Analysis of Cadmium and Chromium Temporal Variations in Muthurajawela Wetland: A Heavy Metal Contamination Assessment from Kerawalapitiya Waste Park

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***Abstract*— This research investigates the temporal variations of cadmium (Cd) and chromium (Cr) contamination in Muthurajawela wetland, Sri Lanka's largest saline wetland ecosystem, resulting from leachate discharge from the adjacent Kerawalapitiya Waste Park. A comprehensive monitoring study was conducted over multiple seasonal periods from March 2024 to October 2024, analyzing heavy metal concentrations across twelve sampling points (SP01-H3SP12) within the wetland system. The study revealed significant spatial and temporal variability in both cadmium and chromium concentrations, with cadmium levels ranging from 0.00004 mg/L to 0.78 mg/L across different sampling locations and seasonal periods, while chromium concentrations varied from 0.00003 mg/L to 8.6 mg/L. Critical contamination hotspots were identified at sampling points SP01, D1SP02, and D2SP3, which consistently exhibited elevated heavy metal concentrations throughout the monitoring period. Seasonal analysis demonstrated that cadmium contamination peaked during the March 2024 period at several locations, while chromium showed maximum concentrations during August 2024 at specific monitoring sites. The proximity to the waste disposal facility emerged as a primary factor influencing contamination levels, with downstream sampling locations showing progressive dilution effects. These findings highlight the urgent need for enhanced leachate management strategies and continuous monitoring protocols to protect this internationally significant wetland ecosystem from persistent heavy metal contamination. The study contributes valuable baseline data for environmental protection measures and informs policy development for sustainable waste management practices in sensitive coastal wetland environments.**

I. INTRODUCTION

Muthurajawela wetland represents the most extensive saline wetland ecosystem of Sri Lanka, encompassing 3,068 hectares between the Negombo lagoon and Kelani River, forming an integrated coastal wetland complex [1]. The wetland ecosystem supports exceptional biodiversity, serving as a critical habitat for numerous endemic and migratory species while providing essential ecological services including flood control, water purification, and carbon sequestration [2]. However, this ecologically significant ecosystem faces unprecedented anthropogenic pressures, particularly from uncontrolled waste disposal and industrial effluent discharge from surrounding urban developments [3].

Heavy metal contamination represents one of the most persistent and hazardous forms of environmental pollution in aquatic ecosystems, with cadmium and chromium being particularly toxic non-essential metals that accumulate in plant and animal tissues, causing severe ecological and health impacts even at low concentrations [4,5]. Landfill leachate serves as a primary source of heavy metal contamination, originating from discarded electronics, batteries, paints, and industrial wastes, with metals such as cadmium and chromium being persistent environmental contaminants that do not break down over time [6].

Kerawalapitiya Waste Park, established as Sri Lanka's largest open waste disposal facility, operates in immediate proximity to the Environmental Protected Zone declared by the Central Environmental Authority, processing approximately 350 metric tons of segregated biodegradable waste daily [7]. The facility's location within the Muthurajawela Development Zone creates direct pathways for leachate contamination to enter the sensitive wetland ecosystem through surface runoff, groundwater infiltration, and direct discharge during monsoon periods [8].

Wetland sediment contamination poses severe risks by harming aquatic organisms, disrupting food webs, and reducing biodiversity, with carcinogenic substances like heavy metals bioaccumulating in sediments and exposing consumers to greater cancer risks [9]. Recent research demonstrates that improperly managed leachate has been linked to groundwater contamination in over 30% of monitored landfill sites, emphasizing the critical need for comprehensive monitoring and assessment protocols [10].

The current knowledge gap regarding heavy metal contamination dynamics in tropical wetland environments necessitates systematic investigation of temporal and spatial variations in contamination patterns. Previous studies have focused primarily on point-source assessments without considering the complex interactions between seasonal climatic variations, waste composition changes, and ecosystem response mechanisms that characterize tropical coastal wetlands [11].

The objectives of the study are to;

1. Quantify temporal variations in cadmium and chromium concentrations across multiple sampling locations within Muthurajawela wetland
2. Identify contamination hotspots and spatial distribution patterns of heavy metal pollution
3. Assess seasonal fluctuations in heavy metal contamination levels and their correlation with climatic factors

II. METHODOLOGY

A. Study Area and Sampling Design

The study area encompasses the northern section of Muthurajawela wetland directly adjacent to Kerawalapitiya Waste Park, covering approximately 500 hectares of interconnected canal systems, marshy areas, and brackish water bodies. The research methodology follows established protocols for wetland heavy metal assessment while incorporating high-resolution spatial sampling strategies to evaluate contamination dispersion patterns from point sources [12].

