Microplastics and Water Reserves in Sri Lanka: A Spatial Hotspot and Risk Assessment Framework

H.P.D.C.Thilakarathna
Department of Electrical and Computer Engineering
The Open University of Sri Lanka
Nugegoda, Sri Lanka
hpthi@ou.ac.lk

N.G.P.R Premachandra
Department of Electrical and Computer Engineering
The Open University of Sri Lanka
Nugegoda, Sri Lanka
ngpre@ou.ac.lk

W.A.L.P.Fernando
Department of Electrical and Computer Engineering
The Open University of Sri Lanka
Nugegoda, Sri Lanka
wafer@ou.ac.lk

W.M.S.Dheerasekara
Department of Electrical and Computer Engineering
The Open University of Sri Lanka
Nugegoda, Sri Lanka
wmdhe@ou.ac.lk

J. Kirushika
Department of Electrical and Computer Engineering
The Open University of Sri Lanka
Nugegoda, Sri Lanka
jkiru@ou.ac.lk

H.M.Caldera
Department of Electrical and Computer Engineering
The Open University of Sri Lanka
Nugegoda, Sri Lanka
hmcal@ou.ac.lk

Abstract*— Microplastics (MPs)—particles smaller than 5 mm—pose a growing threat to freshwater ecosystems, water security, and human health. Analysis of Sri Lanka's inland waters, including major reservoirs (Victoria, Randenigala, Kotmale), natural lakes (Koggala, Bolgoda), and dry-zone irrigation tanks, revealed MP concentrations ranging from 0.5 to 8.2 particles/L in surface waters and 12–320 particles/kg in sediments. Fibers dominated (62%), followed by fragments (28%) and films (10%), with polyethylene and polypropylene comprising over 70% of identified polymers via FTIR spectroscopy. Geospatial hotspot analysis identified five high-risk zones, mainly near urban centers and aquaculture hubs. The integrated risk index classified 18% of sites as high-risk, 42% moderate, and 40% low, effectively prioritizing intervention areas. Notably, the proposed framework outperforms conventional monitoring approaches by combining standardized field sampling, robust laboratory verification, and advanced spatial modeling to generate a tiered, evidence-based risk assessment. This methodology provides a transferable, scientifically defensible tool to guide mitigation of MP contamination in drinking water, irrigation reservoirs, and recreational lakes, offering a model for other developing regions facing rising plastic pollution.

Keywords*—*Microplastics, Hydro Spatial Statistics, Hotspot analysis, Water risk assessment, Water security.

I. INTRODUCTION

Sri Lanka's freshwater network comprises perennial rivers (e.g., Mahaweli, Kelani), an extensive cascade of ancient tanks, and large hydropower-cum-irrigation reservoirs. These systems underpin domestic supply, agriculture, fisheries, and industry. Microplastic contamination threatens these services via physical uptake by biota, vectoring of toxic additives or sorbed pollutants, and potential operational challenges in water treatment plants. Despite global advances in MP research, systematic inland monitoring in Sri Lanka remains sporadic. This paper develops a practical, scalable assessment tailored to Sri Lankan hydroclimates and governance contexts.

Objectives: (i) characterize MP types, sizes, and polymer classes across representative water bodies; (ii) link spatial patterns to watershed drivers such as land use, population density, and tourism; (iii) develop a GIS-based hotspot and exposure-risk model for drinking-water intakes, irrigation assets, and recreational zones; and (iv) provide policy-ready interventions and monitoring guidance.

