2.8 Potential accumulation of selected pollutants in dry zone reservoirs utilised for inland fisheries

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Abstract

Sri Lanka's dry zone reservoirs are one of the oldest historically recorded systems in the world. They are critical sources for water storage, irrigation and inland fisheries, and there is potential to be influenced by anthropogenic pollutants. This study examines the dynamics of the criteria water pollutants, selected pesticides and heavy metals and microplastics in 7 reservoirs utilised for inland fisheries practices. Results indicate significant variations in pH levels, TSS, biochemical oxygen demand (BOD), nutrient concentrations and microbial contamination, driven by anthropogenic activities and natural hydrodynamic conditions. The presence of oil and grease, lead and pesticide residues highlights pollutant retention mechanisms, with Urusita wewa and Wan ela exhibiting notable contamination trends. Microplastic accumulation, particularly in Vijayakatupotha reservoir, suggests site-specific pollution sources and sediment deposition dynamics. Despite localised pollution concerns, most reservoirs maintain water quality parameters within permissible limits, ensuring fisheries sustainability. However, the absence of regulatory thresholds for fecal coliform contamination underscores the need for enhanced water quality monitoring. Understanding pollutant interactions, bioaccumulation risks and environmental retention patterns is vital for sustainable reservoir management and fisheries conservation. This study emphasises the importance of adaptive pollution control strategies, community engagement and policy interventions to mitigate contamination risks and maintain long-term aquatic ecosystem health.

Keywords: *heavy metals, pesticide residues, microplastics, culture-based fisheries, agrarian reservoirs*

Introduction

With globalisation and industrial development, aquatic pollution due to various types of pollutant accumulation in water, sediments and organisms therein, has become an emerging threat that can increase the potential risk for human health. Aquatic pollution occurs when harmful substances, such as chemical contaminants or pathogenic microorganisms enter aquatic systems, including streams, rivers, lakes, oceans and aquifers. This intrusion alters the physical, chemical or biological properties of the water, leading to a deterioration in its quality. As a result, contaminated water can be hazardous for human consumption, aquatic life and the surrounding ecosystem.

Amongst the water resources in Sri Lanka, agrarian reservoirs are significant due to their high number. It has been estimated to have more than 30,000 reservoirs and anicuts throughout the island especially in the dry zone (DAS 2000). This is similar to have about 3 ha of reservoir area for every km^2 of the island, probably the highest density of reservoirs in the world (De Silva 1988; Piet 1996). Most of those reservoirs have been constructed to store rainwater to support paddy culture in the dry zone. That means there is a high potential to receive pesticide residues to these waterbodies from the surrounding paddy lands. With the addition of synthetic fertilisers, heavy metal accumulation in these agricultural areas can also be high (Rajapaksha et al. 2023). Since these reservoirs are popular sources of inland fish production (Amarasinghe 1998), associated health risk to humans through the aquatic food web will be a major concern.

The term 'heavy metal' generally refers to elements with a density exceeding 4 g/cm^3, including metals and metalloids like arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb) and mercury (Hg), according to Duffus (2002), which can contaminate the environment at concentrations above natural levels. Heavy metal pollution primarily arises from industrial discharge, agricultural run-off and urbanisation, leading to contamination of water, air and soil. These metals are toxic even in low concentrations, capable of bioaccumulating in living organisms and disrupting biological systems when ingested through contaminated food or water, potentially causing neurological disorders, kidney damage and cardiovascular issues in humans. In aquatic ecosystems, heavy metals degrade water quality and accumulate in freshwater species like prawns and finfish (Bhakta 2010), posing risks to human health, particularly in countries like Sri Lanka, where such species are vital for consumption and export. Similarly, pesticides which are chemical compounds used in agriculture to manage pests (US EPA 2013) can infiltrate water bodies via run-off, leaching or spray drift, persisting in the environment and accumulating in the food chain. Their presence in freshwater organisms such as prawns and fish (Nayem et al. 2011; Sultana et al. 2012) can lead to chronic human health issues, including hormonal imbalances, cancer and immune suppression, posing challenges to public health and aquaculture in Sri Lanka due to potential contamination of irrigational reservoirs.

Additionally, microplastics (MP), defined as particles smaller than 5 mm (Thompson et al. 2004, 2024), originating from the breakdown of larger plastics, industrial processes and personal care products, have emerged as pollutants in aquatic environments. These particles are ingested by aquatic organisms like fish

and crustaceans, entering the human diet (Pinheiro et al. 2017), while their ability to adsorb heavy metals enhances their toxicity (Khalid et al. 2021). Although extensively studied in marine systems, MP impacts in freshwater ecosystems remain less understood, highlighting the need for research in Sri Lanka's dry-zone reservoirs, where diverse environmental conditions and ecosystem sizes may affect their occurrence and consequences.

This study aims to explore the extent of heavy metal, pesticide and MP pollution in selected dry-zone irrigational reservoirs in Sri Lanka. These reservoirs are not only key sources of freshwater but also critical habitats for aquaculture, particularly for species like *M. rosenbergii* (GFP), tilapia, mrigal and rohu. This research will examine water and sediment samples to identify pollutant levels and investigate contaminant levels of these pollutants in different tissue types of aquatic organisms. Additionally, the research will extend to studying the occurrence of MP in freshwater systems, addressing gaps in existing literature.

Materials and methods

Study area

The study was conducted within 7 dry zone reservoirs selected from Southern Province, Uva Province, North Western Province, North Central Province and Eastern Province in Sri Lanka (Figure 2.8.1).

Urusita (6°19'54"N; 80°56'02"E) and Handapanagala (6°39'40"N; 81°09'09'06"E) reservoirs in Monaragala district, Weerawila reservoir (6°17'13"N; 81°14'19"E) in Hambanthota district, Tabbowa (8°04'26"N; 79°57'17"E) and Vijayakatupotha (7°43'09"N; 79°53'36"E) reservoirs in Puttalam district, Maha Siyambalangamuwa reservoir (7°56'34"N; 80°27'58"E) in

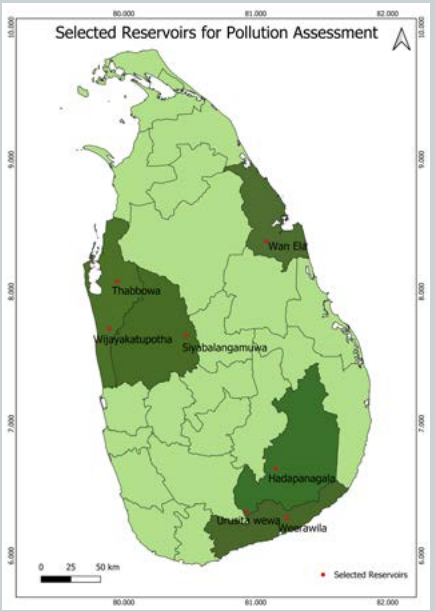

Figure 2.8.1: Selected dry zone reservoir distribution within Sri Lanka

Kurunegala district and Wan Ela (8°22'55"N; 81°04'50"E) in Trincomalee district were selected and background analysis was carried out from October 2022 to March 2023 to select appropriate sites for the sample collection based on their location and size, main inlets and outlets, fish catch information and surrounding/catchment area.

Sample collection and preservation

Sampling was carried out bimonthly from March 2023 to February 2024. Sample preservation and storage techniques were varied according to the selected parameters (Table 2.8.1). Water samples were obtained using a Ruttner sampler for laboratory tests except for MP analysis. Obtained water samples were subdivided into 4 portions as (A), (B), (C) and (D) for different analyses. Where necessary, samples were preserved and stored according to standard methods mentioned in Baird et al. (2017).

Table 2.8.1: List of tested parameters for assessing the reservoir pollution status

Category		Parameters
Criteria water pollutants (in water)		pH
		Nutrients (nitrate and phosphate)
		Total suspended solids (TSS)
		Biochemical oxygen demand (BOD_5)
		Oil and grease
		Pathogenic organisms (Ex: fecal coliform)
Priority toxic pollutants	Heavy metals (in water, sediment and fish tissue)	Lead (Pb), Cadmium (Cd), Chromium (Cr), Arsenic (As)
	Pesticides (in water, sediment and fish tissue)	Azardirachtin A, chlorpyrifos, diazinon, emamectin benzoate, fipronil, MCPA, profenofos, thiamethoxam, fenoxaprop-p-ethyl, etofenprox
	Microplastics (in water and sediment)	Quantitatively analysed for morphometric parameters such as shape and size

Portion (A) of the obtained water sample was collected into 2 reagent bottles and one bottle was preserved with Winkler A and Winkler B while the other one was covered with a black polythene until further analysis for BOD.

The second portion (B) was filtered through a pre-weighted GF/C filter paper using a plastic filter setup connected to a vacuum pump. Filtrate was used to analyse dissolved heavy metals in water after preserving with concentrated nitric acid while filter paper was used to analyse TSS.

