Assessment of Microplastic Pollution: Morphological and Polymer Characterisation of Microplastics in the Lubigi Wetland Ecosystem, Uganda

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ABSTRACT

Urban wetlands are increasingly exposed to microplastic contamination driven by rapid urbanisation, inadequate waste management and expanding wastewater discharges. This study presents a comprehensive assessment of microplastics in the Lubigi Wetland (Kampala, Uganda). Water and sediment samples were collected from nine sites spanning upstream, midstream and downstream zones and from four vertical strata (surface, middle, bottom water and 0–10 cm sediment). Samples were processed by density separation (saturated NaCl), peroxide digestion and vacuum filtration; particles were morphologically classified by stereomicroscopy and polymer types confirmed by Fourier Transform Infrared Spectroscopy (FTIR). A total of 1,118 microplastic particles were recorded: microbeads dominated (58.7%), followed by pellets (15.9%) and fragments (11.4%). Transparent particles comprised 42.8% of the assemblage and 61% of particles were < 0.001), with midstream sediment layers (notably Namungona and Nabweru) identified as depositional hotspots. FTIR confirmed polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), polystyrene (PS), polyvinyl chloride (PVC) and Nylon6, with PET and PP more frequent in water and PE, PS and PVC more common in sediments. The dominance of microbeads and the polymer signature implicate urban and domestic sources (personal care products, packaging, wastewater and textile effluents) and reflect transport and depositional processes governed by hydrodynamics and wetland geomorphology. These findings align with regional and global observations that freshwater and wetland systems are important sinks and conduits for microplastics and underscore the need for targeted waste-management, wastewater controls and routine monitoring to protect wetland ecosystem services and public health.

Keywords: Microplastics; Lubigi Wetland; FTIR; Microbeads; Sediments

INTRODUCTION

Urban wetlands are among the most dynamic and vulnerable ecosystems, providing essential services such as water purification, flood regulation and biodiversity support. In rapidly urbanising regions these systems are exposed to a growing suite of pollutants, and microplastics plastic particles smaller than 5 mm have emerged as a contaminant of global concern because of their persistence, mobility and capacity to adsorb and transport other pollutants (Aragaw, 2021; Saikia & Handique, 2026). Their widespread occurrence in aquatic environments, together with potential impacts on ecological and human health, makes it urgent to understand their distribution, characteristics and sources within critical wetland systems (Wang & Wang, 2020; Latif *et al.*, 2025).

The Lubigi Wetland, situated on the periphery of Kampala, Uganda's capital, exemplifies the pressures confronting urban wetlands in sub-Saharan Africa. Lubigi functions as an important water catchment, supports distinctive wetland vegetation and birdlife, and buffers the city against flooding, yet it is increasingly stressed by urban expansion, inadequate waste management and infrastructural development (NEMA, 2019; Akankwasah, 2025). The infiltration of microplastics into this ecosystem therefore raises pressing questions about the extent of contamination, the types of particles present and the implications for wetland functioning and human wellbeing (Nkuutu, 2025).

Despite growing global attention to microplastic pollution, there remains a paucity of data from African wetlands. This evidence gap constrains the design of effective, locally appropriate management and mitigation strategies. Addressing the gap requires robust, context-specific research that integrates morphological and polymer characterisation with spatial and vertical distribution analyses so that sources, transport pathways and sinks can be identified and managed (Saikia & Handique, 2026; Duong *et al*., 2022).

This study therefore provides a comprehensive assessment of microplastic pollution in the Lubigi Wetland ecosystem. By characterising particle morphology and polymer composition, quantifying abundance in water and sediments, and mapping spatial and vertical distribution, the research aims to inform evidence-based interventions for wetland conservation and urban environmental management in Uganda and comparable settings (Nkuutu, 2025).

Problem Statement

Urban wetlands in Africa, including Lubigi, are increasingly threatened by microplastic pollution driven by rapid urbanisation, inadequate waste management and limited regulatory enforcement (Akankwasah, 2025; NEMA, 2019). The persistence and mobility of microplastics, together with their propensity to sorb toxic substances and enter food webs, pose clear risks to wetland ecosystems and to human populations that rely on wetland services (Latif *et al*., 2025; Tran *et al*., 2025). Yet empirical data on the types, abundance and distribution of microplastics in African wetlands particularly detailed morphological and polymer characterisation remain scarce, limiting the development of targeted policies and practical interventions such as monitoring programmes, improved waste collection and wastewater controls (Aragaw, 2021; Themba *et al*., 2025). This study addresses that evidence gap for Lubigi Wetland by applying standardised field and laboratory methods to generate locally relevant data (Nkuutu, 2025; Duong *et al*., 2022).

