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Utilizing Pied Crows (*Corvus albus*) as Bioindicators to Monitor Environmental Health and Promote Biodiversity Conservation in Rubengera Sector, Karongi District, Rwanda.



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of the requirements for the degree of Master
of Science in Biodiversity Conservation and
Natural Resources Management

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DECLARATION

I, **Cephas MUFEMI**, declare that this master’s dissertation “**Utilizing Pied Crows (Corvus albus) as Bioindicators to Monitor Environmental Health and Promote Biodiversity Conservation in Rubengera Sector, Karongi District, Rwanda**” is the result of my work in partial fulfilment of the requirements for the award of a Master’s degree in Biodiversity Conservation and Natural Resources Management at the University of Rwanda, College of Science and Technology and has not been submitted for any other degree at the University of Rwanda or any other institution. All sources that I have used or quoted have been indicated and acknowledged in the references.

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APPROVAL

I certify that this research project entitled "**Utilizing Pied Crows (Corvus albus) as Bioindicators to Monitor Environmental Health and Promote Biodiversity Conservation in Rubengera Sector, Karongi District, Rwanda**" was done under my supervision and has been submitted for examination with my approval.

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Dedication

This piece is truly dedicated to Providence Advent MUFEMI, my loving son. Throughout this journey, your patience and constant support have been my greatest strength. You supported me during the hardest times, when I was too focused on this task to give you the recognition and encouragement you so richly deserved, and you kept me going. I am grateful for your love, compassion, and fortitude.

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Acronyms

AAS- Atomic Absorption Spectrophotometer

APHA- American Public Health Association

WHO- World Health Organization

POPs- Persistent Organic Pollutants

GPS- Global Positioning System

ICP-MS- Inductively Coupled Plasma Mass Spectrometry

PAHs- Polycyclic aromatic hydrocarbons

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Abstract

This study was carried out in Rwanda's Karongi District's Rubengera Sector. The region is growing quickly due to the tea processing industry, agriculture, and urbanization—all of which have the potential to contaminate the environment and endanger human health. This study evaluated the effectiveness of Pied crows (*Corvus albus*) as bioindicators to monitor environmental contamination and direct biodiversity conservation efforts. To comply with ethical standards and promote the safety of the *Corvus albus*, the researcher collected feathers that had fallen off the birds from the roosting location. At the same time, soil samples were taken from the marsh region where the birds were seen feeding and the dumping site. The water sample was taken from the stream between TTC Rubengera and Kibande Village, which runs through the marsh. Using an Atomic Absorption Spectrophotometer (AAS), the amount of heavy metals in each sample was measured quantitatively. The procedures of ISO 5667 and ISO 17294 were adhered to for water analysis in order to guarantee precision and consistency of findings. According to the theory, *Corvus albus* will have higher levels of heavy metals in its tissues in regions with more anthropogenic activity, which would imply environmental deterioration. The findings revealed that all samples had significant levels of heavy metals. The greatest levels of chromium (0.070 mg/kg) and cadmium (0.005 mg/kg) were detected in the feathers, suggesting bioaccumulation. Additionally, the soil from the dumping site had high amounts of Pb (0.011 mg/kg) and Cr (0.056 mg/kg), indicating that it was probably among the sources of contamination. The results validate that Pied Crows are useful bioindicators of environmental health and reflect the pollutant load in their habitat. It is recommended that environmental authorities adopt bird-based bioindicator monitoring systems, prioritize the control of dumping sites, and introduce safer waste management practices to minimize the release of toxic metals.

Key words:

Bioindicator; Bioaccumulation; Pied crow (*Corvus albus*); Heavy metals; Feather; Rubengera

CHAPTER 1: INTRODUCTION

1.1 Background

Throughout sub-Saharan Africa, the pied crow (*Corvus albus*) is a common bird species that is renowned for its ability to adapt to a variety of habitats, including urban settings. Given their ubiquity and resilience, Pied crows are emerging as potential bioindicators for monitoring environmental health. Bioindicators are species that provide valuable information on the state of the environment and can signal ecological changes or disturbances (Markert et al., 1999). Utilizing Pied crows as bioindicators can be advantageous due to their wide distribution, ease of observation, and the significant data that can be derived from their health and behavior.

Environmental health monitoring is critical in assessing the impacts of pollution, habitat destruction, and climate change on ecosystems (Cairns & Pratt, 1993). Birds, particularly crows, have been instrumental in previous studies as indicators of environmental contaminants, such as heavy metals and pesticides, due to their position in the food web (Burger & Gochfeld, 2001). The Pied crow's feeding habits, which include scavenging, expose them to a variety of pollutants, making them suitable for this role.

Moreover, biodiversity conservation is a global priority, with increasing emphasis on preserving ecosystem functions and services. Pied crows, as part of the avian community, contribute to biodiversity by participating in seed dispersal, pest control, and nutrient cycling (Sekercioglu, 2006). Monitoring their populations can provide insights into the broader health of the ecosystem, facilitating targeted conservation efforts.

The research aimed to evaluate the effectiveness of using *Corvus albus* as bioindicators to monitor environmental health and promote biodiversity conservation. By analyzing pollutant levels in Pied crow feathers, soil, and water samples, and correlating them with habitat characteristics and biodiversity indicators, the research sought to establish a robust framework for monitoring the ecosystem (Newton, 1995). This investigation contributes valuable insights into the ecological impacts of environmental pollutants and informs sustainable management practices (McGeoch, 1998).

1.2 Problem statement

Environmental deterioration is getting worse in Rubengera, and there are growing worries about heavy metal pollution from adjacent human activities, including garbage disposal, agriculture, and industrial tea processing, which could be causes of the pollution. Despite how urgent the problem is, there aren't enough reliable and reasonably priced instruments for efficient environmental monitoring. Conventional techniques are frequently expensive, time-consuming, and technical in nature, which restricts their use and accessibility in environments with low resources. As a result, pollution may go unreported or uncontrolled, putting biodiversity, ecosystem health, and human welfare at risk (McGeoch, 1998). This circumstance emphasizes how urgently effective, low-cost monitoring techniques are needed to identify and control environmental heavy metal contamination. Although pied crows have the potential to be bioindicators of ecosystem health, little is known about their habitat usage, population dynamics, and heavy metal bioaccumulation (Iqbal et al., 2021). In order to evaluate their potential as bioindicators and guide conservation strategies in the face of habitat pollution and climate change, this study looks at their distribution, environmental relationships, and tissue accumulation of pollutants.

Despite widespread studies on Pied crows as bioindicators in Africa, there is limited research specifically addressing their role in monitoring environmental health in Rwanda. This study bridges the gap by providing localized insights into pollution impacts and biodiversity trends, fostering informed conservation strategies and sustainable environmental management in the region.

1.3 Objectives of the study

Main objective

To assess environmental contamination using Pied crows as bioindicators.

Specific objectives

1. To enumerate heavy metal (Cd, Cr, Pb) content in Pied crow feathers
2. To quantify heavy metal (Cd, Cr, Pb) levels in Pied crow foraging sites in Rubengera
3. To compare heavy metal (Cd, Cr, Pb) levels in Pied crow feathers and foraging sites

1.4 Research questions

1. What levels of Cd, Cr, and Pb are present in Pied crow feathers?
2. What are the levels of Cd, Cr, and Pb in Pied crow foraging sites?
3. How do heavy metal levels in Pied crow feathers compare with those in their foraging sites?