The third portion (C) was collected into a glass bottle and preserved with concentrated sulfuric acid to determine nutrient levels, and oil and grease levels.

The fourth portion (D) was collected into a sterilised glass bottle which was used to determine pesticide residues and fecal coliform level. All the collected and preserved water samples, as schematically mentioned in Figure 2.8.2, were stored under 4 °C until transferred to the laboratory.

A metal sieving device coupled with a water pump (Figure 2.8.3) was specifically prepared to collect MP according to their size. Sieves used in this device were completely made of stainless steel to reduce the potential contamination of MP from the sampling devices. Sieves containing MP were covered with aluminium foil papers and stored in 4 °C until transfer for further analysis.

Sediment samples were obtained using an Ekman grab sampler, and the samples were stored in polythene zip lock bags until transferred to the laboratory for heavy metal and pesticide analyses. The sediment samples for MP analysis were grabbed from near shorelines and fish landing sites, and they were stored in glass jars. All the sediment samples were stored in 4 °C until further analysis.

Fish and GFP samples were collected from fishers and stored in a freezer at -20 °C until further analysis.

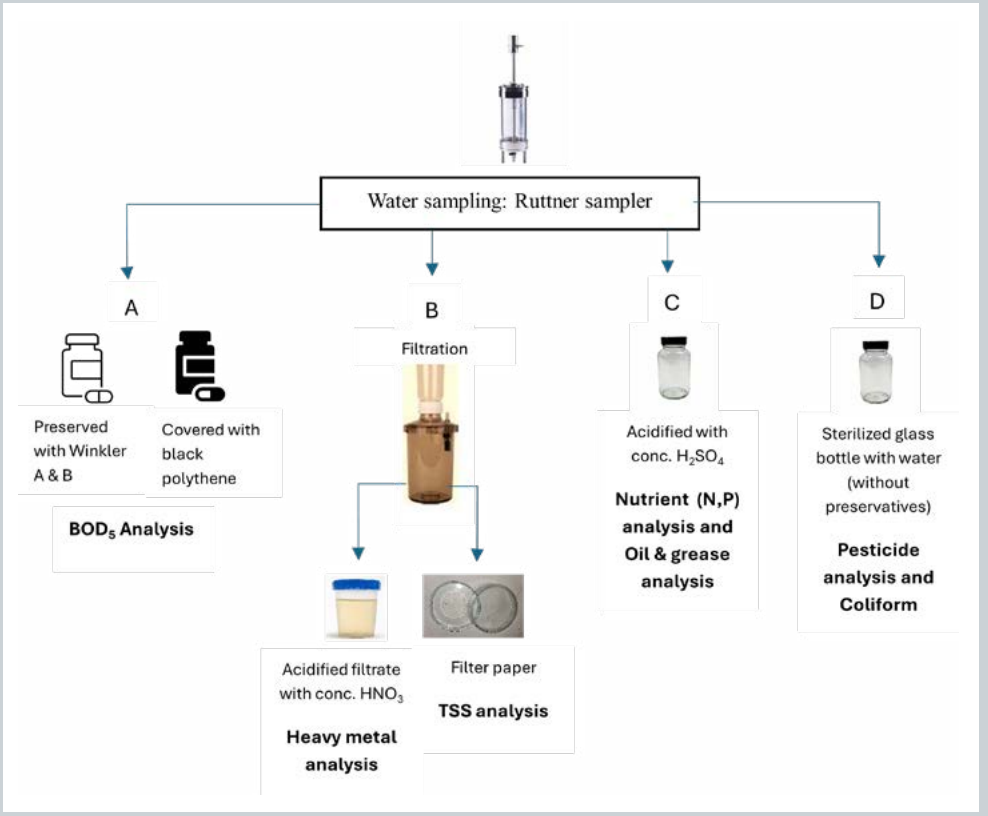

Figure 2.8.2: Schematic diagram of water sampling, and sub-sampling and preservation techniques used in the field

Figure 2.8.3: Sieving device used to sample water for microplastic analysis

Priority toxic pollutant analysis

Physicochemical properties such as temperature, DO and pH were measured on site using a portable water quality meter (HANNA®). Water samples were further analysed for $BOD_{5,}$ TSS, nutrients, oil and grease, and fecal coliform to evaluate the criteria water pollutants.

Iodometric test (Azide modification) was followed to determine BOD_5 in reservoir water (Baird et al. 2017). TSS was determined on site by using a portable spectrophotometer (Hach® DR1900) and the obtained values were confirmed following the gravimetric method (Baird et al. 2017).

TP and TN levels were determined using colorimetric methods as described by Gross and Boyd (1998) and Baird et al. (2017). Acidified water samples with concentrated sulfuric acid (H_2SO_4) were digested using potassium persulfate ($K_2S_2O_8$). TP was determined via the ascorbic acid method, while TN was quantified using the sodium salicylate method. Absorbance measurements were taken using a portable spectrophotometer (Hach® DR1900).

Oil and grease levels were analysed by following the liquid-liquid partition gravimetric method using N-hexane extraction (Baird et al. 2017). Fecal coliform was determined using the multiple tube fermentation technique with Most Probable Number (MPN) statistical method (Baird et al. 2017).

Pesticide analysis

The water samples were pipetted into sample bottles without adding any preservation chemicals and kept under 4 °C until further analysis using High Performance Liquid Chromatography (HPLC). The sediment samples were prepared for HPLC analysis according to a modified method adapted to our specific conditions by referring to Badawi et al. (2016) and Bollmann and Badawi (2020). Samples were air-dried on paper over several weeks and then sieved through a 0.5 mm sieve. A 500 g sample was weighed before and after drying at 105 °C until a constant mass was achieved, typically over 5–8 hours. The dried sample was stored in a desiccator, cooled to room temperature and reweighed to calculate water content. The samples were then ground using mortar and pestle, and approximately 2 g of the ground material was weighed into 50 mL centrifuge tubes. Subsequently, 10 mL of 0.01 M $CaCl_2$ solution (using either bi-distilled or distilled water) and 10 µL of internal pesticide standard were added. The mixture was briefly shaken and placed in an overhead shaker at high speed for 24 hours, followed by 20 minutes in an ultrasonic bath filled with water. The samples were then centrifuged at 4,600 RPM for 90 minutes, after which the clear supernatant was pipetted into a sample bottle, and the sediment tube was either discarded or washed. Sample bottles with extracted solutions were kept under 4 °C until further analysis using HPLC.

The dissected tissue samples were homogenised thoroughly for uniformity, and an appropriate amount of sample was weighed into clean centrifuge tubes. Acetonitrile, buffered with salts provided in the test kits (BEKOlut© QuEChERS kit), was added as the extraction solvent. The mixture was shaken vigorously and centrifuged to separate the organic phase containing the analytes. Dispersive solid-phase extraction was performed using pre-filled tubes with sorbents tailored for clean-up, followed by further shaking and centrifugation to remove unwanted co-extractives. The tissue digestion process was conducted according to a modified

method based on specific requirements for our research (*BEKOlut ® QuEChERS KITS: Instructions for Use* n.d.; Souza et al. 2016). The cleaned extract was transferred to vials for analysis using LC-MS/MS technique (Agilent 6495b) which was equipped with a reverse-phase C-18 column (Phenomenex Synergi 4 µm Hydro-RP 80 Å, LC Column 150 × 3 mm).

Heavy metal analysis

All the water samples were filtered through GF/C filter papers and acidified on site, and they were transferred into polypropylene plastic containers for the determination of dissolved portions of heavy metals in water. Samples were stored under 4 °C until further analysis by Atomic Absorption Spectroscopy (AAS) (Baird et al. 2017).

All the sediment samples were defrosted and spread over pre-cleaned petri dishes for 24 hours to let them air dry in a clean laboratory environment. Air dried samples were ground using a ceramic mortar and pestle. Ground samples were sieved through a 1 mm strainer and subject to acid digestion. Digestion procedure was carried out according to the EPA 3050B method using nitric acid and hydrogen peroxide (US EPA 1996). Final extractions were filtered through GF/C filter papers and diluted up to 50 mL in volumetric flasks.

The fish samples were defrosted, and excess water was swabbed by clean, dry blotting papers. Sample preparation and digestion procedures were carried out following to a modified method (Mohammed et al. 2017). Dissected tissues were dispersed on petri dishes separately. They were kept in an oven at 80 °C for 24 hours. Oven dried samples, after letting them cool to room temperature, were crushed using a pre-cleaned ceramic mortar and pestle. Crushed samples were put into pre-cleaned polythene bags until acid digestion to avoid contamination. Acid digestion for lead was conducted according to the wet digestion method using conc. HNO_3 acid. DOLT 2 reference was used as the certified reference material (CRM) for tissue analysis and exactly similar digestion procedure was followed to digest the reference. All the digested solutions were stored in polypropylene plastic containers and stored in a refrigerator until metal analysis was conducted using the direct flame method in fast sequential atomic absorption spectrometer (SpctraAA 220©/ VARIAN®).

