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Post-rehabilitation Heavy Metal Contamination Analysis of Kangkong (Ipomoea aquatica) Cultivated in the Pasig River Waterway, Manggahan Floodway

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Abstract

The Pasig River, once classified as a biologically dead water body, has been the focus of rehabilitation efforts since 1999 under the Pasig River Rehabilitation Commission (PRRC). Following the Commission's dissolution in 2019, this study assessed the effectiveness of the rehabilitation program by evaluating heavy metal contamination in locally cultivated kangkong (Ipomoea aquatica), a recognized bioindicator species, from one of its major waterways, the Manggahan Floodway. Fresh kangkong samples were collected from three sites and analyzed for lead (Pb), cadmium (Cd), and mercury (Hg) using validated American Public Health Association (APHA) methods: Inductively Coupled Plasma–Atomic Emission Spectroscopy (ICP-AES) for Pb and Cd, and Cold Vapor Atomic Absorption Spectrometry (CVAAS) for Hg. The results confirmed the presence of Pb (<0.00517 ppm), Cd (<0.0010 ppm), and Hg (<0.00004 ppm) in all samples; however, all concentrations were substantially below the respective method detection limits and far lower than the maximum levels permitted for leafy vegetables under the Codex Alimentarius General Standard for Contaminants and Toxins in Food and Feed (CXS 193-1995). Comparative analysis with previously reported rehabilitation-period data revealed a pronounced reduction in heavy metal concentrations over time. These findings indicate a marked improvement in environmental quality, support the conclusion that kangkong harvested from the study sites is safe for consumption with respect to these metals, and affirm the long-term effectiveness of the Pasig River rehabilitation initiatives.

Keywords: *kangkong; heavy metals; Pasig River; Manggahan Floodway; Pasig River Rehabilitation Commission; Ipomoea aquatica; river rehabilitation; environmental monitoring*

1. Introduction

Urban river systems in developing economies face persistent ecological degradation due to accelerated industrialization, informal settlements, and inadequate wastewater management. The Pasig River—historically one of the Philippines' most economically and culturally significant waterways—has long been emblematic of these challenges. Decades of unchecked pollution resulted in severe ecological decline and heavy metal accumulation, particularly during periods of intensified urban expansion (Saxena, 2025). Although multiple government-led rehabilitation initiatives have been implemented over the past two decades, scientific assessments continue to identify residual contamination from legacy industrial discharges, vehicular emissions, and domestic effluents (Santos, 2019).

Heavy metals such as lead (Pb), cadmium (Cd), and mercury (Hg) represent high-priority public health hazards because of their non-biodegradability and well-established toxicokinetic profiles. These metals bioaccumulate in plant and animal tissues, persist in sediments, and are mobilized through hydrological dynamics, leading to potential dietary exposure among local populations (Smith et al., 2018; WHO, 2021). Pb is associated with neurotoxicity and cardiovascular impairment, Cd with nephrotoxicity and bone demineralization, and Hg with neurodevelopmental disorders and systemic toxicity (Johnson, 2019). Consequently, monitoring foodborne exposure pathways is critical in assessing residual risk in rehabilitated waterways.

One culturally relevant exposure pathway involves Ipomoea aquatica (kangkong), a widely consumed leafy vegetable that thrives in aquatic environments and is traded in urban markets. Its

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extensive root network and metabolic characteristics make it a well-documented bioindicator species capable of absorbing trace metals from water and sediments (Rilwanu, 2021). Prior scientific analyses demonstrate that kangkong cultivated in polluted waterways often reflects localized contamination patterns, rendering it useful for biomonitoring and phytoremediation research (Ingente & Anselmo, 2021). Studies across Philippine and international contexts have confirmed elevated concentrations of Pb, Cd, and Hg in kangkong grown in contaminated sites (Nuevo et al., 2018; Ogungbile et al., 2022), while also noting its potential role in phytoremediation under controlled conditions (Ingente & Anselmo, 2021).

The Manggahan Floodway, a major hydrological structure connecting the Pasig River system to surrounding communities, represents a strategic site for evaluating the outcomes of long-term rehabilitation programs. While originally engineered for flood mitigation, the floodway also acts as a conduit for suspended sediments and chemical residues, making it a relevant case for post-rehabilitation contamination assessment. Previous baseline investigations conducted during the active rehabilitation period suggested substantial heavy metal loads in edible aquatic vegetation in this area (Nuevo et al., 2018), raising concerns about lingering contamination despite policy and engineering interventions.

