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ARTICLE

Microplastic distribution in surface water and sediments: Water quality dynamics in Laguna Lake West Bay, Philippines

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ABSTRACT

Laguna Lake West Bay is experiencing severe anthropogenic stress compounded by presence of emerging contaminants. This study evaluates the distribution and profile of microplastics (MPs) in surface water and sediment at four principal fishery locations (Talim Island, Muntinlupa, West Bay Center, and Sta. Rosa), sampled from March to April 2025. Following extraction via wet peroxide oxidation (WPO) and dual-stage density separation, particles were characterized using FTIR spectroscopy. The data confirm widespread MP pollution, showing a uniform spatial distribution with no significant localized variation in total abundance ($p > 0.05$, $\alpha = 0.05$). Notably, benthic sediments serve as the primary depositional reservoir, containing higher MP concentrations compared to the pelagic zone. Fragment-type particles were the most abundant morphologically across all sites. Compositional analysis identified HDPE, LDPE, and EVA as the principal polymers, indicating that single-use packaging, bottle caps, and fishery-related gear were the likely primary sources. Physicochemical analysis revealed that while most water quality parameters met DENR Class C standards, certain sites exhibited elevated ammonia and biochemical oxygen demand (BOD) levels, indicative of organic pollution. Despite these localized environmental stressors, statistical analyses showed no significant correlation ($p > 0.05$; $\alpha = 0.05$) between water quality dynamics and microplastic abundance. These findings highlight the critical threat posed by plastic pollution to the aquatic ecosystems of Laguna de Bay, underscoring the need for strengthened regulatory measures to safeguard ecological stability and public health.

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INTRODUCTION

The production of plastic materials is considered a breakthrough innovation across various product applications due to their lightweight, water-repellent, durable, affordable, and moldable nature (Kabeyi and Olanrewaju 2023; Fredi and Dorigato 2021). However, their non-biodegradability adversely affects human, wildlife, and environmental health (Thompson et al. 2009; Toochukwu 2022; Filho et al. 2022). The natural degradation of plastic material in aquatic ecosystems can take centuries, leading to environmental accumulation (Barnes et al. 2009; Webb et al. 2013). In addition, poor solid waste management, low post-use plastic recycling rates, and a lack of consumer awareness and effective policy contribute to elevated levels of plastic pollution (Kibria et al. 2023; Mihai et al. 2022; Sharma et al. 2021). Microplastics (MPs) pose a serious environmental threat to the Philippines, as they are increasingly recognized as common and emerging pollutants in aquatic habitats worldwide (Jolaosho et al. 2025; Ahmad et al. 2025; Tejano et al. 2025). Two pathways introduce these particles into the environment: primary sources, which consist of intentionally manufactured microscopic plastic particles, and secondary sources, which result from larger macroscopic plastic waste that gradually degrades and fragments in the environment. (Borriello et al. 2022; Osman Ahmed et al. 2023; Rached et al. 2023; Mohsin 2025). The plastic waste that remains in the environment becomes exposed to biological (enzymatic action of microbes), physical (weathering, wear, and tear), thermal (energy from UV radiation, IR, gamma rays), chemical (oxidation from the atmosphere) agents that cause fragmentation of the material into particles <5 mm (microplastics) (Elahi et al. 2021; Pickett et al. 2017; Singh et al. 2019; Kalogerakis et al. 2017).

KEYWORDS

Microplastics, Laguna de Bay, surface water, sediments

Recent global studies emphasize the escalating accumulation and ecological impacts of these pollutants in vital freshwater ecosystems, with MP exposure associated with reduced mobility (via entanglement), gastrointestinal obstruction, and bioaccumulation in the food chain (Nishmitha et al. 2025; Ali et al. 2024; Nguyen et al. 2022; Li et al. 2025). Also, the hydrophobic and high surface areas of MPs are suitable for the adsorption of other emerging contaminants, namely heavy metals, PFAS (PFOS, PFOA), and persistent organic pollutants (POPs that include furan, dioxin, organochlorine pesticides, and PAHs) (Li et al. 2022; Shi et al. 2022; Fu et al. 2021; Conesa 2022; Zhang et al. 2021). Interactions of MPs with other emerging contaminants increase ecological risk across trophic levels (Martin et al. 2022). Among the Southeast Asian countries, the Philippines generates plastic debris in the land, air, and water bodies (Rebuelta-Teh 2022).

Despite the existing regulatory framework for solid waste management, MPs in national water sources are increasing. Laguna de Bay, as the largest source of protein and fresh water in the Philippines, is vulnerable to rapid degradation of ecosystem services due to competitive land use (industrialization), improper land use zoning, unregulated fishery activities (exceeding the prescribed allocation area for aquaculture by the Fishery Code of the Philippines), and effluent discharge of wastewater containing emerging contaminants (Santos-Borja and Nepomuceno 2006).

The impending pressure for rapid development in Laguna and nearby communities has coincided with increasing detection of MPs. Arcadio et al. (2023) identified blue-colored fiber MPs as the predominant contaminants in surface water from Laguna de Bay. In addition, polyethylene terephthalate, polypropylene, and ethylene-vinyl acetate copolymer accounted for 65% of the MP population. The alarming presence of MPs in Laguna de Bay is supported by works by Deocaris et al. (2023) (surface water) and Manalo et al. (2023) (shoreline). The physicochemical properties of polymers (shape, size, and type) in aquatic ecosystems affect their fate and distribution, thereby exposing freshwater organisms through dermal contact or ingestion. MP may affect aquatic life and human health, particularly in areas with greater local fish consumption (Bashir et al. 2020; Landrigan et al. 2020). Recent studies have shown that MP exposure is associated with multiple systemic adverse effects, including inflammatory bowel disease, myocardial injury, neuroinflammation, poor cognition, decreased sperm motility, and disturbances in the gut microbiome, thyroid function, and cellular signaling (Zhao et al. 2024).

While the global literature on MPs continues to expand, there remains a paucity of data on the abundance, spatial distribution, and interaction with site-specific physicochemical parameters in the West Bay of Laguna Lake. Moreover, the transport and fate of these pollutants may be modulated by site-specific physicochemical parameters. In this study, researchers hypothesized that water quality parameters are associated with MP abundance (Fatih et al. 2025; Rivera-Gutiérrez et al. 2025). Due to the lack of routine monitoring, investigating this relationship is highly relevant for determining predictive indicators of MP accumulation (van Asselt et al. 2022). Therefore, to address this research gap, the main objectives of this study are: (1) to extract and quantify the abundance of MP from both surface water and sediment samples in Laguna Lake West Bay; (2) to determine the spatial distribution and identify the polymer types of the extracted particles using Fourier-transform infrared (FTIR) spectroscopy; and (3) to quantitatively evaluate the relationship between the measured water quality parameters and MP abundance across the sampling sites.