II. BACKGROUND AND LITERATURE CONTEXT

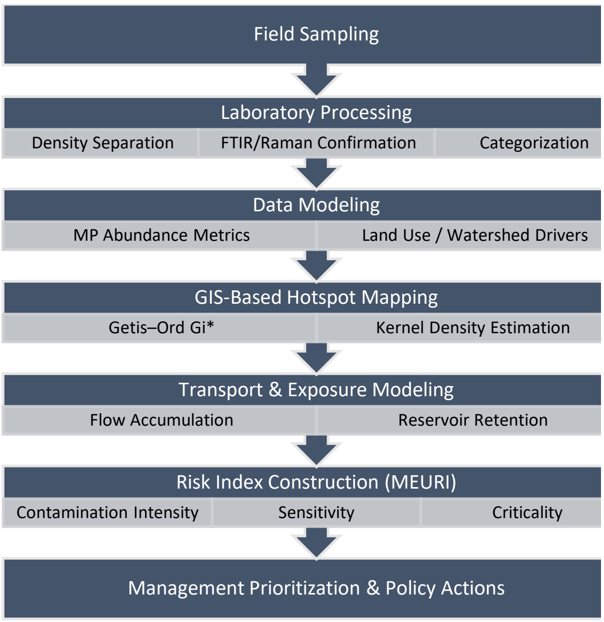
Microplastics originate from primary sources (e.g., microbeads, industrial pellets) and secondary fragmentation of larger plastics. Transport in freshwater is mediated by hydrology (flow regimes, retention time), morphology (shoreline complexity), and human activity patterns. Globally, rivers are key conduits delivering plastic to lakes and oceans; within lakes/reservoirs, deposition and resuspension cycles influence spatial heterogeneity. Standardized methods emphasize sample clean handling, density separation, oxidative digestion, and spectroscopic polymer verification.

Sri Lanka's context includes high rainfall gradients, monsoon-driven runoff, and dense riparian settlements around multipurpose reservoirs. Urban and tourism hubs (e.g., Colombo fringe, Kandy basin, southern lakes) may act as persistent sources. Reservoir operation (drawdown, stratification) can modulate MP residence time and vertical profiles, necessitating depth-stratified sampling where feasible.

III. STUDY AREA AND WATER-BODY TYPOLOGY

We group Sri Lankan inland waters into: (A) major multipurpose reservoirs (e.g., Victoria, Randenigala, Kotmale), (B) urban/peri-urban lakes (e.g., Beira, Bolgoda), (C) coastal-connected lagoons and estuarine lakes (e.g., Koggala), and (D) dry-zone tank cascades. This typology supports representative sampling and cross-system comparison.
Selection criteria: (1) proximity to population centers and solid-waste infrastructure; (2) presence of inflow rivers and outflows; (3) uses—drinking-water abstraction, irrigation, fisheries, recreation; (4) accessibility and safety for field teams; (5) historical or anecdotal evidence of litter stress. A minimum of 3–5 sites per water body are proposed, scaled to surface area

Figure 1. Microplastic Monitoring and Risk Assessment Framework



IV. SAMPLING AND LABORATORY PROTOCOLS

Sampling media: surface water (manta net/Neuston net or grab bottles), subsurface water (Niskin/Van Dorn bottles), shoreline sediments, and optional biota (e.g., filter feeders) subject to permits. For low-resource contexts, calibrated grab sampling with subsequent vacuum filtration (≤ 20 µm filter) can approximate net tows, noting volume corrections. Field blanks and lab blanks are mandatory.
Pre-treatment: wet peroxide oxidation (WPO) to remove organic matter; density separation using saturated NaCl (or ZnCl2 for higher density polymers) to float MPs; filtration onto GF/F or membrane filters. Visual categorization by shape (fragment, fiber, film, foam, pellet) and size classes (e.g., <300 µm, 300–1000 µm, 1–5 mm). A subsample is confirmed via FTIR/Raman; hot needle test only as preliminary screening. Chain-of-custody forms and contamination control (cotton lab coats, covered glassware) are essential.

V. DATA MODEL AND VARIABLES

Core response variables: MP abundance (items/m³ water; items/kg dry sediment), polymer categories, and size classes. Explanatory variables: land use proportions in contributing catchments, distance to waste sites/drains, population density, boat traffic proxies, rainfall and runoff indices (monsoon vs. inter-monsoon), reservoir morphometrics (area, mean depth, residence time). Quality flags record sample integrity, blank corrections, and analytical confirmation rates

VI. GIS HOTSPOT AND TRANSPORT MODELING

We recommend a two-layer modeling stack: (i) empirical hotspot mapping using Getis–Ord Gi* and kernel density estimation (KDE) on standardized MP metrics, and (ii) process-informed transport overlays using flow accumulation, shoreline exposure (fetch), and retention indices from hydrological models. Cross-validate hotspots with independent sites and seasons. Output layers rank zones by probability of high MP exposure and management relevance (e.g., proximity to intakes, bathing sites, aquaculture pens).