1.5 Significance of the study

This study is significant as it introduces a cost-effective and reliable method for monitoring environmental pollution using bioindicators. Detecting heavy metal accumulation in Pied crows offers valuable data that can inform conservation planning and pollution control strategies. The findings contribute to scientific understanding of environmental health, enabling policymakers and conservationists to implement targeted interventions. Additionally, the study encourages community involvement in environmental conservation by increasing public understanding of ecological dangers and pollution sources. It also supports evidence-based policy formulation, helping to bridge the gap between science and decision-making for sustainable management of ecosystems and public health.

CHAPTER 2. LITERATURE REVIEW

2.0 Introduction

Pied crows (*Corvus albus*), widespread in sub-Saharan Africa, are increasingly recognized for their potential role as a bioindicator in environmental health monitoring. As omnivorous and highly adaptable species, they can reflect changes in ecosystem quality, particularly concerning pollutant levels and habitat disturbances (Giammarino et al., 2014). This literature review synthesizes current research on bioindicators, heavy metal pollution, habitat disturbances, and avian ecological functions, laying a foundation for understanding the potential of Pied crows in environmental health monitoring and biodiversity conservation.

2.1 Theoretical framework

The study on Pied crows as bioindicators is grounded in the bioindication and ecosystem health assessment theories (Sperlea et al., 2022). The indicator species concept suggests that certain organisms reflect environmental conditions due to their sensitivity to ecological changes (Carignan & Villard, 2002). Ecotoxicology theory explains how pollutants accumulate in organisms, offering measurable indicators of environmental contamination (Forbes, 1993). The landscape ecology examines spatial patterns and their influence on ecological processes, helping to understand how Pied crows interact with their habitat (Turner et al., 2001).

2.2 Conceptual framework

According to Carignan and Villard (2002), the study conceptualizes the connection between environmental health and the amounts of heavy metal pollutants in Pied crow tissues, soil, and water. Because of their omnivorous diet and capacity to adapt to settings that have been altered by humans, pied crows are thought to act as bioindicators. By accumulating contaminants, organisms reflect the quality of their environment, according to the bioindicator framework (Furness & Greenwood, 1993). Pied crows are good for monitoring heavy metals, including lead (Pb), cadmium (Cd), and chromium (Cr) that originate from anthropogenic sources such as runoff and dumping sites, since they are common scavengers (Ali et al., 2019).

According to Gochfeld (2000), these birds are reliable markers of ecosystem contamination because they accumulate metals in their feathers. Using Atomic Absorption Spectroscopy (AAS) to analyze feathers and environmental materials, we can establish a connection between ecological exposure and metal contents (Workman et al., 2003). High metal levels are a sign of ecological

stress, endangering soil quality and biodiversity. Thus, according to Hollamby (2006), avian bioindicators provide a useful, affordable tool for early pollution detection and directing conservation efforts.

2.3 Overview of environmental contaminants

Heavy metals such as Cadmium (Cd), Chromium (Cr), and Lead (Pb) are among the most persistent and toxic environmental contaminants, posing significant risks to ecosystems and human health. Anthropogenic and natural sources of these metals include mining, industrial processes, inappropriate waste disposal, fertilizer use, and urban runoff (Sardar et al., 2013).

Cadmium is a hazardous heavy metal that is known to bioaccumulate in living things. Batteries, metal plating, mining, and phosphate fertilizers are among the industrial processes that release cadmium. According to Järup (2003), it can linger in soils and water for decades and is extremely dangerous even at low doses. It can enter ecosystems through atmospheric deposition or runoff. Plants can absorb cadmium, which accumulates in soil.

Exposure to cadmium in birds can result in weakened bones, thinner eggshells, liver and kidney damage, and reduced survival rates (Burger, 1995). These effects can affect the success of reproduction. Because cadmium interferes with the immune system and calcium metabolism, chronic exposure is highly dangerous (Burger & Gochfeld, 2000). Additionally, it can accumulate in the food chain, affecting predators and leading to ecosystem imbalances and population declines. Symptoms of cadmium exposure in plants include chlorosis, decreased germination rates, and altered nutrient uptake. Overall growth inhibition can result from cadmium's interference with vital minerals like potassium and magnesium (Kapusta & Sobczyk, 2015). Chlorosis and necrosis are also caused by its interference with enzyme activity and nutrient uptake. This impacts plant health and decreases herbivores' access to food.

The hexavalent form of chromium (Cr^{6+}) is very useful for tanning leather, making steel, and preserving wood. Industrial wastewater discharge frequently causes chromium contamination, which can have a serious negative impact on aquatic life and birds by inducing DNA damage and oxidative stress (Zhitkovich, 2011). Chromium bioaccumulation has been linked to genotoxicity, stunted development, and compromised immunological responses in animals and birds (Burger & Gochfeld, 2001). Reproductive difficulties, behavioral changes, and decreased survival rates can result from exposure. Chromium has an impact on nutrient intake, photosynthetic efficiency, and

root elongation in plants. Reduced production, decreased chlorophyll synthesis, and cellular damage are the results of toxic concentrations. According to Kapusta and Sobczyk (2015), chromium pollution in soil can last for decades, increasing its ecological impact.

Because of its extensive use and enduring presence in ecosystems, lead is one of the most researched environmental contaminants. Lead (Pb) can find its way into ecosystems through paint, smelting, lead-acid batteries, industrial pollutants, and leaded gasoline. Lead binds firmly to soil particles and sediments as it enters the environment, making removal challenging (Wong et al., 2006). Lead poisoning is frequently the result of birds consuming lead either directly by polluted prey or sediments, food, or water, or indirectly through lead particles in their surroundings (Furness, 1993). According to Pain et al. (2009), birds are frequently exposed to lead through the consumption of tainted food, water, or waste munitions. Anemia, slowed growth rates, and poor reproduction are physiological impacts. According to Burger (1995) and Gochfeld (2000), neurological symptoms like disorientation and diminished cognitive function might affect fitness and survival. Inhibiting photosynthesis and enzyme activity is another way that lead causes harm to plants. Chlorosis (leaf yellowing), decreased seed germination, and poor general plant health can result from high lead concentrations. Consequently, this impacts herbivores and the food chain as a whole, which eventually impacts ecosystem productivity (Markert et al., 1999).

Heavy metals have huge impacts on ecosystems, affecting soil fertility, vegetation, water bodies, and wildlife. Heavy metals such as Cadmium (Cd), Chromium (Cr), and Lead (Pb) significantly degrade soil quality by altering pH, reducing microbial activity, and inhibiting nutrient cycling (Sardar et al., 2013). This disruption affects plant growth, leading to reduced biomass, poor seed germination, and metal toxicity symptoms like chlorosis and root necrosis (Nagajyoti et al., 2010). In aquatic ecosystems, these metals can accumulate in sediments and remain biologically active for long periods, impairing aquatic life through reduced reproduction, growth inhibition, and organ damage in fish and invertebrates (Wong et al., 2006). Wildlife, including birds and mammals, absorb these metals through contaminated food or water. Prolonged exposure leads to kidney and liver damage, weakened immunity, reproductive failure, and behavioral changes (Gochfeld, 2000).