Research Questions and Hypotheses

Research questions

- What are the predominant morphological characteristics (shape, colour, size) of microplastics in the Lubigi Wetland ecosystem?
- What is the polymer composition of microplastics present in water and sediment samples from Lubigi Wetland?
- How are microplastics spatially and vertically distributed across different zones and depths within the wetland?
- What are the potential sources and environmental drivers influencing microplastic abundance and distribution in Lubigi Wetland?

Hypotheses

- **H1:** Microbeads and pellets are the most abundant microplastic shapes in Lubigi Wetland, reflecting urban and domestic sources.
- **H2:** Polyethylene terephthalate (PET) and polypropylene (PP) dominate in water samples, while polyethylene (PE), polystyrene (PS) and polyvinyl chloride (PVC) are more prevalent in sediments.
- **H3:** Sediment layers contain significantly higher microplastic loads than the overlying water column, with midstream zones acting as depositional hotspots.
- **H4:** The spatial and vertical distribution of microplastics is influenced by urban runoff, wastewater inputs and wetland geomorphology.

LITERATURE REVIEW

Microplastic pollution has been recorded across marine, freshwater and terrestrial environments worldwide, but the bulk of research has concentrated on marine systems while freshwater and wetland environments remain comparatively understudied (Mutuku *et al*., 2024; Saikia & Handique, 2026). Microplastics originate from primary sources (manufactured microbeads, industrial pellets) and secondary sources (fragmentation of larger plastics), and their persistence and affinity for other pollutants such as heavy metals and persistent organic pollutants amplify ecological risks (Aragaw, 2021; Tran *et al*., 2025).

Morphological characterisation commonly distinguishes microplastics by shape (fibres, fragments, films, pellets, microbeads), colour and size, while polymer identification typically by FTIR or Raman spectroscopy repeatedly finds PE, PP, PET, PS and PVC among the most frequent polymers in environmental samples (Rosal, 2021; Wetzel, 2025; Wang & Wang, 2020). However, methodological inconsistencies in sampling, extraction and identification hinder direct comparisons and meta-analysis; there is no universally adopted protocol for wetland monitoring, and many studies differ in size cutoffs, density-separation media and contamination controls (Saikia & Handique, 2026; Thornton Hampton *et al*., 2025; Ahmad Bhat *et al*., 2024).

Spatial and vertical distribution studies indicate that sediments often act as sinks, accumulating larger and denser particles, whereas the water column tends to contain higher proportions of very small particles that remain mobile and bioavailable (Huang *et al*., 2022; Zhang *et al*., 2025). Hydrodynamics, proximity to urban centres, land use and point sources such as wastewater and textile effluents strongly influence local patterns (Arévalo-Hernández *et al*., 2025; Themba *et al*., 2025). Regionally, African studies are limited and unevenly distributed, which constrains the evidence base needed for locally appropriate management and policy responses (Aragaw, 2021; Akankwasah, 2025).

To address these gaps, the present study applies validated field and laboratory methods including appropriate density-separation solutions, rigorous contamination control, stereomicroscopy and FTIR confirmation to generate a robust, site-specific dataset for Lubigi Wetland that can inform monitoring, risk assessment and practical mitigation in similar urban wetland contexts (Duong *et al*., 2022; Thornton Hampton *et al*., 2025; Nkuutu, 2025).

METHODOLOGY

Study area Lubigi Wetland and Kampala context

Lubigi Wetland forms an irregular semicircle around the northern and western outskirts of Kampala and functions as a critical urban water catchment and biodiversity refuge (Nkuutu, 2025; NEMA, 2019). The wetland receives runoff from densely populated neighbourhoods, is intersected by major transport corridors and is subject to encroachment and pollution from urban expansion, making it a pertinent site for assessing urban microplastic inputs (Nkuutu, 2025; Akankwasah, 2025).

Regulatory and policy context

Uganda's National Environment Act (2019) and the mandate of the National Environment Management Authority (NEMA) provide the statutory framework for wetland protection, but enforcement challenges and resource constraints limit effective implementation, particularly in rapidly urbanising catchments (NEMA, 2019; Akankwasah, 2025).