MATERIALS AND METHODS

Study Area

Laguna de Bay's diverse ecosystem contributes to the socioeconomic well-being of several areas, including agrifishery, residential, industrial, and multipurpose uses for nearby residents and fisheries (Tamayo-Zafaralla et al. 2002). The most significant environmental effect in coastal zones is pollution caused by numerous small— and large-scale industrial activities, rapid urbanization, and other land-use changes (Lu et al. 2011; Hossain et al. 2023). Aquaculture relies heavily on plastic and contributes to various forms of pollution, including waste, excrement, oil spills from fishing and passenger boats, and effluents that contaminate aquatic environments (Lusher et al. 2017; Dabrowska et al. 2021; Diggle and Walker 2022). Iizuka et al. (2017) demonstrated through modeling (business as usual and high sprawl model in 2023 and 2030 using a 2015 data baseline) that the dynamics of the Laguna de Bay region's surrounding region through the built-up class (urban area expansion), which can spread west and south of the lake, as evident in Metro Manila's land use and land cover change.

According to Herrera and Nadaoka (2021), the fishery industry in Laguna de Bay concentrated its operations in the West and Central Bays. This study explored the West Bay area (Figure 1 and Table 1) for MPs due to several factors: (i) concentration of the fishery activity in the West Bay of Laguna Lake; (ii) proximity to built-up areas and high anthropogenic pressure (proximity to urban/industrial zones and potential influence of Metro Manila effluent discharge; and (iii) limited data on MPs in West Bay with high aquaculture presence that supplies the protein requirements of the urban and rural populations. By focusing on the West Bay Area, this investigation can continue monitoring MPs and provide insights into their potential impacts on environmental and human health.

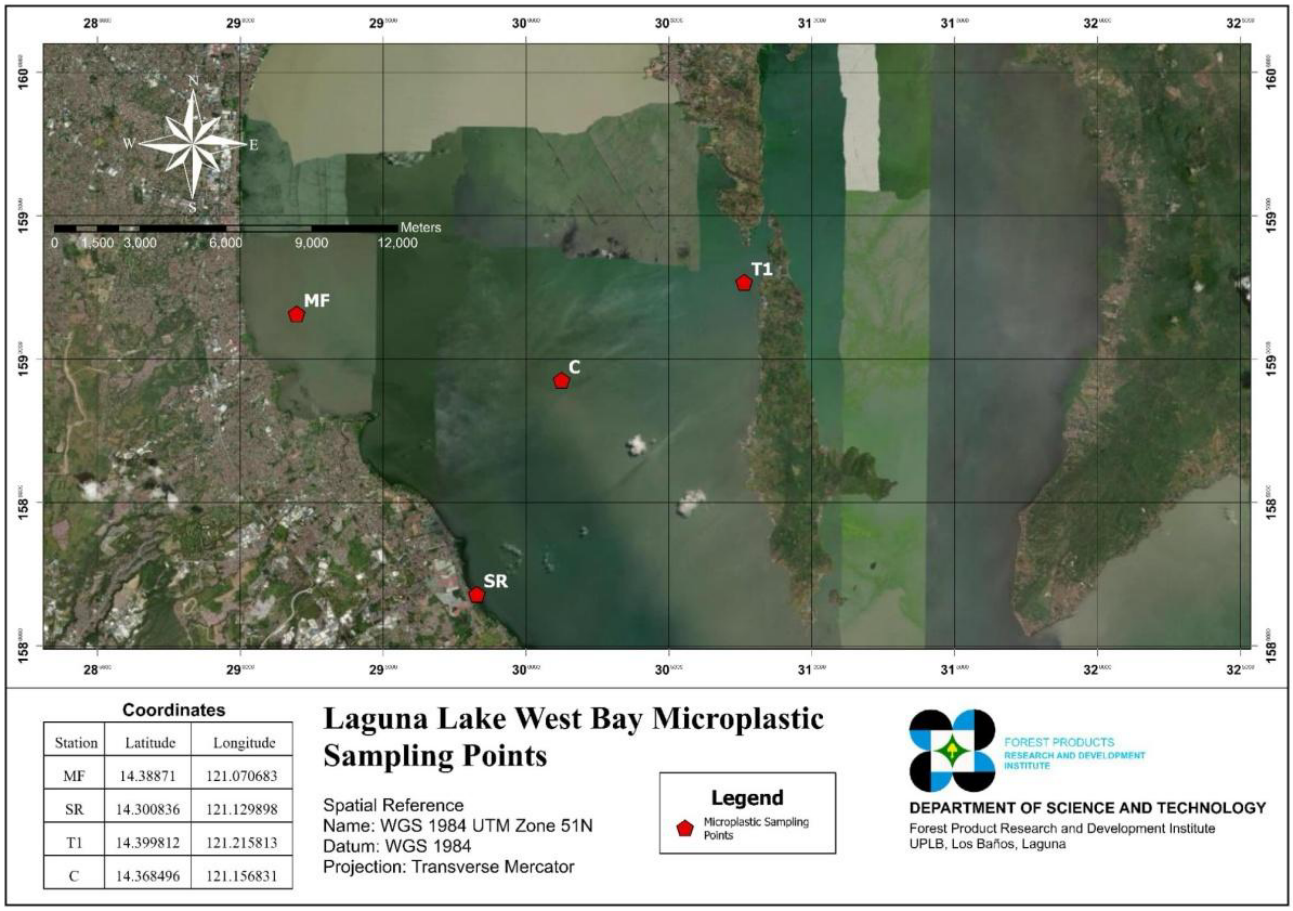

Figure 1: Sampling points in Laguna Lake West Bay: Talim Island (TI), Muntinlupa fish pen (MF), West Bay Center (C), and Sta. Rosa (SR)

Table 1: Location of the sampling points of the study.

Site	Location	Description	Coordinates
TI	Brgy. Bombong, Talim Island, Binangonan, Rizal	Rural area with a Tilapia fish pen	Lat 14.399812 Long 121.215813
MF	Muntinlupa	Urban area with a Tilapia fish pen	Lat 14.388710 Long 121.070683
C	Muntinlupa-Rizal boundary	Limnetic site of the Laguna Bay west area	Lat 14.368496 Long 121.156831
SR	Sinalhan, Sta. Rosa, Laguna	Urban intensive area	Lat 14.300836 Long 121.129898

Sample collection

The surface water and sediments were collected from March to April 2025 in coordination with the local government unit. Based on the work of Osorio et al. (2021), with modifications, surface water was collected using a metal bucket from 0- 12 cm below the surface at each sampling site (N =3) and transferred to a 250 mL amber bottle. The sampling tools were cleaned carefully with distilled water at each collection to reduce cross-contamination.

