

Seasonal and Spatial Variation in Microplastic Morphology in a Protected Tropical Freshwater Ecosystem: Evidence from Okomu National Park, Nigeria

^{*1}Oyewole Omobolanle Oluwatoyin, ²Adetuga Adetola, ³Ajagbe Stephen Oluwabusayo and ¹Ogundiya Ayokunle Tosin

¹Federal College of Forestry, Ibadan, Oyo State, Nigeria.

²University of Ibadan, Oyo State, Nigeria.

³Forestry Research Institute of Nigeria.

*Corresponding authors' email: bollietee@gmail.com Phone: +2348065659538

ABSTRACT

Microplastic (MP) pollution in tropical freshwater ecosystems remains poorly characterized, particularly within protected landscapes. This study assessed the spatial and seasonal variation in MP morphology in surface waters of Okomu National Park, Nigeria. Water samples were collected from five sampling stations across two dry and two wet seasons, yielding 170 particles classified into six morphological categories: filament, fibre, foam, bead, fragment and plastic film. Filaments dominated the assemblage, accounting for 71.0% of particles during the dry season and 49.1% during the wet season. In contrast, fragments increased from 8.1% to 17.6%, while plastic films increased from 0% to 14.8% and occurred at all stations during the wet season. Seasonal morphology composition differed significantly ($\chi^2 = 20.45$, $df = 5$, $p = 0.001$; Cramér's $V = 0.347$), with filaments and plastic films representing the principal contributors to the observed shift. Morphological richness and Shannon diversity generally increased during the wet season, although paired station-level differences were not statistically significant. Spatially, morphological composition showed substantial overlap among stations, with no significant station-level association ($\chi^2 = 18.09$, $df = 20$, $p = 0.581$; Cramér's $V = 0.163$). These findings demonstrate seasonal restructuring of MP morphology despite limited spatial differentiation and provide a baseline for continued monitoring of plastic pollution in protected tropical freshwater ecosystems.

Received: 29 Sep. 2026

Accepted: 13 Oct. 2026

Published: 14 Oct. 2026

Keywords: Microplastics, Freshwater Ecosystem, Morphological Composition, Seasonal Variation

INTRODUCTION

Microplastic (MP) pollution has emerged as a persistent environmental concern in freshwater ecosystems because these particles are widely distributed, environmentally persistent and capable of interacting with aquatic organisms and other contaminants. Freshwater systems are particularly important in the movement of land-derived plastics, providing pathways through which particles can be transported, retained and redistributed across connected water bodies (Horton *et al.*, 2017; Range *et al.*, 2023). Their occurrence and distribution are influenced by watershed characteristics, land-based inputs, precipitation, runoff and hydrological conditions, resulting in substantial spatial and temporal variability among freshwater environments (Talbot & Chang, 2022). Particle morphology is also ecologically relevant because shape and physical characteristics influence transport, retention and vertical movement within aquatic systems (Range *et al.*, 2023).

Despite growing global research, knowledge of MP contamination in African freshwater ecosystems remains comparatively limited and spatially uneven. Recent continental assessments have confirmed the widespread occurrence of MPs in African waters, sediments and biota, with fibres and fragments among the most frequently reported morphologies (Nyaga *et al.*, 2024; Yakubu *et al.*, 2024). However, differences in sampling approaches and environmental conditions continue to constrain comparisons among locations and highlight the need for site-specific and temporally resolved investigations. Recent reviews have also emphasized the scarcity of standardized monitoring data and

the need for improved characterization of MP occurrence and distribution in African freshwater systems (Dinku *et al.*, 2025). In Nigeria, where freshwater resources support ecological functions and human livelihoods, information on the spatial and seasonal behaviour of MPs in relatively protected aquatic environments remains particularly limited. Okomu National Park contains interconnected rivers, streams, lakes and forest-associated aquatic habitats that provide an important setting for examining MP occurrence beyond highly urbanized freshwater systems. Yet, the extent to which MP morphology varies between seasons and among aquatic locations within the park remains insufficiently documented. Understanding these patterns is important for establishing a baseline for environmental monitoring and for identifying morphological changes that may accompany seasonal hydrological variability. This study aims to evaluate seasonal and spatial variation in microplastic morphology in surface waters of Okomu National Park, Nigeria, using compositional and diversity-based measures.

MATERIALS AND METHODS

Study Area

The study was conducted in Okomu National Park, Edo State, southern Nigeria, approximately 60 km north-west of Benin City. The park is one of Nigeria's protected forest areas and receives a mean annual rainfall of approximately 2,100 mm. The drainage system is dominated by the southerly flowing Osse River, which forms the eastern boundary of the park, while the Okomu River forms part of its western boundary (NCF, 2014; BI, 2025). The Okomu River, Arakhua stream

and Lake 36 were selected because of their ecological importance and their interaction with tourists and surrounding communities. Five sampling stations were established across these water bodies: RO Upstream, RO Midstream, RO Downstream, Lake 36 and Arakhua.

