2 g/l was higher than that observed at 2.6 g/l, the difference was not statistically significant compared to 3.8 g/l, indicating that increasing the ferrofluid concentration beyond 3.2 g/l may not provide additional benefits. The study found that increasing the concentration of ferrofluid led to a significant increase in microplastic removal efficiency. This is likely due to the higher surface area of the ferrofluid at higher concentrations, which enhances chemical reactivity and increases the chances of magnetite ions interacting with and binding to microplastics (Wallyn et al., 2019). Similarly, previous research by (Sturm et al., 2021) demonstrated that increasing the dosage of organosilane resulted in higher removal efficiencies, attributed to the increased water solubility of organosilane due to the formation of silanol during the hydrolysis of chlorine groups. Using an aluminium anode and iron cathode resulted in 100% microplastic removal within 20 minutes (Akarsu et al., 2021). This superior performance compared to iron electrodes can be attributed to lower oxidative properties, which may lead to more effective destabilization and aggregation of microplastics.

Effect of Microplastic Type and Size on Removal Efficiency

The removal efficiency of MPs was influenced by both particle size and polymer type. For 38 µm particles, PE showed a higher removal rate (93%) compared to PP (88%), likely due to PE's favorable surface properties enhancing interaction with ferrofluid (Figure 7). Smaller MP particles also showed higher removal efficiencies, attributed to their larger surface area-to-volume ratio, which improves interaction with ferrofluid (Martinez and Kim 2020) Compared to similar studies, the removal efficiency in this research was slightly higher. For example, (Nizam, et al., 2023) reported a 91.09% removal rate for polystyrene MPs using ferrofluid, while this study optimized parameters to achieve 93% for PE. These findings emphasize the importance of optimizing treatment parameters, such as ferrofluid concentration and contact

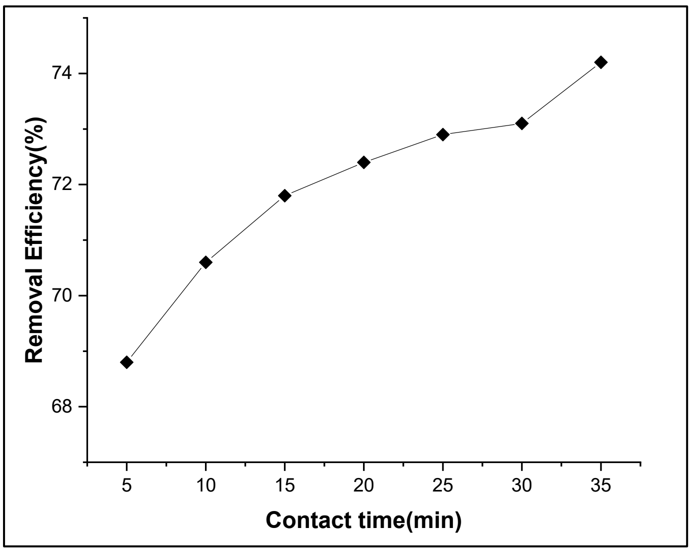

Fig. 6. Removal rates of microplastics after magnetization at different durations.