The top sediment (0–2 cm) was collected using a stainless-steel surface grab and pooled in an aluminum container for sampling. Approximately 1 kg of sediment was collected at each sampling site, pooled, and covered with aluminum foil (N=3, triplicate pooled samples). Surface water and sediment samples were placed in a 5 °C sampling box to avoid shaking and contamination during transportation. No rainfall occurred within 7 days before sampling or during sample collection. The sediments were collected after the surface water to avoid incorporating the suspended materials.

Water quality analysis

Separate surface water samples were immediately stored in an insulated sampling box maintained at 4 °C to prevent microbial and chemical degradation during transit. The samples were transported within 6 hours of collection to a DENR-recognized third-party analytical facility for physicochemical and bacteriological testing. All analyses were performed in compliance with the protocols established in the Standard Methods for the Examination of Water and Wastewater to evaluate compliance with Class C water quality criteria outlined in DENR Administrative Order No. 2016-08 (DAO 2016-08).

Class C water is intended for fishery, agriculture, and livestock purposes. Due to land-use changes in nearby communities surrounding the identified aquaculture areas, it is essential to

determine and monitor the status of surface water in the West Bay of Laguna Lake. The water quality parameters analyzed in this study include pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), total suspended solids (TSS), turbidity, fecal/total coliform, ammonia, phosphate, and nitrate concentrations. Due to the unavailability of field-deployable instrumentation preventing *in situ* measurements, parameters highly sensitive to time and transport, such as temperature, were excluded from the final analysis to prevent data inaccuracies.

Method optimization

Method optimization for microplastic extraction from surface water and sediment was performed using two approaches, both of which were modified from those described by Manalo and colleagues (2023). A positive control was conducted in two modes: low load (5 pieces) and high load (20 pieces) to assess the separation efficiency of control particles (<5 mm) from the matrix. A negative control approach was used to determine whether contamination could occur in the experimental setup. Results from the method optimization were used to evaluate the quality, reliability, and consistency of the analytical method.

For the MP extraction optimization of sediment, 30 g of sand with 5.54 g of commercial fish feed were used to simulate organic matter, as adapted from Yokoyama (2010), and the MP control samples were mixed accordingly. The sand-MP mixture was subjected to wet peroxide oxidation (WPO) by adding 50 mL of 30% hydrogen peroxide to digest the organic matter. It was then stirred and left to stand for one hour. Upon completion of the hydrogen peroxide digestion, a saturated sodium chloride (NaCl) solution was added directly into the flask containing the sediment-peroxide mixture to facilitate density separation and enhance MP recovery. The mixture was left to stand for 5 hours so the sediments would settle to the bottom. Following this, the liquid supernatant was decanted and filtered by gravity through Whatman qualitative filter paper no. 2 to recover the MPs. A second extraction was then conducted with a 49.4% w/v sodium iodide (NaI) solution, using the same sediment sample to further optimize MP recovery. This mixture was left to stand for 5 hours to allow the sediments to settle to the bottom, after which it was decanted again and poured onto the filtration setup. The filter papers were covered with paper towels and air-dried for 2–5 days. After drying, quantification was done in three independent replicates.

To optimize the extraction method for aqueous matrices and evaluate recovery efficiency, a simulated water sample was prepared by mixing 250 mL of distilled water with 5.54 g of commercial fish feed and spiking it with known quantities of the MP reference. A 100 mL aliquot of 30% H_2O_2 solution was added to the samples in a 1 L Erlenmeyer flask. The mixture was allowed to stand in the dark for 72 hours to achieve WPO of the organic matter. Following complete digestion, the sample was vigorously agitated to ensure a homogeneous suspension of particles, then immediately divided into two equal aliquots. This division was necessary to maximize recovery efficiency by using two different density solutions: the first aliquot was mixed with 100 mL of saturated NaCl solution, while the second was mixed with 100 mL of 49.4% w/v NaI solution to capture high-density polymers. Unlike sediment extraction, water samples were processed in parallel rather than sequentially to minimize particle loss associated with repeated filtration and transfer steps. Both mixtures were allowed to stand for 5 hours to allow the MPs to float to the surface. The supernatant from each aliquot was then decanted and filtered through Whatman No. 2 filter paper. Finally, the filter papers were covered with paper towels and air-dried for 2–5 days prior to quantification.

Sample preparation and extraction

Surface water

The extraction of MP from surface water was performed according to the methods of Loayza et al. (2022) and Osorio et al. (2021) with modifications (Figure 2). The wet peroxide oxidation (WPO) method was applied to all collected water samples to remove organic matter. At room temperature, 100 mL of 30% H_2O_2 solution was added to a 1 L Erlenmeyer flask containing the sieved surface water samples, and the mixture was allowed to stand in the dark for 72 hours to digest organic matter. Immediately after the wet peroxide oxidation (WPO) digestion, the sample was vigorously agitated to create a uniform particle suspension, then swiftly divided into two equal aliquots for density separation. Density separation was performed by adding 100 mL of saturated NaCl solution, standing for 5 hours, and filtering through a Whatman filter paper No. 2 with a pore size of 8 µm (the target size range for the MPs investigated in this study was established as 100 µm to 5 mm). Density separation allows MPs to float to the surface. Surface water samples were decanted onto a Whatman filter paper and covered with paper towels. The 2nd portion was added with 100 mL of 49.4 % w/v NaI solution, filtered, and air-dried for 2–5 days. This division was necessary to enhance recovery efficiency by using a standard, low-cost saturated NaCl solution and a high-density NaI solution to capture high- and low-density polymers in an aqueous matrix. The collected samples were visually examined using a compound microscope at 40X magnification. The results from both extractions were combined and expressed as MP/L in surface water (N=3) to align with globally recognized reporting metrics for MP pollution, allowing for direct comparability with other international studies (GESAMP 2019; Masura et al. 2015).