Sampling Design and Water Collection

Water sampling was conducted over four sampling periods spanning two consecutive years, from late 2024 to early 2026. The sampling periods represented two dry-season and two wet-season surveys, corresponding broadly to the dry season (November–March) and wet season (April–October). Each of the five stations was sampled once during each sampling period, resulting in 20 grab water samples in total.

At each station, surface water was collected using clean 250-mL glass bottles. Prior to sampling, the bottles were thoroughly washed and rinsed with 1–2 mL of 2% industrial hydrochloric acid (HCl) and subsequently rinsed with water from the sampling location. Samples were collected directly from the water column, securely capped, labelled according to station and sampling period, and transported to the laboratory for microplastic analysis. The sampling design therefore provided repeated seasonal observations at the same five spatial stations, but did not include independent within-station replicate samples during individual sampling occasions.

Microplastic Identification and Classification

Microplastic particles recovered from the water samples were examined under a stereomicroscope and characterized according to their physical morphology, colour and size. Morphological categories comprised filament, fibre, foam, bead, fragment and plastic film. These categories were retained consistently throughout the analysis to permit comparison among stations and seasons.

Where polymer identification was undertaken, suspected particles were further characterized using attenuated total reflectance Fourier-transform infrared (ATR-FTIR) spectroscopy. The spectroscopic approach was used to determine polymer composition based on infrared spectral characteristics. Morphological observations and polymer identification were considered complementary descriptors of the recovered particles; however, the statistical analyses reported in this study focused on morphological composition.

Data Preparation and Statistical Analysis

The statistical approach was formulated to assess seasonal and spatial variations in microplastic morphology composition and diversity, explicitly accounting for the hierarchical sampling design. Raw particle counts were aggregated by morphology, sampling station, and season. The relative abundance of each morphology was calculated as the proportion of particles corresponding to that morphology out of the total particles recovered within the relevant seasonal or spatial grouping, then expressed as a percentage. Seasonal differences in the aggregated morphology composition were first examined using Pearson's chi-square (χ^2) test of independence on a 2×6 contingency matrix, representing two seasonal categories (dry and wet) and six morphology classes. To address the potential bias arising from low-frequency categories, the χ^2 results were corroborated using a fixed-margin Monte Carlo randomization procedure, enhancing the robustness of statistical inference. The effect size of the association was quantified using Cramér's V statistic, providing a measure of association strength independent of sample size.

To pinpoint which morphological categories contributed to observed seasonal variations, particle counts by morphology were compared between dry and wet seasons through Fisher's exact tests. Given multiple comparisons across six morphological categories, p-values were adjusted with the Holm-Bonferroni procedure to control for family-wise error rate inflation. Statistical significance was determined at $\alpha = 0.05$. Spatial differences in morphology composition across five sampling stations were assessed via a 5×6 Pearson χ^2 contingency test, using station as the factor and morphology categories as responses. Similar to the seasonal analysis, Cramér's V quantified association strength, and fixed-margin Monte Carlo randomization provided supplementary validation of test significance.

For each station and season, two complementary diversity metrics were calculated. Morphological richness (S) was defined as the number of distinct morphology categories observed at each station per season. The Shannon–Wiener diversity index (H) was computed from the proportional abundance of morphologies within each station-season combination, according to:

$$H = -\sum (p_i \ln p_i) \quad (1)$$

Where (p_i) denotes the proportion of the i th morphology and (S) is the total number of morphology categories observed (Shannon and Weaver, 1949).

Seasonal differences in richness and Shannon diversity were tested with paired Wilcoxon signed-rank tests, considering the five stations as paired spatial units. Exact p-values were reported to accommodate the limited sample size. Seasonal shifts in morphology composition at each station were further characterized using Bray–Curtis dissimilarity indices calculated between dry and wet seasonal profiles. Bray–Curtis dissimilarity values range from 0 (identical composition) to 1 (complete dissimilarity) and were used descriptively due to the sampling design not incorporating independent replicates within stations (Bray and Curtis, 1957). This analytical framework aligns with established methodologies in ecological community analyses and microplastic pollution research, emphasizing care in interpreting compositional data and controlling Type I error in multiple testing contexts (Anderson, 2001; McDonald, 2009).

