Distribution, abundance, and characteristics of microplastics in surficial beach sediments of Miagao, Iloilo

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ABSTRACT

The Philippines is a major contributor to global oceanic plastic pollution, yet localized studies on microplastic (MP) contamination in coastal sediments remain scarce. This study aimed to provide the first quantification and characterization of MP distribution in the coastal sediments of Miagao, Iloilo. Surface beach sediment samples were collected following harmonized protocols. The samples were dried and sieved to exclude particles >5 mm, then subjected to density separation using 5.5 M zinc chloride (ZnCl2; density = 1.5 g mL-1). Wet peroxide oxidation was performed to remove organic matter. Extracted microplastics (MPs) were filtered, dried, and characterized using a stereomicroscope and fluorescence staining with Nile red under ultraviolet (UV) light (365 nm) to aid visualization and identification. Quality control measures, including procedural blanks and spiked samples, were implemented. Although fibers were detected in the blanks, high recovery rates were observed for spiked polymers using ZnCl2. A total of 401 MPs were identified across the sampled transects. The average MP abundance ranged from 34 ± 18.4 to 57 ± 12.0 particles per 100 g of sediment. Fibers were the most abundant shape type, comprising 67% of the total, followed by films (17%) and fragments (16%). Fluorescence analysis under UV light (365 nm) suggested the potential presence of various polymers, including polyester (PET), polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polyamide (PA), and cotton-polyester blends (CPB). The predominance of fibers may indicate significant contributions from domestic wastewater, fishing gear, or textiles. The findings suggest that while beach cleaning may address larger debris, it appears less effective against smaller MPs, particularly embedded fibers.

INTRODUCTION

Plastic pollution is one of the most pressing environmental challenges of the 21st century, with severe consequences for marine ecosystems. The Philippines is the third-largest contributor to global marine plastic pollution, with approximately 0.75 million metric tons (MMT) of mismanaged plastic waste entering the ocean annually (World Bank Group, 2021), placing the country at the forefront of this global crisis. The extensive use of plastics has led to significant waste accumulation, disrupting the ecological balance of aquatic systems. Mismanaged plastic waste enters marine environments through various pathways, including terrestrial runoff, fishing activities, wastewater effluents, and other commercial and maritime operations (Matavos-Aramyan, 2024). Owing to their durability, plastics persist in the environment for extended periods and undergo fragmentation through photo-oxidation, mechanical abrasion, and biological processes, producing microplastics (MPs), defined as plastic particles smaller than 5 mm.

MPs pose a persistent threat to marine ecosystems because of their small size, ubiquity, and capacity to transport chemical and biological contaminants (Caruso, 2019). Marine organisms often ingest MPs unintentionally because these particles resemble food items but are indigestible. Consequently, MPs and associated contaminants accumulate within organisms and biomagnify through the food web, ultimately posing risks to human health (Smith et al., 2018). Despite extensive global research on MP pollution, localized empirical data from the Philippines remain limited. Although the country is a major contributor to marine plastic pollution, documented studies in Philippine settings remain relatively few, such as those conducted in the coastal areas of Puerto Princesa, Palawan (Sajorne et al., 2022) and Laguna de Bay (Arcadio et al., 2022). This gap hinders the development of effective, context-specific mitigation strategies.

Miagao, a coastal municipality in southern Iloilo, supports diverse marine ecosystems and active fishing communities that depend heavily on coastal resources for livelihood and food security. The area's rich marine biodiversity sustains subsistence and small-scale fisheries, underscoring the importance of maintaining coastal ecosystem health for local economic resilience. Increasing MP contamination in coastal environments presents a growing concern for communities such as Miagao, where fisheries play a critical socioeconomic role. MP pollution threatens marine habitats and the long-term sustainability of fishing-dependent livelihoods. Establishing baseline data on MP contamination is therefore essential for evaluating environmental risks and informing local management strategies.

While previous studies have documented MP presence in beach sediments across selected coastal areas of Panay Island (Colacion et al., 2020), no published studies have examined MP contamination in the coastal sediments of Miagao. This absence of site-specific data limits assessment of the anthropogenic impacts associated with fishing and recreational activities on local coastal ecosystems, despite ongoing environmental initiatives such as coastal clean-up programs.

To address this gap, this study presents the first assessment of MP prevalence in coastal sediments of Miagao, Iloilo. The study applies Nile red (NR) fluorescence staining, an emerging and cost-effective method for distinguishing MPs from non-plastic materials through stereomicroscopy. However, NR staining has recognized limitations, including reduced staining efficiency at higher concentrations and variability among polymer types (Prata, 2021; Gao, 2022). Accordingly, this study highlights the need for complementary spectroscopic analyses to confirm polymer composition. By establishing baseline data on MP contamination in Miagao, this research provides essential information to support local environmental management and future MP studies in the region.

MATERIALS AND METHODS

Chemical Reagents and Solvents
Analytical-grade Nile red dye was obtained from D'Malt Industrial Sales Corporation and dissolved in 100 mL of acetone to prepare the stock staining solution. Zinc chloride ($ZnCl_2$, technical grade), sourced from Dalkem Corporation, was dissolved in distilled water to formulate the density separation solution. Additionally, 7.5 g of ferrous sulfate heptahydrate ($FeSO_4 \cdot 7H_2O$; molecular weight = 278.02 g/mol) was dissolved in distilled water for use in the digestion steps. Other solvents and reagents used included methanol (laboratory grade), concentrated hydrochloric acid (HCl), concentrated sulfuric acid (H_2SO_4), and 30% hydrogen peroxide (H_2O_2).