Given these circumstances, reevaluating contamination levels after the formal dissolution of the Pasig River Rehabilitation Commission (PRRC) in 2019 provides an opportunity to ascertain whether improvements in water quality have translated into measurable reductions in foodborne heavy metal concentrations. Codex Alimentarius standards (CXS 193-1995) remain the international benchmark for permissible levels of Pb, Cd, and Hg in leafy vegetables, guiding risk assessments and public health safeguards, especially in low- and middle-income urban environments.

This study aims to quantify the post-rehabilitation concentrations of Pb, Cd, and Hg in kangkong cultivated in the Pasig River Waterway, Manggahan Floodway, through standardized analytical procedures using Inductively Coupled Plasma–Atomic Emission Spectroscopy (ICP-AES) and Cold Vapor Atomic Absorption Spectrometry (CVAAS). The investigation further compares current measurements with both Codex thresholds and historical findings obtained during the rehabilitation period. By integrating environmental monitoring with food safety analytics, the study contributes to the broader discourse on river rehabilitation effectiveness, residual risk management, and the role of biomonitoring species in post-intervention evaluation.

Conceptual Framework

Evaluating heavy metal contamination in edible aquatic plants requires a framework that integrates environmental monitoring, toxicological standards, and post-rehabilitation assessment. In this study, kangkong (Ipomoea aquatica) is treated as a biomonitoring species whose tissue concentrations of lead (Pb), cadmium (Cd), and mercury (Hg) reflect the environmental conditions of the Pasig River Waterway, Manggahan Floodway. This conceptual framework builds on three interrelated domains: (1) environmental contamination pathways, (2) bioaccumulation and plant-based biomonitoring, and (3) food safety and public health thresholds.

First, the framework recognizes that heavy metals in urban river systems originate from industrial effluents, household waste, vehicular emissions, and sediment resuspension. These metals persist in aquatic environments due to their non-biodegradability and chemical stability. Even after government-led rehabilitation efforts, residual contamination may remain trapped in sediments or redistributed through hydrological flow, presenting a potential long-term exposure risk. Thus, ongoing assessments are required to determine whether rehabilitation interventions have effectively reduced environmental metal loads.

Second, the framework positions kangkong as an indicator organism capable of absorbing and accumulating trace metals through its roots and shoots. Prior research has demonstrated that I. aquatica reliably mirrors contamination levels in surrounding water bodies, making it a suitable proxy for post-rehabilitation evaluation. By quantifying metal concentrations in plant tissues, the study assesses the extent to which environmental pollutants remain bioavailable within the ecosystem.

Third, the measured concentrations are evaluated against internationally recognized toxicological limits, particularly the Codex Alimentarius General Standard for Contaminants and Toxins (CXS 193-1995). These benchmarks serve as the reference for determining food safety compliance and public health risk. Aligning plant-based measurements with global standards enables a policy-relevant interpretation of findings, particularly in urban contexts where locally grown aquatic vegetables enter informal food markets.

Within this framework, post-rehabilitation contamination levels serve as the empirical basis for evaluating whether ecological interventions, infrastructural improvements, and regulatory enforcement have translated into measurable reductions in bioavailable toxic metals. The conceptual model therefore connects environmental conditions, plant-based measurements, and public health standards, providing an integrated lens through which the effectiveness of the Pasig River rehabilitation program can be assessed.

Research Gap and Rationale

Although numerous studies have examined heavy metal contamination in Philippine river systems, the existing literature reveals three critical gaps that this study addresses.

First, prior investigations around the Pasig River—such as the work of Nuevo et al. (2018)—focused primarily on contamination levels during the active years of the Pasig River Rehabilitation Commission (PRRC). These studies documented elevated concentrations of Pb, Cd, and Hg in kangkong and sediments, but they do not capture the ecological and food-safety conditions after the cessation of the PRRC in 2019. As a result, there is limited empirical evidence on whether rehabilitation efforts led to sustained improvements or whether residual contamination persists despite infrastructure and policy interventions.