One of the most alarming impacts of heavy metals is biomagnification, the progressive increase in contaminant concentration as it moves up the food chain. Predatory species such as raptors, scavengers, and carnivorous fish accumulate high levels of metals, often surpassing toxicity

thresholds (Furness, 1993). Reduced populations, changed relationships between species, and even local extinctions may result from this. Biodiversity is further threatened as species with low tolerance to pollutants disappear, leading to ecosystem imbalance and loss of ecosystem services (Gochfeld, 2000). The long-term accumulation of heavy metals thus poses a serious ecological risk, demanding routine monitoring and conservation interventions to prevent irreversible ecosystem damage.

Briefly, these pollutants jeopardize ecological integrity, human health, and biodiversity. Continuous environmental monitoring is essential due to their capacity to bioaccumulate and biomagnify throughout the food chain. The development of focused mitigation methods and sustainable ecosystem management is aided by an understanding of their causes and impacts (Pereira & Cooper, 2006).

2.3.1 Heavy metal pollution in Rwanda

Rwanda's rapid development has led to increased industrial processes, agricultural practices, mining, and agricultural activities, waste management, and transportation, significantly contributing to heavy metal pollution in ecosystems, impacting environmental and public health. Studies in Bugesera Agricultural Wetlands reveal elevated levels of metals like Pb and Cu, attributed to agricultural runoff and industrial discharge (Nsengiyumva et al., 2021). The ecotoxicological implications are that heavy metals persist in ecosystems, affecting soil and water quality (Sastre et al., 2002). Accumulation in food chains poses risks to wildlife and humans, underscoring the need for effective monitoring and mitigation strategies (Nriagu & Pacyna, 1988).

Mining, smelting, and extraction of metals and minerals often involve the release of heavy metals such as lead (Pb), mercury (Hg), and arsenic (As) into the environment. Smelting processes also emit these metals as airborne particulates or liquid wastes (Finley et al., 2025). Manufacturing industrial activities, such as the production of batteries, electronics, and pigments, involve heavy metals. According to Skoog et al. (1996), improper industrial waste disposal can contaminate water and soil.

Agriculture uses environmentally harmful herbicides that include heavy metals including arsenic (As) and cadmium (Cd). Contamination of land and water can result from ongoing usage and inappropriate disposal (Gochfeld, M., & Burger, J. (1998). Apparent paralytic shellfish poisoning in captive herring gulls fed commercial scallops. *Toxicon*, 36(2), 411-415.). Heavy metals like copper and zinc,

which are frequently found in fertilizers and can build up in soil and water bodies, are present in tiny amounts in certain phosphate fertilizers (Sastre et al., 2002). Excessive use may cause metals to build up in the soil and leak into waterways.

Heavy metals, including lead, mercury, and cadmium, are frequently present in improperly disposed of waste, including electronic waste. These metals can contaminate land and water if they are not recycled or disposed of appropriately (Baird et al., 2014). Furthermore, if hazardous trash is not sufficiently screened, landfills may discharge heavy metals from decomposing waste into nearby soil and groundwater (Finley et al., 2025).

Furthermore, exhaust emissions from vehicles, especially those running on leaded gasoline, contribute to atmospheric lead pollution. This can settle on land and water, causing contamination (Ropkins et al., 2009). On the other hand, the wear and tear of vehicle tires and brake linings can release metals such as zinc (Zn) and copper (Cu) into the environment through road runoff (Ropkins et al., 2009). Although Rwanda is making great strides in reducing its carbon footprint, much still needs to be done to realize remarkable changes in this regard.

Pollution sources play a vital role in determining heavy metal levels not only in the ecosystem but also in plants and animals, including humans. Heavy metal contamination in Pied crow tissues is influenced by pollution sources within their habitat (Wu et al., 2021). Factories and smelting operations can release heavy metals such as lead, mercury, and cadmium into the environment, entering the food chain through contaminated soil, water, and vegetation (Wu et al., 2021). Improper disposal of industrial and household waste, including electronic waste, can lead to the leaching of heavy metals into the environment.

The quality and type of habitat where *Corvus albus* live significantly impact their exposure to heavy metals. Urban habitats are often more contaminated due to higher concentrations of industrial activities, traffic emissions, and waste (Wu et al., 2021). In contrast, rural areas might have lower pollution levels but can still be affected by agricultural runoff. Habitats closer to sources of pollution are more likely to have higher concentrations of heavy metals in the food web, which can directly affect the *Corvus albus*. Areas with poor vegetation and contaminated soil are

less capable of filtering pollutants, leading to higher metal accumulation in the food chain (Finley et al., 2025).

Habitat disturbance, including deforestation, urbanization, and agricultural expansion, profoundly affects bird communities. Riparian corridors, vital for many bird species, are particularly vulnerable (Croonquist & Brooks, 1993). Fragmentation and degradation reduce biodiversity and disrupt ecosystem functioning. Birds respond to habitat alteration through changes in abundance, diversity, and behavior (Muhammad, 2018). Specialist species are more susceptible to habitat loss, while generalists like Pied crows can adapt and exploit disturbed environments (Newton, 1995). Monitoring such responses provides insights into ecosystem health.

Because of these human activities, soil, water, and air are contaminated with heavy metals. Stricter laws, improved waste management techniques, and the creation of cleaner technologies are needed to address these sources and lessen their negative effects on the environment and human health.

2.4 Studies on the use of birds for pollution monitoring

Due to their ability to integrate pollutants across time, place, and trophic levels, birds have long been recognized as sensitive sentinels of chemical stress (Furness et al., 1993). An outline of example case studies that demonstrate the use of birds as bioindicators to identify environmental contamination and direct management is provided below, initially from Africa and subsequently from other continents.

Odino et al. (2014) examined the metal loads of urban sparrows in Nairobi, Kenya, and those from periurban reference sites. The amounts of Cd, Pb, and Zn in feathers and internal organs were noticeably greater in the vicinity of open dumps and traffic corridors. The use of sparrows in East African cities was supported by spatial correlations with soil metal levels, which verified that the birds monitored local pollution hotspots.

In order to measure aquatic contamination, Hollamby (2003) examined the liver and serum of fish eagles from large river systems in Uganda. Elevated levels of mercury, cadmium, and persistent organic pollutants (POPs) were found downstream of industrial centers, but birds from protected headwaters displayed background levels. The study showed that, in addition to point source water monitoring, wide-ranging raptors integrate contamination burdens throughout broad catchments.

Giammarino (2014) gathered feathers from crows that were roosting close to metal smelters in the Helwan Industrial Zone in Egypt. Feather $\delta^{34}\text{S}$ fingerprints matched local stack emissions, establishing a connection between industrial fallout and bioaccumulation. Mean Pb values ($25 \mu\text{g g}^{-1}$) exceeded international toxicity standards for birds. Routine crow feather monitoring was suggested by the authors as an inexpensive industrial audit.