Sampling Area
Beach sediment samples were collected along the coastline adjacent to the Ocean Weather Laboratory of the University of the Philippines Visayas, located in Miagao, Iloilo. Situated on the southern coast of Panay Island in the Western Visayas region (Region VI), Miagao is a first-class municipality characterized by rich marine biodiversity and heavy reliance on coastal and marine resources. The selected sampling site was chosen for its accessibility, proximity to active local fishing activities, and potential exposure to land-based sources of microplastic pollution, including domestic waste and surface runoff. The geographical location of the sampling area is illustrated in Figure 1.
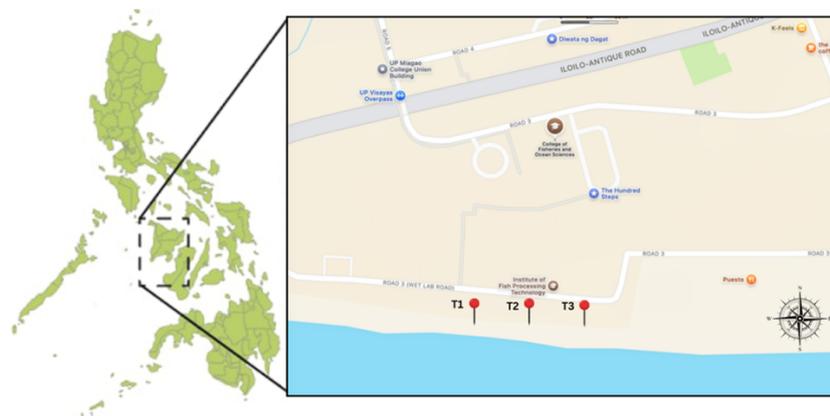

Figure 1: Geographical location of the Study Area

Sample Collection
Beach sediment sample collection followed the harmonized protocols of the Microbial Transformation of Plastics in Southeast Asian Seas: A Hazard and a Solution (MicroSEAP) consortium (Microbial Oceanography Laboratory, 2023), with minor modifications. At the strandline, or high-tide mark, three 30 m transect lines were established parallel to the shoreline, with a minimum spacing of 2 m between transects. Along each transect, quadrats measuring 25 × 25 cm and subdivided into 3 × 3 grids were placed at 5 m intervals. From each quadrat, the top 5 cm of surface sediment was collected using a metal shovel from a randomly selected grid. To minimize contamination from plastic containers, samples were stored in 250 mL glass jars sealed with clean aluminum foil before the metal lids were secured, following

the recommendations of Hidalgo-Ruz (2012). Clean filter papers placed in petri dishes were positioned around the processing area to detect potential airborne contamination. A total of six sediment samples were collected per transect. Sampling was conducted during low tide in December to optimize area coverage. All collected samples were then transported to the laboratory for further processing.

Sample Processing

Preparation of Experimental Controls for Method Optimization

The preparation of procedural blanks and spiked samples is an essential component of experimental control for microplastic quantification. To prepare the spiked samples, beach sediment samples collected from each transect were initially sieved using a 5 mm mesh and pre-combusted in a furnace at 550 °C for six hours to remove plastics and organic matter.

For each transect, 100 g of pre-combusted beach sediment, hereafter referred to as "clean" sediment, was transferred into an individual beaker. Based on data reported in Philippine-based surveys, these samples were then spiked with known quantities of commonly encountered consumer plastic types (PlastiCount Pilipinas, 2022). The MPs used for spiking were initially cut into smaller pieces (<25 mm) using a pair of scissors. These plastics represented various polymer types, including PET from water bottles, PP from straws, LDPE fragments from ice bags and plastic bags, HDPE fragments from shampoo containers, PVC shavings from pipes, and PS from yogurt cups. PA/nylon fibers from fish nets were also included. Five MP particles from each plastic category were added to each clean sediment sample.

Organic matter was added to the spiked samples. Wood chips and seaweed were oven-dried at 60 °C until brittle. The dried organic matter was then mechanically fragmented using a grinder and added to the clean sediment sample.

Pre-extraction: Drying and Sieving

This method was modified from the study by De-la-Torre et al. (2021). Sediment samples collected from each transect line were pooled and oven-dried for 48 h at 60 °C. The dried sediment samples were then sieved using stacked stainless-steel meshes (5 mm, 2.5 mm, and 1 mm) to remove macro- and mesolitter and to facilitate the flotation method. Particles larger than 5 mm were discarded. The sediment that passed through the mesh was then divided into triplicates of 100 g each for MP extraction.