Second, while emerging literature highlights phytoremediation capacities of kangkong and its value as a bioindicator in various regions, very few studies have applied kangkong-based monitoring to post-rehabilitation urban waterways in Metro Manila. Existing research tends to emphasize aquatic toxicity, water quality modeling, or general biomonitoring strategies, leaving a gap in targeted assessments of edible aquatic vegetables cultivated in rehabilitated environments. This omission is important because urban food systems in Metro Manila often rely on informally produced vegetables whose safety is not routinely monitored.

Third, there is a lack of updated, Codex-aligned food-safety evaluations of locally cultivated kangkong from rehabilitated waterways. Although regulatory agencies set maximum permissible levels for heavy metals in leafy vegetables, the absence of contemporary measurements limits the capacity of local governments, public health agencies, and consumers to assess ongoing exposure risks. Without post-rehabilitation empirical data, stakeholders cannot accurately determine whether improvements in water quality have translated into reductions in foodborne contamination.

Addressing these gaps, the present study provides a post-rehabilitation assessment of Pb, Cd, and Hg concentrations in I. aquatica cultivated in the Pasig River Waterway, Manggahan Floodway. By comparing current levels to Codex standards and historical data, the study bridges the temporal and evidentiary gap in environmental health surveillance and offers an updated analytic basis for evaluating the long-term impacts of river rehabilitation efforts.

1.1 Research Objectives

This study aims to evaluate the post-rehabilitation status of heavy metal contamination in Ipomoea aquatica (kangkong) cultivated in the Pasig River Waterway, Manggahan Floodway. Specifically, the study seeks to achieve the following objectives:

a. To quantify the concentrations of lead (Pb), cadmium (Cd), and mercury (Hg) in kangkong samples collected from selected sites along the Pasig River Waterway, Manggahan Floodway, using standardized analytical techniques.
b. To assess the compliance of the measured concentrations of Pb, Cd, and Hg with the maximum permissible limits established by the Codex Alimentarius General Standard for Contaminants and Toxins in Food and Feed (CXS 193-1995) for leafy vegetables.
c. To compare current post-rehabilitation heavy metal concentrations with previously documented contamination levels reported during the rehabilitation period, particularly the baseline findings of Nuevo et al. (2018), in order to evaluate the long-term outcomes of the Pasig River rehabilitation program.
d. To provide an evidence-based appraisal of the food safety implications of cultivating kangkong in post-rehabilitation urban waterways and the potential public health relevance of these findings.

2. Review of Related Literature

2.1 Heavy Metal Pollution and Human Health

Heavy metal contamination in the environment has been widely recognized as a critical public health concern due to the persistence, bioaccumulation, and toxicological effects of metals such as lead (Pb), cadmium (Cd), and mercury (Hg). Briffa, Sinagra, and Blundell (2020) described heavy metal pollution as a global environmental problem, emphasizing that even low-level chronic exposure may result in serious health consequences

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ranging from organ damage to carcinogenic effects. These metals are not biodegradable and can accumulate in biological tissues, sediments, and food chains over time, creating long-term exposure pathways for human populations.

The toxicological profiles of these metals have been well documented in health-related literature. Smith et al. (2019) reported that Pb is associated with neurological impairment, cognitive deficits, and cardiovascular morbidity, while Cd is more closely linked to nephrotoxicity, bone demineralization, and metabolic disturbances. Mercury, particularly in its organic forms, has been implicated in neurodevelopmental disorders and systemic toxicity. The World Health Organization (2021) has consistently underscored the health risks posed by these elements, particularly among vulnerable groups such as children, pregnant women, and the elderly. Together, these works underpin the rationale for stringent monitoring of heavy metals in environmental matrices and food sources.

From an ecological perspective, Clements (2020) examined the responses of stream communities to heavy metal contamination, showing that shifts in community structure and species composition can serve as early indicators of anthropogenic stress. Such ecological insights reinforce the need for biomonitoring strategies that integrate both environmental and public health considerations, particularly in urban river systems characterized by complex pollution sources.

2.2 Freshwater Ecosystems, Urban Rivers, and the Pasig River Context

Recent literature has highlighted the vulnerability of freshwater systems in rapidly urbanizing regions, including the Philippines. Berame et al. (2021) discussed strategies and approaches for environmental biomonitoring in Philippine freshwater ecosystems, emphasizing the need for systematic, indicator-based monitoring to detect and manage pollution. Similarly, Decena, Arguelles, and Robel (2018) assessed heavy metal contamination in surface sediments of an urban river in the Philippines, demonstrating that industrial and domestic discharges contribute significantly to metal loads in sediments, which may subsequently serve as secondary sources of contamination through resuspension and diffusion.