Metals in gull eggs and feathers were observed by Burger and Gochfeld (2000) in three estuaries on the New Jersey Coast, USA. Pb and Hg concentrations at sites close to Superfund sites were twice as high as those at reference wetlands. The use of gulls to monitor remediation effectiveness was validated when feather losses occurred over time in tandem with local sediment cleaning milestones.

In their 2024 study of the Bald Eagle in the USA–Canada Great Lakes, Eakin et al. discovered that nestling plasma and feather mercury levels decreased by 70% between 1991 and 2000, which corresponded with mercury emission regulations in the Great Lakes basin. Nevertheless, certain tributaries continued to produce chicks that were over sublethal criteria. The outcomes guided specific action programs for watersheds.

Research on the Great Tit was conducted by Koivula et al. (2011) in Flanders, Belgium, where they sampled nestlings along a 15km gradient from a metal smelter. Plots with the highest levels of pollution had chicks with lower body mass and immunocompetence, and feather Cd and Zn were very distance-dependent. Underpinning European air quality regulations, the study established causal relationships between metal exposure and passerine fitness impacts.

Ferguson (2001) evaluated the effects of a cyanide and metal spill from a mine in Romania in Hungary using the blood of Black-headed Gulls. The significance of colonial waterbirds for long-term disaster surveillance was demonstrated by the elevated As and Cu that remained for five breeding seasons.

In another investigation, the concentrations of mercury (Hg) in kingfisher feathers along the Japanese Shiranui Sea coast, mercury levels were greater where sewage effluent ratios were higher, supporting the birds' use for identifying diffuse aquatic sources in densely populated catchments (Rattner et al., 2011).

In the Ross Sea in Antarctica, Lewis (2024) assessed POPs and mercury in penguin feathers and blood. Temporal trends revealed rising perfluorinated chemicals despite remoteness, even if total levels were lower than those of mid-latitude species. This underscores the significance of sentinel species in pristine regions and the worldwide movement of pollutants.

In Madrid, Spain, Giovanetti (2024) searched for metals from traffic and polycyclic aromatic hydrocarbons (PAHs) in urban breeding falcons. Nestlings had higher levels of Ba and Zn than their rural counterparts, which was consistent with measures of road density. The study supported the use of raptor biomonitoring as a stand-in for urban air quality.

Generally, studies of birds share four themes across continents and biomes. Initially, birds consistently reflect geographical pollution patterns, whether they are diffuse (traffic, agricultural) or point source (industrial stacks). Second, non-lethal sampling made possible by feather or egg studies promotes long-term, moral programs (Burger, 1993). Third, integrating GPS tracking or isotopes with metal data aids in source identification, improving management accuracy (Giammarino et al., 2014). The importance of birds for assessing the effectiveness of regulations is further supported by decreases in tissue burdens after policy changes, such as Pb ban laws (Sastre et al., 2002).

In places with limited resources, such as Rwanda, where laboratory infrastructure and regulatory enforcement are still in their infancy, the above research findings collectively confirm the viability of using bird bioindicators for routine, inexpensive environmental surveillance.

2.5 Ecology and use of Pied crow (*Corvus albus*) as a bioindicator

Native to Rwanda and other parts of Africa, *Corvus albus* are more than just visually attractive birds with their striking black and white plumage; they are essential to ecological balance and environmental health monitoring (Furness & Greenwood, 2013). They are important bioindicators because their existence and actions provide insightful information about the condition of the environment.

Because they are omnivores with great adaptability, Pied crows can inhabit a range of ecological niches. They eat a variety of foods, including fruits, carrion, tiny animals, and insects (Burger & Gochfeld, 2001). Their capacity to scavenge garbage, regulate insect populations, and disperse seeds is facilitated by their adaptable diet. They aid in controlling prey populations and lowering

the number of possible pests by devouring a variety of creatures (Burger & Gochfeld, 2001). Their wide range and broad diet make them effective indicators of ecosystem health across different habitats (Kushlan, 1993).

Their scavenging behavior also contributes significantly to nutrient cycling. By consuming carrion, *Corvus albus* facilitates the decomposition process and the return of nutrients to the soil, thereby supporting plant growth and maintaining soil fertility (Gosler, 2017). Pied crows boost plant growth and preserve soil health by aiding in the breakdown of carrion and replenishing the soil with vital nutrients (Gosler, 2017). The propagation of different plant species is aided by their function in seed distribution, which increases ecosystem resilience and vegetation diversity.

Due to their ecological significance, adaptability, and sensitivity to environmental changes, Pied crows are excellent bioindicators (Iqbal et al., 2021). Bioindicators are living organisms used to assess the health of ecosystems by reflecting the presence, concentration, or biological effects of pollutants. These organisms respond to changes in environmental conditions, making them valuable tools for monitoring contamination and detecting ecological stress (Furness et al., 1993). They offer insights into environmental conditions through their presence, abundance, behavior, or physiological responses (McGeoch, 1998). Unlike chemical sensors, bioindicators provide integrative, long-term insights into pollutant exposure, including cumulative and sublethal effects across ecosystems (Markert et al., 2003).

Biomarkers are often selected based on their sensitivity to environmental changes, their ecological roles, and their ability to accumulate pollutants (Sutherland, 2006). Pereira & Cooper (2006) state that the effectiveness of a bioindicator hinges on its responsiveness to environmental changes and its relevance within the ecosystem. As omnivores and scavengers, Pied crows are directly exposed to pollutants, toxins, and habitat alterations. Their health and behavior can reflect the condition of their habitat and the presence of pollutants (Iqbal et al., 2021). For example, changes in their population dynamics, reproductive success, or foraging patterns can indicate shifts in environmental quality. Effective bioindicators exhibit predictable responses to specific environmental stressors, such as chemical pollutants or habitat alterations, and their ecological significance often correlates with broader ecosystem health (McGeoch & Chown, 1998).

Various taxa, including plants, insects, birds, and aquatic organisms, can serve as bioindicators. According to Burger (1993), birds' trophic diversity, mobility, vast geographic distribution, and

sensitivity to environmental changes make them especially useful bioindicators. Their varied eating patterns enable them to interact with different types of flora, soil, water, and environmental media, which can lead to the accumulation of contaminants such as heavy metals. Since feathers preserve trace elements accumulated during maturation, feather analysis, for instance, offers a non-invasive way to evaluate long-term contamination exposure (Gochfeld, 2000). Furthermore, because of their varying positions in the food chain, birds can biomagnify and reflect contaminants across the entire ecosystem. Because they feed at different trophic levels and can reflect a wider range of environmental health, species like omnivores and scavengers are especially helpful (Iqbal et al., 2021). Their physiological state, abundance, and presence are observable, and shifts in these parameters may indicate ecological recovery or deterioration (Gochfeld, 2000). Birds are useful and affordable instruments for environmental monitoring in both urban and rural areas, particularly in those with little access to advanced laboratory equipment. The information obtained from bird bioindicators helps to conserve biodiversity and raise public awareness of health issues, in addition to informing pollution control measures (Hollamby, 2003).