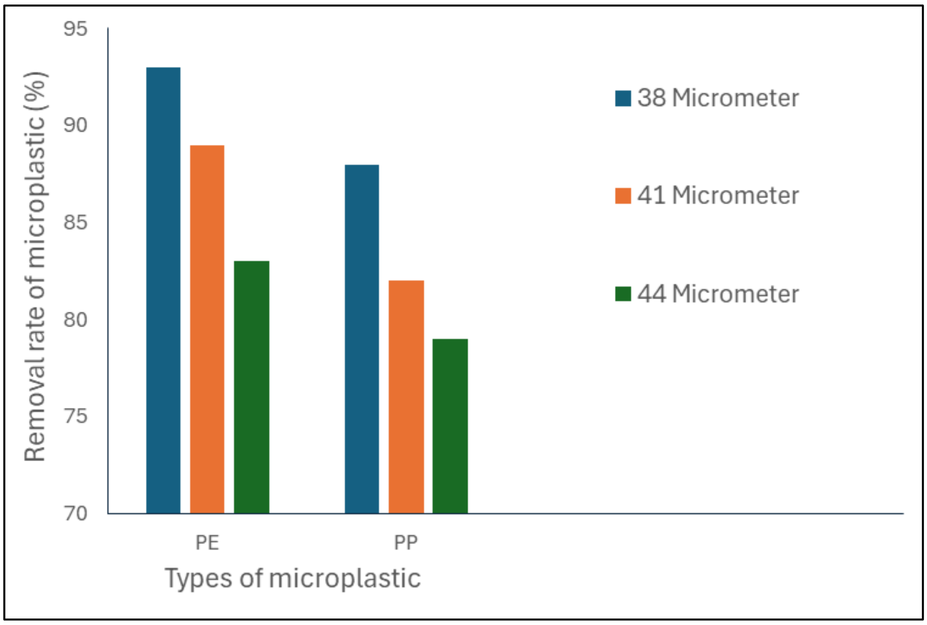

Fig. 7. Removal rates of various-diameter PE and PP particles

Table 1. The results of Physicochemical parameters of water in Kibangu River (n=3) (Field work, March 2024)

Parameters	Riverside Interchange	Bonde La Mchicha	Nida Textile	Kigogo Mbuyuni	Tanzania Bureau of Standards
pH	8.3± 0.21	7.57 ± 0.32	8.73 ± 0.15	8.52 ± 0.16	6.5 – 8.5
Temperature(^{0}C)	28.9 ± 0.53	26.4 ± 0.125	27.8 ± 0.4	27.23 ± 0.35	N/A
Electrical conductivity (µs/cm)	1721.33 ±67.5	2025 ± 13.08	2055.67 ± 16.04	2016.67 ± 17.38	1500
Salinity (ppm)	0.845 ± 0.04	1.00 ± 0.01	1.02 ± 0.01	1.01± 0.01	N/A

N/A- not available

time and considering polymer type and particle size in improving MP removal methods. For example, (Wang et al., 2014) reported 92.47% removal of PE using froth flotation combined with alkaline treatment. (Grbic et al., 2019) reported 92% removal of 10-20 µm polyethylene from water samples. These lower efficiencies compared to the current study may be attributed to using different surfactants in magnetite ion dispersion. While previous studies employed hexadecyltrimethoxysilane (HDTMS) as a surfactant, which shows weak repulsive forces, this study used vegetable oil, potentially leading to a highly effective dispersion of magnetic particles.

Microplastic Removal Efficiency Comparison

To evaluate the efficiency of sand filtration and ferrofluid-based separation in removing microplastics from wastewater at Kibangu River, we conducted a controlled experiment. The influent wastewater contained microplastics ranging from 1 to 500 µm, with the highest concentration—1,000 particles per liter—found in the smallest size fraction (1–10 µm), while larger microplastics appeared at lower concentrations. By systematically analyzing the removal efficiencies of both methods, we gained valuable insights into their effectiveness across different microplastic sizes. The findings of this study are summarized in Table 1.

The findings indicate that while sand filtration shows moderate effectiveness in removing larger microplastics (>100 µm), achieving removal rates of 80% to 90%, its efficiency declines sharply for smaller particles. For microplastics in the 1–10 µm range, sand filtration achieved