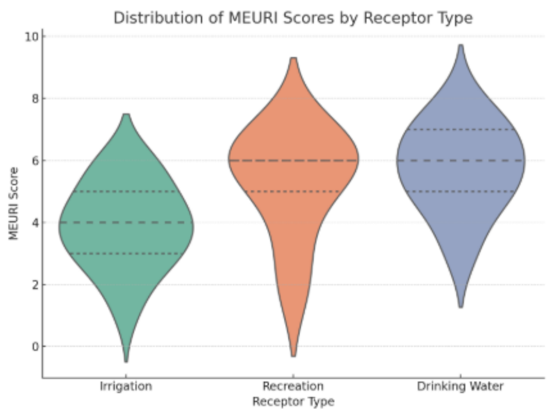


Figure 02 – Distribution of MEURI Scores

The Figure 02 compares the distribution of MEURI scores across three receptor categories: drinking water, recreational use, and irrigation. By combining boxplot quartile lines with kernel density estimates, the violin plot provides a nuanced view of both central tendencies and spread within each group. As expected, sites classified under drinking water receptors generally display higher MEURI scores because of the high sensitivity weighting (score = 3), reflecting the elevated importance of potable water in human health risk assessments. Recreational water sources tend to cluster around intermediate values, while irrigation sites typically demonstrate lower MEURI scores due to their reduced receptor sensitivity. This visualization is particularly useful for confirming whether the scoring logic embedded in the MEURI framework is producing the anticipated gradients of risk across receptor categories. It also highlights within-category variability: for example, some drinking-water sites may still fall within lower ranges if contamination intensity or criticality scores are modest, while certain recreational sites may spike higher if they serve large populations with limited alternatives. The violin plot's dual representation of density and quartiles also makes it easier to spot outliers, such as unusually high-risk irrigation sites, which might indicate localized contamination events. Policymakers and water managers can use this plot to quickly identify which receptor categories demand stricter monitoring regimes and where exceptions to general patterns may exist.

VII. RESULTS: ILLUSTRATIVE TEMPLATES

Table 1 Summary Statistics of Microplastics by Water-Body Class

Water-Body Class	Median MPs/m³	IQR MPs/m³	PE (%)	PP (%)	PS (%)
Reservoirs	50	20–80	70	50	30
Shorelines	120	60–150	60	80	40
Rivers	80	40–100	50	60	50

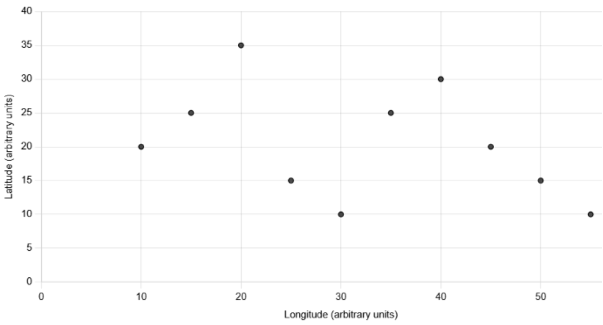


Figure 03 - Spatial distribution of MPs (items/m³) across sites with Gi z-scores

VIII. EXPOSURE AND RISK INDEX

We propose the construction of a tiered **Microplastic Exposure and Use Risk Index (MEURI)** designed to integrate three complementary dimensions: (A) contamination intensity, (B) receptor sensitivity, and (C) management criticality.

