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MICROPLASTIC CONTAMINATION IN SELECTED SHRIMP FARMS AND ADJACENT WATER BODIES IN PUTTALAM DISTRICT, SRI LANKA

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Microplastics (MPs) have emerged as a widespread environmental pollutant, posing significant threats to aquatic ecosystems and human health. This study investigated the prevalence, distribution, and characteristics of MPs in shrimp farms, and adjacent lagoons (Puttalam, Mundel, and Chilaw) in Puttalam District, focusing on water, sediment, and shrimp tissues of *Litopenaeus vannamei*. Samples were collected from six shrimp farms and their associated lagoons, with MPs isolated and analyzed using density separation, alkaline digestion, wet peroxide digestion, stereomicroscopy, and Fourier-transform infrared spectroscopy (FTIR). Results revealed significant spatial heterogeneity in MP concentrations. Chilaw Lagoon exhibited the highest MP levels in water (3294.7 ± 153.6 MPs/m^3) and sediment (962.3 ± 58.9 MPs/kg), attributed to anthropogenic activities such as urbanization, fishing, and tourism, while Mundel Lagoon showed the lowest contamination (1637.3 ± 159.2 MPs/m^3 in water; 521.0 ± 38.2 MPs/kg in sediment), likely due to lower human impact and efficient hydrodynamic dispersion. Shrimp farms mirrored these trends, with ponds exhibiting higher MP concentrations than water inlets, suggesting accumulation due to restricted water exchange and inputs from feed and plastic equipment. MPs predominantly were fragments (35–36%) and fibers (29–31%), with darker colors (e.g., blue, red, black) being more abundant. Smaller MPs (0.10–0.50 mm) dominated across all samples, particularly in shrimp tissues, where the gut showed the highest contamination (10.32 ± 1.80 MPs/g), followed by gills and muscles (0.67 ± 0.10 MPs/g). A strong positive correlation (R^2 = 0.9025) between shrimp muscle weight and MP abundance, indicated bioaccumulation over time. FTIR analysis identified common polymers, including polyethylene, polyvinyl chloride, and polyethylene terephthalate, originating from packaging, fishing gear, and industrial waste. Mainly MP pollutions have come to shrimp farms from water sources and plastic materials which are used for aquaculture practices. Microplastics can be minimized using ground water or purified water before aquaculture practices and substitute materials can be used instead of plastics. The study highlights the warning signs for the shrimp industry of Sri Lanka as farms showed considerable MP levels, with implications for food safety and export quality. The findings underscore the need for improved waste management, regulatory measures, and sustainable practices to mitigate MP pollution in aquaculture. Future research should prioritize long-term monitoring and the development of biodegradable alternatives to reduce environmental and health risks.

Keywords: microplastics, bioaccumulation, polymer analysis, food safety

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Introduction:

Microplastics (MPs) have become a ubiquitous environmental pollutant, posing significant threats to both aquatic ecosystems and human health (Ghosh *et al*., 2023) and affecting ecological health and food safety (Rubio-Armendáriz *et al*., 2022). Their ability to accumulate in aquatic organisms and transfer through trophic levels raises serious concerns, particularly in aquaculture systems, where contamination could directly impact human consumers (Huang *et al*., 2021). In Sri Lanka, shrimp farming is a key economic sector with growing global export demands(Ekanayake *et al*., 2024). However, the extent of MP contamination in shrimp farms and adjacent ecosystems remains underexplored.

The main aim of this research was to investigate the prevalence, sources, and distribution of MPs in the water, sediments and biological samples from shrimp farms and adjacent water bodies which are Puttalam, Mundel, and Chilaw Lagoons. Additionally, the study aimed to develop effective strategies to monitor, reduce, and prevent MP contamination to ensure the sustainability and safety of shrimp aquaculture. Specific objectives of the study were to investigate the abundance of MP on shrimp tissue, surface water and sediment in shrimp farms and adjacent water bodies including Puttalam, Mundel, and Chilaw Lagoon in the Puttalam District and to analyse the concentration and types of MPs present in shrimp farms and adjacent water bodies which are Puttalam, Mundel, and Chilaw Lagoon in the Puttalam District. To identify the primary sources and pathways of MP contamination in these water bodies, aiming to inform and develop effective mitigation strategies to reduce MP pollution.

Methodology:

The research aimed to understand the impact of these farms on the production of *Litopenaeus vannamei*, a species that is cultured in aquaculture farms and exported to European countries and the U.S.A., which have strict food safety concerns.

Sediment samples were collected from six shrimp farms near Puttalam Lagoon, Mundel Lagoon, and Chilaw Lagoon, and 6 locations from each lagoon using Ekman grab sampler. Water samples were collected from six shrimp farms in Puttalam, Mundel, and Chilaw Lagoon, and filtered in situ through a 20 µm plankton net. Biological samples were collected from shrimp farms around Chilaw Lagoon and stored at 4°C until analysis. Sediment samples were dried in a drying oven, followed by adding 5% sodium hexametaphosphate solution to disaggregate the dried bed sediments (Amrutha *et al*., 2023). The samples were then filtered through a 0.02 mm sieve. Biological samples were thawed at room temperature, and the shrimp was carefully dissected, the gill filaments detached, and the gut, gills, and muscles were ground separately. Density separation and wet sieve processes were performed for sediment and water samples, with the solids collected on the 0.02mm sieve being transferred into clean dry beakers and solids collected on the 5.0 mm sieve discarded.