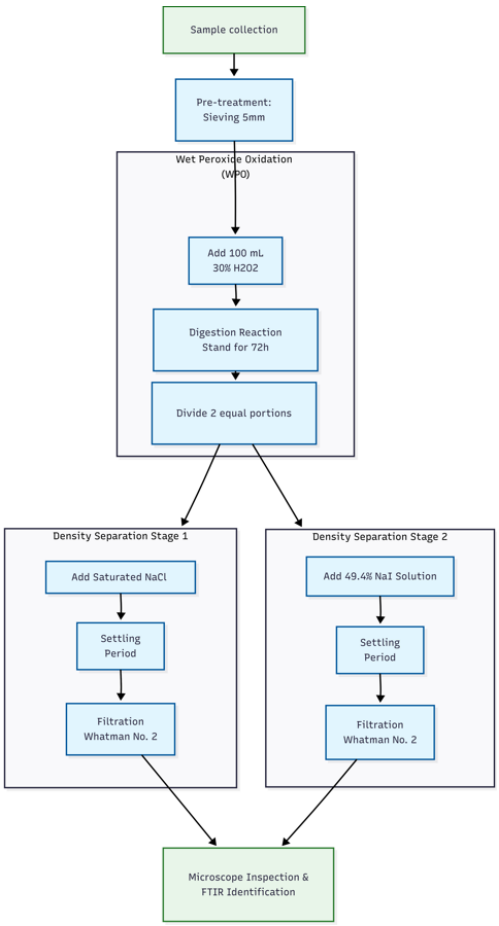

Figure 1: MP extraction from surface water

Sediments

The collected sediments were processed using the method described by Besley et al. (2017) as shown in Figure 3. The pooled sediments were thoroughly homogenized, sieved through a 5-mm mesh, and subjected to continuous, rigorous physical mixing to ensure bulk homogeneity across the entire matrix prior to extracting a representative 30 g subsample. All sediment samples were stored in an aluminum tray with foil until analysis. The wet peroxide oxidation (WPO) method of Manalo and colleagues (2022) was used, with modifications, to extract MP from sediments. Thirty grams (30 g) of the dried sample in an Erlenmeyer flask was added with 100 mL of 30% hydrogen peroxide, stirred, and left for 1 hour. Three hundred to four hundred milliliters (300-400 mL) of hydrogen peroxide were added to each sample to completely digest the organic matter. After this, the mixture was added to a saturated NaCl solution to enhance the MP recovery. The mixture was allowed to stand for five (5) hours to allow sediments to settle at the bottom. The liquid was decanted again and poured onto the filtration setup with Whatman filter paper No. 2. A 2nd extraction with 49.4 % w/v NaI solution was performed using the same sediment sample to optimize MP extraction. The filter paper was covered with a paper towels, left to dry for 2–5 days, and then inspected for MPs. A visual inspection and needle test were used to assess the suspected MPs under a microscope (40X). MPs were counted and recorded as MPs per kilogram (kg) of dry sediment (MP/kg) (GESAMP 2019; Masura et al. 2015).

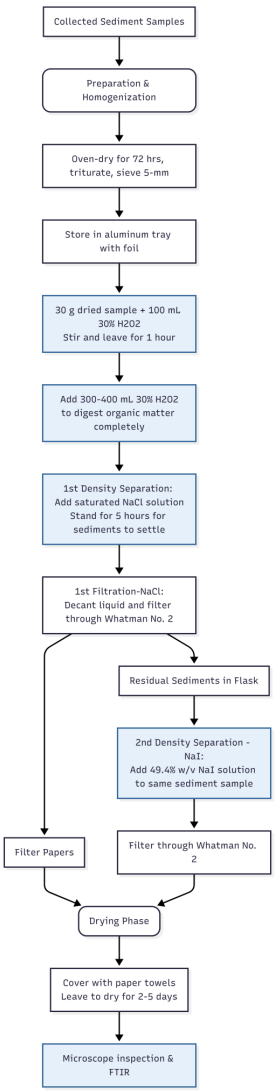

Figure 2: MP extraction from sediment

Quality Control and Quality Assurance (QC/QA)

Strict quality assurance and quality control (QC/QA) measures were implemented throughout the sampling, extraction, and analysis phases to minimize contamination and maximize recovery. To prevent airborne contamination, all laboratory procedures were conducted in a fume hood, and work surfaces were regularly wiped down with 70% ethanol. All dedicated glassware for MP analysis was washed, rinsed with distilled water, and covered with aluminum foil when not in use. Cotton laboratory coats and nitrile gloves were always worn.

To validate the reliability of the extraction protocol, both positive and negative controls were utilized. Negative controls consisting of filtered distilled water were processed alongside the environmental samples using the same extraction methodologies to monitor for procedural contamination. Positive controls were prepared by spiking clean sediment and distilled water with known quantities of reference MP materials to assess the recovery efficiency of the wet peroxide oxidation and density separation protocols. The spiked polymers were derived from PE (ice cream containers, cup lids), LDPE (soft packaging), HDPE (bottle caps), polyester (sachets), PET (soda bottles), and PVC (identification cards) (Manalo et al. 2023).

Identification

The polymer composition of the MP subsamples collected from surface water and sediments was characterized by using a Bruker Alpha II Fourier Transform Infrared (FTIR) spectrometer. Particle identities were confirmed by comparing the acquired spectra against established literature reference spectra. Strict QC/QA protocols were maintained throughout the analysis, including routine background measurements with atmospheric compensation. Spectral smoothing was applied to each sample run, and each particle was analyzed using 45 scans at a resolution of 2 cm^{-1} with a Happ-Genzel apodization function.

Statistical analysis

The Shapiro-Wilk test was followed by Levene's test for homogeneity to assess the normality of the study samples. If the MP count meets the conditions for parametric analysis, a post-hoc test (Tukey's HSD) for independent samples was performed following ANOVA. Otherwise, the nonparametric Kruskal-Wallis test was performed, followed by Dunn's test, to compare MP concentrations among sampling sites. The Kendall's tau-b test was conducted to evaluate the strength and direction of association among MP counts from various sampling sites, MP counts based on shape, and water quality parameters. Results were expressed as the mean ± standard deviation (N=3), and statistical analyses were performed using Jamovi version 2.6.

RESULTS AND DISCUSSION

Method optimization and recovery of MP from surface water and sediment

The optimized extraction method, utilizing wet peroxide oxidation (WPO) and two-stage density separation, yielded MP recoveries ranging from 93.33% to 100% across both low-load (LL) and high-load (HL) conditions. In surface water, the protocol effectively isolated particles from the aqueous matrix, achieving 100% recovery for PP, polyester, and PVC across both load conditions, and complete recovery for HDPE (LL) and PS (HL). The remaining polymers in surface water exhibited strong recovery rates of 93.33%- 96.67%. The method proved equally effective for the sediment matrix. The strong buoyancy of low-density plastics likely contributed to the complete 100% recovery of PP and HDPE under both LL and HL sediment conditions. Furthermore, even when trapped within the complex sediment matrix, the remaining

polymers (LDPE, PS, polyester, PET, and PVC) were successfully recovered at rates ranging from 93.33% to 96.67%. Ultimately, these consistently high recovery yields confirm the robustness of the optimized WPO and density separation protocol for isolating both low-density (PP, HDPE, LDPE) and higher-density (PET, PVC) MPs from diverse environmental samples.