Microplastics analysis

Water sampling and digestion procedures were carried out by referring to Prata et al. (2019) and Razeghi et al. (2022) with slight modifications. Reservoir water was pumped and filtered using the prepared filter device (Figure 2.8.4) onsite. The filter device was composed of a series of stainless steel filters arranged in descending order of pore size. From top to bottom, the filters consisted with pore sizes of 3 mm, 1 mm, 500 µm, 100 µm and 30 µm, respectively. This configuration ensures a sequential filtration process, effectively capturing particles of varying sizes at each stage.

After the filtration process, the stainless steel filters were backwashed using distilled water, and the washed water was passed through a GF/C filter paper to collect MPs on it. In cases where the turbidity of the reservoir was high, the stainless steel filters were backwashed using a sodium chloride solution and the resulting washed water was collected in a sediment microplastic isolation unit (SMI unit) (Figure 2.8.4). After allowing the samples to settle for 24 hours, the floating particles were separated by filtering them onto a GF/C filter paper. This step ensured that any remaining suspended particles were effectively removed from the sample.

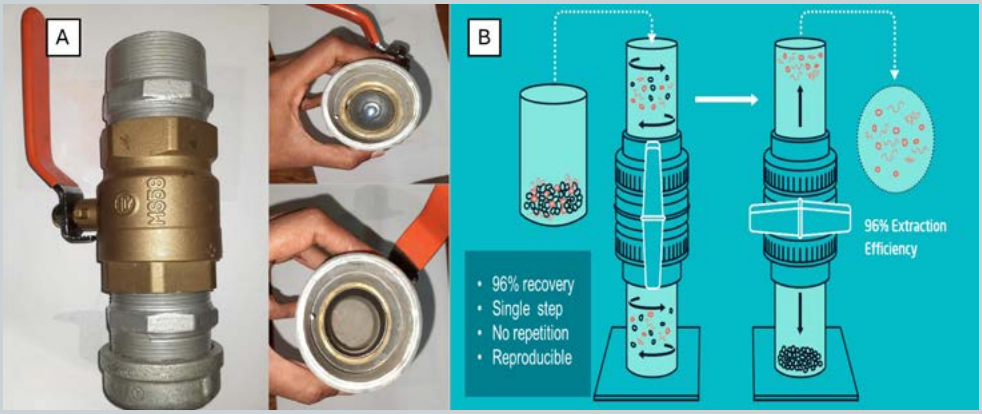

Figure 2.8.4: Sediment microplastic isolation unit; (A) newly prepared device and (B) schematic diagram from Cole n.d.

Sediment samples were subject to pre-treatment and extraction processes prior to isolating MP from sediments after a clear review of literature (Lakchani et al. 2025; Prata et al. 2019; Razeghi et al. 2022; Schrank et al. 2022). Each sediment sample was homogenised, and a known weight was stirred with sodium chloride in a beaker followed by ultrasonication for 10–20 minutes at room temperature. The resulting solution was transferred into the SMI unit for density-dependent separation as described above.

Isolated MPs on GF/C filters were stained by Nile red dye and observed under a dissecting microscope coupled with florescence light. This ensured the easy quantification of MP particles into different morphological categories such as fibre, fragments, foams and films.

Data analysis

The dataset obtained was systematically processed and analysed using Microsoft© Office Excel 365 version and IBM© SPSS Statistics 25 software allowing for a comprehensive examination of trends, correlations and key findings relevant to the study objectives. Graphical presentations were used to visualise the distribution of data within 7 reservoirs throughout the one-year sampling period. Pollutant distribution across 7 reservoirs was compared using one-way ANOVA tests. The one-sample t-test was used to determine whether the pollutant levels in reservoirs are within the standard permissible levels. The assessment of water quality in the reservoirs was conducted in accordance with the Maximum Permissible Levels (MPL) outlined in the National Environmental (Ambient Water Quality) Regulations, No. 01 of 2019.

Results

Criteria water pollutants

The concentration levels of criteria water pollutants across 7 selected dry zone reservoirs are represented in Figure 2.8.5, highlighting differences in contamination severity throughout the one-year period from March 2023 to January 2024.

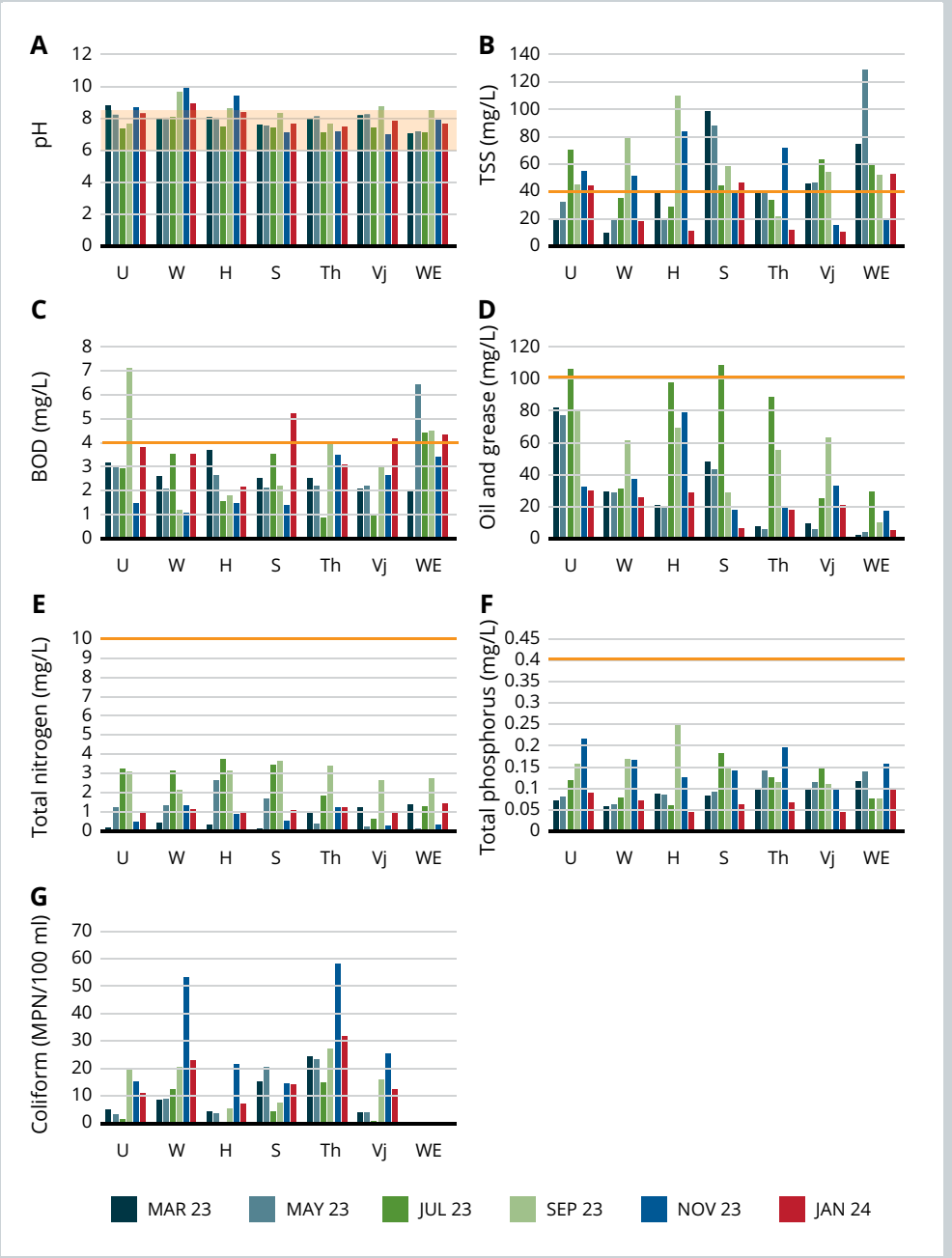

Figure 2.8.5: Graphical presentation of criteria water pollutants

Notes: (A) pH, (B) TSS, (C) BOD, (D) Oil and grease, (E) TN, (F) TP and (G) Fecal coliform, distribution within 7 reservoirs (U:Urusita, W:Weerawila, H:Handapanagala, S:Siyambalangamuwa, Th:Tabbowa, Vj:Vijayakatupotha and WE:Wan ela). Maximum permissible levels are indicated by an orange line for each parameter.