RESULTS AND DISCUSSION

Seasonal Variation in Microplastic Morphology

A total of 170 microplastic particles were recorded, comprising 62 particles during the dry season and 108 during the wet season (Table 1). Microplastics were detected at all sampling sites in both seasons, whereas plastic films occurred exclusively during the wet season, demonstrating their broad distribution across the sampled water bodies (Thanh *et al.*, 2026). Filaments were the predominant morphology in both seasons, although their relative contribution declined from 71.0% in the dry season to 49.1% in the wet season, alongside increases in fragments from 8.1% to 17.6% and plastic films from 0% to 14.8%. Fibre contribution remained relatively consistent between seasons (9.7–10.2%), while foam increased modestly from 6.5% to 8.3%; beads were recorded only during the dry season (4.8%). This seasonal restructuring is consistent with the role of hydrological processes in microplastic transport and redistribution, whereby increased runoff and water movement can mobilise particles with different physical characteristics (Thanh *et al.*, 2026). Wada *et al.* (2026) similarly reported the prevalence of polyethylene and polypropylene in freshwater microplastics, linking secondary particles to the degradation of packaging materials and agricultural films, while polyester and polyamide fibres

were associated with textile-washing effluents. Hu and Kuan (2025) likewise reported the predominance of synthetic fibres across seasons, highlighting the contribution of anthropogenic sources to microplastic contamination. The observed pattern suggests that the wet season modified the

relative composition of microplastic morphologies rather than merely increasing their occurrence, with the decline in filament dominance and greater representation of fragments and films constituting the principal seasonal changes (Figure 1).

Table 1: Seasonal Composition of Microplastic Morphologies

Microplastic morphology	Dry	RA%	Wet	RA%	Overall
Filament	44	71.0	53	49.1	97
Fibre	6	9.7	11	10.2	17
Foam	4	6.5	9	8.3	13
Bead	3	4.8	0	0.0	3
Fragment	5	8.1	19	17.6	24
Plastic film	0	0.0	16	14.8	16
Total	62	100.0	108	100.0	170

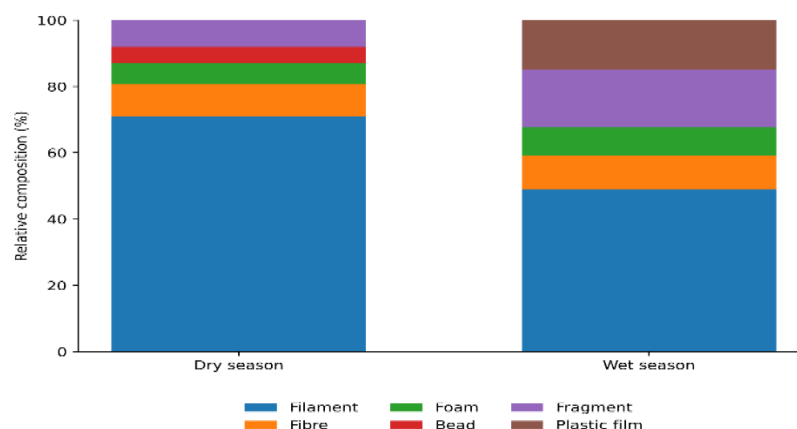


Figure 1: Seasonal composition of microplastic morphologies in water samples from Okomu National Park. NB: Bars represent the relative contribution (%) of each morphology during the dry and wet seasons

The pooled season $\times$ morphology analysis showed a statistically detectable difference in microplastic composition between the dry and wet seasons ($\chi^2 = 20.445$, $df = 5$, $p = 0.001$; Cramér's $V = 0.347$), with the fixed-margin Monte Carlo test providing a comparable result ($p \approx 0.001$). The moderate effect size indicates that the seasonal difference was not solely attributable to sampling variation in the pooled morphology counts. Seasonal variation in freshwater microplastics has been linked to changes in precipitation, runoff, water flow and resuspension, which can alter the transport and distribution of particles within aquatic systems (Cheung *et al.*, 2019; Talbot & Chang, 2022; Gutierrez-Rial *et al.*, 2025). The observed seasonal restructuring in Okomu is therefore consistent with the broader evidence that hydrological conditions can influence microplastic composition and movement in freshwater environments. However, because the present analysis used pooled particle counts rather than independent within-station environmental replicates, the result demonstrates a difference in pooled morphology composition between seasons, not a replicated causal effect of season on environmental microplastic abundance. This distinction is important because freshwater microplastic distributions are strongly influenced by sampling scale, analytical methods and spatial-temporal structure.

Morphologies Contributing To Seasonal Restructuring

The seasonal restructuring was most clearly associated with changes in the representation of filaments and plastic films. Filament counts increased from 44 particles during the dry

season to 53 during the wet season, but their relative contribution declined by 21.9 percentage points. Plastic films showed the opposite pattern, increasing from zero particles in the dry season to 16 particles in the wet season and accounting for 14.8% of the wet-season assemblage. Plastic films were detected at all five stations during the wet season but were absent from all stations during the dry season. Fragments also increased from five to 19 particles, corresponding to an increase in relative contribution from 8.1% to 17.6%, although this change was not statistically significant after correction for multiple comparisons. Morphology-specific Fisher's exact tests, followed by Holm adjustment, confirmed significant seasonal differences for filaments (unadjusted $p = 0.0063$; Holm-adjusted $p = 0.0315$) and plastic films (unadjusted $p = 0.00062$; Holm-adjusted $p = 0.0037$). Differences in fibre (Holm-adjusted $p = 1.000$), foam ($p = 1.000$), beads ($p = 0.1881$) and fragments ($p = 0.3301$) were not statistically significant after adjustment. Accordingly, the strongest evidence for seasonal restructuring was associated with the reduced relative dominance of filaments and the emergence of plastic films during the wet season.