Twelve strategically positioned sampling locations (SP01, D1SP02, D2SP3, D3SP04, S1SP05, S2SP06, S1SP07, H2SP08, S2SP09, S1SP10, H1SP11, H3SP12) as shown in Fig. 1 were established based on hydrodynamic flow patterns, proximity to waste disposal facilities, and ecological significance within the wetland system. Sampling points were georeferenced using GPS coordinates and marked with permanent markers to ensure consistent monitoring locations throughout the study period [13].

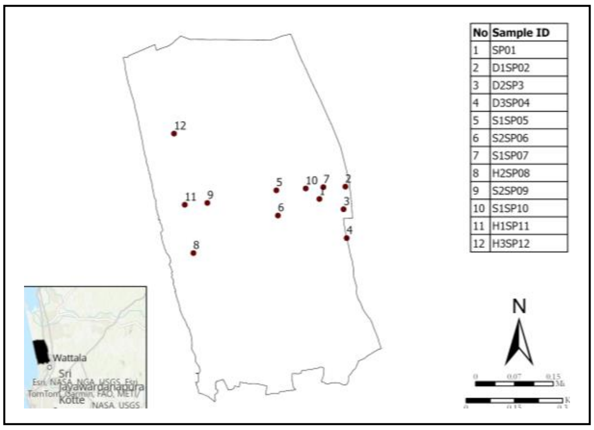

Figure 1. Sampling Locations in the Muthurajawela wetland, Sri Lanka

B. Sample Collection and Preservation

Water samples were collected monthly from March 2024 to October 2024, covering wet season (April-May), intermediate periods (March, June-July), and dry season conditions (August-October) to capture seasonal variations in heavy metal concentrations. All samples were collected using acid-cleaned polyethylene containers following standard environmental sampling protocols [14].

Sample collection procedures included field measurement of basic parameters (pH, temperature, electrical conductivity) using calibrated portable instruments, immediate preservation with nitric acid (HNO_3) to achieve pH < 2 for heavy metal analysis, and cold storage at 4°C during transportation to analytical laboratories [15]. Chain of custody protocols were maintained throughout the sampling and analysis process to ensure data quality and traceability.

C. Heavy Metal Analysis

Cadmium and chromium concentrations were determined using inductively coupled plasma mass spectrometry (ICP-MS) following EPA Method 200.8, providing detection limits of 0.1 µg/L for cadmium and 0.5 µg/L for chromium [16]. Quality control measures included analysis of certified reference materials, duplicate analyses, and blank samples to verify analytical accuracy and precision.

Results were expressed as percentage values relative to the maximum value observed in each heavy metal, with 100% representing the maximum. The allowable concentration for ecosystem protection as defined by Sri Lankan environmental quality standards and international guidelines were used to check for abnormalities [17].

D. Data Analysis and Statistical Methods

Statistical analysis included descriptive statistics to identify significant differences between sampling locations and temporal periods, while correlation analysis assessed relationships between heavy metal concentrations and environmental parameters [18].

III. Results and Discussion

The analysis of cadmium concentrations across the monitoring period revealed substantial temporal and spatial variability within the Muthurajawela wetland system. Cadmium levels demonstrated extreme fluctuations, ranging from a minimum (0.0%) at multiple sampling locations during certain periods to a relative maximum reaching 100.0% of environmental standards at critical contamination hotspots.

The March 2024 monitoring period exhibited the highest cadmium contamination levels across the study area, with sampling locations SP01, D2SP3, and S1SP10 recording peaks of 99.1%, 100.0%, and 4.7%, respectively. This temporal pattern suggests acute contamination events potentially linked to increased leachate generation during the early wet season period, when elevated precipitation mobilizes accumulated heavy metals from waste disposal areas [19].

Subsequent monitoring periods showed variable cadmium concentrations, with April 2024 maintaining elevated levels at SP01 (100.0%) while other locations demonstrated significant reductions as in Fig. 2. The temporal progression through May, June, and August 2024 revealed a general declining trend in cadmium contamination, potentially reflecting dilution effects during peak wet season conditions and improved waste management practices implemented during the monitoring period.