Density Separation

To remove residual organic material and further isolate MPs from the sample, a wet peroxide oxidation (WPO) process was employed. The digestion procedure was adapted from Espiritu (2019) with minor modifications. Specifically, 20 mL of 0.05 M aqueous ferrous solution was added to the sample, followed by 20 mL of 30% H_2O_2. The mixture was allowed to stand at ambient temperature for 5 min to settle and to allow the initial reaction to subside. The sample was then stirred and heated on a hot plate at 60 °C. Once bubbling was observed, the sample was removed from heat and allowed to cool until the bubbling subsided. This heating-and-cooling cycle was repeated for an additional 30 minutes. To ensure complete digestion of organic material, 5 mL increments of 30% H_2O_2 were added until no visible organic matter remained.

Post-treatment Density Separation

To separate MPs from residual sediments and other non-plastic particles, two rounds of density separation were performed. The residue was transferred to a density separation setup (see Appendix A) using $ZnCl_2$ solution (ρ = 1.5 g/mL), and the mixture was allowed to settle for at least 6 hours. After the allotted time, the non-plastic particles that settled at the bottom were drained into one beaker, while floating MPs in the supernatant were drained into another. The funnel was repeatedly washed with distilled water to recover MPs that may have adhered to its sides. To ensure optimal extraction efficiency, a second round of density separation was performed on the settled particles.

Filtration and Drying

The supernatant containing MPs from both rounds of density separation was pooled and filtered through 0.45 μm filter paper. This process was performed twice to ensure complete MP extraction. The filter paper was washed with distilled water and stored in a glass petri dish to minimize contamination. All samples were oven-dried for 24 h at 40 °C (Vianello, 2013). Positive controls (spiked samples) and negative controls (procedural blanks) were processed alongside the environmental samples to account for possible procedural errors and extraneous contamination.

Preparation of working solution for Nile red staining

A stock solution was prepared by dissolving 100 mg of Nile red in 100 mL of acetone to obtain a stock concentration of 1 mg mL−1. The resulting solution was filtered through a 0.45 μm syringe filter and stored in an amber reagent bottle covered with aluminum foil at 4 °C. A working solution with a concentration of 10 μg mL−1 was prepared by diluting 1 mL of the stock solution in 100 mL of methanol (Maes, 2017).

Characterization of Extracted MPs

Confocal Microscopy Analysis

To obtain high-resolution images of the MPs, two filter papers containing the dried samples were sent to the School of Materials Science and Engineering at Nanyang Technological University in Singapore for confocal microscopy analysis. For sample preparation, 5–10 mg of the filtrate was dispersed in 1 mL of methanol, followed by the addition of 10 μL of a 1 mg mL−1 Nile red solution in acetone. The mixture was incubated at room temperature for 24 h to allow dye adsorption. After incubation, the sample was washed three times with distilled water by microcentrifugation at 14,800 rpm for 15 min per cycle to remove excess unbound dye. The resulting pellet was redispersed in 200 μL of distilled water and sonicated for 5 min to ensure homogeneity. Confocal imaging was performed using a Cytation 10 instrument with 10× and 40× objectives. Brightfield and red fluorescence (RFP, Ex531/Em593) channels were used for imaging. A fused silica standard was used as a control, confirming that Nile red did not adsorb onto SiO_2 (see Appendix B).

Nile red Staining

Nile red staining was employed to facilitate the visualization and quantification of MPs in beach sediment samples. Each sample was treated with 600 μL of the working solution, which was carefully applied dropwise across the entire surface of the filter paper. After staining, the filter papers containing MP particles were examined under a stereomicroscope at 40× magnification equipped with a UV light source (365 nm) to assist in particle observation and characterization. Suspected MPs were photographed using a smartphone camera (iPhone 11; 12 MP; 2× optical zoom). The particles were then counted systematically, grid by grid, and categorized as fibers, films, fragments, or pellets. The fluorescence characteristics exhibited by the isolated MP particles were subsequently compared with existing literature to infer their potential polymer composition.

Quality Control Measures

To minimize and address potential contamination, this study implemented strict protocols. The use of plastic materials was minimized as much as possible during sampling and laboratory procedures. Polymer-free gloves were worn throughout the experiment to prevent contamination. Before the experiment, the workspace was cleaned with paper towels and 70% ethanol, and a lint remover was applied to the researcher's clothing and lab gown before entering the laboratory. Processed samples were covered with aluminum foil whenever possible. In addition, all reagents used in the experiment were pre-filtered through GF/C filters (0.45 µm pore size) prior to use (Bonita, 2023).

RESULTS AND DISCUSSION

Stringent contamination control measures were implemented throughout all stages of the study, including sample collection, processing, and analysis, to minimize the risk of external microplastic (MP) contamination. Importantly, no MPs were detected in the air contamination controls, supporting the effectiveness of the laboratory precautions and confirming that airborne contamination did not influence the measured environmental MP concentrations. A small number of MP fibers were, however, detected in the negative procedural controls,

indicating a low but non-negligible risk of contamination arising during sample handling or laboratory processing. To account for this background contamination and ensure conservative and reliable estimates, MP counts from environmental samples were corrected by subtracting the average blank value.

In contrast, the positive controls conducted for each transect demonstrated consistently high recovery rates for the spiked sediment samples, indicating that the analytical methods were robust and efficient and that MP loss during extraction and analysis was minimal. Identified MP particles were less than 5 mm, consistent with the operational definition of MPs and the mesh size used during filtration of the supernatant from the density separation procedure (Table 1). All reported values are based on counts obtained through fluorescence microscopy.