The decline in filament dominance and emergence of films during the wet season are consistent with evidence that microplastic transport is strongly influenced by particle shape and prevailing hydrological conditions. Fibrous particles have distinct settling and transport behavior, while changes in flow and turbulence can alter the vertical distribution and resuspension of differently shaped particles (Waldschläger & Schütttrumpf, 2019; de Carvalho *et al.*, 2021). Freshwater reviews likewise identify fibres, fragments and films among

the most frequently reported morphologies, including in African aquatic systems (Chen *et al.*, 2024; Yakubu, *et al.*, 2024; Dinku *et al.*, 2025). The increased representation of films and fragments during the wet season may therefore reflect enhanced mobilization and redistribution under higher-flow conditions, although the present study did not directly measure rainfall, discharge or source inputs. Recent evidence from South African rivers similarly reported higher suspended and settled microplastic occurrence during the wet season and linked seasonal patterns to hydrological transport and deposition processes (Nel & Froneman, 2015). Thus, the strongest evidence in the present study is for seasonal restructuring of morphology, particularly the reduced relative dominance of filaments and the emergence of plastic films, rather than a demonstrated seasonal increase in any specific environmental source.

Seasonal Richness, Diversity and Compositional Dissimilarity

Morphological richness increased during the wet season at four of the five stations, whereas RO Downstream maintained the same number of morphology categories in both seasons (Table 2). Gutierrez-Rial *et al.* (2025) reported that wetter periods, characterized by more intense rainfall events, can generate greater surface runoff and consequently increase the influx of debris, including MPs, into rivers. The largest increase occurred at Lake 36, where richness increased from two to five morphology categories. Such seasonal changes are consistent with the role of rivers and connected water bodies as pathways for transporting land-derived plastic debris, particularly during periods of increased runoff and hydrological connectivity (Schmidt *et al.*, 2017; Talbot & Chang, 2022; Treillesn *et al.*, 2022). Hydrological conditions can alter the transport, retention and redistribution of particles according to their size, density and shape, thereby changing the composition of microplastics observed in the water column (Range *et al.*, 2023; Guo *et al.*, 2024; Li *et al.*, 2023). Recent studies further demonstrate that seasonal hydrology can produce marked changes in microplastic distribution, although the direction and magnitude of these changes vary among systems depending on flow conditions and local sources (Dahms & Greenfield, 2025; Owowenu *et al.*, 2025; Tanaka & Nihei, 2026). Thus, the higher wet-season richness observed at most Okomu stations may reflect increased

hydrological connectivity and redistribution of morphologically diverse particles, although this mechanism was not directly measured in the present study.

Shannon diversity increased consistently at all five stations, with the largest change again occurring at Lake 36 (0.305–1.175), followed by RO Upstream (0.755–1.365) and RO Midstream (0.759–1.300). However, the paired Wilcoxon tests did not indicate statistically significant seasonal differences in either richness ($W = 0$, exact $p = 0.125$) or Shannon diversity ($W = 0$, exact $p = 0.0625$). The consistent direction of change therefore provides descriptive evidence of greater morphological heterogeneity during the wet season, but should not be interpreted as a statistically confirmed seasonal effect. Similar caution is warranted because freshwater microplastic distributions can vary substantially with sampling scale, hydrological regime and local environmental conditions (Talbot & Chang, 2022; Range *et al.*, 2023; Dahms & Greenfield, 2025). The relatively small number of paired spatial units in the present study ($n = 5$) further limits the power to detect seasonal differences.

Bray–Curtis dissimilarity likewise indicated varying degrees of seasonal restructuring among stations, ranging from 0.232 at Arakhua to 0.471 at RO Midstream. The higher dissimilarity at RO Midstream and Lake 36 suggests greater changes in morphology composition between seasons at these locations, whereas the lower value at Arakhua indicates greater compositional stability. Differences in seasonal restructuring among sites are plausible because local flow characteristics, channel morphology, retention processes and hydrological connectivity can influence microplastic transport and redistribution (Range *et al.*, 2023; Gigault *et al.*, 2024; Owowenu *et al.*, 2025). Recent South African evidence also demonstrates that microplastic distributions can vary among seasons and hydraulic settings, emphasizing that riverine microplastic patterns are not spatially or temporally uniform (Dahms & Greenfield, 2025; Owowenu *et al.*, 2025). However, the Bray–Curtis values in the present study are descriptive because no inferential permutation test was applied to the five paired station profiles. The results indicate a consistent tendency towards greater morphological richness and diversity during the wet season, accompanied by station-specific compositional restructuring, but provide insufficient replicated evidence to infer a statistically significant seasonal effect on richness or diversity.