Research design and sampling strategy

A cross-sectional, field-based design was used to capture spatial and vertical variation in microplastic occurrence. Nine sites (S1–S9) were selected to represent upstream, midstream and downstream zones and to capture gradients of urban influence and hydrological conditions (Nkuutu, 2025). At each site, samples were collected from four vertical strata surface water, middle water, bottom water and sediment cores (0–10 cm) enabling analysis of both horizontal and vertical distribution patterns (Thornton Hampton *et al*., 2025; Duong *et al*., 2022).

Sample collection and contamination control

Water samples (surface, middle, bottom) were collected using pre-cleaned glass bottles and stainless-steel samplers to minimise contamination (Thornton Hampton *et al*., 2025). Sediment cores were obtained with stainless-steel corers to 10 cm depth following international guidance for sediment monitoring (Thornton Hampton *et al*., 2025). Field blanks and procedural blanks were included throughout sampling and laboratory processing to quantify and correct for background contamination, and personnel used cotton clothing and nitrile gloves while equipment was rinsed with filtered distilled water (Ahmad Bhat *et al*., 2024; Duong *et al*., 2022).

Laboratory processing and analytical methods

Density separation was performed using a saturated NaCl solution ($\approx 1.19\ g \cdot cm^{-3}$) for initial extraction of buoyant microplastics from water and sediment matrices, following validated protocols for tropical sediments (Duong *et al*., 2022). Organic matter was digested with 30% H_2O_2 at controlled temperature to reduce biological interference while minimising alteration of plastic particles (Thornton Hampton *et al*., 2025). Filtered residues were retained on 0.45 µm cellulose nitrate membranes and stored in glass petri dishes under aluminium foil until analysis (Duong *et al*., 2022).

Particles were visually classified by shape, colour and size using stereomicroscopy at 10×–135× magnification (Rosal, 2021). Polymer identification was confirmed by Fourier Transform Infrared Spectroscopy (FTIR) on a randomly selected subset of particles, with spectra matched to reference libraries to identify PE, PP, PET, PS, PVC and Nylon-6 among other polymers (Wetzel, 2025; Rosal, 2021). Methodological choices including size class boundaries, morphological categories and polymer targets followed best practice recommendations to enhance comparability with other studies (Saikia & Handique, 2026; Thornton Hampton *et al*., 2025).

Quantification, standardisation and statistical analysis

Abundance was standardised to $particles \cdot m^{-3}$ for water and $particles \cdot kg^{-1}$ dry weight for sediments, with relative proportions by shape, colour, size and polymer calculated for comparative analyses (Wang & Wang, 2020). Statistical tests (three-way ANOVA, Kruskal–Wallis, Chi-square) were used to assess differences across sites, depths and morphological categories, and spatial patterns were interpreted in relation to urban runoff, wastewater inputs and wetland geomorphology (Arévalo-Hernández *et al*., 2025; Huang *et al*., 2022).

Quality assurance, ethics and data availability

Quality assurance included analysis of field and laboratory blanks, instrument calibration with certified reference materials and replication of analyses in triplicate to ensure reproducibility (Ahmad Bhat *et al*., 2024; Wetzel, 2025). The study received ethical and institutional approvals and field permits in accordance with national requirements (Nkuutu, 2025; UNCST, 2025). Data and supplementary materials are available from the corresponding author on reasonable request to support transparency and future comparative work (Nkuutu, 2025).

RESULTS

Morphological characterisation

Microscopic analysis confirmed the presence of six morphological categories: fibres, filaments, films, fragments, microbeads, and pellets. Their distribution varied both spatially and vertically.

Table 1. Abundance and Relative Proportion (%) of Microplastic Shapes in Sediment and Surface Water Samples from Lubigi Wetland

Shape	Sediment n (%)	Water n (%)	Total n (%)
Fibres	29 (7.6%)	86 (11.7%)	115 (10.3%)
Filaments	1 (0.3%)	11 (1.5%)	12 (1.1%)
Films	1 (0.3%)	28 (3.8%)	29 (2.6%)

Fragments	24 (6.3%)	104 (14.1%)	128 (11.4%)
Microbeads	306 (80.1%)	350 (47.6%)	656 (58.7%)
Pellets	21 (5.5%)	157 (21.3%)	178 (15.9%)
Total	**382 (100%)**	**736 (100%)**	**1,118 (100%)**

Microbeads were the most abundant shape overall (58.7%), particularly in sediments and bottom waters. Pellets (15.9%) and fragments (11.4%) were also prevalent, while fibres (10.3%), films (2.6%), and filaments (1.1%) were less common. Upstream sites recorded the highest overall counts, with microbeads dominating sediments and bottom layers, while fibres were more common in surface and middle waters. Midstream sites, especially Namungona and Nabweru, showed strong microbead presence in sediments, with notable contributions from pellets and fragments. Downstream sites contained fewer particles overall but still showed consistent presence of microbeads and pellets.