One limitation of the study is the narrow spacing of the sampling transects, which may have affected the variation in MPs detected across the study area. Because the transects were located close together, they may have experienced similar environmental conditions, thereby reducing spatial heterogeneity. Consequently, the abundance, composition, and size distribution of MPs documented in this study may not fully capture wider regional variability.

Table 1: Description of the sampling points and MP count in coastal sediments of Miagao, Iloilo

Sampling Area	Latitude	Longitude	Classification	No. of MPs	Average MP Count (particles/100 g)
T1	10.638013	122.229683	Non-residential	103	34 ± 18.4
T2	10.638004	122.230025	Non-residential	128	43 ± 3.1
T3	10.637984	122.230332	Non-residential	170	57 ± 12.0

Note. T1 = Transect 1, T2 = Transect 2, T3 = Transect 3

The results revealed varying levels of MP abundance across the three transects along the coastline adjacent to the Ocean Weather Laboratory in Miagao, Iloilo. Overall, 401 MPs were counted on nine filter papers. Each transect included three samples labeled Sample 1 (S1), Sample 2 (S2), and Sample 3 (S3). Among the sampling points, T3 recorded the highest concentration, with an average of 56.7 ± 12.0 MP particles per 100 g of sediment, followed by T2 with 42.7 ± 3.1 MP particles per 100 g, and T1 with the lowest average count of 34 ± 18.4 MP particles per 100 g. The distribution of MP content in each sample across the three transects is illustrated in Figure 2. This spatial variability suggests that MP pollution is not uniformly distributed but is influenced by localized factors.
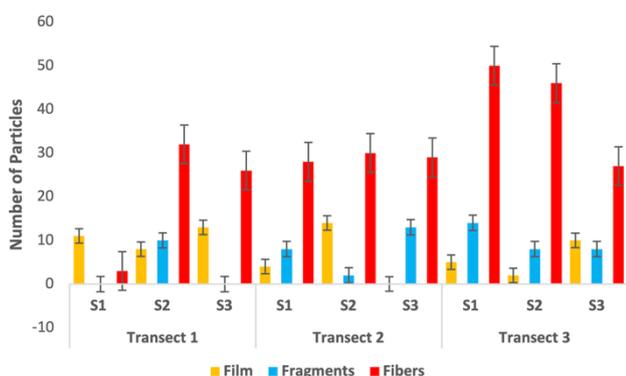
marine debris. However, multiple studies have indicated that the transport and accumulation of MPs are influenced by a range of environmental and anthropogenic factors (Prata, 2021; Thammasanya, 2024). The gradient of increasing abundance from T1 to T3 suggests a localized point source near T3, overriding the broader pattern of diffuse pollution.

Based on the coastal activity survey, all three sampling points are located in non-residential areas, yet they are situated near fishing facilities and a nearby creek, which may serve as both a source and a sink for MPs. These features may facilitate the entry of MPs into the marine environment through human activities and sewage discharges that act as conduits for plastic waste. Creeks are known to be significant vectors of MPs, funneling land-based waste from upstream sources during rainfall events (Leslie et al., 2013). The consistently lower abundance at T1 and T2 may therefore be strongly influenced by this hydrological pathway.

Notably, T3, despite being non-residential, is located close to local beach resorts. The presence of these resorts may contribute to the elevated MP concentrations because of increased human activity, recreational use, and improper waste disposal. This observation aligns with findings from other studies reporting that coastal tourism, particularly in beach resort areas, significantly contributes to plastic and MP pollution because of high human traffic and inadequate waste management (Browne, 2011; Quinn, 2017; Sajorne et al., 2022; Arcadio et al., 2022). The marked increase in abundance at T3 suggests that direct local deposition from beachgoers and resort activities may be a more immediate and potent source than creek transport for this specific transect (Dowarah and Devipriya, 2019). Furthermore, prevailing wind and wave directions along the coast may transport buoyant plastics

Figure 2: Distribution of MP abundance in the coastal sediments in Miagao, Iloilo

As shown in Figure 2, T3 exhibited the highest concentration of MPs among the three transects. These MPs are generally thought to originate from the mechanical or chemical breakdown of larger

from other areas and deposit them near T3, making it an accumulation zone (Zhang, 2017).

When placed in a national context, the microplastic abundance recorded in Miagao (34–57 particles/100 g sediment) is notably lower than values reported for highly urbanized Philippine coastal systems, particularly Manila Bay, where studies by Abreo et al. (2020) and De-la-Torre et al. (2021) documented concentrations often exceeding 100–300 particles/100 g because of intense urbanization, industrial activity, and wastewater discharge. In contrast, the levels observed in Miagao are comparable to those reported for less urbanized or tourism-influenced Philippine beaches, including Palawan (Argamino & Janairo, 2016) and Bohol (Abreo, 2018), which similarly showed moderate MP abundances dominated by fibers. The occurrence of fiber-shaped particles and the variety of inferred polymers in Miagao align with trends observed in coastal sediments throughout the Philippines, indicating typical sources such as household wastewater, tourism, and fishing activities. Overall, these comparisons support a national trend of increasing microplastic contamination with urban intensity while showing that rural and developing tourist areas already experience persistent, fiber-dominated microplastic pollution. These findings suggest that the MP burden in Miagao reflects its specific land-use mix of fishing, limited residential input, and tourism rather than intense industrialization or urbanization. Additionally, Wen (2018) emphasized that small tributaries and creeks can significantly contribute to microplastic accumulation in adjacent coastal sediments through runoff events and tidal exchange.