Table 2: Seasonal Morphological Richness, Shannon Diversity and Bray–Curtis Dissimilarity by Station

Station	Dry richness	Wet richness	Dry Shannon H'	Wet Shannon H'	Bray–Curtis dissimilarity
RO Upstream	4	5	0.755	1.365	0.331
RO Midstream	3	5	0.759	1.300	0.471
RO Downstream	5	5	1.128	1.264	0.271
Lake 36	2	5	0.305	1.175	0.429
Arakhua	4	5	1.215	1.516	0.232

Note: Bray–Curtis values are descriptive measures of seasonal compositional dissimilarity between paired station profiles; no permutation-based significance test was applied.

Spatial Variation in Microplastic Morphology

Microplastic morphology showed substantial overlap among the five sampling stations (Table 3). Filaments were the dominant morphology at all stations, contributing 60.6% of particles at RO Upstream, 58.1% at RO Midstream and RO Downstream, 68.8% at Lake 36 and 38.7% at Arakhua. Arakhua was comparatively more heterogeneous, with the lowest filament contribution and higher proportions of fragments (22.6%), fibres (16.1%) and foam (16.1%). Such differences among locations are plausible because microplastic distribution within river systems is influenced by

flow velocity, channel morphology, vegetation, particle density and shape, which can promote differential transport and retention (Range *et al.*, 2023; Li *et al.*, 2023; Gigault *et al.*, 2024).

The predominance of filaments across all stations is also consistent with evidence from African freshwater systems, where fibres and fragments are frequently the dominant morphological categories (Yakubu *et al.*, 2024; Nyaga *et al.*, 2024; Dinku *et al.*, 2025). The relatively greater representation of fragments, fibres and foam at Arakhua may reflect local differences in hydrodynamic conditions or

particle retention, but these mechanisms cannot be confirmed without measurements of flow, channel characteristics or potential sources. Studies from South African rivers similarly demonstrate that microplastic distribution can vary among hydraulic zones and sampling locations, with particle characteristics and local flow conditions influencing spatial patterns (Dahms & Greenfield, 2025; Owowenu *et al.*, 2025). RO Downstream yielded the largest pooled particle count ($n = 43$), compared with 31–33 particles at the other stations, but these counts should not be interpreted as differences in contamination levels because independent within-station

replicates were unavailable. This caution is important because microplastic abundance and morphology can be strongly affected by sampling methodology and local hydraulic conditions (Nyaga *et al.*, 2024; Adewuyi & Li, 2024). The substantial overlap in morphology among stations suggests limited spatial differentiation in the pooled assemblage, despite localized differences in the relative contribution of individual morphologies. The results therefore support spatial heterogeneity at the descriptive level, but not sufficient evidence to attribute these differences to station-specific contamination gradients.

Table 3: Spatial Composition of Microplastic Morphologies across Sampling Stations

Station	Filament, n (%)	Fibre, n (%)	Foam, n (%)	Bead, n (%)	Fragment, n (%)	Plastic film, n (%)	Total
RO Upstream	20 (60.6)	2 (6.1)	3 (9.1)	0 (0.0)	5 (15.2)	3 (9.1)	33
RO Midstream	18 (58.1)	4 (12.9)	1 (3.2)	1 (3.2)	2 (6.5)	5 (16.1)	31
RO Downstream	25 (58.1)	5 (11.6)	3 (7.0)	1 (2.3)	5 (11.6)	4 (9.3)	43
Lake 36	22 (68.8)	1 (3.1)	1 (3.1)	1 (3.1)	5 (15.6)	2 (6.3)	32
Arakhua	12 (38.7)	5 (16.1)	5 (16.1)	0 (0.0)	7 (22.6)	2 (6.5)	31
Total	97 (57.1)	17 (10.0)	13 (7.6)	3 (1.8)	24 (14.1)	16 (9.4)	170

Note: Values are pooled across the two dry and two wet sampling periods. Percentages are calculated within station. The pooled station $\times$ morphology association was not significant (Pearson $\chi^2 = 18.091$, $df = 20$, $p = 0.581$; Cramér's $V = 0.163$).