Table 2 presents the average MP count in surface water and sediment across four sampling areas on the west bay of Laguna Lake. Based on the Kruskal-Wallis test ($p > 0.05$, $\alpha=0.05$), there is no significant difference between the MP count in all sampling sites. The absence of statistical variation indicates that MP pollution is pervasive across the measured areas of Laguna West Bay. No single sampling area among the four study sites can be reliably classified as cleaner or dirtier than the others, highlighting the ongoing lake-wide challenge posed by diffuse, high-volume pollution inputs.

Table 2: MP concentration of surface water and sediment from the four sampling sites

Sampling site	Surface water (MP count/L)	Sediment (MP count/kg)
TI	2,254.68±1,013.76	167,698.80±81,146.44
MF	3,160±498.36	325,629.71±43,274.68
C	3,272.00±797.76	156,720.79±1,098.90
SR	3,685.32±436.44	115,695.19±5,952.71

Although differences were not statistically significant, mean MP/L increased from the sparsely populated Talim Island to the densely urbanized Santa Rosa. Ta et al. (2024) confirmed a high-count trend in regions near industrialized and densely populated areas, such as the SR (3,685.32±436.44 MP/L) and MF (3,160±498.36 MP/L). These values are higher than the initial baseline density documented for Laguna de Bay by Arcadio et al. (2023), which was 14.29 items/m³ (conversion: 1,000 L = 1 m³). In this baseline study, surface water MPs were collected at 10 sampling stations using a 20-µm-mesh plankton net that was submerged to a depth of 20 cm. The collected solids were processed in the laboratory by soaking in a KOH solution and heating at 60°C for 24 hours to digest organic material, followed by flotation in a 30% NaCl solution to separate plastic debris by density. The extracted particles were then isolated via vacuum filtration onto Whatman glass filters, examined under an optical microscope at 40x magnification for morphological characterization, and analytically identified via ATR-FTIR.

This severe concentration in West Bay strongly indicates a localized pollution hotspot driven by its direct proximity to the highly urbanized and industrialized centers of Metro Manila, which discharge substantial volumes of domestic wastewater, industrial effluents, and mismanaged solid waste into the lake (Arcadio et al. 2023; Contreras 2025).

The sheer scale of this environmental degradation becomes distinctly apparent when comparing Laguna de Bay to the nearby Seven Lakes of San Pablo, which provide identical vital ecosystem services to the region—namely, extensive aquaculture (fisheries) and ecotourism. For instance, Natuel et al. (2023) examined Lake Sampaloc (an urbanized aquaculture lake) and Lake Yambo (a rural ecotourism lake) using volume-reduced surface water sampling sieved through a 63 µm mesh, digestion with 30% hydrogen peroxide, and direct filtration. Using visual stereomicroscopy (5-10 X magnification), they reported microplastic concentrations of 483-989 MP/m^3 and 344-789 MP/m^3, respectively.

While both lake systems are fundamentally relied upon for food provisioning and local livelihood, the MP burden in Laguna Lake's West Bay is magnitudes more severe. This disparity highlights how unchecked anthropogenic pressure is degrading the water quality of Laguna de Bay, threatening its capacity to sustain the critical ecosystem services that both local communities and the broader region depend on (Chakraborty et al. 2019; World Bank 2016).

The MF has the highest sediment count (325,629.71±43,274.68 MP/kg), followed by TI (167,698.80±81,146.44 MP/kg), while SR has the lowest (115,695.19±5,952.71 MP/kg). To compare the magnitudes of these values, West Bay serves as a massive, localized sink, comparable to the highly urbanized depositional zones of the North American Great Lakes. For instance, offshore sediment cores from Lake Ontario—a major freshwater body similarly impacted by intense urban and industrial land use—have recorded MP accumulations peaking at 488.4 particles/g dry weight. In this study, 15 cm sediment cores were extracted using a box corer and sectioned at 1 cm intervals. The processing involved wet sieving through a 45-µm metal sieve to discard particles below that threshold, density separation using a 1.5 g/cm³ sodium polytungstate solution under magnetic stirring and settling in a glass separation funnel. The extracted particles, isolated between 53 µm and 2 mm, were categorized using a stereomicroscope and verified by FTIR (Belontz et al. 2024).

By comparison, MP concentrations in shoreline sediment analyses in the northern regions of Laguna Lake (Binangonan, Tanay, and Angono) were higher than those in the northern regions, ranging from 295.51 to 1,826.05 MP/kg across the wet and dry seasons. In this shoreline baseline assessment, sediment samples were collected using a stainless-steel spatula from a 5.0 m × 5.0 m transect area dug 1 meter away from the low-tide waterline. After being air-dried and sieved through a 2-mm mesh, microplastics were extracted from the sediment matrix using 30% hydrogen peroxide and 2-step density flotation with a saturated NaCl solution. The recovered particles were analyzed using ATR-FTIR spectroscopy (Manalo et al. 2023).

This can be attributed to the hydrological assessment, which indicates that West Bay is highly susceptible to seawater intrusion from Manila Bay via the Pasig River, which triggers flocculation (Herrera et al. 2014). In such transition zones, shifting salinity causes suspended fine-grained cohesive sediments to rapidly bind with MP, forming dense aggregates that settle to the benthic zone at accelerated rates (Andersen et al. 2021; Wu et al. 2024).

Although the Kendall's tau-b analysis revealed specific directional trends, the high p-values ($p > 0.05$) indicate that these correlations are not statistically significant. Further targeted research with larger sample sizes is required to definitively confirm these associations within the broader lake ecosystem. Despite the lack of a statistically significant correlation, there is a modest positive correlation (tau-b = 0.364) between surface water and the sampling site. An inverse relationship between MP surface water and sediment was observed by weak negative correlation (tau-b= -0.212), which can be explained as the concentration of MP in surface water (pelagic) versus sediment (benthic) being a function of their partitioning—the dynamic exchange between the two compartments that were affected by various factors like MP particle density, size, shape, and biofouling (Li et al. 2023; Lin et al. 2023).

Some studies have found a similar inverse association in certain seasonal or hydrodynamic conditions. In contrast, many have found no meaningful correlation between the amounts of MPs in surface water and sediment at the same location. This frequently happens due to factors such as water flow dynamics and MP

properties. For example, the Daya Bay study found no significant correlation between MP concentrations in sediment and surface water (Liu et al. 2023). Tian and Pei (2025) found a different distribution pattern, with MP concentrations increasing from south to north in surface waters.