The October 2024 data indicated persistent cadmium contamination at specific locations, with D2SP3 showing 100.0% and several other sites maintaining detectable levels, suggesting ongoing contamination sources and limited natural attenuation processes within the wetland ecosystem.

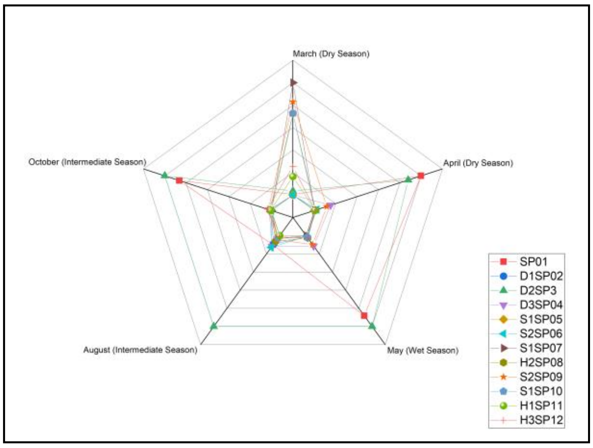

Figure 2. Variation of Cadmium in selected locations of Muthurajawela wetland, Sri Lanka across multiple seasons

Chromium contamination patterns exhibited distinct temporal characteristics compared to cadmium, with peak concentrations occurring during the August 2024 monitoring period. The spatial distribution of chromium contamination showed a strong correlation with proximity to the waste disposal facility, with upstream and adjacent sampling locations consistently recording higher concentrations throughout the study period.

Critical contamination levels were observed at SP01 during multiple monitoring periods, reaching 39.6% in March 2024, 44.0% in April 2024, as shown in Fig. 3, and maintaining elevated concentrations through subsequent monitoring cycles. The D1SP02 location demonstrated variable chromium levels, with concentrations ranging from 24.5% in April 2024 to complete absence during certain periods, indicating irregular contamination inputs and complex transport mechanisms within the wetland system.

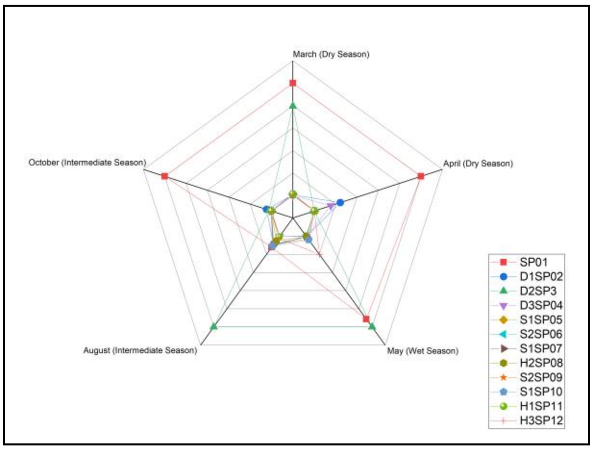

Figure 3. Variation of Chromium in selected locations of Muthurajawela wetland, Sri Lanka across multiple seasons

The August 2024 period marked the peak chromium contamination event, with multiple sampling locations recording maximum concentrations. This temporal pattern correlates with dry season conditions when reduced dilution effects and concentrated leachate conditions enhance heavy metal mobility and bioavailability within the aquatic environment [20].

Spatial analysis revealed distinct contamination zones within the wetland system, with sampling locations SP01, D1SP02, and D2SP3 consistently identified as primary contamination hotspots throughout the monitoring period. These locations demonstrate the direct influence of leachate discharge from Kerawalapitiya Waste Park, with contamination levels decreasing progressively with distance from the primary source.

The downstream sampling locations (S1SP05 through H3SP12) showed variable contamination patterns, with some sites maintaining consistently low heavy metal concentrations while others exhibited sporadic contamination events.

Sampling location D2SP3 emerged as the most critically contaminated site, recording maximum cadmium concentrations (100.0%) during multiple monitoring periods and maintaining persistent contamination levels throughout the study. This location's consistent contamination status indicates direct leachate input pathways and limited natural remediation capacity within the immediate vicinity.