The distribution of pH (Graph A) within the reservoirs exhibits a statistically significant variation ($p<0.05$). The highest mean pH was observed in Weerawila reservoir (8.75±0.83), indicating relatively alkaline conditions, whereas the lowest mean pH was indicated in Wan Ela (7.51±0.54). When assessing the MPL of pH for aquatic life (6.0–8.5), Weerawila reservoir and Handapanagala reservoir exhibited statistically similar values ($p>0.05$) when compared to the established test value of 8.5. However, both reservoirs recorded pH values exceeding the standard range, indicating potential alkalinity concerns.

The TSS distribution within reservoirs (Graph B) reveals a statistically significant variation ($p<0.05$). Among the reservoirs examined, Wan Ela exhibited the highest mean TSS concentration (67.67±36.73 mg/L), indicating elevated particulate matter levels, while Weerawila recorded the lowest mean TSS (33.65±26.75 mg/L), suggesting relatively clearer water conditions. The evaluation of TSS against the MPL for aquatic life (40 mg/L) revealed higher significant deviations in Siyambalangamuwa reservoir and Wan Ela, both exhibiting statistically significant variations ($p<0.05$) from the established standard. In contrast, the remaining reservoirs recorded considerably lower TSS values, indicating relatively stable sediment concentrations within permissible limits.

The BOD distribution within the reservoirs (Graph C) indicates no statistically significant variation ($p>0.05$) across the different water bodies. Among them, Wan Ela exhibited the highest mean BOD value (4.08±3.81 mg/L), suggesting relatively higher organic matter presence and potential microbial activity, while Handapanagala recorded the lowest mean BOD concentration (2.31±1.37 mg/L), indicating comparatively lower organic pollution levels. The evaluation of BOD in Urusita and Wan Ela reservoirs against the MPL reveals no statistically significant difference ($p>0.05$) from the established standard (4 mg/L). However, both reservoirs exhibit BOD values exceeding the permissible limit, suggesting elevated organic matter decomposition and microbial activity.

The analysis of oil and grease distribution across reservoirs, as depicted in Graph D, reveals a statistically significant variation ($p<0.05$), indicating remarkable differences in contamination levels among water bodies. Urusita Wewa recorded the highest mean oil and grease concentration (66.75±38.87 mg/L), suggesting greater pollutant input or retention in this reservoir, potentially due to anthropogenic activities, industrial run-off or hydrodynamic conditions. Conversely, Wan Ela exhibited the lowest mean concentration (9.91±11.48 mg/L), indicating lower contamination levels in comparison to other reservoirs.

The nitrogen distribution within the reservoirs (Graph E) reveals no statistically significant variation ($p>0.05$) among the different water bodies. Handapanagala reservoir recorded the highest mean nitrogen concentration (1.930±1.66 mg/L), suggesting increased nitrogen inputs, potentially from agricultural run-off or organic matter decomposition. In contrast, Vijayakatupotha reservoir exhibited the lowest mean nitrogen value (1.002±0.84 mg/L), indicating comparatively lower nitrogen pollution levels. Nitrogen concentrations against the MPL reveals a statistically significant variation ($p<0.05$) from the established test value (10 mg/L). This indicates notable differences in lower nitrogen levels across the reservoirs.

The analysis of phosphorus distribution within the reservoirs (Graph F) indicates statistically significant variation ($p<0.05$) across the different water bodies. Thabbowa reservoir recorded the highest mean phosphorus concentration (0.122±0.06 mg/L), suggesting elevated phosphorus inputs, potentially from agricultural run-off or other external sources. In contrast, Weerawila reservoir exhibited the lowest mean phosphorus value (0.089±0.06 mg/L), indicating comparatively lower phosphorus pollution levels. Phosphorus concentrations in all the 7 reservoirs revealed a statistically significant difference ($p<0.05$) from the established standard (0.4 mg/L). This suggests notable lower concentrations of phosphorus levels from the MPL, indicating no present phosphorus pollution in reservoirs.

The distribution of fecal coliform within the reservoirs (Graph G) exhibits a statistically significant difference ($p<0.05$). Among the reservoirs analysed, Tabbowa recorded the highest fecal coliform levels (28.81±24.30 MPN/100 mL), indicating potential contamination sources, whereas Wan Ela showed no detectable coliform presence throughout the sampling period. Notably, no MPL has been established for fecal coliform concentrations in water designated for aquatic life under the National Environmental (Ambient Water Quality) Regulations, No. 01 of 2019.

Pesticides

The distribution of selected pesticides across the 7 reservoirs reveals distinct variation patterns as shown in Figure 2.8.6. Among the 10 selected pesticides, 5 (MCPA, Azadirachtin A, Emamectin Benzoate, Thiamethoxam and Fipronil) were detected in water samples, while the remaining 5 (Chlorpyrifos, Diazinon, Etofenprox, Fenoxaprop-P-Ethyl and Profenofos) were not present. Azadirachtin A and Emamectin Benzoate exhibit statistically similar distributions ($p>0.05$), indicating relatively uniform presence across all reservoirs. However, due to a technical error, peaks of Azadirachtin were found to be incorrectly identified by the HPLC machine; therefore, those detections are not reliable. Though Azadirachtin values are shown in result graphs, it will not be considered for discussion in this report.

In contrast, Fipronil, Thiamethoxam and MCPA show significant differences ($p<0.05$) among reservoirs, suggesting potential localised contamination sources or differential environmental transport mechanisms. The analysis identified MCPA as the most highly contaminated pesticide, with an average concentration of 0.075±0.017 µg/L in the reservoir water. The statistical analysis confirms ($p<0.05$) that pesticide concentrations in water remain within the standard permissible limits (5 µg/L) established by the World Health Organization (WHO) and FAO, as regulated by the Central Environmental Authority (CEA) of Sri Lanka under the National Environmental (Protection and Quality) Regulations, No. 1 of 2008.

In sediment samples, only 2 pesticides (MCPA and Emamectin Benzoate) were identified, indicating selective retention within the sediment matrix. The analysis of pesticide concentrations in sediment samples (Figure 2.8.7) indicates statistically similar distribution across all reservoirs, with no significant variation ($p>0.05$). This uniformity suggests that sediment-bound pesticides are relatively stable across different water bodies, likely influenced by consistent environmental factors such as sediment composition, deposition rates and limited external contamination sources.

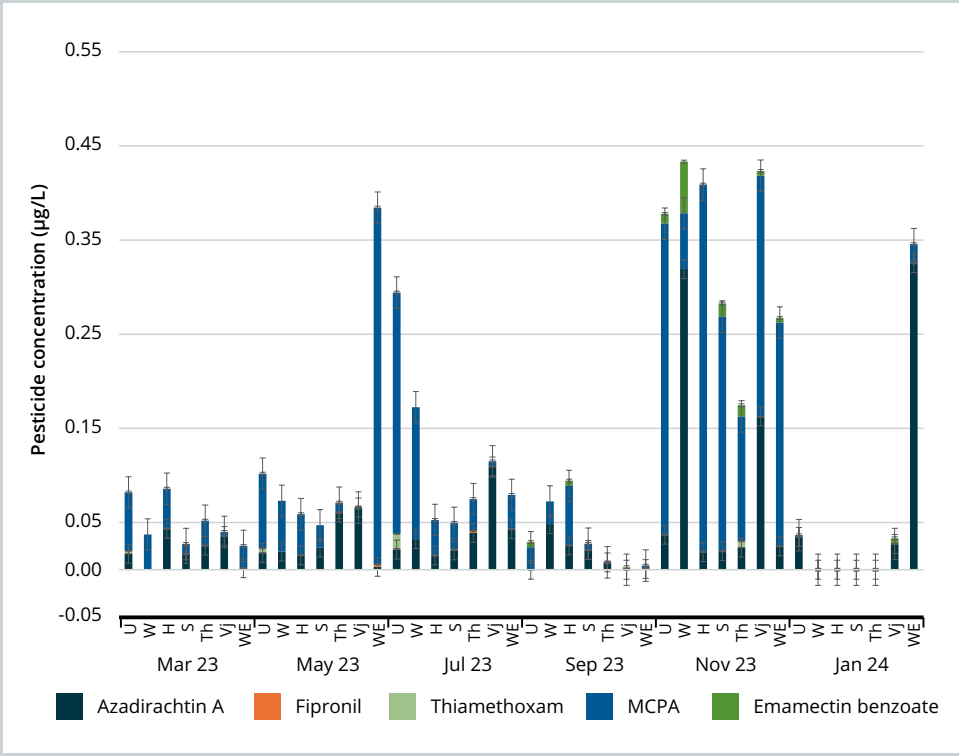

Figure 2.8.6: Temporal variation of pesticide distribution in reservoir water over a one-year sampling period

Note: U:Urusita, W:Weerawila, H:Handapanagala, S:Siyambalangamuwa, Th:Tabbowa, Vj:Vijayakatupotha and WE:Wan ela.

Pesticide residue analyses in fish tissue samples are still being carried out; therefore, the results are not included in this report.