The recovery rate obtained through density separation with $ZnCl_2$ solution for spiked sediments from each transect is presented in Table 2. Out of the 35 MPs added per transect, plastic types including PET, PP, LDPE, HDPE, PVC, and PS were consistently recovered at 100%. This indicates excellent extraction efficiency using the $ZnCl_2$ density separation method for these polymers, comparable to or higher than recovery rates reported in other studies using similar salt solutions (Quinn et al., 2017). However, recovery rates for PA/nylon were slightly lower, with only 60% recovery in T1 and 80% recovery in both T2 and T3. This suggests that while the method is highly effective for most common plastic types, it may be slightly less efficient for PA/nylon particles, possibly because of differences in surface properties.

Table 2: Percent recovery rate of spiked sediment samples in each transect

	% R.R of Extracted MPs							
	PET	**PP**	**LDPE**	**HDPE**	**PVC**	**PS**	**PA/nylon**	**Av. % R.R**
T1	100	100	100	100	100	100	60	94.29
T2	100	100	100	100	100	100	80	97.14
T3	100	100	100	100	100	100	80	97.14

Note. T1 = Transect 1, T2 = Transect 2, T3= Transect 3; % R.R = percent recovery rate

The discrepancy in recovery is likely due to the intrinsic properties of nylon. According to Shim (2016), fluorescence staining using lipophilic dyes such as NR effectively quantifies small particles of highly hydrophobic polymers such as PE, PP, PS, and PC. In contrast, polymers with lower hydrophobicity and greater surface charge, such as PA, exhibit limited affinity for NR, thereby reducing staining efficiency and subsequent detection (Shim, 2016). This physicochemical limitation, rather than the density separation itself, likely explains the incomplete recovery of PA fibers during MP recovery tests, as unstained or faintly stained particles are more easily missed during visual counting (Prata et al., 2021). Therefore, the reported abundances of PA fibers in environmental samples may be underestimates.

Microplastic Types in Coastal Sediments of Miagao, Iloilo
The MPs identified in the beach sediments of Miagao, Iloilo, exhibited three predominant shapes. Fibers were the most abundant, comprising 67% of the total MPs observed across all three transects. This was followed by films (17%) and fragments (16%). This distribution provides strong clues about the predominant sources of MP pollution in the area. The high prevalence of fibers suggests a strong influence from domestic wastewater, fishing gear, or textile-derived pollution, which are commonly associated with fiber-type MPs (Sajorne et al., 2022). The distribution and representative images of these shapes across the sampling points are shown in Figures 3 and 4.
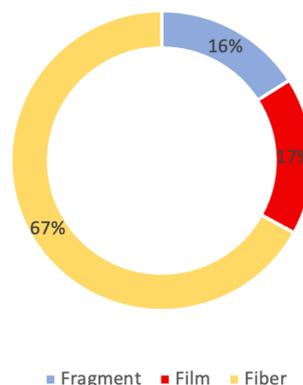
Figure 3: Distribution of MP types obtained from the coastal sediment samples in Miagao, Iloilo

The relatively high abundance of fibers (67%) observed in the samples may be attributed to wastewater discharges from nearby residential areas, particularly where wastewater treatment systems do not completely remove MPs. Previous studies have identified wastewater as a significant source of MP pollution in marine environments (Conley, 2019; Lares, 2019). The general transport direction of these pollutants appears to be southward, with an onshore component suggesting that impacts are likely concentrated in nearshore waters and potentially within the sampling area. This is an important finding because it implies that even non-residential coastal zones are vulnerable to MP pollution originating from upstream or up-current residential areas, challenging the view that such areas are relatively pristine (Browne et al., 2011).
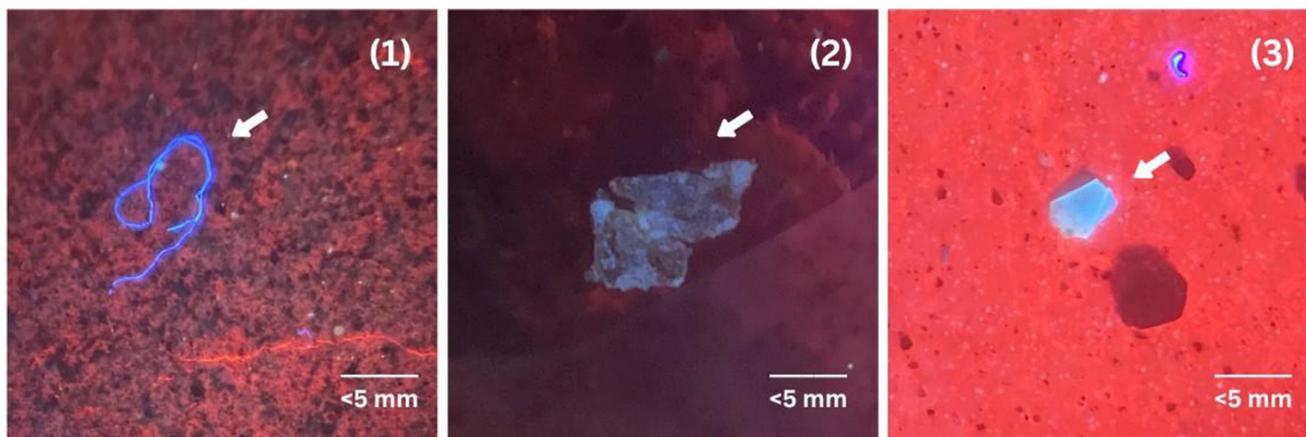
Figure 4: MP types found in the shoreline sediment of Miagao observed with a UV flashlight (365 nm) under a microscope: (1) fiber, (2) film, and (3) fragment.