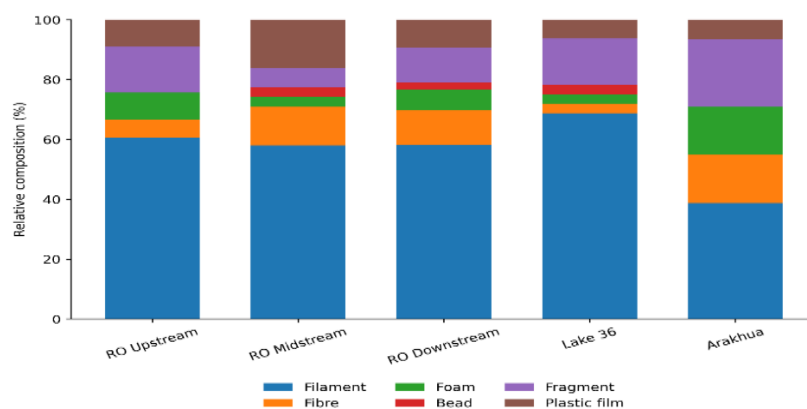


Figure 2: Spatial composition of microplastic morphologies across sampling stations in Okomu National Park. NB: Bars represent the relative contribution (%) of each morphology within each station based on particles pooled across the sampling periods

Spatial Statistical Assessment of Microplastic Morphology

Table 4 shows the statistical assessment of spatial and seasonal patterns in microplastic morphology. The station $\times$ morphology contingency analysis showed no statistically significant association between sampling station and morphology (Pearson $\chi^2 = 18.091$, $df = 20$, $p = 0.581$; Cramér's $V = 0.163$), with the fixed-margin Monte Carlo test giving a comparable result ($p = 0.596$). Thus, although individual stations differed descriptively in the relative contribution of particular morphologies, the pooled assemblage showed no pronounced spatial structuring among the five stations. This limited spatial differentiation is consistent with evidence that microplastic assemblages within river systems can overlap substantially where particles are transported through connected watercourses, although local hydraulic conditions may still modify their distribution and retention (Range *et al.*, 2023; Owowenu *et al.*, 2023; Gigault *et al.*, 2024).

The relatively small Cramér's V (0.163) further indicates that the association between station and morphology was weak. This finding does not imply spatial uniformity, but rather that the observed differences were insufficiently consistent to produce a detectable station-level pattern. Microplastic

distributions can vary with flow velocity, channel morphology, bed characteristics, vegetation and particle properties, resulting in localized accumulation without necessarily producing broad spatial differences among sampling stations (Owowenu *et al.*, 2023; Range *et al.*, 2023). Recent evidence from South African rivers similarly demonstrates that microplastic distributions may differ among hydraulic zones, with flow conditions, particle density and size influencing retention and transport (Owowenu *et al.*, 2025).

Morphological richness ranged from five categories at RO Upstream and Arakhua to six at RO Midstream, RO Downstream and Lake 36. The occurrence of most morphology categories across stations, together with the absence of a significant station $\times$ morphology association, suggests that the sampled water bodies shared a broadly similar morphological assemblage. Comparable overlap among African freshwater systems has been reported, although differences in sampling methods can substantially influence measured morphology and abundance (Yakubu *et al.*, 2024; Nyaga *et al.*, 2024). The results indicate weak spatial structuring of pooled microplastic morphology, while localized differences should be interpreted descriptively rather than as evidence of distinct contamination gradients.

Table 4: Statistical Assessment of Seasonal and Spatial Patterns in Microplastic Morphology

Response/comparison	Statistical approach	Statistic	df	p-value	Effect size/adjusted p	Interpretation
Season × morphology	Pearson χ^2	20.445	5	0.001	Cramér's V = 0.347	Significant pooled seasonal association
Filament: dry vs wet	Fisher's exact test	—	—	0.0063	Holm p = 0.0315	Significant after adjustment
Fibre: dry vs wet	Fisher's exact test	—	—	1.000	Holm p = 1.000	Not significant
Foam: dry vs wet	Fisher's exact test	—	—	0.7707	Holm p = 1.000	Not significant
Bead: dry vs wet	Fisher's exact test	—	—	0.0470	Holm p = 0.1881	Not significant after adjustment
Fragment: dry vs wet	Fisher's exact test	—	—	0.1100	Holm p = 0.3301	Not significant after adjustment
Plastic film: dry vs wet	Fisher's exact test	—	—	0.00062	Holm p = 0.0037	Significant after adjustment
Richness: dry vs wet	Wilcoxon signed-rank	W = 0	—	0.125	Exact p	Not significant
Shannon diversity: dry vs wet	Wilcoxon signed-rank	W = 0	—	0.0625	Exact p	Not significant
Station × morphology	Pearson χ^2	18.091	20	0.581	Cramér's V = 0.163	No significant spatial association

Note: Seasonal χ^2 and morphology-specific Fisher tests were based on pooled particle counts. Richness and Shannon comparisons used the five stations as paired spatial units. The spatial contingency analysis was also based on pooled particle counts. The absence of independent within-station replicates limits interpretation of particle-level inferential tests as replicated environmental effects.