Heavy metals

This study is still ongoing, and by the time of drafting this manuscript, only the lead (Pb) analysis was complete. The distribution of lead across reservoir water and sediment reveals distinct spatial patterns. In water samples, lead concentrations exhibit a statistically significant variation ($p<0.05$) among reservoirs, suggesting differences in contamination sources, hydrodynamic factors or water chemistry influencing its mobility. In contrast, lead distribution in sediment is statistically similar ($p>0.05$) across all reservoirs, indicating consistent sediment deposition and retention processes.

The lead concentrations in reservoir water (Figure 2.8.8) reveal notable variations among locations. The highest recorded concentration was observed in the Urusita reservoir, with an average of 0.012±0.005 mg/L, suggesting potential localised contamination sources or differing hydrodynamic conditions. In contrast, the lowest concentration was detected in the Vijayakatupotha reservoir, averaging

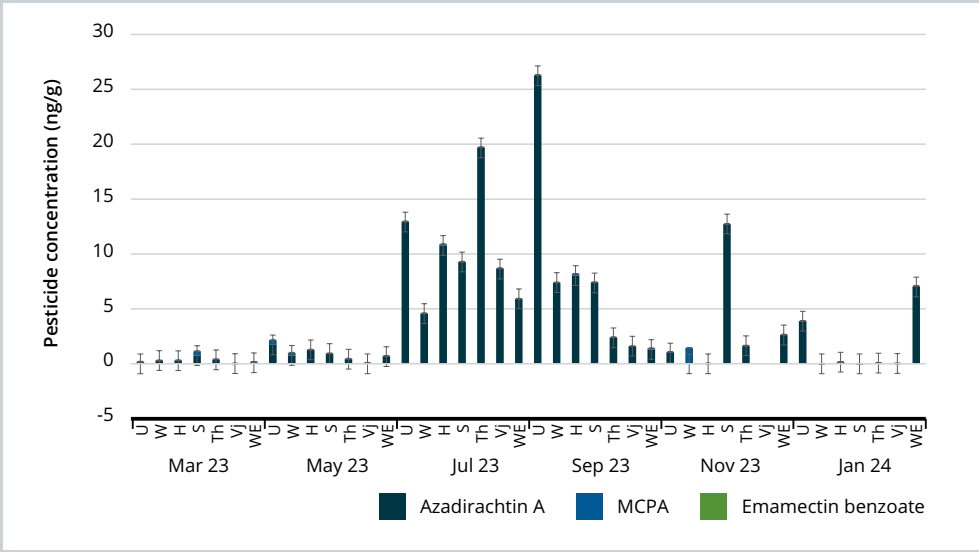

Figure 2.8.7: Temporal variation of pesticide distribution in reservoir sediment over a one-year sampling period

Note: U:Urusita, W:Weerawila, H:Handapanagala, S:Siyambalangamuwa, Th:Tabbowa, Vj:Vijayakatupotha and WE:Wan ela.

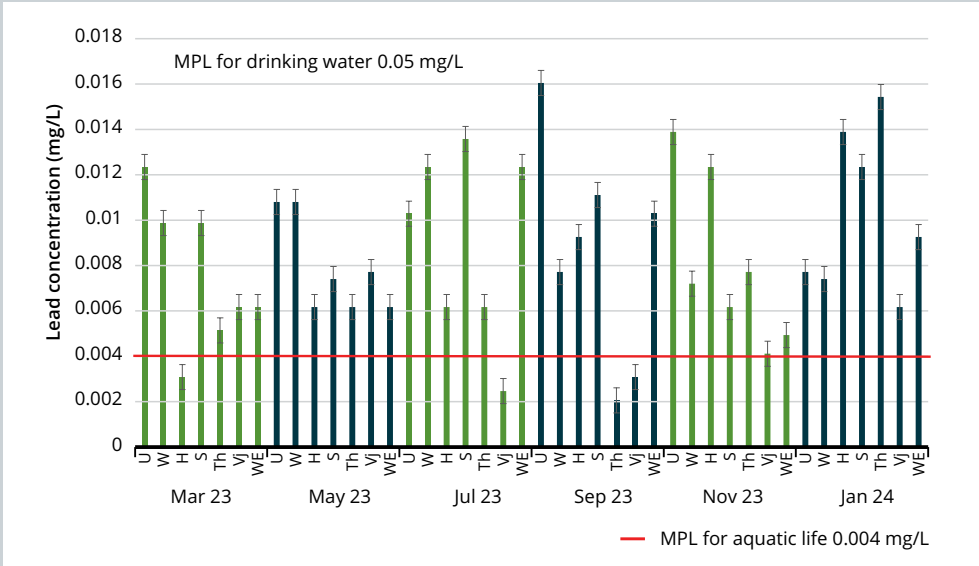

Figure 2.8.8: Temporal variation of lead (Pb) concentration in reservoir water over a one-year period

Note: U:Urusita, W:Weerawila, H:Handapanagala, S:Siyambalangamuwa, Th:Tabbowa, Vj:Vijayakatupotha and WE:Wan ela.

0.005±0.005 mg/L, indicating a relatively lower impact of lead contamination on this site. The analysis of lead concentrations in reservoir water, compared against established MPLs, indicates notable variations in suitability for aquatic life and drinking water. The National Environmental (Ambient Water Quality) Regulations, No. 01 of 2019, suggests an MPL of 0.004 mg/L for aquatic life, while the 0.05 mg/L as the limit for drinking water after simple treatment. Only Vijayakatupotha reservoir meets the MPL standard for aquatic life ($p>0.05$), implying minimal risk for aquatic organisms. All the reservoirs are suitable for drinking water consumption after simple treatment, as their lead concentrations fall within the MPL guideline (0.05 mg/L).

The lead concentrations in reservoir sediment (Figure 2.8.9) revealed Vijayakatupotha as the site with the highest recorded average lead levels (15.081±11.32 mg/L), indicating possible localised contamination sources or sediment retention mechanisms. In contrast, Tabbowa exhibited the lowest average lead concentration (8.742±7.04 mg/L), suggesting reduced lead deposition or external influence in that area. The Pb concentrations in sediment reveals that the recorded levels fall below the range (35.8 mg/kg – 128 mg/kg: dry weight) suggested by Sediment Quality Guidelines (SQGs) as US EPA (2006); Recommended Guidelines for Evaluating Contaminant Concentrations in Freshwater Sediments and the Potential for Those Contaminants to Adversely Affect Aquatic Biota (2016). This indicates that lead contamination in sediment does not exceed the thresholds typically associated with significant ecological risks. Correlation analysis between lead concentrations in reservoir water and sediment showed no statistically significant association.

The lead analysis for tissue samples was conducted by comparing fish muscle tissues and GFP muscle and exoskeleton tissues to assess differences in metal accumulation patterns between fish and GFP (muscle and exoskeleton) (Figure 2.8.10). Pb levels in fish tissue samples indicate significant variation among samples from different reservoirs ($p<0.05$). Accumulation of lead into GFP muscles and exoskeleton indicates a similar distribution ($p>0.05$) among the samples from reservoirs. According to the world heavy metals regulations, the maximum permissible limit for lead in fishery products is 0.2 mg/kg of fresh weight, and for crustaceans, an increased limit of 0.4 mg/kg is considered (FAO 2003). Lead accumulation in fish and GFP muscle tissues indicates that levels remain within permissible limits for 6 reservoirs out of 7, ensuring compliance with established safety standards. However, Wan Ela exceeds these thresholds, suggesting potential contamination risks. Lead accumulation in exoskeleton tissues from all reservoirs is significantly higher than muscle tissues, suggesting that consuming these parts may pose health risks due to potential heavy metal toxicity.

Microplastics

MP contamination was detected in both water and sediment samples across all surveyed locations, with varying concentrations observed among sites. MP concentrations in sediment were generally higher than in water, suggesting a tendency for accumulation and deposition over time. Statistical analysis revealed significant variation in MP abundance, with certain sites exhibiting markedly higher concentrations, possibly due to anthropogenic influence. Figure 2.8.11 illustrates the particle size distribution of microplastics across reservoir water, revealing a high concentration within

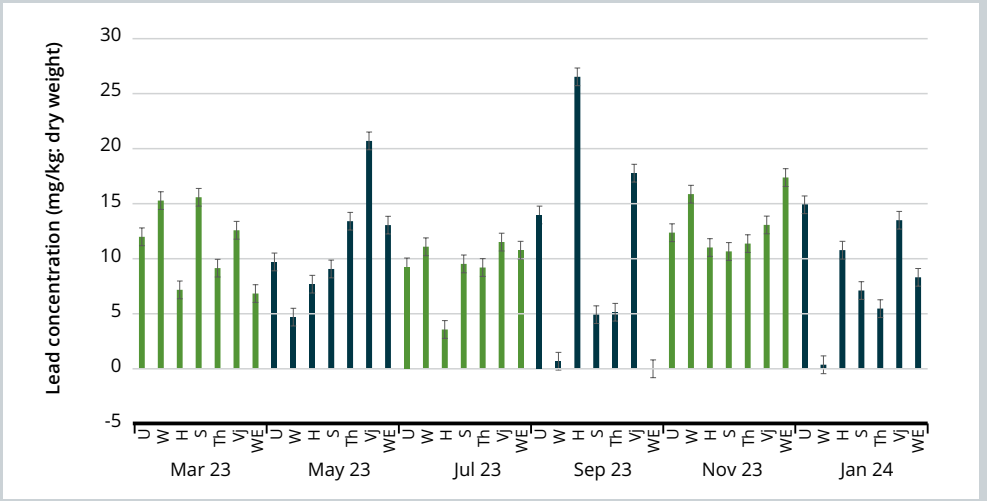

Figure 2.8.9: Temporal variation of lead (Pb) concentration in reservoir sediment over a one-year sampling period

Note: U:Urusita, W:Weerawila, H:Handapanagala, S:Siyambalangamuwa, Th:Tabbowa, Vj:Vijayakatupotha and WE:Wan ela.