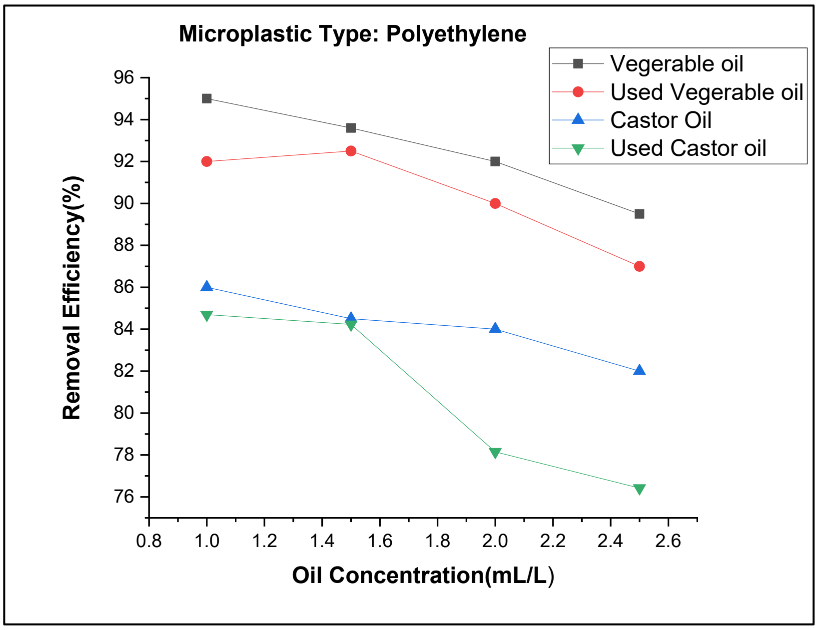

Fig. 8. Effects of oil (types & volumes) and polyethylene on the removal efficiency

only 30% to 50% removal, suggesting that fine particles either pass through the filter pores or are only partially kept due to their small size and low settling velocity. Ferrofluid-based separation consistently delivered superior removal efficiency across all particle sizes, with rates ranging from 85% to 99%. This exceptional performance is attributed to the strong magnetic adsorption properties of ferrofluid, which effectively capture microplastics and enable their removal through magnetic extraction. Ferrofluid separation maintained its effectiveness even for the smallest microplastics (1–10 µm), achieving up to 99% removal—an area where sand filtration proved least effective. Sand filtration removes microplastics from water and wastewater primarily through retention within the filter media and deposition on its surface (Talvitie et al., 2017). The efficiency of this process depends on the characteristics of the sand filter, with larger microplastics being removed more effectively than smaller ones (Wang et al., 2020; Babel & Dork, 2021; Kankanige & Babel, 2020). Additionally, research suggests that fiber-shaped microplastics are captured more efficiently by sand filtration than other shapes (Wang et al., 2020; Babel & Dork, 2021). Given that membrane filtration features much smaller pore sizes than sand filtration media, it serves as a more effective alternative for capturing fine microplastics that escape conventional sand filtration (Katrivesis et al., 2021).

Removal Efficiency of Microplastics Using Ferrofluid-Oil Mixtures

The efficiency of ferrofluids mixed with fresh and used vegetable and castor oils in removing PE and PP MPs was evaluated. For PE MPs, fresh vegetable oil showed the highest removal efficiency, (Figure 8) achieving 95% at a 1 ml concentration, followed by fresh castor oil at 87%. Used vegetable and castor oils showed lower efficiencies, with 92% and 84.3%, respectively. This pattern aligns with the findings of (Martinez and Kim, 2020), who reported that fresh oils outperform used oils due to reduced contamination and the preservation of active adsorption sites.

Similarly, for PP MPs, fresh vegetable oil achieved the highest removal efficiency (Figure 9) (89.5% at 1 ml), followed by fresh castor oil (84.9%). Used vegetable and castor oils achieved slightly lower efficiencies of 87.5% and 82.97%, respectively. These observations follow those of Hamzah et al., (2021), who noted that fresh oils enhance MP removal due to their higher adsorption capacities and lower levels of degradation products.

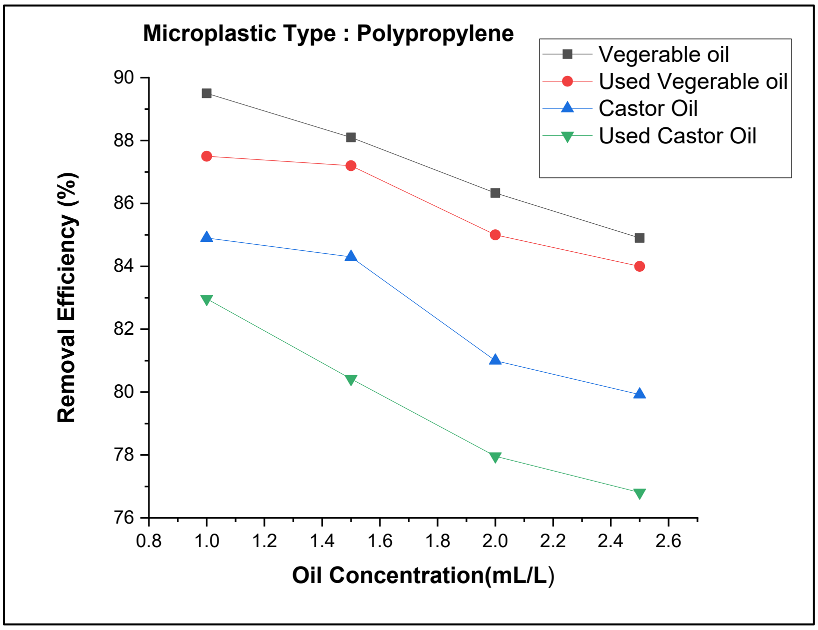

Fig. 9. Effects of oil (types & volumes) and polypropylene on the removal efficiency