Fishing activities in the vicinity may also contribute to the prevalence of fiber-type MPs, particularly through the degradation of fishing lines and nets. Tourism in nearby resorts may likewise contribute through improper litter disposal, which eventually fragments into smaller particles over time (De-la-Torre, 2021). De Falco (2019) further demonstrated that washing machine effluents release large quantities of synthetic fibers into aquatic systems, reinforcing the importance of domestic sources in fiber pollution. A similar trend was reported by Sajorne et al. (2022), who found high fiber abundance (79%) on a sandy beach in Palawan, attributed to both wastewater discharge and tourism-related activities. The predominance of fibers in beach sediments is commonly linked to proximity to urbanized or populated regions (Maciel, 2022). Prata (2019) noted that fibers often escape complete filtration during wastewater treatment and are subsequently released into the environment, contributing to their abundance in coastal sediments. The convergence of these multiple pathways underscores the complex and interconnected nature of MP pollution sources affecting Miagao's coastline.

Many global studies report high abundances of plastic fragments and foams in coastal environments, often attributed to the lack of regular beach clean-up activities and the accumulation of litter from fishing operations (Alvarez-Zeferino, 2020; Gray, 2018). In contrast, the sampling area in this study, located along the beachfront of the University of the Philippines Visayas (UPV), undergoes periodic cleaning efforts. These clean-ups likely help remove visible litter and larger plastic fragments but are less effective at eliminating MP fibers, which are more difficult to detect and collect (Masura, 2015). This presents a clear example of the "clean coast paradox," in which beaches may appear visually clean while still harboring significant microplastic contamination.

According to Bissen (2020), beach cleaning has been recognized as an effective and direct mitigation strategy, particularly when targeting larger debris along the strandline. However, while such efforts may successfully reduce macroparticles, they often fail to address the presence of MPs, which persist in the environment due to their small size and tendency to become embedded in sediments. Consequently, small-sized plastics are often overlooked during routine beach cleaning, leading to their continued accumulation on shorelines worldwide. Compared with findings from beaches in other regions, this study highlights a similar trend where MPs, particularly fibers, persist in the environment despite regular cleaning efforts. This suggests that while beach maintenance can effectively reduce visible debris, it may not significantly mitigate the MP burden in coastal sediments. Therefore, the MP profile of a beach, dominated by fibers rather than fragments, can itself serve

as an indicator of the history of the beach management practices and the primary sources of pollution affecting it (Fischer 2016).

The dominance of fibers poses a particular threat to marine biota because of their high potential for ingestion by a wide range of organisms, from filter feeders to benthic invertebrates, as well as their capacity to leach additives or concentrate pollutants (Wright, 2013). The persistence of this unseen pollution despite cleaning efforts highlights a critical gap in current mitigation strategies and points to the urgent need for source-reduction measures, such as improved wastewater treatment, rather than reliance solely on end-point cleanup.

Potential Polymer Composition Based on Microplastic Fluorescence

Because residual organic matter was present in the sample, the potential polymer composition of the Nile red-stained particles was inferred from the observed fluorescence characteristics and patterns. Images of the fluorescent MP particles captured using a smartphone are shown in Figures 5 and 6, together with the distribution of various MP particles obtained from the sediment samples across all three transects.
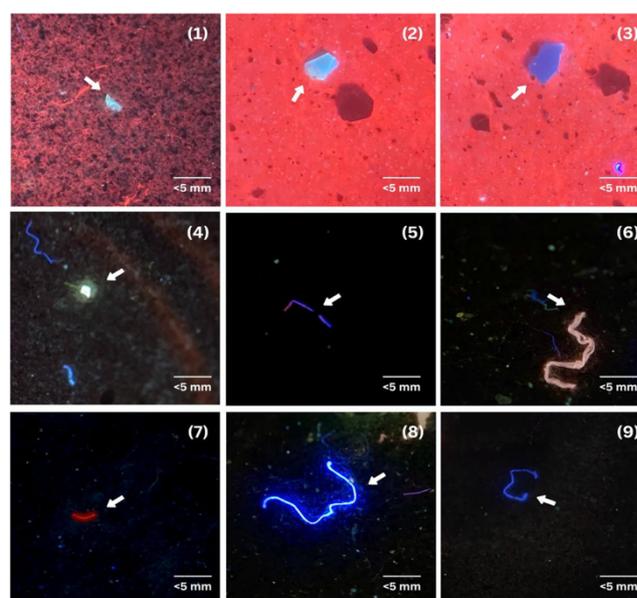