In conclusion, *Corvus albus* plays a crucial role in its ecosystem by dispersing seeds, scavenging, and controlling pests. Since fluctuations in their populations can indicate more significant ecological problems, their position as bioindicators is essential for keeping an eye on the health of the ecosystem. Conservationists can create successful strategies to enhance biodiversity conservation and provide important insights into ecosystem health by concentrating on *Corvus albus*. As a result, research on Pied crows advances both wider environmental and conservation objectives and our knowledge of ecological dynamics. Therefore, including bird-based bioindicator techniques in environmental monitoring initiatives provides a comprehensive, accessible, and sustainable approach to ecosystem management and protection.

CHAPTER 3: MATERIALS AND METHODS

3.1 Study area

This study was conducted in Rubengera Sector, Rwanda. Rubengera, formally known as Mabanza, is a sector and town in Rwanda. The town is the capital of Karongi District in Western Province, Rwanda (Figure 1).

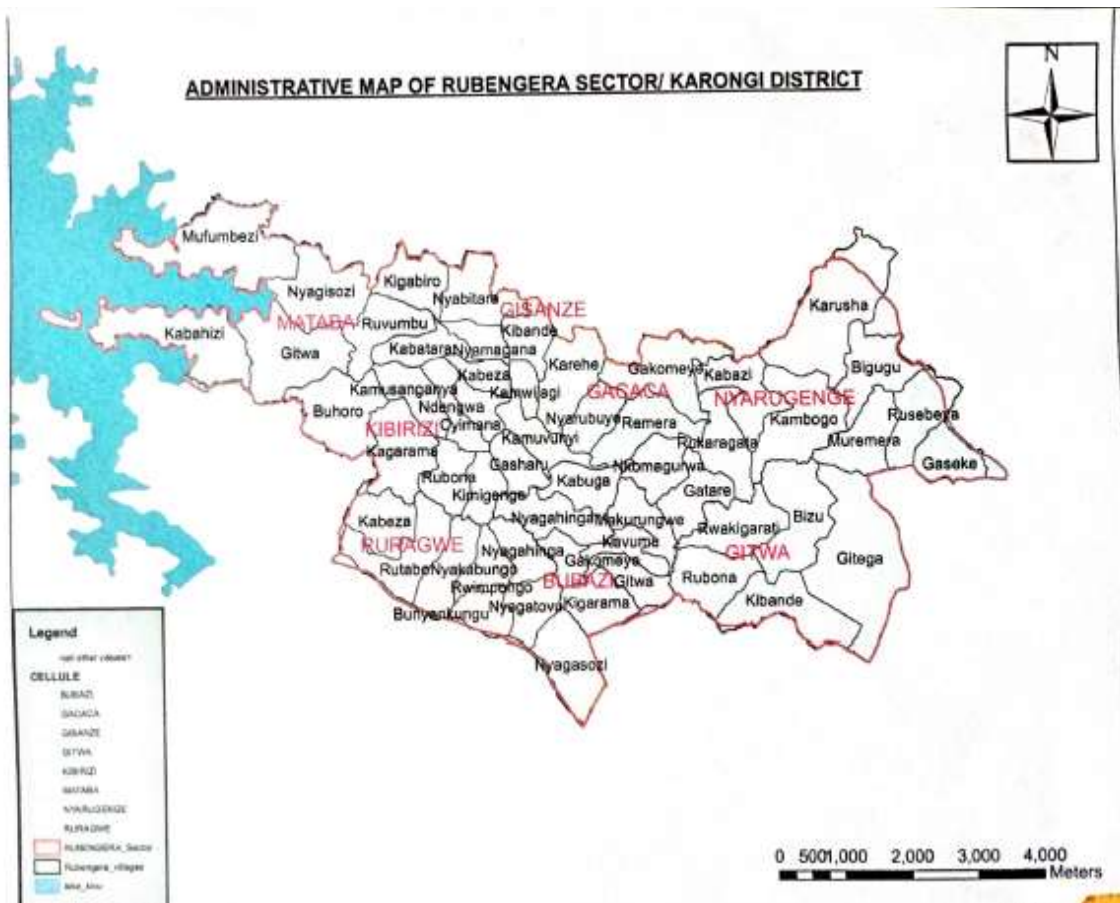


Figure 1: Map of the Rubengera sector

Rubengera is located in Rwanda's western mountains, between Lake Kivu and the border separating the Nile and the Congo River's western catchments. Rubengera is characterized by a variety of landscapes, such as hills, marshes, and agricultural areas (D'Amour & Nyongesah, 2023). The industry is well known for its abundant biodiversity, which includes a wide variety of bird species as the African Sacred Ibis and Pied Crows (D'Amour & Nyonesah, 2023). Yet, it is a prime site for this investigation of pollution bioaccumulation bioindicators because of

environmental issues such as agricultural runoff and possible heavy metal contamination (D'Amour & Nyongesah, 2023).

3.2 Data collection

This study involved the systematic collection of four types of environmental samples: Pied crow feathers, stream water, marsh soil, and soil from a dumping site where Pied crows were observed or roosting. GPS coordinates for each sampled site were recorded as shown in Figure 2., below.