Table 2. Comparison of microplastic removal efficiency between Sand Filtration and Ferrofluid-based Separation

Microplastic Size (µm)	Initial Concentration (particles/L)	Removal Efficiency (%) – Sand Filter	Removal Efficiency (%) – Ferrofluid-based
1-10	1000	45	90
10-50	800	63	92
50-100	600	78	97
100-500	400	84	95

Interestingly, a decline in efficiency was observed for all oils at higher concentrations (2–2.5 ml). For example, fresh vegetable oil efficiency dropped to 89% for PE and 84.9% for PP, while used castor oil efficiency fell to 76.42% for PE and 76.85% for PP. This decline is likely caused by the saturation of active adsorption sites or the aggregation of ferrofluid particles, as previously reported by (Hamzah et al., 2021).

In comparing vegetable and castor oils, fresh vegetable oil consistently outperformed castor oil, which may be attributed to its lower viscosity, enhancing mixing and adsorption. This is supported by (Martinez and Kim 2020), who demonstrated that lower-viscosity oils improve MP removal efficiency by promoting better interaction between MPs and the ferrofluid.

These results align with previous studies by (Hamzah et al., 2021) which reported similar trends in MP removal using ferrofluid-oil systems. The findings reinforce the importance of selecting appropriate oil types and concentrations to optimize removal efficiency, particularly in addressing real-world wastewater conditions.

CONCLUSIONS

This study aimed to investigate the abundance of MPs in the Kibangu River and to explore the effectiveness of ferrofluid-based methods for their removal. The findings provide critical insights into the scale of MP pollution in the river, and the best conditions influencing the removal efficiency of different types of MPs. Below are the key conclusions drawn from the research.

• The abundance of MPs in the Kibangu River ranged from 9 to 21 particles/l, and the average abundance was 15 particles/l. The Riverside Interchange showed a high MP abundance of 21 particles/l, but Nida Textiles had the lowest MP abundance of 9 particles/l.

• The best conditions for efficient MP removal using ferrofluid were found to be a concentration of 3.2 g/l and a contact time of 25 minutes, as higher concentrations or longer durations showed no significant improvements.

• MP removal efficiency is influenced by both particle size and polymer type. Smaller particles (38 µm) showed higher removal rates due to their larger surface area to volume ratio, with PE achieving 93% efficiency compared to 88% for PP. These findings highlight the importance of considering particle size and polymer characteristics when optimizing MP removal methods.

• Fresh vegetable and castor oils, particularly at lower concentrations (1–1.5 ml), play a crucial role in enhancing the efficiency of ferrofluids for removing PE and PP MPs from river water. Among the oils tested, fresh vegetable oil showed the highest removal efficiency, making it the most effective option. Its superior performance highlights the importance of using high-quality, fresh oils to maximize MP removal. Higher concentrations and used oils were less effective, emphasizing the need for optimized oil selection to maintain the ferrofluid's functionality and achieve the best environmental outcomes.

• This study introduced an innovative method for removing MPs from water, offering promising potential for addressing MP pollution. The proposed method is economically affordable, ensuring cost-effectiveness and feasibility for large-scale application.

RECOMMENDATION

Ferrofluid-based systems should be optimized and scaled for real-world application, prioritizing fresh vegetable oils at low concentrations (1–1.5 ml) to enhance MP removal efficiency. Policymakers and stakeholders should integrate these methods into water treatment strategies, focusing on high-pollution areas like industrial zones. Further research is needed to assess long-term environmental impacts of ferrofluid use and alternative methods for microplastic removal that might be more environmentally sustainable.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or it's Supplementary Information.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

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