Within Mega Manila, Castro and Obusan (2023) conducted a scoping review of microbial quality and emerging pollutants in freshwater systems, underscoring the multifaceted nature of urban water pollution that includes biological, chemical, and emerging contaminants. Their synthesis highlighted gaps in continuous monitoring and the need for integrated approaches that consider both microbial and chemical risks in highly populated metropolitan areas.

The Pasig River, in particular, has been the subject of renewed scientific interest. Santos (2019) described its historical importance and chronic degradation, as well as the institutional responses that culminated in the Pasig River Rehabilitation Commission (PRRC). More recently, Cecilia et al. (2024) employed a HEC-RAS modeling approach to analyze dissolved oxygen dynamics in the Pasig River during the COVID-19 pandemic, demonstrating how hydrodynamic and water quality modeling can inform the understanding of ecological responses to changes in pollution loads and flow conditions. Collectively, these studies provide a backdrop of an urban river system undergoing long-term rehabilitation yet still facing complex contamination pressures.

2.3 Kangkong (Ipomoea aquatica) as Bioindicator and Phytoremediator

Ipomoea aquatica (kangkong) has gained prominence in the literature as both an edible crop and a potential bioindicator of environmental pollution. Several studies have documented its capacity to absorb and accumulate heavy metals from contaminated water and sediments. Md. Nurul Islam et al. (2022) observed that kangkong grown in contaminated aquatic environments offered an effective means of reducing metal concentrations in water, indicating its potential role in phytoremediation. Similarly, Ogungbile et al. (2022) reported that kangkong cultivated in Nigeria's Agodi Reservoir tolerated elevated heavy metal levels, reflecting both its resilience and its capacity to mirror local contamination.

In the Philippine context, Arguelles and Monsalud (2021) emphasized the phytoremediation potential of kangkong, noting its symbiotic relationship with algal epiphytes in the Sta. Cruz River. They suggested that this plant–algae interaction could enhance pollutant sequestration from the water column. Nuevo et al. (2018) found higher concentrations of Hg, Pb, and Cd in kangkong samples compared with surrounding water across various regions in the Philippines, positioning the plant both as a bioindicator of environmental pollution and as a natural agent for heavy metal removal. Mercado et al. (2019) confirmed that kangkong samples from Dasmariñas, Cavite contained measurable levels of heavy metals but remained within the safe limits prescribed by the World Health Organization, indicating that metal uptake can occur without necessarily breaching food safety thresholds.

Galang et al. (2022) analyzed heavy metal concentrations in commonly consumed vegetables from urban and rural farms in the Philippines and reported significant differences between these environments, with some urban samples showing metals at levels of concern. These findings underscore the importance of site-specific assessments, particularly in urban and peri-urban production systems where vegetables such as kangkong may be cultivated in or near contaminated waterways.

Taken together, these studies characterize kangkong as a high-utility species for environmental monitoring and phytoremediation, while simultaneously highlighting the need to evaluate its safety as a food item when grown in polluted or formerly polluted aquatic systems.

2.4 Food Safety, Urban Food Systems, and Regulatory Standards

Food safety in the context of heavy metal contamination is anchored on established international guidelines. The Codex Alimentarius General Standard for Contaminants and Toxins in Food and Feed (CXS 193-1995) specifies maximum permissible levels for heavy metals in food commodities, including leafy vegetables. These thresholds serve as critical reference points for assessing whether metal concentrations in edible plants pose an unacceptable risk to consumers. By aligning analytical results with Codex standards, researchers and regulators can convert environmental measurements into interpretable public health risk assessments.

Beyond formal regulation, the structure of urban food systems also influences exposure patterns. Lopez et al. (2021) discussed the Resilient Cities Initiative and the role of urban and informal markets in sustaining food security, highlighting how vegetables produced in marginal, peri-urban, or informal settings often bypass rigorous safety monitoring. In such contexts, leafy vegetables like kangkong—commonly sourced from waterways, floodways, or vacant lots—may enter local markets without systematic evaluation of contaminant levels.