CONCLUSION

This study demonstrates clear seasonal restructuring of microplastic morphology in surface waters of Okomu National Park, despite limited evidence for pronounced spatial differentiation among the five sampling stations. Filaments dominated the assemblage in both seasons but declined substantially in relative contribution during the wet season, while plastic films emerged across all stations and fragments became more prominent. Wet-season morphological richness and Shannon diversity also increased consistently across stations, although these changes were not statistically significant at the station-pair level. The findings suggest that hydrological and runoff-related processes may influence the seasonal redistribution of differently shaped particles, consistent with the recognized role of precipitation, flow and particle characteristics in freshwater microplastic transport. The results establish Okomu National Park as an important freshwater setting for continued microplastic surveillance and provide a baseline for understanding seasonal changes in particle morphology. However, the absence of independent within-station replicates limits causal inference and source attribution. Future monitoring should incorporate replicated sampling, standardized water volumes, rainfall and hydrological measurements, particle-size distributions, and polymer-specific confirmation to resolve transport pathways and ecological exposure more robustly.

REFERENCES

- Adewuyi, A., & Li, Q. (2024). Emergence of microplastics in African environmental drinking water sources: A review on sources, analysis and treatment strategies. *Journal of Hazardous Materials Advances*, 16. <https://doi.org/10.1016/j.hazadv.2024.100465>
- Anderson, M. J. (2001). A new method for non-parametric multivariate analysis of variance. *Austral Ecology*, 26(1), 32–46.
- Andrady, A. L. (2011). Microplastics in the marine environment. *Marine Pollution Bulletin*, 62(8), 1596–1605. <https://doi.org/10.1016/j.marpolbul.2011.05.030>
- Bray, J. R., & Curtis, J. T. (1957). An ordination of the upland forest communities of southern Wisconsin. *Ecological Monographs*, 27(4), 325–349.
- Chen, D., Wang, P., Liu, S., Wang, R., Wu, Y., Zhu, A. X., & Deng, C. (2024). Global patterns of lake microplastic pollution: Insights from regional human development levels. *Science of the Total Environment* 954, 176620. <https://doi.org/10.1016/j.scitotenv.2024.176620>
- Cheung, P.K., Hung, P.L., Fok, L., 2019. River microplastic contamination and dynamics upon a rainfall event in Hong Kong, China. *Environmental Processes* 6 (1), 253–264.
- Cole, M., Lindeque, P., Halsband, C., & Galloway, T. S. (2011). Microplastics as contaminants in the marine environment: A review. *Marine Pollution Bulletin*, 62(12), 2588–2597. <https://doi.org/10.1016/j.marpolbul.2011.09.025>
- Dahms, H. T. J., & Greenfield, R. (2025). Profiling microplastics in a forgotten river system in Southern Africa. *Environmental Monitoring Assessment*, 197(4), 351. <https://doi.org/10.1007/s10661-025-13800-5>
- de Carvalho, A. R., Garcia, F., Riem-Galliano, L., Tudesque, L., Albignac, M., Ter Halle, A., & Cucherousset, J. (2021). Urbanization and hydrological conditions drive the spatial and temporal variability of microplastic pollution in the Garonne River. *Science of the Total Environment*, 769, 144479. <https://doi.org/10.1016/j.scitotenv.2020.144479>
- Dinku, D. E., Ndur, S., Gyimah, E., Fosu, S., & Korley, P. (2025). Microplastics in African freshwater sediments: A systematic review of characteristics, abundance and analytical methods. *Cleaner Water*, 4. <https://doi.org/10.1016/j.clwat.2025.100095>
- Guo, M., Noori, R., & Abolfathi, S. (2024). Microplastics in freshwater systems: Dynamic behaviour and transport processes. *Resources, Conservation and Recycling*, 205. <https://doi.org/10.1016/j.resconrec.2024.107578>
- Gutierrez-Rial, D., Villar, I., Lagoa, A., Feijoo, P., Soto, B., Garrido, J., & Mato, S. (2025). Dynamics of microplastics in urban rivers under varying hydrological regimes. *Journal of Hazardous Materials*, 498, 139843. <https://doi.org/10.1016/j.jhazmat.2025.139843>
- Hidalgo-Ruz, V., Gutow, L., Thompson, R. C., & Thiel, M. (2012). Microplastics in the marine environment: A review of the methods used for identification and quantification. *Environmental Science & Technology*, 46(6), 3060–3075. <https://doi.org/10.1021/es2031505>