The study involved alkaline digestion of ground tissue, wet peroxide digestion (WPO), density separation, and microscopic analysis to identify MPs (MPs). The alkaline digestion process involved adding 10% Potassium Hydroxide (KOH) to dissolve tissues in shrimp dissecting samples, which were then sieved through a 20-micrometre sieve (Dawson *et al*., 2020). The solids were collected into beakers with filtered Mili-Q water. The WPO solution was then transferred to the density separation funnel, and the solids were drained or discarded. Filtration was conducted using Whatman filter paper No. 41, aided by a vacuum pump to speed up the filtering process. Microscopic analysis was performed using OPTICA PROVIEW software, and the size of MPs was measured using ImageJ software.

Identification tests of MPs included Fourier Transform Infrared spectroscopy (FTIR) analysis to analyse the chemical composition of MPs polymers, and confirmation tests using the Hot Needle Test and Nile Red Method. Quality control was maintained by using Milli-Q water and handling materials and glassware with care to avoid cross-contamination. Statistical analysis was conducted using Microsoft Office Excel 365 and SPSS 30.0.0, with One-way ANOVA for parametric data sets and a parametric two-sample t-test to compare the variance in mean abundance of MP between three Lagoons, water inlet, and ponds of shrimp farms.

Results and Discussion

This study provides a comprehensive quantification of MP pollution across the aquaculture ecosystem of the Puttalam District, revealing significant contamination gradients and uptake in commercially reared shrimp (*Litopenaeus vannamei*). The data indicate that MP abundance is governed by a combination of anthropogenic source strength, hydrodynamic processes, and farm management practices, culminating in bioaccumulation within shrimp tissues.

The significant variance in MP loads between the three lagoons (Chilaw > Puttalam > Mundel; $p < 0.05$, ANOVA) is a direct reflection of differential anthropogenic pressure. Chilaw Lagoon's status as the most contaminated site (3294.67 ± 153.60 MPs/m^3 in water; 962.33 ± 58.87 MPs/kg in sediment) is mechanistically explained by its proximity to urban centres, riverine input (e.g., Deduru Oya), and intense fishing and tourism activities. Rivers are established major conduits for terrestrial plastic waste, and their estuaries often act as temporary sinks, explaining the elevated sediment concentrations (Amrutha & Warrier, 2020). This pattern is globally consistent; for example, urbanized estuaries in China's Yangtze River Delta show MP concentrations an order of magnitude higher than nearby less-developed coastal regions (Li *et al*., 2022).

Conversely, Mundel Lagoon's significantly lower contamination (1637.33 ± 159.23 MPs/m³; 521.00 ± 38.22 MPs/kg) suggests limited land-based sources and potentially more efficient hydrodynamic flushing, preventing the same degree of particle retention. The statistical significance of the pairwise comparisons underscores that these are not random variations but represent distinct pollution regimes.

A critical finding of this study is the consistent and statistically significant ($p < 0.05$, t-test) enrichment of MPs within shrimp farm ponds compared to their water inlets. This identifies the ponds not merely as passive recipients of lagoon water but as active accumulation zones. The mechanisms for this are multifactorial such as Limited Hydrodynamic Energy - The semi-closed, static nature of pond systems promotes the settling and retention of suspended particles, including high-density MPs, Internal Source Contributions - Aquaculture practices are a likely direct source. The fragmentation of plastic infrastructure (liners, pipes, feeding equipment), synthetic fibres from protective netting, and even MPs potentially embedded in commercial feed pellets contribute to the internal load (Vaid *et al*., 2024), Sediment-Water Interactions - The higher MP concentrations in pond sediments result from continuous sedimentation and potential biofouling, which increases particle density and sinking rates (Kaiser *et al*., 2017). This phenomenon of "self-contamination" elevates the exposure risk for farmed species beyond the background environmental levels and is a documented concern in global aquaculture. Studies on Scottish salmon farms found higher MP counts within cage sediments than in immediate surrounding areas, attributed to fouling debris from plastic infrastructure (Skirtun *et al*., 2022).

The tissue-specific analysis revealed a predictable yet concerning uptake gradient: Gut (10.32 ± 1.80 MPs/g) > Gills (9.46 ± 1.70 MPs/g) > Muscle (0.67 ± 0.10 MPs/g). The high gut burden is a direct consequence of ingestion, where MPs are either mistaken for food (e.g., based on size or color) or consumed incidentally with detritus *(Catarino et al*., 2018). The gills, as a primary interface for water exchange, accumulate MPs through passive filtration of suspended particles.