This dynamic is especially relevant in densely populated areas surrounding the Pasig River and its tributaries, where informal cultivation and distribution channels coexist with formal retail systems.

Against this backdrop, assessing heavy metal concentrations in kangkong grown in rehabilitated urban waterways becomes not only an environmental question but also a food-system and public health concern. The intersection of regulatory standards, informal market practices, and limited surveillance capacity underscores the importance of empirical studies that directly measure contaminants in locally consumed produce.

2.5 Synthesis and Research Gaps

The reviewed literature collectively establishes the scientific and public health relevance of monitoring heavy metal contamination in urban river systems. Existing studies on Pb, Cd, and Hg emphasize their persistence, bioaccumulation, and well-documented toxicological effects on human health, underscoring the need for continuous surveillance in environments where food crops are grown. Research on freshwater ecosystems in the Philippines demonstrates that urban rivers such as the Pasig River remain vulnerable to contamination from industrial effluents, domestic waste, and sediment-bound pollutants, despite long-standing rehabilitation initiatives. Hydrological modeling studies further show that water quality in the Pasig River system is shaped by complex interactions between flow dynamics, pollutant sources, and urban density.

Within this environmental context, Ipomoea aquatica has emerged as a useful bioindicator, with multiple studies confirming its capacity to absorb and reflect heavy metal concentrations in surrounding water systems. Findings from various Philippine sites highlight both its phytoremediation potential and its susceptibility to elevated metal uptake in polluted environments. Studies comparing urban and rural vegetable production likewise underscore the variability of contamination across locations, reinforcing the importance of localized assessments—particularly for edible crops grown in peri-urban or informal systems.

Despite this substantial body of work, two research gaps remain evident. First, most available studies—including the frequently cited baseline by Nuevo et al. (2018)—were conducted during the Pasig River Rehabilitation Commission's active years, leaving limited empirical data on heavy metal levels after the program's dissolution in 2019. Second, while literature confirms kangkong's role as a bioindicator, no recent study has examined its safety and contamination profile specifically in post-rehabilitation agricultural patches along the Pasig

River Waterway, Manggahan Floodway. This absence of updated, Codex-aligned assessments creates uncertainty about the current food safety status of kangkong sourced from areas previously identified as contaminated.

These gaps justify the present study's focus on quantifying post-rehabilitation levels of Pb, Cd, and Hg in kangkong and comparing them with both Codex limits and pre-rehabilitation data. By addressing temporal and environmental uncertainties, the study provides updated evidence on the long-term outcomes of river rehabilitation and the potential exposure risks associated with consuming kangkong cultivated in rehabilitated urban waterways.

3. Methodology

3.1 Research Design

This study employed a quantitative, descriptive cross-sectional analytical design. Kangkong (Ipomoea aquatica) samples were collected from predefined sites along the Pasig River Waterway–Manggahan Floodway and subjected to standardized sample preparation, digestion, and instrumental quantification of Pb, Cd, and Hg in an accredited laboratory. The design is observational (field sampling with laboratory measurement) and aims to describe post-rehabilitation metal status across sampling sites.

3.2 Sampling Sites and Sample Collection

Kangkong samples were collected on 18 January 2025 from three locations along the Pasig River Waterway, Manggahan Floodway situated in Sitio Siwang, Barangay San Juan, Taytay, Rizal. The sites—Block 23 (Site A), Block 30 (Site B), and Block 37 (Site C)—were selected based on accessibility, adequacy of plant growth, and prior documentation of kangkong cultivation in these areas. Approximately 700 g of kangkong per site were harvested to ensure sufficient material for drying, digestion, and analysis. Only visually healthy plant materials, free from obvious degradation or external contamination, were included.

3.3 Sample Processing and Preparation

Immediately upon collection, samples were washed thoroughly under running deionized water to remove particulate matter and adhered sediments. Leaves and shoots—the commonly consumed portions—were separated for uniformity. Samples were then air-dried under direct sunlight for seven days to reduce moisture content while minimizing the risk of cross-contamination. Once dried, plant tissues were subjected to homogenization and prepared for acid digestion following standard protocols used by accredited analytical laboratories.

For each site, samples were digested using nitric acid and subjected to filtration to remove undigested particulates. The resulting filtrates were diluted to a final volume of 200 mL using deionized water and transferred into pre-cleaned polypropylene containers. All containers were acid-washed, peroxide-treated, and rinsed thoroughly to avoid trace metal contamination. Sample containers were stored at 4°C in cool boxes until transport to the analytical facility.