- Horton, A. A., Walton, A., Spurgeon, D. J., Lahive, E., & Svendsen, C. (2017). Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities. *Science of the Total Environment*, 586, 127–141. <https://doi.org/10.1016/j.scitotenv.2017.01.190>
- Hu, T.-Y., & Kuan, W.-H. (2025). Seasonal rainfall and land-use impacts on microplastic characteristics in an endangered salmon stream. *Scientific Reports*, 16(1). <https://doi.org/10.1038/s41598-025-33600-8>
- Li, J., Liu, H., & Chen, J. P. (2018). Microplastics in freshwater systems: A review on occurrence, environmental effects, and methods for microplastics detection. *Water Research*, 137, 362–374. <https://doi.org/10.1016/j.watres.2017.12.056>
- Lusher, A. L., Hollman, P. C. H., & Mendoza-Hill, J. J. (2017). Microplastics in fisheries and aquaculture: Status of knowledge on their occurrence and implications for aquatic organisms and food safety. FAO Fisheries and Aquaculture Technical Paper No. 615. Rome, FAO.
- McDonald, J. H. (2009). *Handbook of Biological Statistics* (2nd ed.). Sparky House Publishing.
- Nel, H. A. & Froneman, P. W., 2015. A quantitative analysis of microplastic pollution along the south-eastern coastline of South Africa. *Marine Pollution Bulletin* 101, 274–279. <https://doi.org/10.1016/J.MARPOLBUL.2015.09.043>
- Nyaga, M. P., Shabaka, S., Oh, S., Osman, D. M., Yuan, W., Zhang, W., & Yang, Y. (2024). Microplastics in aquatic ecosystems of Africa: A comprehensive review and meta-analysis. *Environmental Research*, 248, 118307. <https://doi.org/10.1016/j.envres.2024.118307>
- Owowenu, E. K., Nnadozie, C. F., Akamagwuna, F., Noundou, X. S., Uku, J. E., & Odume, O. N. (2023). A critical review of environmental factors influencing the transport dynamics of microplastics in riverine systems: implications for ecological studies. *Aquatic Ecology*, 57(2), 557–570. <https://doi.org/10.1007/s10452-023-10029-7>
- Range, D., Scherer, C., Stock, F., Ternes, T. A., & Hoffmann, T. O. (2023). Hydro-geomorphic perspectives on microplastic distribution in freshwater river systems: A critical review. *Water Research*, 245, 120567. <https://doi.org/10.1016/j.watres.2023.120567>
- Schmidt, C., Krauth, T., & Wagner, S. (2017). Export of Plastic Debris by Rivers into the Sea. *Environmental Science & Technology* 51(21), 12246–12253. <https://doi.org/10.1021/acs.est.7b02368>
- Shannon, C. E., & Weaver, W. (1949). *The Mathematical Theory of Communication*. University of Illinois Press.
- Talbot, R., & Chang, H. (2022). Microplastics in freshwater: A global review of factors affecting spatial and temporal variations. *Environmental Pollution*, 292(Pt B), 118393. <https://doi.org/10.1016/j.envpol.2021.118393>
- Tanaka, M., & Nihei, Y. (2026). How flooding rivers deliver plastic to the ocean: A case study of microplastic and mesoplastic load-discharge relationships. *Water Research*, 291, 125175. <https://doi.org/10.1016/j.watres.2025.125175>
- Thanh, N. T., Toan, P. V., Minh, H. V. T., Lavane, K., Ngan, N. V. C., Ngan, L. T. K., Toan, V. T., Tuyen, N. V., & Kumar, P. (2026). Seasonal and Spatial Distribution of Microplastics in the Can Tho River (Mekong Delta, Vietnam): Occurrence and Characteristics. *Microplastics*, 5(3). <https://doi.org/10.3390/microplastics5030136>
- Treilles, R., Gasperi, J., Tramoy, R., Dris, R., Gallard, A., Partibane, C., & Tassin, B. (2022). Microplastic and microfiber fluxes in the Seine River: Flood events versus dry periods. *Sci Total Environ*, 805, 150123. <https://doi.org/10.1016/j.scitotenv.2021.150123>
- Wada, O. Z., Ijiwade, J. O., Ige, A. O., & Olawade, D. B. (2026). Recent occurrence of microplastics in freshwater and efficiency of available treatment technologies. *Next Research*, 3. <https://doi.org/10.1016/j.nexres.2025.101074>
- Waldschläger K, & Schütttrumpf H. 2019. Effects of Particle Properties on the Settling and Rise Velocities of Microplastics in Freshwater under Laboratory Conditions. *Environmental Science Technology* 2019 Feb 19;53(4):1958-1966. doi: 10.1021/acs.est.8b06794. Epub 2019 Feb 11. PMID: 30688437
- Yakubu, S., Miao, B., Hou, M., & Zhao, Y. (2024). A review of the ecotoxicological status of microplastic pollution in African freshwater systems. *Science of the Total Environment*, 946, 174092. <https://doi.org/10.1016/j.scitotenv.2024.174092>