Another possible reason for the observed relationship is that when low-density polymers like PE and PP predominate in the water, they remain buoyant and do not settle, or when the water is highly turbulent and prevents sedimentation, a high surface water MP count and low sediment MP count may result (Abdipour et al. 2023; Pourebrahimi and Pirooz 2023). The low surface water MP count and high sediment MP count, on the other hand, occur in locations where the water body is the final sink (Shikwambana et al. 2024).

Water quality

The water quality parameters measured at the four test sites, as shown in Table 3 below, have essential implications for aquatic resources and human health. At the same time, most results are within the acceptable range of the DENR Class C standard; a few exceedances and near-threshold data show areas of concern. The surface waters from all sites were within the DENR Class C guideline of 6.5–9.0. However, sensitive fish species may already be under stress due to the slightly acidic value at Talim Island (6.72), which can affect reproductive and metabolic activities (Ikuta et al. 2000; Mukherjee et al. 2019). Tilapia can withstand gradual pH changes to pH 4, which can affect juvenile growth performance by decreasing feeding, slowing growth, weakening immunity, and reducing reproductive success in the adult stage (Çagiltay et al. 2015; Ginneken et al. 1997; Rebouças et al. 2015).

Table 3: Water quality results of 4 sampling sites

Parameters	Unit	Sampling location				DENR Class C water standard DAO 2016-08
		TI	MF	C	SR	
pH	-	6.72	7.31	7.51	7.45	6.5-9.0
Ammonia	mg/L	0.13	<0.03	0.06	<0.03	0.05
BOD	mg/L	15.0	<5	<5	<5	7
DO	mg/L	5.20	7.42	7.52	7.42	5 (minimum)
Nitrate as nitrogen	mg/L	1.21	<0.10	<0.10	<0.10	7
Phosphate as phosphorus	mg/L	<0.1	0.48	0.48	0.48	0.5
Total suspended solids	mg/L	<2.5	64	46	64	80
Turbidity	NTU	30.89	89	43	89	150
Fecal coliform	MPN/100 mL	47	400	140	68,000	200
Total coliform	MPN/100 mL	320	680	<18	14,000	10,000

Turbidity levels ranged widely, from 89 NTU in Muntinlupa and Sta. Rosa to 30.89 NTU in Talim Island, all below the 150 NTU DENR guidelines. On the other hand, all sites were within the TSS limit; Sta. Rosa approached the threshold (64 mg/L vs 80 mg/L). Although not immediately harmful to humans, high turbidity reduces water quality, posing safety and aesthetic concerns by potentially harboring pathogens through biofilm formation (WHO 2021; Ye et al. 2021). High turbidity hinders fish spawning success and decreases visual foraging effectiveness (Chapman et al. 2014; Rowe et al. 2003). In addition, increased TSS may block the gills (reducing oxygen transfer capacity), causing respiratory strain due to prolonged exposure to high solids (Montoya et al. 2024; Cumming and Hebert 2016).

Ammonia, a typical water pollutant, was identified to exceed the prescribed limit of DAO 2016-08 at the Talim Island fishery area and Wet Bay Center (C) (0.13 mg/L), which is above the permissible limit of 0.05 mg/L. Various anthropogenic activities, such as agricultural runoff, industrial waste, and sewage effluents from adjacent areas, contribute to water contamination (Dey et al. 2022, p. 2772). Ammonia accumulation has been associated with river and lake acidification, eutrophication, and direct toxicity to aquatic organisms (Edwards et al. 2024). In humans, prolonged exposure to ammonia can impact liver and renal function, and high amounts can irritate the skin, eyes, and mucous membranes (National Research Council (US) Committee on Acute Exposure Guideline Levels, 2008). On the other hand, ammonia exposure can harm fish gill tissues, disrupt oxygen intake, and hinder development and reproduction (Soler et al. 2021; Zhang et al. 2023).

BOD indicates the amount of oxygen microbial organisms use to decompose organic matter in the water. BOD is also interpreted as a measure of the concentration of organic material that can serve as a substrate for microbial growth (Kumar and Kumar 2004; Abu Shmeis 2018). Thus, good quality water has a low BOD, while polluted water has a high BOD. In this study, the BOD at Talim Island (15.0 mg/L) exceeds the standard limit of 7 mg/L, indicating pollution that promotes microbial breakdown in the aquatic environment (Nagaraju et al. 2023, p. 2). The DO measurement at Talim Island (5.20 mg/L), which is just above the lowest permitted concentration of 5 mg/L, reflects this. High BOD in humans is an indirect indicator of an elevated pathogen load, increasing the risk of gastrointestinal illnesses from ingestion (Chahal et al. 2016; Pandey et al. 2014). In waters with high BOD, fish have less oxygen available, which can lead to hypoxia that can kill them, impair their immune systems, and hinder their ability to reproduce. In contrast, comparatively healthier aquatic conditions are indicated by DO values in other sites (7.42–7.52 mg/L).

Talim Island had the highest nitrate concentration (1.21 mg/L), although all locations remained below the Class C limit of 7 mg/L. When paired with phosphorus, nitrate enrichment may quicken eutrophication processes, but only within safe bounds (Wu 2008; Khan and Mohammad 2014)—the phosphate concentrations at Muntinlupa, West Bay, and Sta. Rosa (0.48 mg/L) are near the 0.5 mg/L standard limit. High phosphate levels increase eutrophication, promoting excessive algal growth (Akinnawo 2023, p. 1). Aquatic creatures may experience increased hypoxic stress due to oxygen loss resulting from the death and decomposition of algae (Brenckman et al. 2024). In enclosed systems like Laguna de Bay, where nutrient inputs build up over time, this risk is significant.

In addition to the physicochemical parameters, the microbial indicator was used to determine fecal and total coliform levels in the study area. The results indicate that fecal coliform levels exceeded the DENR Class C standard (200 MPN/100 mL) in highly urbanized areas, such as Sta. Rosa (68×10^3 MPN/100 mL) and Muntinlupa (400 MPN/100 mL). Talim Island (47 MPN/100 mL) and West Bay (140 MPN/100 mL) remain within the acceptable range. Elevated coliform counts in feces indicate contamination by animal or human waste. Through direct touch or unintentional consumption, this presents serious dangers to human health for gastrointestinal illnesses such as cholera, diarrhea, and dysentery (Penakalapati et al. 2017; Xu et al. 2021). Fecal pollution lowers oxygen levels and degrades habitat quality, as at Sta. Rosa, which exhibits high anthropogenic inputs, most likely from wastewater discharges from residential and commercial establishments (Eriksen et al. 2022; Kumar et al. 2020). In addition, the high total coliform levels indicate extensive microbial contamination, even though they fall under the DENR Class C limit of 10,000 MPN/100 mL.