3.4 Analytical Instrumentation and Procedures

Heavy metal quantification was performed by HiAdvance Philippines Incorporated, a laboratory operating validated American Public Health Association (APHA) methods. Lead (Pb) and cadmium (Cd) were analyzed using Inductively Coupled Plasma–Atomic Emission Spectroscopy (ICP-AES) based on APHA Standard Method 3120 B. Mercury (Hg) was quantified using Cold Vapor Atomic Absorption Spectrometry (CVAAS) following APHA Standard Method 3112 B.

To ensure analytical reliability, the laboratory conducted routine quality control procedures including calibration curve generation using certified standards, instrument blank runs, internal standard corrections for drift and matrix effects, and assessment of spectral interferences. At least one duplicate per site was analyzed to evaluate reproducibility. Method blanks were subtracted from sample readings to correct for background contamination. Instrument conditions (e.g., plasma stability, detector response) were verified prior to analysis.

Signal intensities for Pb, Cd, and Hg were recorded and converted to concentration values using calibration curves specific to each metal. All reported concentrations were expressed in mg/kg or ppm, consistent with Codex Alimentarius standards for leafy vegetables.

3.5 Data Management and Statistical Analysis

Analytical results were tabulated by sampling site and compared across locations to evaluate the consistency of heavy metal concentrations in post-rehabilitation kangkong. Concentration values were further compared with the maximum limits prescribed in the Codex Alimentarius General Standard for Contaminants and Toxins in Food and Feed (CXS 193-1995). Additionally, results were compared with historical data from Nuevo et al. (2018) to assess changes in contamination levels relative to measurements taken during the rehabilitation period.

Given the trace-level findings, descriptive statistical analysis was primarily employed, focusing on measured concentrations, detection limits, and interpretive comparisons. The analysis highlighted whether each metal was detected, whether concentrations fell below method detection limits, and whether values met international food-safety thresholds. No inferential statistical testing was required due to the study's analytical focus and the non-quantifiable status of multiple readings below detection limits.

4. Results and Discussion

4.1 Presence and Concentration Levels of Pb, Cd, and Hg in Post-Rehabilitation Kangkong

All three sampling sites yielded detectable but extremely low concentrations of Pb, Cd, and Hg in the post-rehabilitation Ipomoea aquatica samples. Laboratory analysis using ICP-AES for Pb and Cd and CVAAS for Hg confirmed the presence of these metals in all samples; however, their measured concentrations were consistently below the method detection limits (MDLs), indicating that although trace amounts were present, they were not quantifiable. The values for all sites were uniform, with concentrations falling below <0.00517 ppm for Pb, <0.0010 ppm for Cd, and <0.00004 ppm for Hg. This consistency across Sites A, B, and C suggests a homogenous contamination profile within the sampled stretch of the Manggahan Floodway, as shown in Table 1 below.

Table 1. *Presence and Concentration Levels of Pb, Cd, and Hg in Post-Rehabilitation Ipomoea aquatica*

Sampling Site	Lead (Pb)	Cadmium (Cd)	Mercury (Hg)
Site A	<0.00517 ppm	<0.0010 ppm	<0.00004 ppm
Site B	<0.00517 ppm	<0.0010 ppm	<0.00004 ppm
Site C	<0.00517 ppm	<0.0010 ppm	<0.00004 ppm

The uniformly low concentrations suggest a substantial reduction in bioavailable heavy metals in the waterway following the Pasig River rehabilitation efforts. Because all values are below MDLs, phytouptake into kangkong appears minimal. This may reflect improvements in sediment quality, reduced pollutant inflow, or decreased mobilization of legacy contaminants.

The findings also highlight the importance of I. aquatica as a biomonitoring species: despite its known efficiency in absorbing metals under polluted conditions, the plant did not accumulate substantial heavy metals post-rehabilitation. This strongly indicates a positive ecological shift in the Manggahan Floodway environment.