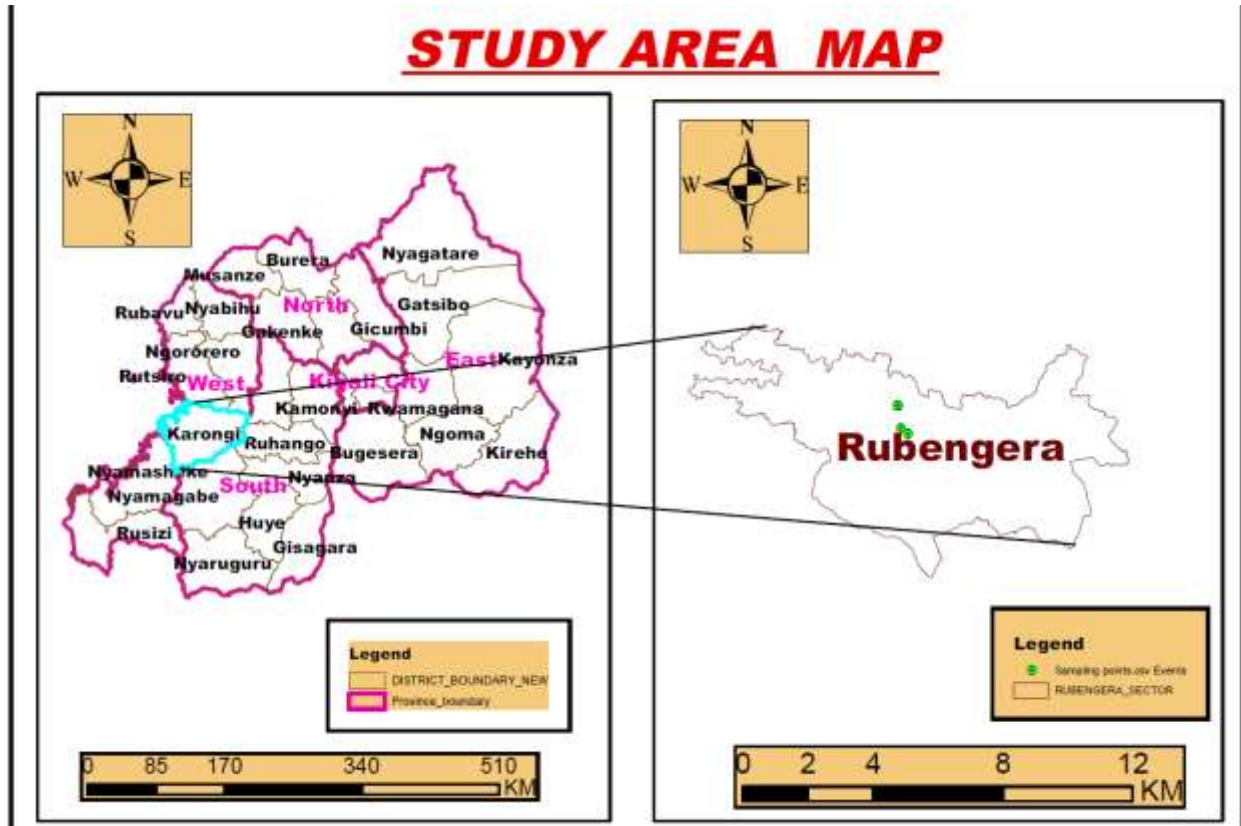


Figure 2: Study area map

A total of four composite samples were collected, one from each sample type, at distinct locations within Rubengera Sector, Karongi District. Feather samples from Pied crows were collected from their roosting area across the study area to ensure a representative sample (Gochfeld & Burger, 1998). To guarantee the safety and protection of the birds, we visited the roosting area early in the morning to collect feathers that had fallen off until a desired sample size of 3g was collected (Gaunt et al., 1997). Early in the morning, when birds were most active, each site was visited (Hutton & Symon, 1986). Stream water and marsh soil were sampled from lowland marshes where the Pied

crows were observed hunting for insects and carrion and drinking and swimming in the stream. The dumping site soil was taken directly from the most active waste disposal area. These samples were sealed in sterilized polythene bags (Sharma & Tyagi, 2013) to avoid contamination, carefully stored, and transported for laboratory analysis using standard procedures.

3.3 Sample preparation

Accurate heavy metal analysis using Atomic Absorption Spectroscopy (AAS) requires rigorous sample preparation to ensure the removal of external contaminants and achieve complete digestion of target metals. This study followed standard protocols for the preparation of feathers, soil, and water samples before AAS analysis.

Using distilled water, non-ionic detergent, and acetone, the feathers were first cleaned to remove surface impurities and outside debris (Gochfeld, 2000). After rinsing, the feathers were air-dried at room temperature and then oven-dried at 60°C for 24 hours to remove residual moisture (Nriagu, 1989). The dried samples were cut into small pieces, homogenized using a mortar and pestle to ensure uniformity, and accurately weighed using an analytical balance before digestion. A hotplate digestion apparatus was used to digest a known weight (1g) of the homogenized material using a solution of hydrochloric acid (HCl) and nitric acid (HNO₃) (Sastre et al., 2002). Filtered and diluted with deionized water, the digested samples were then moved to volumetric flasks for analysis.

To exclude stones and plant matter, soil samples were air-dried, homogenized, and sieved (Nriagu, 1989) until a consistent dry weight was achieved (Janaydeh et al., 2016). The same acid technique was used to weigh and digest a representative sub-sample (Sastre et al., 2002). Before analysis, water samples were kept in plastic bottles after being filtered through Whatman filter paper to eliminate particles and acidified with HNO₃ to preserve metal ions (Salihu & Bakar, 2018).

In the digestion of samples for heavy metal analysis, the choice of acids is crucial for effectively dissolving the sample matrix and ensuring accurate detection of metal contaminants. Nitric acid (HNO₃) and hydrochloric acid (HCl) were used for this purpose due to their specific advantages over other acids (Finley et al., 2025). Acid digestion converts metal compounds into their ionic forms, which are suitable for detection by AAS, following procedures recommended by the U.S. EPA and other validated protocols (Workman et al., 2003). Digestion was conducted using

hotplate-assisted heating until complete decomposition of organic material was achieved. The resulting solutions were filtered and diluted with deionized water, and stored in sterile plastic containers before AAS analysis (Janaydeh et al., 2016).

When used together, nitric acid (HNO_3) and hydrochloric acid (HCl), in sample digestion, offer several complementary benefits. HNO_3 acts as a strong oxidizing agent that effectively dissolves a wide range of metals and complex organic matrices, while HCl is effective in breaking down metal chlorides and silicate matrices. Together, these acids enhance digestion efficiency, form aqua regia for dissolving noble metals, and reduce interference, making them highly effective for comprehensive heavy metal analysis (Finley et al., 2025). The combination of HNO_3 and HCl can achieve a more complete digestion of complex matrices compared to using either acid alone. HNO_3 's oxidative properties help in breaking down organic material, while HCl 's ability to dissolve metal chlorides ensures a thorough dissolution process (Finley et al., 2025). A very strong digesting solution called aqua regia is created when HNO_3 and HCl are combined in the right proportions. It may dissolve noble metals like gold and platinum that are normally resistant to other acids. In cases where heavy metals are of relevance, aqua regia is especially helpful for thorough analyses (Finley et al., 2025). Using both acids together can minimize the risk of interference from non-dissolved residues or incomplete digestion. This ensures that metal ions are fully liberated and available for accurate measurement (Finley et al., 2025).

3.4 Laboratory analysis

The INES Ruhengeri Laboratory in Musanze, one of Rwanda's biggest private institutions, served as the site of the laboratory experiments. Both flame/graphite Atomic Absorption Spectroscopy (AAS) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) generally require calibration, analysis, and quantification. We used Inductively Coupled Plasma Mass Spectrometry (ICP-MS) to analyze the heavy metals in water. Using a nebulizer, the prepared water sample was injected into the ICP-MS device, turning the liquid into an aerosol. Atoms are ionized when this aerosol reaches a high-temperature argon plasma, in accordance with APHA and WHO requirements (Salihu & Bakar, 2018; Edition, 2011; Alloway, 2012). A mass spectrometer receives the resultant ions and separates them according to their mass-to-charge ratio. The ions are measured by a detector, which yields accurate concentrations of different heavy metals. According

to Skoog et al. (1996), ICP-MS is extremely sensitive, can detect trace levels (parts per trillion), and enables the accurate and repeatable simultaneous measurement of numerous metals.

To achieve prescribed standards and quality control procedures, calibration curves were prepared from National Institute of Standards and Technology (NIST) traceable stock solutions (1,000 mg/L⁻¹) diluted to 0.0, 0.5, 1.0, 2.0, and 5.0 mg L⁻¹ in 2 % HNO₃. Each curve showed correlation coefficients (R^2) > 0.999, satisfying linearity requirements of U.S. EPA Method 7000B (Khalek et al. 2011). Procedural blanks and reagent blanks were analyzed every ten samples to detect contamination; blank signals never exceeded 5 % of the lowest standard. Instrument drift was monitored with mid-range check standards (1.0 mg/L⁻¹) run after every 15 measurements; results remained within ±3 % of initial values, meeting APHA (2012) criteria.