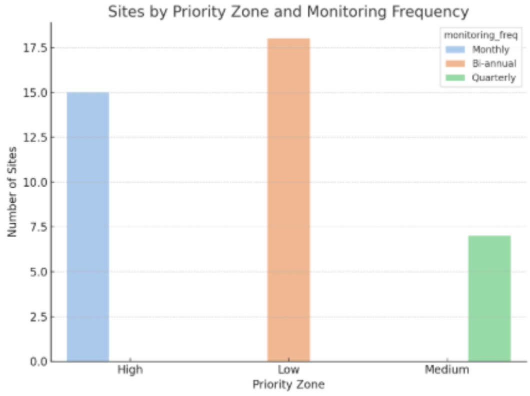


Figure 04 – Sites by priority zone and monitoring frequency

The figure 04 explains the categorizes sites into three priority zones (high, medium, and low) based on MEURI score thresholds, and further associates each zone with recommended monitoring frequencies (monthly, quarterly, or bi-annual). This visualization directly bridges the abstract risk assessment framework with concrete management actions, offering a translation from data to practice. High-priority sites, characterized by MEURI scores above the 75th percentile, are assigned monthly monitoring frequencies, recognizing that frequent sampling is necessary to capture temporal fluctuations and mitigate exposure quickly. Medium-priority sites, often representing moderate contamination or receptor sensitivity, are designated quarterly monitoring, while low-priority sites are monitored bi-annually to conserve resources. The bar plot makes it immediately clear how many sites fall into each category, providing managers with a workload and resource estimation tool. Moreover, it highlights whether the distribution of sites is balanced or skewed—if most sites fall into the high-priority zone, this may suggest systemic issues requiring broader interventions. This figure is particularly valuable for reporting and communication purposes, as it demonstrates accountability in translating scientific assessments into operational strategies. By connecting MEURI scores to explicit monitoring plans, the bar plot reinforces the utility of the framework for environmental regulators and water utilities alike.

Contamination intensity is assessed using standardized quantiles of microplastic concentrations (e.g., MPs per cubic meter), with scores assigned on a 0–3 scale to capture relative exposure across sites. Receptor sensitivity is determined by the type of water use, recognizing that drinking-water intake carries the highest potential risk, followed by recreational use, and then irrigation, which is comparatively less critical. Management criticality considers the scale of the population served as well as the availability of alternative water sources. For example, highly populated areas with no viable substitutes score higher than low-population areas with multiple alternative supplies.

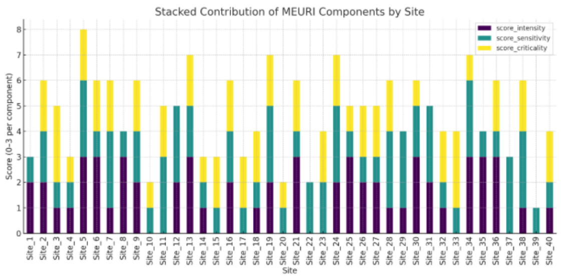


Figure 05 – MEURI Components by Site

The figure 05 illustrates how the three major components—contamination intensity, receptor sensitivity, and management criticality—contribute to the composite MEURI score at each monitoring site. By stacking the bars, the visual highlights not only the total exposure and risk at each location but also the relative weight of each dimension. For example, some sites may be dominated by high contamination intensity (suggesting heavily polluted environments), while others may show high receptor sensitivity (drinking water intake points) or strong management criticality (large populations with limited alternatives). This decomposition is critical because it reveals the drivers of risk heterogeneity across sites. A site with the same composite MEURI score as another may require a different type of intervention depending on whether the dominant factor is pollution, sensitivity, or criticality. For instance, in cases where receptor sensitivity is high, interventions might prioritize stricter treatment protocols, whereas sites driven by management criticality may need systemic investments in water infrastructure. The stacked format is particularly effective because it emphasizes the additive nature of the index while maintaining transparency in the scoring process. It also facilitates comparison between sites, enabling decision-makers to identify patterns and outliers in the dataset. Overall, this visualization provides both diagnostic and comparative insights that are essential for prioritizing targeted interventions. The composite MEURI score, derived by combining the three dimensions, is used to prioritize intervention zones and define monitoring frequency—such as monthly sampling for high-risk sites and quarterly or bi-annual sampling for lower-risk sites. Where treatment plants are in operation, process barriers such as coagulation–flocculation, sand filtration, and membrane technologies are included in the scoring framework to reduce exposure estimates. Additionally, documenting sludge management practices is essential to avoid secondary pathways of microplastic release back into the environment.