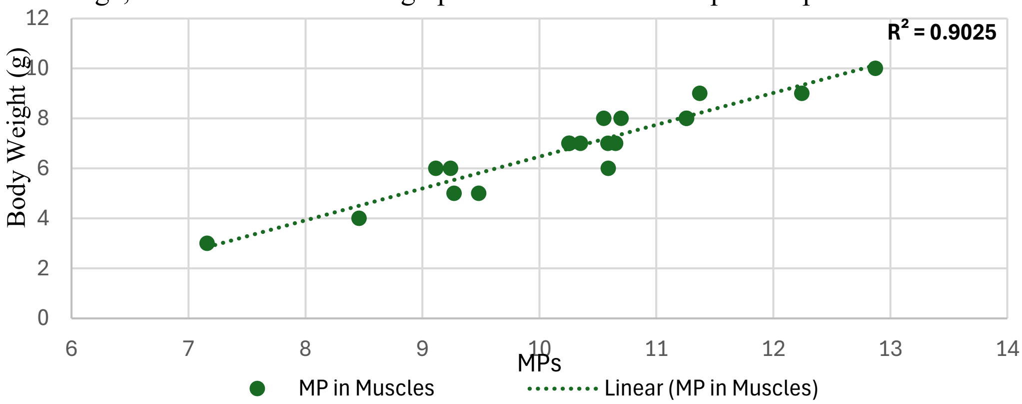

Figure 1: A positive, significant linear relationship between muscle weight and number of MPs in muscle tissues

The detection of MPs in muscle tissue, though low, is highly significant from a food safety perspective. The strong positive correlation between muscle weight and MP abundance (R^2 = 0.9025, Fig. 1) provides compelling evidence for bioaccumulation over time. This suggests that larger, older shrimp pose a higher potential risk of MP transfer to human consumers. While the translocation mechanism from gut to muscle is not fully elucidated, potential pathways include translocation via the circulatory system after the uptake in the gut or adherence during processing. This finding aligns with studies on crustaceans globally; for instance, research on crabs from India has also reported MPs in muscle tissue, confirming the potential for trophic transfer (Daniel *et al*., 2021).

The dominance of fragments (35-36%) and fibres (29-31%) (Fig. 3.7, 3.8) is a classic signature of secondary MPs, derived from the breakdown of larger plastic items. Fragments originate from brittle materials like packaging and fishing gear, while fibres are indicative of synthetic textiles and fishing nets. The prevalence of small particles (<0.5 mm), particularly in tissues, is a major concern as their bioavailability is higher, and they can more readily translocate across biological membranes (Zhang *et al*., 2023).

Analysis of MP colour revealed a clear dominance of dark-coloured particles (e.g., blue, black, red) across all environmental matrices and within shrimp tissues. In shrimp tissues, the gut contained the highest burden of these dark MPs, followed by the gills and muscle. Notably, blue-coloured fragments were the most frequently identified type across the study. The prevalence of dark-coloured MPs is critically significant for both ecological and food safety reasons. Their high visual contrast in the water column makes them more likely to be mistaken for natural prey by visual feeders like shrimp, leading to preferential ingestion (Kandeyaya *et al*., 2023; Lusher *et al*., 2017). This study confirms this selective uptake, as evidenced by the highest abundance found in the gastrointestinal tract. Furthermore, the colour serves as a key indicator of source attribution. The abundance of blue fragments strongly points to the degradation of fishing gear (nets, ropes) as a major anthropogenic source (Ruairuen *et al*., 2022). The presence of black particles suggests contributions from terrestrial runoff, including tire wear (Esfandiari *et al*., 2022; Sommer *et al*., 2018), confirming the transfer of land-based pollution to the coastal aquaculture environment.

The FTIR-identified polymer suite—PE (LDPE/HDPE), PP, PET, PVC, Nylon, PS, and PMMA represents a “fingerprint” of common consumer and industrial plastics. This diversity points to a diffuse pollution source, integrating municipal waste (packaging), fishing industry debris (nets, ropes), and industrial products. The presence of dense polymers like PET and PVC in water columns suggests they are likely transported while biofouled or adhered to organic matter (Berezina *et al*., 2021).

Conclusion:

Scientifically, this study demonstrated that MP contamination in the Puttalam aquaculture ecosystem is a function of Anthropogenic forcing, dictating input loads into adjacent lagoons, farm hydrodynamics promoting the accumulation of particles within ponds, Biological processes leading to tissue-specific bioaccumulation in *L. vannamei*.

The results underscored that shrimp farms are not isolated from environmental pollution but can intensify exposure for cultured species. The transfer of MPs into edible muscle tissue, coupled with evidence of bioaccumulation, raises non-trivial concerns for food safety and export quality. These findings necessitate a shift towards sustainable aquaculture practices, including improved waste management, careful selection of plastic equipment, and the development of non-plastic alternatives, to mitigate this emerging risk and ensure the long-term viability of the industry.

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