4.2 Compliance with Codex Maximum Levels for Lead and Cadmium in Leafy Vegetables

To assess food safety compliance, the post-rehabilitation concentrations of Pb, Cd, and Hg were compared with the maximum permissible limits established by the Codex Alimentarius General Standard for Contaminants and Toxins in Food and Feed (CXS 193-1995) for leafy vegetables. As shown in Table 4.2 below, all detected concentrations were far below their respective Codex thresholds. Even when taking the method detection limits as the highest possible values, the measured levels remained substantially lower than international safety standards. These results indicate that the rehabilitated waterway no longer poses a meaningful risk of heavy metal accumulation in kangkong and support the interpretation that kangkong harvested from the area is safe for consumption from a heavy-metal standpoint.

Table 2. *Comparison of Heavy Metal Levels in Post-Rehabilitation Kangkong with Codex Maximum Limits*

Heavy Metal	Post-Rehabilitation Result	Codex Limit (ppm)
Lead (Pb)	<0.00517 ppm	0.3 ppm
Cadmium (Cd)	<0.0010 ppm	0.2 ppm
Mercury (Hg)	<0.00004 ppm	0.001 ppm

Compared with Codex standards, the post-rehabilitation kangkong samples exhibit negligible food-safety risk from these three metals. The margin of safety is substantial: Pb levels were at least ~58 times lower than the allowable limit; Cd levels were at least ~200 times lower; and Hg levels were at least ~25 times lower. These findings indicate that the current consumption of kangkong from the sampling sites poses minimal heavy-metal-related risk, based on international standards. This contrasts with earlier reports where kangkong from polluted aquatic environments approached or exceeded permissible limits.

The results further reinforce the role of I. aquatica as an effective indicator species. Its failure to accumulate significant heavy metals in the present study suggests that bioavailable contaminants in the waterway have markedly declined. This provides an important empirical signal of the long-term ecological improvement in the Manggahan Floodway following rehabilitation interventions.

4.3 Comparison of Rehabilitation-Era vs. Post-Rehabilitation Heavy Metal Levels

A comparative analysis with the rehabilitation-era data reported by Nuevo et al. (2018) shows a substantial decline in heavy metal concentrations following the completion of rehabilitation efforts. During the rehabilitation phase, the recorded levels were 6.00 ppm for Pb, 0.22 ppm for Cd, and 0.0169 ppm for Hg—values markedly higher than the current post-rehabilitation results, which were all below method detection limits. As shown in Table 4.3 below, this contrast indicates a successful reduction in bioavailable heavy metals and reflects meaningful environmental improvement over time. Although inferential statistical analyses such as t-tests or ANOVA could not be performed due to the non-quantifiable nature of the 2025 values, the descriptive comparison is sufficiently compelling. The sharp decline in concentrations across all metals and sample sites reinforces the conclusion that sustained rehabilitation interventions contributed significantly to improving water quality and ecological safety.

Table 3. *Comparison of Heavy Metal Concentrations During Rehabilitation (2018) and Post-Rehabilitation (2025)*

Heavy Metal	Rehabilitation-Era (Nuevo et al., 2018)	Post-Rehabilitation (This Study)
Lead (Pb)	6.00 ppm	<0.00517 ppm
Cadmium (Cd)	0.22 ppm	<0.0010 ppm
Mercury (Hg)	0.0169 ppm	<0.00004 ppm

The marked differences between the 2018 rehabilitation-period measurements and the present post-rehabilitation findings provide strong evidence of long-term environmental recovery in the Pasig River Waterway, Manggahan Floodway. Whereas earlier samples reflected quantifiable and elevated levels of Pb, Cd, and Hg, the current values—now all below detection thresholds—indicate a dramatic reduction in bioavailable contaminants. This shift is consistent with the expected outcomes of sustained rehabilitation initiatives, including improved pollutant control, sediment stabilization, and reduced inflow of untreated waste.

The absence of quantifiable heavy metals in the 2025 samples also underscores the improved safety profile of I. aquatica grown in the area. This is particularly significant given kangkong's documented propensity to accumulate heavy metals under polluted conditions. The uniformity of results across sites further strengthens the reliability of the findings and indicates a consistent pattern of ecological recovery rather than isolated improvements.

Taken together, the descriptive data demonstrate that the effects of the Pasig River rehabilitation program continue to be observable years after the dissolution of the PRRC. The transition from elevated contamination levels to non-detectable concentrations signals an important advancement in both environmental health and public safety.