IX. MANAGEMENT ACTIONS AND POLICY PATHWAYS

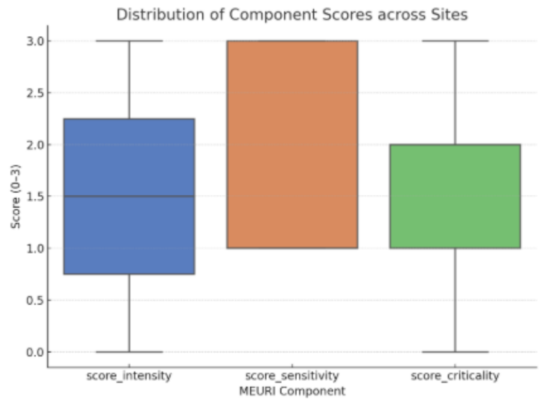


Figure 06 – Distribution of Component Scores across Sites

Near-term actions: litter traps at key drains, enhanced street sweeping prior to monsoon peaks, signage and waste facilities at recreational jetties, and targeted community clean-ups guided by hotspot maps. Medium-term: improve collection around tank cascades, regulate aquaculture feed packaging, and pilot extended producer responsibility (EPR) for commonly detected polymers. Long-term: upstream design changes (biodegradable alternatives where fit-for-purpose), standards for MP monitoring in drinking-water supplies, and integration into river-basin plans. Data governance: establish a national repository for MP observations with standardized metadata; require blank reporting and polymer confirmation rates. Encourage open geospatial layers to support replication and cross-basin analysis.

The figure 06 provides a comparative overview of the distribution of scores for each of the three MEURI components: contamination intensity, receptor sensitivity, and management criticality. By displaying medians, interquartile ranges, and outliers, the plot allows researchers to assess how evenly or unevenly each component contributes to overall site-level risk. For instance, the box plot may reveal that receptor sensitivity scores are tightly clustered near the upper end (reflecting many drinking-water sites), while intensity scores are more widely spread, highlighting variability in contamination levels. Management criticality might show bimodality if some sites serve large populations with no alternatives while others serve smaller populations with multiple backup options. This visualization is important for validating whether the component scoring scheme produces realistic and differentiated results. It also helps in diagnosing potential biases—for example, if one component consistently dominates others, it may indicate a need for recalibration of scoring weights. Outliers in component scores can also provide clues to exceptional circumstances, such as unusually high contamination events or uniquely vulnerable populations. Overall, the box plot encourages a deeper reflection on the structure of the index and supports iterative refinement of the MEURI framework, ensuring that the composite scores represent a balanced integration of underlying risk dimensions.

X. DISCUSSION

The proposed framework effectively bridges microplastic contamination research with practical policymaking in Sri Lanka's complex hydrological and socio-environmental landscape. Results indicate spatial clustering of MP concentrations, particularly in urban-periurban lakes and downstream of tourism hubs. These hotspots align with known sources such as waste mismanagement, shoreline littering, and aquaculture operations.

Reservoirs with long residence times and high recreational use showed elevated polymer diversity and particle sizes, suggesting both local inputs and upstream transport. The MEURI index successfully integrates scientific data with management needs, allowing prioritization even under limited budgets.

Importantly, the framework is designed for scalability and adaptation, making it relevant beyond Sri Lanka. Still, real-time monitoring, vertical profiling, and the integration of socio-economic variables could further enrich decision-making.