Colour distribution

Seven colour categories were identified: **black, blue, green, purple, transparent, yellow, and white**. Transparent particles were the most common overall, particularly among microbeads (n = 479), and were present across all sites and depths.

Table 2. Distribution of Microplastic Colours by Shape across Sites S1–S9, Lubigi Wetland

Shape	Dominant Colours (n)	Notable Observations
Fibres	Transparent (44); Blue (24)	Yellow fibres (n = 3) at S5 and S6
Filaments	Blue (7); Transparent (3)	Rare overall
Films	Red (8); White (8); Green (7)	Red films concentrated at S4
Fragments	Blue (53); Red (26); Transparent (20)	Purple fragments (22) at S9
Microbeads	Transparent (479); Purple (82); Red (58)	High purple counts at S7
Pellets	Red (60); White (34); Blue (28)	Yellow pellets (21) at S4

Transparent particles dominated (42.8%), followed by blue (24.8%), black (18.0%), red (13.1%), purple (9.3%), yellow (2.1%), and white (2.6%). Colour composition differed significantly between sites ($\chi^2(15) = 28.47$, $p = 0.019$), with transparent/white particles most common, followed by blue, black, and red. Three-way ANOVA revealed a significant **Colour × Depth** interaction ($F = 3.87$, $df = 12$, $p = 0.002$, $\eta = 0.041$).

Size classes

Particles <300 µm accounted for 61% of total counts, particularly in the water column. Median and mean particle sizes varied by shape and colour, with fibres generally larger (mean 83.8 µm) and microbeads smaller (mean 28.7 µm).

Table 3. Size Class Boundaries and Observed Size Ranges of Microplastic Particles (µm)

Order	Class Name	Minimum Size (µm)	Maximum Size (µm)
1	Ultrafine	3.78	<9.0
2	Fine	9.09	<21.4
3	Moderate	22.46	<50.6
4	Coarse	53.57	<120.4
5	Very Coarse	121.21	<285.2
6	Macro	304.99	≥285.2

Polymer composition

FTIR analysis (n = 100 particles) identified **PE, PP, PET, PS, PVC** and **Nylon-6**. PE and PP were ubiquitous across depths and sites, PET was more prevalent in water, and Nylon-6 was concentrated at sites adjacent to textile or wastewater inputs (S1, S2, S5). Three-way ANOVA for polymer composition showed a significant **Polymer × Site** interaction ($F = 4.56$, df = 16, $p < 0.001$, partial $\eta = 0.072$).

Table 4. Polymer Types of Microplastics Identified in Water and Sediment Samples across Sites S1–S9, Lubigi Wetland

Site	Water (Polymers)	Sediment (Polymers)
S1	PET; PP	PE; PS
S2	PET; PP	PE; PS; PVC
S3	PET; PP	PE; PS
S4	PET	PVC; PE
S5	PET; PP	PVC
S6	PET; PP	PE; PS
S7	PET; PP; Nylon	PE; PVC
S8	PET; PP	PE; PS
S9	PET; Nylon	PE; PS; PVC

Quantification of microplastic abundance

Overall abundance and particle dimension statistics are summarised below.

Table 5. Descriptive Statistics for Microplastic Abundance and Particle Dimensions across All Samples

Variable	N	Min	Max	Mean	Std. Dev.
Number of particles	55,530	1	65	8.87	12.17
Area (µm²)	55,530	10.98	13,749.7	438.9	1,478.7
Perimeter (µm)	55,530	10.4	1,775.3	94.1	188.2
Length/Diameter (µm)	55,530	3.78	687.5	32.9	73.5

Microbeads were the most abundant shape overall (58.7%), with transparent particles dominating colour profiles (42.8%). Particles <300 µm accounted for 61% of all counts. PE, PP, PET, PS, and PVC were the dominant polymers, with PET and PP prevalent in water samples and PE, PS, and PVC more common in sediments.