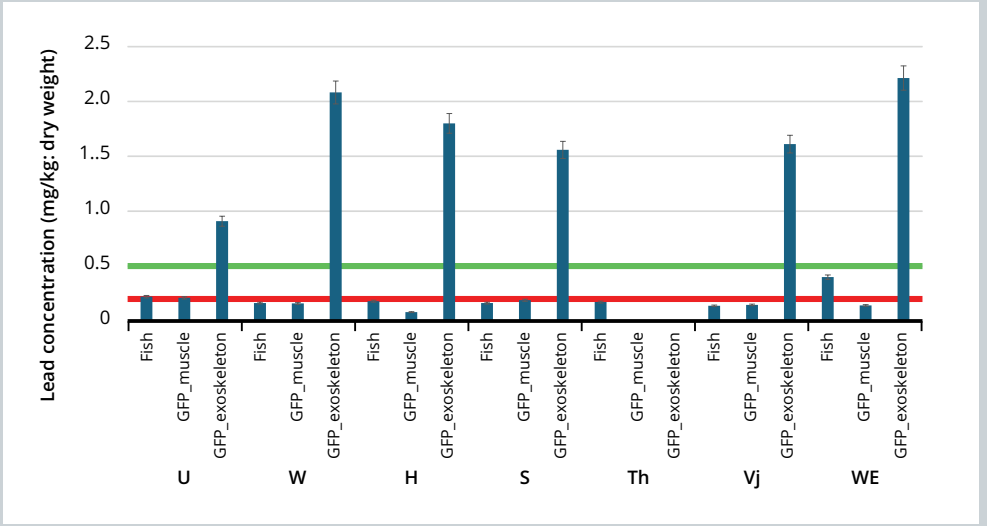

Figure 2.8.10: A comparative graphical representation lead (Pb) accumulation in fish and prawn tissues: muscle versus exoskeleton distribution

Note: Red line: mean total lead content for fish_0.2 mg/kg, green line: mean of total lead content for crustaceans_0.5 mg/kg); U:Urusita, W:Weerawila, H:Handapanagala, S:Siyambalangamuwa, Th:Tabbowa, Vj:Vijayakatupotha and WE:Wan ela.

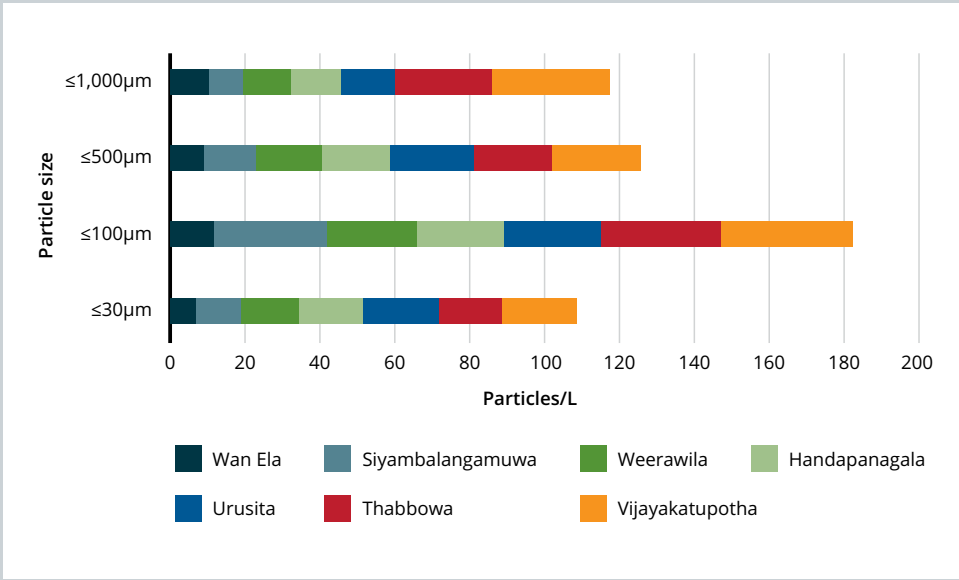

Figure 2.8.11: Microplastic size distribution across reservoirs selected for the study

the 100–30 µm size range. The MP concentration was observed in particles below 30 µm, indicating a lesser abundance of extremely fine microplastic fragments in reservoir samples.

As shown in Figure 2.8.12, fragments are the most abundant MP shape accumulating within reservoirs, indicating a prevalence of plastic degradation and fragmentation processes in these aquatic environments. Additionally, Vijayakatupotha reservoir exhibits a high concentration of MP in water, suggesting potential anthropogenic influence, surface run-off or direct plastic pollution sources contributing to elevated MP levels. Statistical analysis confirms that MP size distribution and particle shape distribution in water differ significantly across reservoirs ($p<0.05$), highlighting site-specific contamination patterns. Figure 2.8.13 represents the particle size distribution of MP in reservoir sediment, showing a high concentration within the 100–30 µm size range, whereas the lowest MP portion is observed below 30 µm.

Figure 2.8.14 illustrates that fragments are the most prevalent MP shape accumulating within reservoir sediments, highlighting the dominance of plastic degradation and fragmentation processes in these environments. Furthermore, Vijayakatupotha reservoir displays a notably high concentration of MP in sediment. MP size distribution and MP particle shape distribution in sediment exhibit significant variations across reservoirs ($p<0.05$), suggesting that environmental factors, pollution sources and sediment retention dynamics influence MP accumulation uniquely at each location.

There is a strong positive correlation between MP accumulation in water and sediment, suggesting that MP contamination is closely linked across these matrices, regardless of the particle

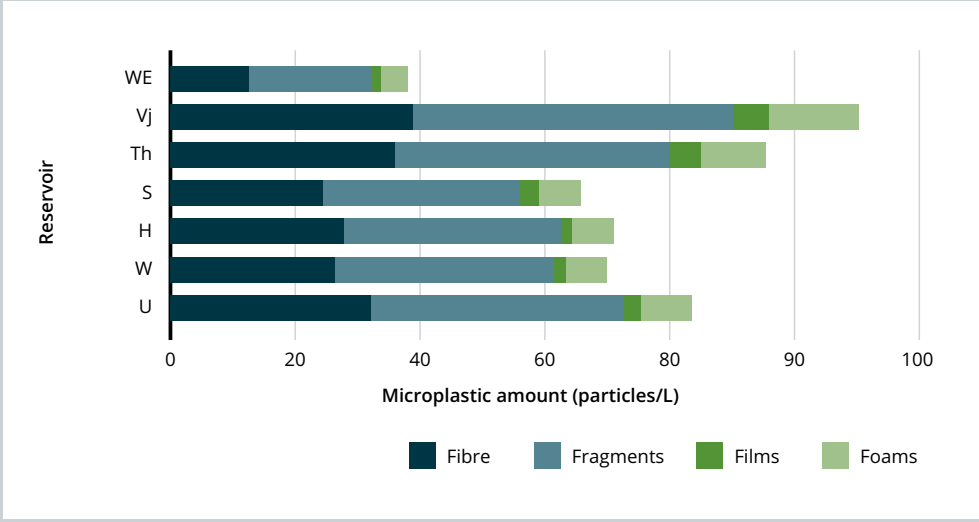

Figure 2.8.12: Shapes of microplastic distribution across the 7 reservoirs

Note: U:Urusita, W:Weerawila, H:Handapanagala, S:Siyambalangamuwa, Th:Tabbowa, Vj:Vijayakatupotha and WE:Wan ela.