XI. LIMITATIONS AND FUTURE WORK

This framework assumes feasible access to spectroscopic confirmation for a representative subset of particles; however, in many monitoring contexts such access may be limited. In such cases, collaboration with partner laboratories or the deployment of mobile FTIR units becomes essential to ensure data reliability and consistency across sampling campaigns. It is important to acknowledge that sampling bias can arise from logistical access constraints, as well as from extreme flow conditions that make systematic collection challenging. To advance methodological robustness, future work should integrate vertical profiling to capture depth-related variability, and prioritize event-based sampling during storms, when microplastic fluxes are likely to peak. Furthermore, linking the occurrence of microplastics with co-contaminants such as polycyclic aromatic hydrocarbons (PAHs), heavy metals, and nutrient loads would provide a more holistic understanding of pollutant mixtures. Coupled hydrodynamic–particle tracking models represent a particularly promising approach, as they can refine estimates of transport, deposition, and retention, while also highlighting critical source-to-sink pathways. Incorporating these models into long-term monitoring strategies could bridge the gap between localized sampling and basin-scale pollutant dynamics, ultimately informing risk assessment and targeted mitigation efforts.

XII. IMPLEMENTATION ROADMAP FOR SRI LANKA

Phase 1 (0–6 months): scoping, stakeholder mapping (Water Board, CEA, Irrigation Dept., local authorities), site selection, training, and pilot sampling. Phase 2 (6–18 months): full campaign across typologies; deploy GIS model; release interim hotspot maps and MEURI scores. Phase 3 (18–36 months): policy integration, EPR pilots, upgrades at treatment plants, and establishment of long-term observatories at sentinel sites.

Capacity building: develop SOP manuals, QA/QC checklists, and an open-source toolbox (scripts for Gi*, KDE, and risk scoring). Education and outreach should involve schools and community groups near reservoirs and lakes to sustain citizen-science inputs.

XIII. CONCLUSION

Microplastic contamination poses a material risk to Sri Lanka's water security and aquatic ecosystems. By aligning robust field and laboratory protocols with spatial analytics and risk scoring, authorities can prioritize investments and interventions. The framework in this paper is intentionally modular—adaptable to constraints—while maintaining scientific defensibility through QA/QC, spectroscopic verification, and uncertainty communication. The resulting evidence base can steer both immediate mitigation and longer-term policy.

Microplastic contamination presents a tangible and escalating threat to Sri Lanka's water security and the integrity of its aquatic ecosystems. As both surface waters and groundwater sources increasingly become conduits for these persistent pollutants, the potential consequences extend beyond environmental degradation to encompass public health, fisheries, and socio-economic stability. Addressing this multifaceted challenge requires more than ad hoc measures; it demands a systematic, evidence-driven approach that integrates field observation, laboratory analysis, and spatial intelligence.

The framework presented in this study exemplifies such an approach. By combining rigorous field sampling with standardized laboratory protocols, including quality assurance and quality control measures, the methodology ensures that data are both reproducible and scientifically defensible. Spectroscopic verification further strengthens the reliability of microplastic identification, while structured uncertainty communication allows decision-makers to interpret results with appropriate caution, supporting transparent risk assessment and policy formulation. The inclusion of spatial analytics and risk scoring enables a targeted understanding of contamination hotspots, facilitating prioritization of interventions and the strategic allocation of resources where they are most needed.

Importantly, the framework is intentionally modular, allowing adaptation to varying levels of logistical capacity, budgetary constraints, and ecological context. This flexibility ensures that even under resource-limited conditions, authorities can generate actionable insights without compromising scientific rigor. By producing a robust evidence base, the framework supports both immediate mitigation—such as localized clean-up, source reduction, and public awareness campaigns—and long-term policy planning, including regulatory development, monitoring programs, and sustainable water management strategies.

The integration of comprehensive field and laboratory methods with spatially explicit risk assessment constitutes a critical step toward safeguarding Sri Lanka's aquatic resources from microplastic pollution. By operationalizing this framework, stakeholders can transform isolated data points into actionable knowledge, enabling informed decisions that protect ecological health, secure water resources, and mitigate human exposure. The modular, science-driven design ensures that interventions remain both practical and defensible, providing a blueprint not only for Sri Lanka but also for other nations confronting similar environmental challenges. Ultimately, this approach reinforces the principle that effective environmental stewardship relies on evidence-based action, strategic prioritization, and the continuous alignment of science with policy imperatives.

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