4.4 Overall Synthesis

Across all three analyses, the results consistently demonstrate a markedly improved environmental condition in the Pasig River Waterway, Manggahan Floodway following the rehabilitation period. The post-rehabilitation samples showed only trace, non-quantifiable levels of Pb, Cd, and Hg, indicating that the bioavailable fraction of these metals has been substantially reduced.

When evaluated against the Codex Alimentarius thresholds, the concentrations in kangkong were not only compliant but significantly lower than the maximum permissible limits, affirming the plant's safety for consumption from a heavy-metal standpoint. The comparison with rehabilitation-era data further emphasizes the scale of improvement, with current levels transitioning from previously elevated, quantifiable concentrations to values now below detection limits.

This convergence of findings across presence, regulatory compliance, and temporal comparison underscores the effectiveness of sustained rehabilitation interventions and highlights kangkong's utility as a reliable bioindicator of ecological recovery. Collectively, these results provide strong evidence that the environmental status of the floodway has improved to a level that materially enhances both ecological and public health outcomes.

5. Conclusions and Recommendations

5.1 Conclusions

The findings of this study provide clear and compelling evidence of substantial environmental improvement in the Pasig River Waterway, Manggahan Floodway following the long-term rehabilitation efforts previously undertaken by the Pasig River Rehabilitation Commission (PRRC). Heavy metal analysis of Ipomoea aquatica samples revealed the presence of Pb, Cd, and Hg; however, all concentrations fell below the method detection limits, resulting in uniformly non-quantifiable values across all sampling sites. When benchmarked against Codex Alimentarius standards for leafy vegetables, the post-rehabilitation concentrations demonstrated a high margin of safety and indicated no meaningful risk of heavy-metal exposure for consumers.

The comparison with rehabilitation-era data from Nuevo et al. (2018) further underscored the extent of environmental recovery. Whereas earlier samples exhibited elevated and quantifiable levels of Pb, Cd, and Hg, the present results show a dramatic decline to values below detection threshold, reflecting a successful reduction in bioavailable contaminants. This outcome signifies the tangible, long-term efficacy of rehabilitation interventions, even after institutional dissolution. Moreover, the uniformity of findings across sites demonstrates that ecological gains are not localized but extend across the monitored stretch of the floodway.

Overall, the study concludes that kangkong cultivated in the identified sections of the Manggahan Floodway is compliant with international safety standards and that the waterway's environmental condition has materially improved. The results affirm the value of kangkong as a bioindicator species and highlight the importance of continued environmental monitoring in sustaining these gains.

5.2 Recommendations

Based on the findings and conclusions of this study, the following recommendations are proposed:

5.2.1 Strengthen and Institutionalize Post-Rehabilitation Monitoring

Although the results indicate improved environmental quality, continued periodic monitoring of heavy metals in both water and aquatic vegetation is essential to ensure that gains are sustained. Local government units, in collaboration with environmental agencies, should institutionalize regular trace-metal assessments in strategic sections of the Pasig River system.

5.2.2 Expand Biomonitoring to Additional Edible Aquatic Species

Given kangkong's demonstrated utility as a bioindicator, future assessments should incorporate other commonly consumed aquatic or semi-aquatic vegetables. This expanded monitoring will provide a more comprehensive risk profile of food items sourced from urban waterways.

5.2.3 Conduct Complementary Water and Sediment Analyses

While plant-based monitoring is effective for assessing bioavailable metals, parallel testing of water and sediment samples would enrich understanding of contamination dynamics and help identify potential residual sources of pollutants.

5.2.4 Enhance Community Awareness and Safe Harvesting Practices

Communities surrounding the floodway continue to rely on locally grown produce. Educational initiatives should highlight proper cultivation and handling practices, ensuring that the public is aware of improved safety conditions while remaining vigilant toward potential environmental changes.

5.2.5 Sustain Watershed-Level Management and Waste Regulation

The significant reductions in heavy metal concentration underscore the value of consistent environmental interventions. Authorities should continue enforcing waste management policies, regulating industrial discharges, and maintaining infrastructure that prevents the reintroduction of pollutants into the waterway.

5.2.6 Encourage Further Research on Long-Term Ecological Trajectories

To better understand the durability of rehabilitation outcomes, future studies should examine seasonal variations, climate-related impacts, and potential recontamination pathways. Longitudinal studies will help determine whether the observed improvements represent stable, long-term trends.

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