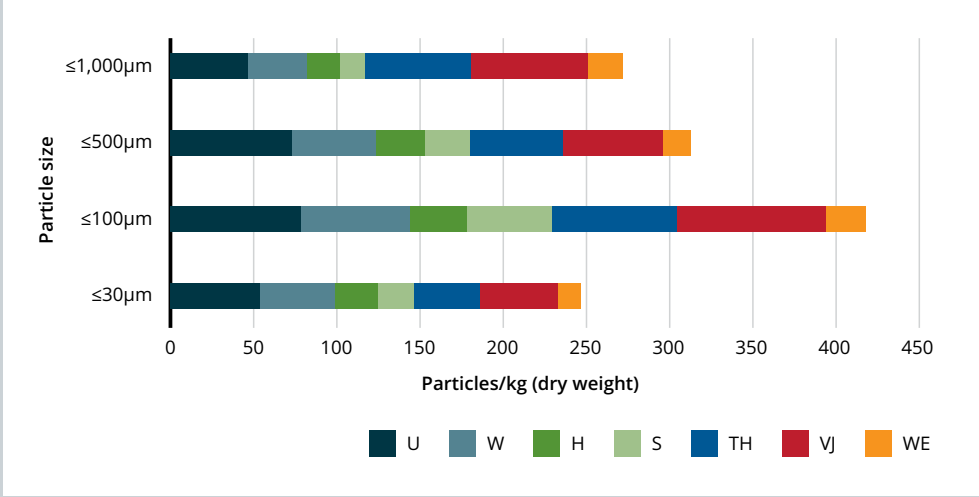

Figure 2.8.13: Microplastic size distribution across sediments from reservoirs selected for the study

Note: U:Urusita, W:Weerawila, H:Handapanagala, S:Siyambalangamuwa, Th:Tabbowa, Vj:Vijayakatupotha and WE:Wan ela.

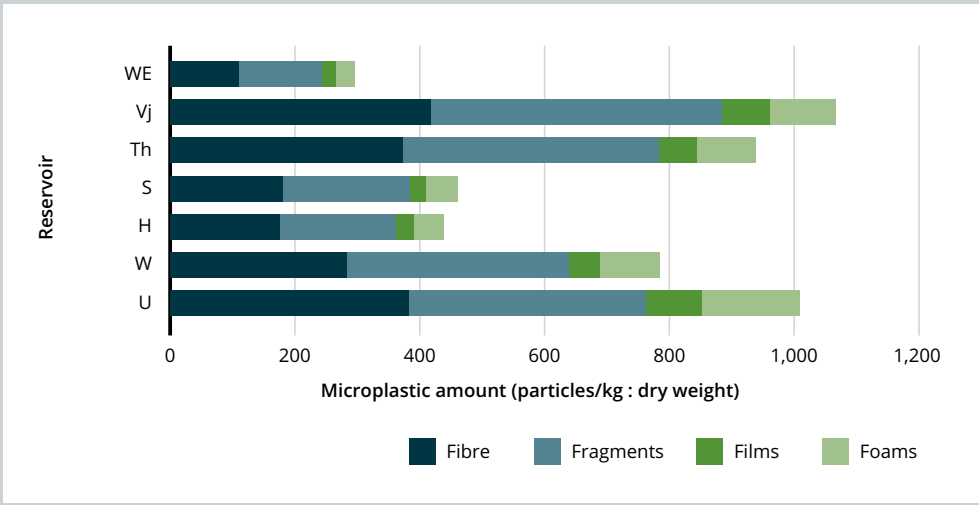

Figure 2.8.14: Shapes of microplastic distribution across the sediments from 7 reservoirs

Note: U:Urusita, W:Weerawila, H:Handapanagala, S:Siyambalangamuwa, Th:Tabbowa, Vj:Vijayakatupotha and WE:Wan ela.

size (Pearson correlation: 0.916) or shape (Pearson correlation: 0.932). This relationship implies that waterborne MP eventually settle into sediment, contributing to long-term environmental deposition and potential ecological impacts. In the analysis, MP sizes and shapes (Figure 2.8.15) were identified as morphometric characteristics, allowing for classification based on their physical dimensions and structural forms.

Discussion

Sri Lanka's dry zone reservoirs play a crucial role in water storage, irrigation and inland fisheries, but they are increasingly affected by various pollutants. Understanding the impact of conventional water pollutants, heavy metals, pesticides and MPs is essential for ensuring sustainable fisheries and ecosystem health.

The pH distribution across reservoirs reveals significant variations suggesting distinct water chemistry conditions influenced by environmental and anthropogenic factors such as geological variations, water source and anthropogenic activities affecting each reservoir. Elevated pH levels can influence nutrient availability, aquatic species composition and metabolic functions, potentially affecting ecosystem stability (Muniz 1990; Nolan 2024). The pH levels in Weerawila and Handapanagala reservoirs surpass the ideal threshold for sustaining aquatic organisms, indicating alkaline conditions that may impact ecosystem stability. Some species, like tilapia (*O. mossambicus*), exhibit greater tolerance to pH fluctuations, making them more suitable for such reservoirs (Russell et al. 2012).

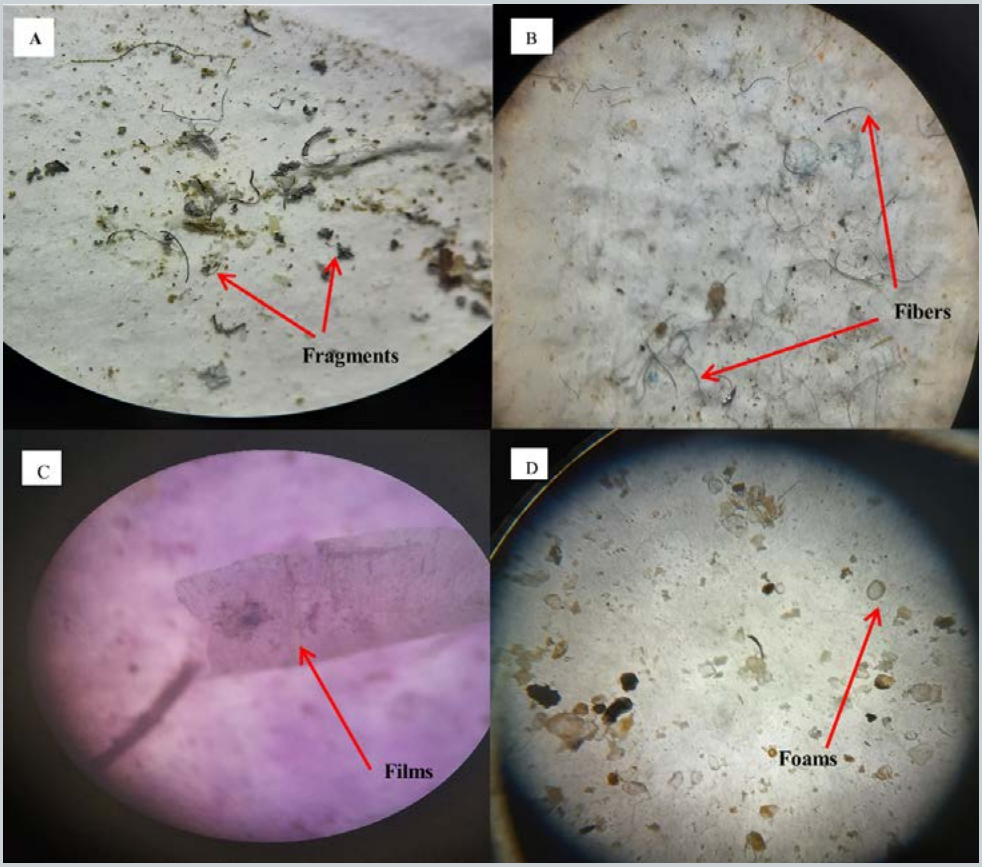

Figure 2.8.15: Dissecting microscope images showing different microplastic shapes

Note: (A) Fragments under ×4 (B) Fibres under ×4 (C) Films under ×10 (D) Foams under × 4.

TSS in dry zone reservoirs play an important role in shaping aquatic ecosystems and fisheries productivity. Fluctuating water levels and sediment dynamics within these reservoirs due to seasonal rainfall patterns support TSS level variations in reservoirs impacting fish populations, water quality and overall reservoir ecology. Reservoirs with high TSS concentrations, such as Wan Ela, tend to have reduced light penetration, affecting primary productivity (Buana et al. 2021) and fish feeding behaviour (Kjelland et al. 2015). Conversely, reservoirs with lower TSS levels, like Weerawila, provide clearer water conditions, potentially benefiting visual predators (Turesson and Brönmark 2007) and enhancing fish growth rates (Bunnell et al. 2021; Engström-Öst and Mattila 2008). In reservoirs like Siyambalangamuwa and Wan Ela, when TSS levels exceed the MPL for aquatic life (40 mg/L), fish populations may experience stress due to reduced oxygen levels and clogged gills (Cavanagh et al. 2014; Montoya 2024).