Accuracy was verified with certified reference materials (CRM): NIST SRM 1643f (trace elements in water) for aqueous samples and SRM 2711a (Montana II soil) for soil digests. Recoveries ranged from 93 % to 105 % for all target metals, demonstrating acceptable analytical bias (ISO 17025:2017). Precision was assessed by triplicate digestion and analysis of 10 % of all samples; relative standard deviations were <5 %. Matrix-spike duplicates yielded recoveries between 88 % and 107 %, confirming minimal matrix interference. Together, the rigorous calibration strategy, continuous performance checks, and CRM validation ensured that the AAS data generated in this study are both accurate and reliable, thereby providing a solid foundation for subsequent ecological interpretation.

Heavy-metal concentrations in soil and feather samples were determined using a flame Atomic Absorption Spectroscopy (AAS; PerkinElmer AAnalyst 400), a widely accepted instrument for trace-metal quantification because of its high selectivity, sensitivity, and relatively low running costs (Workman et al., 2003). The AAS was calibrated using standard solutions that had known concentrations of each heavy metal. For the measurement of heavy metals, the samples were placed into the AAS apparatus, flame-atomized, and their absorbance was measured at wavelengths that corresponded to each metal (Grodzinska et al., 1990). By contrasting the absorbance values with those of the calibration standards, the amounts of heavy metals present in the samples were measured. For Cadmium (228.8 nm), Chromium (357.9 nm), and Lead (217.0 nm), separate hollow cathode lamps were used; slit widths and lamp currents were in accordance with

manufacturer specifications. To increase detection limits ($<0.1 \mu\text{g L}^{-1}$), Cd, which was present at sub $\mu\text{g L}^{-1}$ levels, was examined in graphite furnace mode. For Pb and Cr, samples were introduced using an air-acetylene flame. The results' accuracy and dependability are guaranteed by quality control procedures such as the use of blanks and reference materials (Grodzinska et al., 1990).

AAS is widely applicable for detecting a wide range of metals, including lead, cadmium, mercury, and arsenic, in diverse sample matrices such as water, soil, and biological tissues (Finley et al. 2025). This technique also allows for the simultaneous analysis of multiple samples with relatively short analysis times, making it suitable for routine environmental monitoring (Miller & Rutzke, 2010). Additionally, AAS is easy to operate with established methodologies and well-understood instrumentation. It is less complex compared to more advanced techniques, making it accessible to many laboratories (Miller & Rutzke, 2010). Its cost-effectiveness makes it the most abundant analysis instrument in most laboratories. The initial setup cost for AAS is generally lower than that for GFAAS, and operational costs are also relatively modest. This makes it a cost-effective choice for routine analyses (Miller & Rutzke, 2010).

3.5 Data analysis

Data analysis in this study was conducted to show the concentrations of heavy metals, Cadmium, Chromium, and Lead, found in environmental samples collected from the Rubengera Sector. The aim was to evaluate patterns of metal distribution and identify possible relationships between sampling sites and contamination levels. Statistical analysis and graphical tools were applied using Microsoft.

Descriptive statistics were used to summarize the variability of metal concentrations across the four sample types: Pied crow feathers, stream water, marsh soil, and dumping site soil (StatSoft, Inc., 2004). Parameters such as minimum and maximum values were calculated to understand the concentration range of each metal (Miller & Rutzke, 2010). Tables and composite graphs were created to visually compare the levels of each metal across the four sample types.

CHAPTER 4: RESULTS

In the present study, the concentrations of heavy metals (Cd, Cr, and Pb) in Pied crow feathers, soil, and water samples were analyzed using AAS, and the results show the presence of the toxic heavy metals in Pied crow feathers and environmental samples (Figure 3 below). Cadmium (Cd), Chromium (Cr), and Lead (Pb) across four different environmental samples: Pied crow feathers, stream water, dumping site soil, and marsh soil, with Chromium presenting the highest concentration among the samples (Figure 3 below).

4.1 What levels of Cd, Cr, and Pb are present in Pied crow feathers?

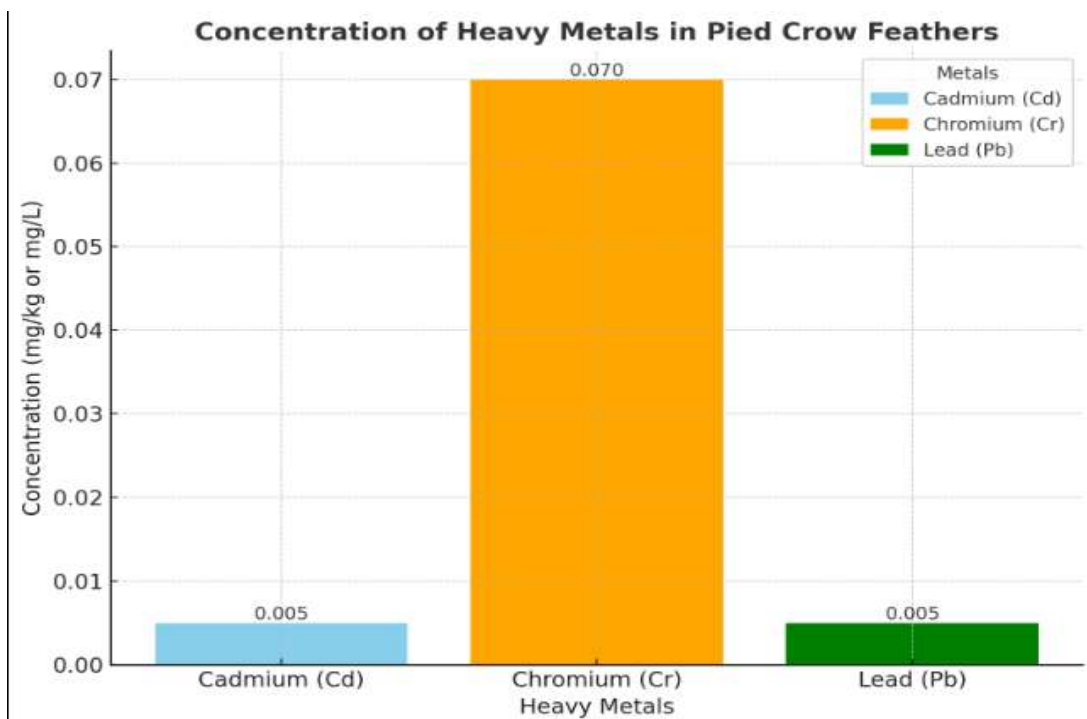


Figure 3: Concentration of heavy metals in Pied crow feathers

The results indicate Cd (0.005), Cr (0.070), and Pb (0.005) in Pied crow feathers. Chromium is notably higher than cadmium and lead, suggesting greater environmental availability or bioaccumulation of Cr. The low Cd and Pb levels imply limited exposure, but elevated Cr warrants closer monitoring of ecological risks.