A Kendall's tau-b correlation analysis was conducted to evaluate the relationship between physicochemical and biological water quality parameters and the mean MP abundance across the sampling sites. The analysis revealed no statistically significant correlations ($p > 0.05$) between MP counts and any of the tested parameters. Specifically, physical and basic chemical indicators such as pH (tau-b = 0.667, p = 0.333), DO, TSS, and turbidity (tau-b = 0.548, p = 0.279) showed positive but non-significant trends. Nutrient and organic load parameters exhibited non-significant negative correlations, including nitrate and BOD (tau-b = -0.707, p = 0.180), and ammonia (tau-b = -0.548, p = 0.279), whereas phosphate showed a non-significant positive trend (tau-b = 0.707, p = 0.180).

Furthermore, fecal and total coliforms similarly yielded no significant relationships (tau-b= 0.667, p = 0.333 and tau-b = 0.333, p = 0.750, respectively). These overall findings suggest that, within Laguna Lake West Bay, these water quality parameters are not the primary drivers of MP distribution. Instead, the spatial accumulation of MP in this specific aquatic environment may be more heavily influenced by other complex, large-scale environmental variables.

MP Identification

Characterizing MP contamination in environmental samples requires optical microscopy to count isolated pollutants after extraction and two-step purification. The visual characteristics of isolated particles enable their classification into discrete morphological categories, such as fiber, film, fragment, and microbead, which often provide clues to their source and production mechanism.

The analysis of MP revealed variations in concentration and morphological type between the sediment and surface water across the four sampling sites, as shown in Table 4. MP concentration in sediment was consistently highest for the fragment morphology across all four sites, indicating that fragments are the dominant type settling in the benthic environment. The fragment concentration of 179,882.01±38,755.46 MP/kg in SR was the highest among the sediments based on morphology. In addition, SR had the highest film concentration (24,097.59±7,628.24 MP/kg) and the highest bead concentration (28,752.79±7,644.24 MP/kg). On the other hand, site MF had the highest fiber concentration (14,798.52±19.33 MP/kg) among sites.

Table 4: Mean distribution of MP from sediment and surface water based on shape

Sampling site	Sediment (MP count/kg)				Surface water (MP count/L)			
	Bead	Fiber	Film	Fragment	Bead	Fiber	Film	Fragment
TI	57,794.22±25,733.09	1,933.14±793.25	10,732.26±6,932.64	97,390.26±49,337.73	112.00±80.88	36.00±34.64	281.32±116.56	1,825.32±7,819.60
SR	120,921.24±3,530.65	999.90±770.59	24,097.59±7,628.24	179,882.01±38,755.46	552.00±401.92	34.68±18.48	410.68±240.72	2,161.32±362.44
C	28,752.79±7,644.24	266.64±96.32	3,244.01±1,877.15	124,787.52±37,921.54	586.68±314.76	30.68±12.84	182.68±53.72	2,472.00±569.12
MF	3,543.98±2,295.10	14,798.52±19.33	4,932.84±866.58	107,255.94±7,636.60	1,350.68±422.88	61.32±32.08	282.68±65.04	1,990.68±83.28

A comparison of the matrices revealed that MP accumulation in surface water was generally lower than in sediments. Across all locations, fragments constituted the dominant morphotype. Site C exhibited the highest surface water MP concentration at 2,472.00 ± 569.12 MP/L. Conversely, fibers were consistently the least abundant shape in surface waters (yielding the lowest mean concentrations from 30.68 ± 12.84 MP/L at Site C to 61.32 ± 32.08 MP/L at Site MF), while films reached their peak concentration at Site SR (410.68 ± 240.72 MP/L)

The presence of fragments in both surface water and sediment suggests that the primary source of contamination is secondary MP produced when larger plastic waste breaks down (Yarahmadi et al. 2024; Bexeitova et al. 2024). The dense fragment pieces are easily maintained and resist remobilization due to the high flow velocities (Hoellein et al. 2019, p 4). Possible sources and transport dynamics are inferred from the diversity of less common MP types (Rani 2022). For example, the sediment at MF had the highest fiber content, suggesting a significant, localized contribution from fishing activities through the abrasion and degradation of fishing gear, such as nylon nets, lines, ropes, and aquaculture cages used in fish farming operations (Montarsolo et al. 2018; Ramos et al. 2014).

The high concentration of microbeads in the sediment at SR could indicate a nearby industrial source or local hydrodynamics favoring

deposition, leading to their discharge and accumulation (Prapanchan et al. 2022; Möhlenkamp et al. 2018). Figure 4 and Table 5 show distinctive absorption bands at 2915 cm^{-1} and 2848 cm^{-1} (asymmetric and symmetric C–H stretching) and at 1465 cm^{-1} (CH_2 bending). A rocking doublet at 730 cm^{-1} and 717 cm^{-1} confirmed the identification of the test sample as LDPE on account of a clear peak at 1377 cm^{-1} that corresponds to CH_3 symmetric bending and shows polymer chain branching. Additional oxidation-related bands at about 1730 cm^{-1} (C=O stretching) and about 3400 cm^{-1} (O–H stretching) indicate surface hydroxylation and photo-oxidative deterioration resulting from environmental exposure (Jung et al. 2018).

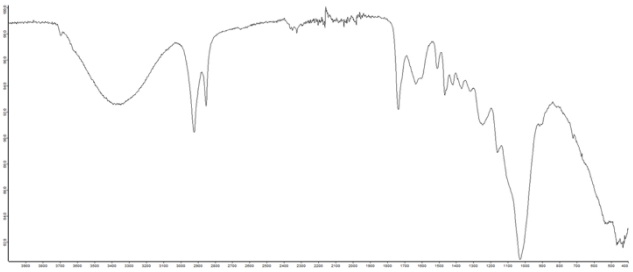

Figure 3: IR spectra of LDPE isolated from surface water from C

Table 5: IR absorption bands and assignments for the isolated LDPE sample

Band (cm^{-1})	Assignment
3400*	O–H stretching
2915	Asymmetric C–H stretching of CH_2
2848	Symmetric C–H stretching of CH_2
1730*	C=O stretching
1465	CH_2 scissoring (bending)
1377	CH_3 symmetric bending vibration
1170*	C–O stretching
1020*	Si–O stretching
720	CH_2 rocking
600–650*	Weak bending vibrations

Furthermore, Campanale et al. (2023) found that Si–O vibrations are represented by tiny peaks in the 1200 cm^{-1} area, indicating the presence of mineral particles adhered to the polymer surface. Weak features at 600–650 cm^{-1} may also indicate inorganic contamination from silicates. The combination of these characteristics, which exhibit both polymer-specific absorptions and degradation-related functional groups, supports the hypothesis that the examined material is an environmentally weathered MP. Another interesting finding supporting ongoing MP contamination in the aquaculture environment of Talim Island was the detection of recently fragmented HDPE in surface water (Figure 5 and Table 6), a polymer used in agrifishery structures such as net pens and fish cages (Wang et al. 2023).