Figure 5: Smartphone camera images of the various fluorescent MPs observed from the coastal sediment samples: (1) light green, (2) cyan, (3) non-fluorescent blue, (4) bright yellow, (5) violet/magenta, (6) light orange, (7) red, (8) high-intensity blue, and (9) low-intensity blue

The red-orange backgrounds seen in Images 1–3 of Figure 5 were caused by the use of white filter paper, which developed a red hue under UV illumination after staining with Nile red. When exposed to UV light at 365 nm, the white stage reflected more light, producing a reddish-orange background because of overexposure and interference with the fluorescent signal. This hue likely resulted from the interaction of Nile red with the white filter paper under UV light, producing strong red fluorescence that may appear orange depending on intensity, lighting, and camera exposure. A black stage would have minimized this reflection and provided a more neutral background.

In contrast, the black backgrounds in Figure 5 (Images 4–9) were achieved through photo optimization, in which image exposure and brightness were intentionally lowered during or after capture to enhance the visibility of fluorescence emitted by the stained fibers. Without such adjustments, the actual fluorescent colors were washed out or not visible under standard lighting and exposure conditions. This optimization was necessary to capture the fluorescent response of different MP types stained with Nile red accurately.
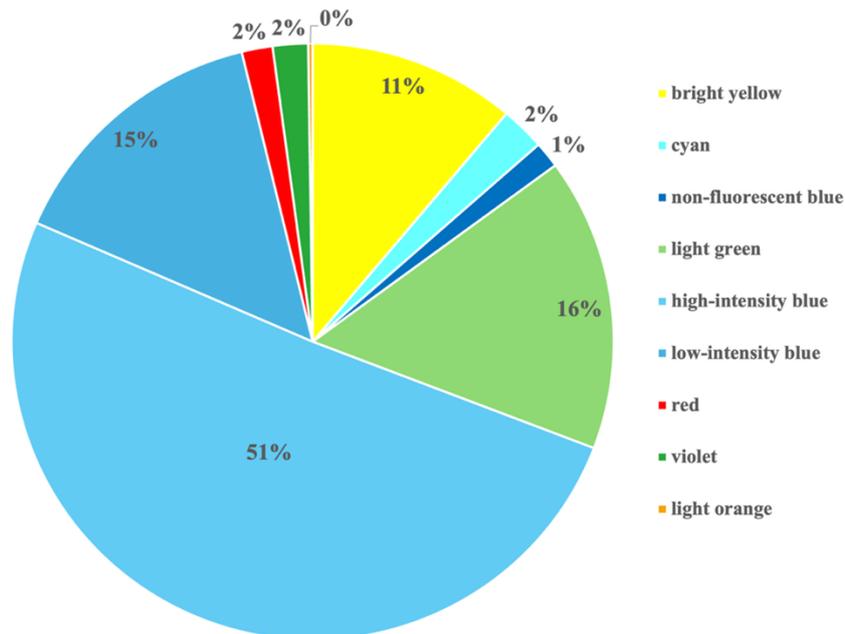

Figure 6: Distribution of fluorescent colors observed from the coastal sediment samples in Miagao, Iloilo

As shown in Figure 6, the majority of observed MPs exhibited high-intensity blue fluorescence (50.71%), followed by light green (15.88%), low-intensity blue (14.69%), and bright yellow (11.14%). The remaining colors, including cyan, violet/magenta, red, light orange, and non-fluorescent blue, each accounted for only 1% to 2% of the total. Because Nile red adheres to the surface of stained plastics and causes them to fluoresce under UV light at 365 nm, the fluorescence characteristics and patterns of the isolated MPs were compared with existing literature to infer potential polymer composition (Munno, 2017). The diversity of fluorescence colors suggests that the coastline is influenced by multiple polymer sources rather than a single dominant source.

High-intensity blue fluorescence was predominantly observed among the fluorescent fibers. A similar finding was reported by Thammasanya (2024), who used a UVA-band (320 nm) UV flashlight to excite Nile red-stained particles for fluorescence-based detection. In that study, a fiber exhibiting strong blue and red fluorescence was chemically identified as PET through FTIR spectroscopy. Although the red fluorescent fibers observed in the present study were less common than the high-intensity blue fibers, they remain notable.

Given the comparable fluorescence characteristics and the use of UV light (365 nm) within the same excitation range as in the study of Thammasanya (2024), it is likely that the red and high intensity blue, fluorescent fibers observed in the study are also composed of PET. PET is a common synthetic textile polymer widely used in garments and industrial fabrics. Numerous studies have demonstrated that microfibers from synthetic clothing are readily released during laundering, with wastewater discharge serving as the primary transport pathway into aquatic environments (Browne

2011; Tamminga 2017; De Falco 2019). The inferred dominance of PET provides strong circumstantial evidence that implicates laundry wastewater as a major source, even without a direct pipe connection, suggesting these fibers are transported effectively through surface runoff or groundwater (Napper, 2016).

Alongside the high-intensity blue fluorescence, some fibers exhibited weaker or low-intensity blue fluorescence. According to Thammasanya (2024), this pattern is consistent with cotton-polyester blends (CPB), which are known to emit weak fluorescence under Nile red staining. Hartline (2016) noted that CPB textiles dominate much of the clothing market and contribute significantly to microfiber pollution.