The pH analysis across the monitoring period reveals critical insights into the biogeochemical processes controlling heavy metal mobility and bioavailability within the Muthurajawela wetland system. pH values demonstrated substantial temporal and spatial variability, ranging from highly alkaline conditions (99.1% at SP01 in March 2024) to near-neutral conditions across different sampling locations and seasonal periods (Fig. 4).

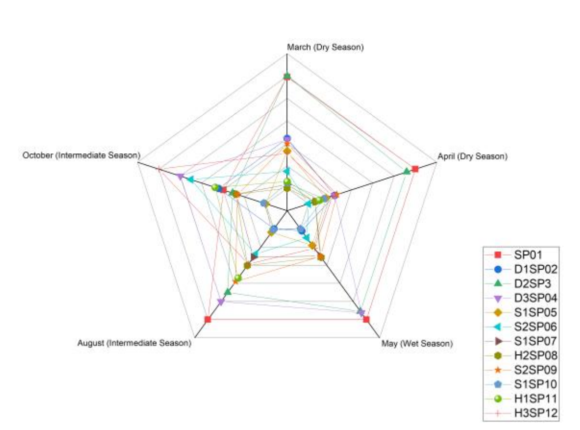

Figure 4. Variation of pH in selected locations of Muthurajawela wetland, Sri Lanka across multiple seasons

The relationship between pH and heavy metal concentrations exhibits complex patterns that reflect the fundamental role of hydrogen ion activity in controlling metal solubility and speciation. The solubility of most heavy metal ions is lower in the basic pH range whereas it is higher in the range of acidic pH range, with studies showing that a one-unit decrease in pH value resulted in about a two-fold increase in the bioavailable concentration of certain elements [21].

Analysis of pH-cadmium correlations reveals inverse relationships during specific monitoring periods, particularly evident at sampling locations SP01 and D2SP3. During March 2024, when SP01 recorded maximum pH values (99.1%), cadmium concentrations also reached peak levels (99.1%), suggesting that alkaline conditions may enhance cadmium mobility through the formation of soluble hydroxo-complexes. Hydroxo-metal complexes formed with cadmium are generally soluble, and in the pH range 3 to 8, release of unspecific adsorbed Cd occurs, which increases with increasing salinity [22,23].

The temporal progression shows contrasting patterns, with D2SP3 maintaining consistently high cadmium levels (100.0%) across multiple monitoring periods while exhibiting variable pH conditions. This suggests that cadmium contamination at this location may be controlled by continuous leachate inputs rather than pH-dependent mobilization mechanisms, indicating direct discharge pathways from waste disposal operations.

Chromium contamination patterns demonstrate distinct pH dependencies compared to cadmium, reflecting the different geochemical behavior of these metals in aquatic systems. Chromium indicated the lowest degree of release under various pH conditions compared to other heavy metals, with different oxidation states exhibiting variable solubility characteristics [24].

The August 2024 monitoring period, which recorded peak chromium contamination levels, coincided with specific pH ranges that may favor chromium mobilization. At sampling location SP01, chromium concentrations varied from 39.6% (March 2024) to 44.0% (April 2024), with corresponding pH fluctuations suggesting pH-controlled release mechanisms from sediment-bound phases.

The spatial distribution of chromium contamination shows stronger correlation with proximity to contamination sources rather than pH variations, indicating that direct leachate inputs may override pH-dependent mobility controls at heavily contaminated locations near the waste disposal facility.

Seasonal analysis reveals distinct patterns in pH fluctuations that correlate with monsoon rainfall patterns and associated hydrochemical changes within the wetland system. The March 2024 period, representing early wet season conditions, showed maximum pH values at several locations, potentially reflecting increased alkalinity from enhanced groundwater discharge and reduced acid-generating processes.

Landfill leachate typically exhibits stable pH ranges (6.90-7.80) due to high alkalinity concentrations, but seasonal variations can significantly affect metal mobility patterns [25]. The observed pH variations in Muthurajawela wetland exceed typical leachate pH ranges, suggesting complex interactions between leachate inputs, natural buffering systems, and seasonal hydrochemical processes.

Rainfall influences on pH-metal relationships appear most pronounced during transition periods between wet and dry seasons. The April-May 2024 monitoring periods showed variable pH-metal correlations, potentially reflecting dilution effects during peak rainfall periods followed by concentration effects as water levels receded.

The pH-heavy metal relationships observed in this study have significant implications for bioavailability and ecosystem health impacts. Electrical conductivity and pH levels in soil showed increased cadmium concentrations, with findings collectively inferring that seasonal changes can increase soil complexities affecting the bioavailability of metals [26].