Table 6. Mean Microplastic Abundance by Depth Layer across All Sites

Depth Layer	Mean abundance	SD
Sediment Layer	17.68	18.9
Bottom Water	12.61	12.4
Middle Water	5.02	3.7
Surface Water	3.10	2.4

Sediment layers contained significantly more particles than the overlying water column ($t = 9.87$, $p < 0.001$). The water column contained a higher proportion of ultrafine particles (<300 µm).

Table 7. Spatial Trends in Mean Microplastic Particle Size across Lubigi–Mayanja Wetland

Site ID	Zone	Mean Particle Size Trend	Likely Source/Process
S1–S3	Upstream	Smallest (Ultrafine/Fine)	Urban runoff; cosmetics; packaging waste
S4–S7	Midstream	Moderate	Mixed inputs; sedimentation; side-channel inflow
S8–S10	Downstream	Largest (Coarse)	Hydrodynamic sorting; sediment retention; vegetation trapping

Three-way ANOVA revealed a significant **Site × Depth** interaction ($F = 672.34$, df = 24, $p < 0.001$, $\eta = 0.075$). Midstream sediment layers, particularly Namungona (41.08 ± 29.88 particles m^{-}) and Nabweru (20.70 ± 15.37

particles m^{-}), recorded the highest abundances. Binomial tests confirmed categorical dominance: Microbeads (58.7%) significantly exceeded the expected 50% threshold ($p < 0.001$).

DISCUSSION

The patterns observed in Lubigi Wetland are consistent with global reports of microplastic pollution, where microbeads, fibres and fragments commonly dominate particle assemblages and polymers such as PE, PP, PET, PS and PVC are frequently recorded (Aragaw, 2021; Wang & Wang, 2020). The strong dominance of microbeads and pellets in Lubigi points to urban and domestic sources personal care products, packaging and wastewater effluent as important contributors, a conclusion supported by studies of inland and urban water bodies elsewhere (Zhang *et al*., 2025; Saikia & Handique, 2026). The high proportion of transparent microbeads in our samples mirrors findings from other wetland and freshwater systems and likely reflects the widespread use of clear or lightly coloured microbead formulations and packaging materials (Rosal, 2021; Ahmad Bhat *et al*., 2024).

The vertical distribution recorded in Lubigi, with sediments acting as sinks for larger and denser particles while the water column contains a higher share of ultrafine particles, accords with observations from Lake Victoria and other regional studies (Mutuku *et al*., 2024; Huang *et al*., 2022). This partitioning is important because sediments may store contaminants over long periods, whereas very small particles in the water column remain mobile and more bioavailable, increasing the potential for uptake by organisms (Huang *et al*., 2022; Latif *et al*., 2025). Spatially, the concentration of microplastics in midstream depositional zones reflects the combined influence of urban runoff, wastewater inputs and wetland geomorphology, a pattern reported in other tropical and subtropical watersheds where reduced flow and sedimentation promote particle retention (Arévalo-Hernández *et al*., 2025; Ahmed *et al*., 2025).

Environmental and human health implications

The presence of microplastics across sediments and water in Lubigi raises clear ecological concerns. Microplastics can be ingested by benthic and pelagic organisms, cause physical harm and act as vectors for adsorbed pollutants, thereby increasing the risk of trophic transfer and bioaccumulation (Tran *et al*., 2025; Latif *et al*., 2025). The polymer mix observed PET and PP common in the water column and PE, PS and PVC concentrated in sediments suggests multiple source pathways including packaging, textiles and wastewater effluents, with implications for exposure routes to wildlife and humans.

Management implications

Findings point to the need for targeted waste-management interventions, improved wastewater treatment, and routine monitoring of urban wetlands. Reducing inputs from personal care products, packaging and textile effluents, combined with community waste collection improvements and enforcement of wetland protection regulations, would reduce ongoing microplastic loading to Lubigi.

CONCLUSION

Lubigi Wetland is moderately contaminated by microplastics, with microbeads dominating the particle assemblage and sediments acting as the principal sink. Spatial heterogeneity notably elevated midstream sediment loads and the polymer signatures observed point to multiple urban and domestic sources (e.g., cosmetics, packaging, wastewater and textile effluents) and to transport processes governed by hydrodynamics and geomorphology. The study underscores the need for targeted waste-management, wastewater controls and routine monitoring to protect wetland ecosystem services and public health in Kampala and comparable urban settings.

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