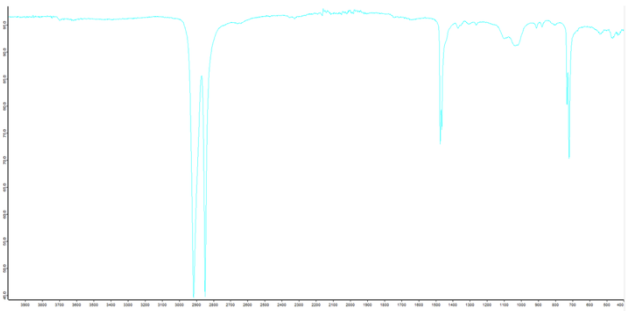

Figure 4: IR spectra of HDPE isolated from the surface water of TI

Table 6: IR absorption bands and assignments of the HDPE from TI surface water

Band (cm^{-1})	Assignment
2915	CH_2 asymmetric stretching
2848	CH_2 symmetric stretching
1472	CH_2 bending (scissoring)
1463	CH_2 scissoring
730	CH_2 rocking

The IR ethylene vinyl acetate (EVA) fingerprint displays distinct peaks that combine the characteristics of both pure polyolefins (PE) and esters (vinyl acetate), as noted in Figure 6 and Table 7. Broad weak band around 3400 cm^{-1} from O–H stretching, strong C–H stretches near 2950–2850 cm^{-1} from aliphatic or alkyl C–H (polyethylene backbone), strong sharp absorption around ~1730 cm^{-1} from a carbonyl (C=O) group (ester functional group), C–H bending around 1500 and 1300 cm^{-1}, strong C–O stretching bands in ~1150–1020 cm^{-1} region, and C–H bends around ~750 cm^{-1} supports the presence of an ethylene backbone $–(CH_2)_{n>4}–$ (Giurginca et al. 2003; Nakajima et al. 2025; Hisam et al.2023).

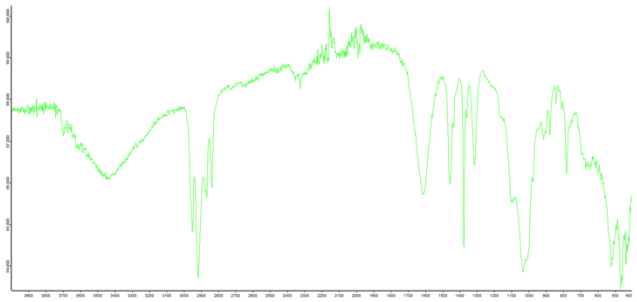

Figure 5: IR Spectra of EVA recovered from MF sediment

Table 7: IR absorption bands and assignments of the EVA sample

Band (cm^{-1})	Assignment
3400	O–H stretching
2915	Asymmetric C–H stretching (CH_2 from ethylene segments)
2848	Symmetric C–H stretching (CH_2 from ethylene segments)
1730	C=O stretching (from vinyl acetate units)
1472	CH_2 bending (scissoring)
1377	CH_3 symmetric bending
1150-1020	C–O single bond
730-717	CH bends

Limitations of the Study

While this study has several limitations that must be acknowledged. Principal among these are constraints on field sample sizes and subsequent data normalization protocols. In the sediment analysis, MP extraction was performed using 30 g of dry sediment per replicate to report final concentrations as MP/kg, while surface water metrics were standardized to MP/L from 250 mL samples. Although this normalization is necessary to facilitate direct comparisons with broader regional and international literature, these relatively small initial sample sizes introduce an inherent "multiplier effect" that amplifies minor sample-to-sample variations during scaling. This scaling is further compounded by the high spatial heterogeneity of aquatic environments, where MPs exhibit strong localized clustering driven by wind-driven surface currents, hydrodynamic forces, and the microenvironment of the sample.

Beyond scaling effects, several procedural and physical boundaries inherent to laboratory MP extraction workflows may introduce experimental error or underestimations. First, the recovery

efficiency of the sample matrix is fundamentally constrained by the density of the separation solution; target polymers with a density exceeding this threshold may fail to float, leading to an underestimation of denser MP fractions. Second, although the initial surface water filtration utilized filter paper with 8 µm pores, reliable visual quantification under a compound microscope (40X magnification) was restricted to a lower limit of 100 µm. The reported visual counts are therefore strictly bound to the 100 µm to 5 mm size range, meaning that nanoplastics and MPs smaller than this threshold were excluded, potentially underrepresenting the total MPs count.

Furthermore, distinct boundaries exist regarding particle characterization and the study's temporal scope. Due to the high volume of suspected particles recovered, chemical identification via FTIR spectroscopy was performed on a representative subsample rather than the entire extracted pool. Although statistical randomization was strictly employed to minimize selection bias during subsampling, some minor polymer types may not have been captured in the spectral analysis.

Lastly, the temporal scope of this sampling was limited to a specific seasonal window. Longitudinal studies are required to understand how shifting seasonal dynamics, annual variations, and extreme weather events influence the long-term distribution and abundance of MP in the lake. To reduce the variance introduced by value normalization, future studies would benefit from processing larger sample volumes or mass or from expanding the number of spatial replicates.

CONCLUSION

This study establishes the widespread and uniform distribution of microplastic (MP) pollution in the West Bay of Laguna Lake, with MP abundance showing no significant spatial variation among four distinct sampling sites ($p > 0.05$, $\alpha = 0.05$). Sediments serve as the primary depositional sink, exhibiting MP concentrations that are vastly higher than those in surface water and pose a long-term ecological risk. The dominance of fragmented microplastics, primarily composed of HDPE, LDPE, and EVA, indicates that the fragmentation of secondary plastics—specifically single-use packaging and fishing gear—drives the contamination.
Also, the research demonstrates a dual-stressor dynamic: MP pollution coincides with localized exceedances in conventional water quality, including high fecal coliform at Muntinlupa and Sta. Rosa, and elevated BOD and ammonia at Talim Island. This combined pollution profile severely threatens the lake's essential ecosystem services, necessitating immediate, integrated management interventions to safeguard local ecological and public health.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

CONTRIBUTIONS OF INDIVIDUAL AUTHORS

ECKamantigue, AHFradejas, JSNastor, JVPeyrube, and HMNacorda conceptualized and supervised the study. ECKamantigue secured the loan, conducted the sampling and optimization experiments, and analyzed the data. ECKamantigue, AHFradejas, JSNastor, JVPeyrube, and HMNacorda prepared the manuscript draft for submission. All authors approved the final version of the manuscript.

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