Alkaline pH conditions recorded at multiple sampling locations may enhance the mobility of certain metal species while reducing the bioavailability of others, creating complex exposure scenarios for aquatic organisms. The temporal variability in pH-metal relationships indicates that seasonal management approaches must consider these dynamic interactions to effectively predict and mitigate contamination risks.

The buffering capacity of the wetland system appears limited in areas receiving direct leachate inputs, as evidenced by the extreme pH variations recorded at contamination hotspots. This suggests that natural attenuation processes may be overwhelmed by the magnitude of contamination loads, requiring engineered intervention to restore ecosystem equilibrium.

The documented heavy metal contamination levels pose significant environmental risks to the Muthurajawela wetland ecosystem. Cadmium exposure is linked to kidney dysfunction, bone damage, and cancer, while chronic exposure to these metals can cause bioaccumulation in food webs, potentially affecting the diverse bird populations and aquatic species that depend on this wetland habitat [27].

The temporal variability in contamination levels indicates that static assessment approaches are inadequate for characterizing the dynamic nature of heavy metal pollution in wetland environments. The observed peak contamination events during specific seasonal periods highlight the need for continuous monitoring protocols and adaptive management strategies that can respond to changing contamination conditions [28].

Heavy metals represent major pollutants in wetland habitats, with cadmium and chromium being particularly concerning due to their persistence and bioaccumulation potential, emphasizing the critical importance of implementing immediate intervention measures to prevent irreversible ecosystem damage [29].

The proximity of contamination hotspots to ecologically sensitive areas within the wetland raises concerns about potential impacts on breeding habitats, feeding grounds, and migration corridors used by internationally significant bird populations. The wetland's role as a critical stopover point for migratory species amplifies the potential for contaminant exposure and transfer to broader regional ecosystems [30].

IV. Conclusion

This comprehensive investigation of cadmium and chromium contamination in Muthurajawela wetland reveals significant temporal and spatial variations in heavy metal pollution directly attributable to leachate discharge from Kerawalapitiya Waste Park. The study demonstrates that contamination levels vary dramatically across different monitoring periods and sampling locations, with peak cadmium concentrations occurring during March 2024 and maximum chromium levels recorded during August 2024.

The identification of persistent contamination hotspots at sampling locations SP01, D1SP02, and D2SP3 provides clear evidence of ongoing heavy metal inputs from waste disposal operations, with contamination levels consistently exceeding environmental protection standards throughout the monitoring period. The spatial distribution patterns confirm the direct relationship between proximity to waste disposal facilities and heavy metal contamination intensity, while also revealing complex transport mechanisms within the wetland ecosystem.

The temporal variability observed in both cadmium and chromium concentrations underscores the inadequacy of single-point assessments for characterizing contamination risks in dynamic wetland environments. The documented seasonal fluctuations in contamination levels highlight the critical importance of continuous monitoring protocols and adaptive management approaches that can respond to changing environmental conditions and contamination sources.

These findings emphasize the urgent need for enhanced leachate management strategies at Kerawalapitiya Waste Park, including improved collection systems, treatment technologies, and containment measures to prevent continued contamination of this internationally significant wetland ecosystem. The study provides essential baseline data for developing targeted remediation strategies and supports evidence-based policy development for sustainable waste management practices in sensitive coastal environments.

The research contributes valuable insights into heavy metal contamination dynamics in tropical wetland systems while highlighting the critical importance of protecting Muthurajawela wetland from irreversible environmental degradation. The pH-heavy metal relationship analysis provides fundamental understanding of biogeochemical processes controlling contaminant mobility, with alkaline conditions potentially enhancing cadmium solubility while chromium mobility appears less pH-dependent. Seasonal variations in pH correlate with rainfall patterns and significantly influence heavy metal bioavailability, necessitating season-specific management approaches that account for these dynamic interactions.

Future research should focus on developing comprehensive remediation strategies that consider pH-dependent metal mobility, assessing ecosystem health indicators across different seasonal conditions, and implementing long-term monitoring programs that integrate pH measurements with heavy metal analysis to track contamination trends and remediation effectiveness. Additionally, investigation of buffering capacity enhancement and pH stabilization techniques should be prioritized to restore natural attenuation processes within the contaminated wetland areas.

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