Meanwhile, bright yellow fluorescence was predominantly observed among the fluorescent fragments. According to Prata (2019), yellow fluorescence under UV light at 365 nm is characteristic of PE. PE is one of the most widely used polymers globally, with applications in reusable bags, containers, agricultural films, and food packaging (Tursi, 2022). Because of its widespread use and environmental persistence, PE is among the polymers most frequently detected in marine environments (Malankowska, 2021). It has been reported not only along beaches and coastlines but also in oceans, seas, and deep seabed sediments (Ajith, 2020; Lavers, 2016). The presence of PE fragments therefore aligns with the global ubiquity of plastic packaging and indicates that Miagao is similarly affected by this widespread contaminant.

Urban and highway runoff also plays a significant role in the transport of MPs into aquatic ecosystems. Lutz (2021) reported that MPs carried through stormwater drainage systems often include PE

as a dominant type. Depending on their size, density, and surface characteristics, such fragments may either float or settle into sediments during transport to marine environments.

Similarly, fragments exhibiting cyan fluorescence were observed across the sampling site. This visual similarity suggests that the cyan fluorescent fragments may be composed of PVC, given their comparable emission profiles and excitation conditions. PVC in the environment is often attributed to the fragmentation of construction debris, improper disposal of consumer goods, and degradation of marine equipment (Lambert, 2016). Although detected in low quantities, the presence of PVC is significant because it points to more durable plastic waste sources beyond packaging and textiles, such as construction materials or electrical insulation, which have longer lifespans and distinct degradation pathways (Turner, 2016).

Non-fluorescent blue fragments were also observed in this study and likely correspond to PP (Thammasanya, 2024). Maes (2017) noted that, unlike PET, PP exhibits poor Nile red adsorption, rendering it non-fluorescent or only faintly fluorescent under UV light. PP is widely used in various consumer products, including food packaging, wrappers, bottle caps, and microwave-safe containers (Tursi, 2022). It is also common in disposable household items, many of which contribute frequently to marine litter. Given Miagao's proximity to residential and domestic activities, the detection of PP MPs is not unexpected, as these products may enter coastal environments through improper disposal, drainage systems, or surface runoff. The likely presence of PP highlights a common limitation of Nile red studies: the potential underestimation of certain common polymers because of low staining affinity.

Lastly, the light green fluorescent films (Image 1) observed in the study suggest the possible presence of polyethyl cyanoacrylate (PECA), a polymer commonly used in adhesives and surface coatings. Although not frequently reported in beach sediments, such polymers may originate from household adhesives, degraded packaging, or other consumer products (Maes, 2017). Their presence may indicate more urbanized or anthropogenic inputs. This tentative inference underscores the broad and often overlooked diversity of plastic products that can contribute to microplastic pollution (Gewert 2015).

Although this fluorescence-based inference is a valuable and cost-effective screening tool, the polymer assignments remain hypothetical. Spectroscopic validation is therefore essential, as dye adsorption may be influenced by surface weathering, biofilm formation, and additive content, all of which may lead to misidentification (Prata, 2021).

CONCLUSION

The total number of microplastics identified in this study was 401, with average abundances ranging from 34 ± 18.4 to 57 ± 12.0 MP particles per 100 g of sediment across transects. The dominant shape was fiber (67%), followed by films (17%) and fragments (16%). Fluorescence microscopy showed that high-intensity blue fluorescence (51%) was the most prevalent, suggesting potential polymer compositions such as PET, PE, PVC, PP, PA, and PECA. The abundance gradient and fiber dominance suggest pollution inputs from creek transport, tourism-related activities, and wastewater discharge of synthetic microfibers. The diversity of inferred polymers indicates contributions from textiles, packaging, and other anthropogenic materials. The persistent fiber-dominated MP profile exemplifies the "clean coast paradox," in which beaches may appear clean while still containing significant microplastic pollution. Although microplastic studies in the Philippines have increased, access to advanced analytical technologies remains limited. Most studies still rely on visual identification, which is less precise than the density separation and fluorescence microscopy techniques used in this research. The inferred polymer identities, particularly the possible underestimation of PP because of low Nile red affinity, further highlight the need for spectroscopic validation in future studies. Overall, this research provides important baseline information on MP prevalence and characteristics in Miagao, Iloilo, an area influenced by fishing activities, and underscores the need to shift management strategies from cleanup to source reduction through improved wastewater treatment, washing-machine filtration, and better waste management in tourism and fishing sectors.

Further characterization of the microplastic samples is recommended. Future research should prioritize FTIR or Raman analysis to confirm the study's initial findings, validate polymer identification, and address limitations associated with Nile red staining, particularly for polymers with low fluorescence affinity such as PP. Establishing standardized methodologies would also improve comparability across studies in the Philippines. Furthermore, future sampling transects should be spaced farther apart to reduce potential sampling bias and ensure greater independence among samples.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

CONTRIBUTIONS OF INDIVIDUAL AUTHORS

LSR, RGG, and SJGB designed the study, drafted the manuscript, and carried out the experiments. ELOS, MSS, GTAC, and EREM edited the manuscript. JOM and SLE participated in research coordination. JOM provided the Nile red used in the experiments.

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