BOD serves as a key indicator of organic pollution and microbial activity, influencing fish productivity and overall reservoir health. Reservoirs with higher BOD levels, such as Wan Ela, indicate increased organic matter decomposition, leading to oxygen depletion. Oxygen scarcity can stress fish populations, particularly species which require well-oxygenated waters for survival and growth. Elevated BOD values suggest heightened microbial activity, which can accelerate nutrient cycling but also contribute to eutrophication and excessive microbial decomposition (Aziz et al. 2024; Svobodová et al. 1993) that may lead to algal blooms, reducing DO levels and negatively impacting fish health.

The presence of oil and grease pollutants in certain reservoirs suggests a higher pollutant retention, potentially affecting aquatic ecosystems and fish productivity. Oil and grease pollutants can coat fish gills, impairing oxygen absorption and leading to stress or mortality (Svobodová et al. 1993). Therefore, Urusita Wewa, with the highest mean oil and grease concentration, may experience reduced oxygen levels, affecting fish respiration and overall health. But the reservoirs' water flow and mixing patterns may help disperse oil pollutants, preventing excessive accumulation in critical fish habitats. Despite oil contamination, nutrient cycling may still support plankton growth, ensuring a stable food supply for fish populations. If organic matter decomposition is well balanced, fish productivity may remain unaffected (Aziz et al. 2024) as Urusita wewa has relatively high BOD concentration levels.

Moderate nitrogen and phosphorus levels support plankton growth, ensuring a stable food source for fish populations. But excessive nutrient loading can lead to eutrophication, causing algal blooms which may deplete oxygen levels and stress fish. Therein nutrient levels in a reservoir are playing a major role in shaping aquatic ecosystems and inland fisheries productivity. Handapanagala reservoir exhibited the highest concentration of nitrogen, maybe due to agricultural run-off and organic matter decomposition, while Vijayakatupotha recorded the lowest. Despite these variations, nitrogen levels remain well below the MPL of 10 mg/L, suggesting no excessive nitrogen pollution. In contrast, Thabbowa reservoir recorded the highest mean phosphorus concentration, likely due to external nutrient inputs, while Weerawila reservoir showed the lowest. However, all reservoirs maintain phosphorus levels below the MPL of 0.4 mg/L, indicating no excessive phosphorus pollution. Balanced nutrient concentrations contribute to healthy aquatic ecosystems, promoting optimal fish growth and reproduction.

The presence of fecal coliform in selected dry zone reservoirs exhibits a statistically significant variation, with Tabbowa reservoir showing the highest contamination levels, likely due to anthropogenic activities such as untreated sewage discharge or agricultural run-off, while Wan Ela recorded no detectable coliform presence throughout the study. The presence of fecal coliform in reservoirs could impact inland fisheries by introducing pathogens that may threaten fish health, alter microbial activity and potentially reduce oxygen levels due to increased organic matter decomposition (Wu et al. 2021). The absence of significant fecal contamination in certain reservoirs suggests varied pollution sources and differences in watershed management practices. Although fecal coliform contamination poses potential risks to water quality and aquatic health, no MPL has been established for fecal coliform in water designated for aquatic life by national

regulations, highlighting a regulatory gap in microbial water quality assessment for aquaculture applications. This underscores the need for additional monitoring and evaluation to ensure optimal water conditions for sustaining aquatic ecosystems.

The presence of pesticide residues in reservoirs highlights the influence of agricultural run-off, chemical persistence and environmental transport mechanisms on water quality and fisheries sustainability (Mitra et al. 2024; Rashad et al. 2025). The study reveals differential contamination patterns across water, sediment and biological tissue, with MCPA, Emamectin Benzoate, Thiamethoxam and Fipronil detected in water samples, while Chlorpyrifos, Diazinon, Etofenprox, Fenoxaprop-p-ethyl, and Profenofos were absent. Emamectin Benzoate exhibit uniform distribution within reservoir water, while Fipronil, Thiamethoxam and MCPA show localised contamination, indicating site-specific pollution sources. However, MCPA, identified as the most highly contaminated pesticide, remains steady within permissible limits (5 µg/L), ensuring regulated environmental exposure.

In sediment samples, MCPA and Emamectin Benzoate were selectively retained, indicating chemical persistence within the sediment matrix. The presence of these detected pesticides suggests potential contamination sources, primarily linked to agricultural run-off and pesticide application practices in the surrounding catchment areas. Factors such as hydrophobicity (K_{ow} : n-Octanol/Water Partition Coefficient values), sediment composition and pesticide application sources may influence their distribution across these matrices (Mitra et al. 2024; Nendza et al. 2025).

The analysis of fish tissue samples revealed no detectable pesticide residues, suggesting limited bioaccumulation within the examined aquatic organisms, minimising concerns for human consumption. Out of the 5 detected pesticides, 2 have relatively high log K_{ow} values (Fipronil: 3.75, Emamectin benzoate: 5.0) (University of Hertfordshire n.d.) but low concentrations in water and sediment. In contrast, highly observed pesticides in both matrices have low log K_{ow} values (Thiamethoxam: -0.13 and MCPA: -0.81) indicating a higher affinity for the aqueous phase rather than accumulation in biological tissues (University of Hertfordshire n.d.). These findings highlight the potential mobility and persistence of such pesticides in the aquatic environment while minimising direct incorporation into the food chain.

The study reveals considerable variations in lead concentrations across water, sediment and biological tissues, with Urusita reservoir recording the highest lead levels in water while Vijayakatupotha reservoir exhibited the lowest. Only Vijayakatupotha reservoir exceeds the MPL for aquatic life (0.004 mg/L), implying minimal risk for aquatic organisms, whereas all reservoirs remain suitable for drinking water consumption after simple treatment (0.05 mg/L) according to National Environmental (Ambient Water Quality) Regulations, No. 01 of 2019. Elevated lead levels in Wan Ela reservoir exceeding the MPL (0.2 mg/kg for fish, 0.4 mg/kg for crustaceans) for fishery products based on heavy metal regulations legal notice No 666/2003 (FAO 2003), suggest bioaccumulation risks, potentially affecting fish metabolism and reproduction. Lead accumulation in GFP exoskeleton tissues is significantly high, suggesting that consuming these parts may pose

health risks such as neurological disorders, cardiovascular diseases, kidney dysfunction and reproductive complications, due to heavy metal toxicity (Collin et al. 2022). The negative correlation between lead concentrations in GFP muscle and exoskeleton tissues suggests differential metal retention mechanisms.

The presence of MPs, with fragments being the most abundant form, indicates plastic degradation and fragmentation processes. The 100–30 µm size range dominates both water and sediment samples, while larger particles and smallest particles are less abundant. This trend suggests that fragmentation processes primarily break plastics down into mid-sized particles, while smaller MPs may be more susceptible to further degradation or dispersion, making them harder to detect (Sutkar et al. 2023). High MP concentrations in Vijayakatupotha reservoir suggest anthropogenic influence, surface run-off or direct plastic pollution sources, potentially affecting fish respiration and digestion. MP can be ingested by fish, leading to digestive blockages, reduced nutrient absorption and potential toxic exposure (Jo et al. 2025; Yin et al. 2021). The strong positive correlation between MP accumulation in water and sediment indicates that waterborne MPs eventually settle into sediment, contributing to long-term environmental deposition. This MP retention in sediment may alter benthic habitats, affecting bottom-dwelling organisms and food chain stability (Silva et al. 2022). Their persistence highlights the need for effective pollution management strategies to reduce plastic waste and minimise contamination in reservoirs. The standardised guidelines for MP contamination are still evolving, with no globally accepted levels for their presence in water bodies, sediments or aquatic organisms. While regulatory bodies such as the WHO, FAO and the United Nations Environment Programme (UNEP) have highlighted the risks associated with MP pollution (Gamarro and Costanzo 2022; Lusher et al. 2017; Marsden et al. 2019; Zehel 2023), specific threshold limits for MP concentrations in aquatic environments and seafood have yet to be established.

Conclusion

This study highlights the complex interactions between conventional pollutants, heavy metals, pesticides and MPs, demonstrating site-specific contamination patterns that influence water quality and fishery sustainability. While most reservoirs maintain water parameters within permissible limits, concerns such as MP accumulation, lead retention and fecal coliform presence emphasise the need for enhanced monitoring and pollution management strategies. The variability in pH, nutrient levels and suspended solids further underscores the dynamic nature of these ecosystems, necessitating adaptive reservoir management approaches. To ensure long-term sustainability, efforts must focus on strengthening regulatory frameworks, implementing wastewater treatment measures and promoting community-driven conservation initiatives. Addressing pollutant retention mechanisms, bioaccumulation risks and hydrodynamic influences will help optimise water quality management and support resilient fish populations. By integrating scientific research with policy interventions, Sri Lanka can foster sustainable inland fisheries while preserving the ecological integrity of its dry zone reservoirs. Continued environmental assessments and stakeholder engagement will be pivotal in mitigating contamination risks and safeguarding aquatic ecosystems for future generations.

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