4.2 What are the levels of Cd, Cr, and Pb in Pied crow foraging sites?

4.2.1 Heavy metal levels in the Dumping Site soil

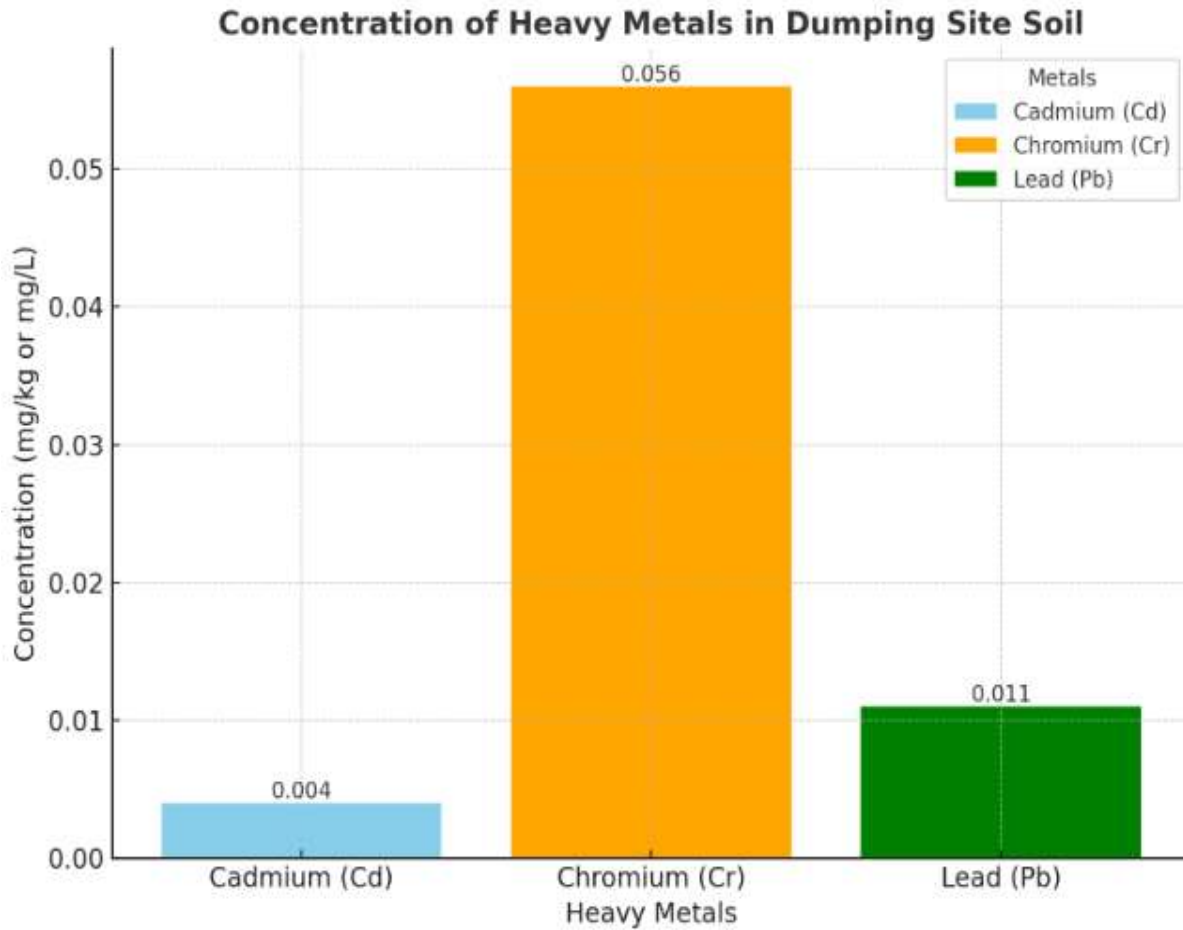


Figure 4: Concentration of heavy metals in dumping site soil

The results show that chromium (0.056 mg/kg) has the highest concentration in dumping site soil, followed by lead (0.011 mg/kg) and cadmium (0.004 mg/kg). This pattern suggests significant chromium contamination, likely from waste materials. Although cadmium and lead levels are lower, their presence indicates anthropogenic pollution, posing potential ecological and health risks in the dumping site area.

4.2.2 Heavy metal levels in marsh soil

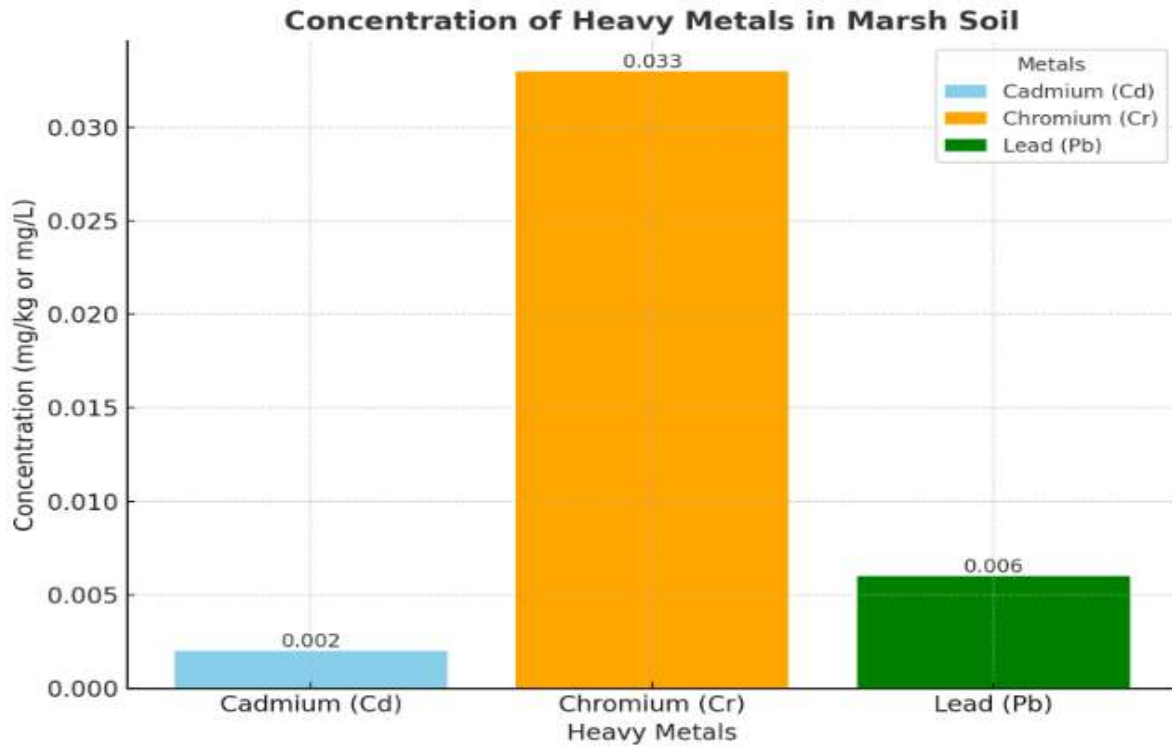


Figure 5: Concentration of heavy metals in marsh soil

The results indicate that chromium (0.033 mg/kg) is the most abundant heavy metal in marsh soil, followed by lead (0.006 mg/kg) and cadmium (0.002 mg/kg). Chromium's dominance suggests moderate environmental exposure, possibly from runoff or nearby human activities. The relatively low cadmium and lead levels imply limited contamination but still warrant continued environmental monitoring.

4.2.3 Heavy metal levels in stream water

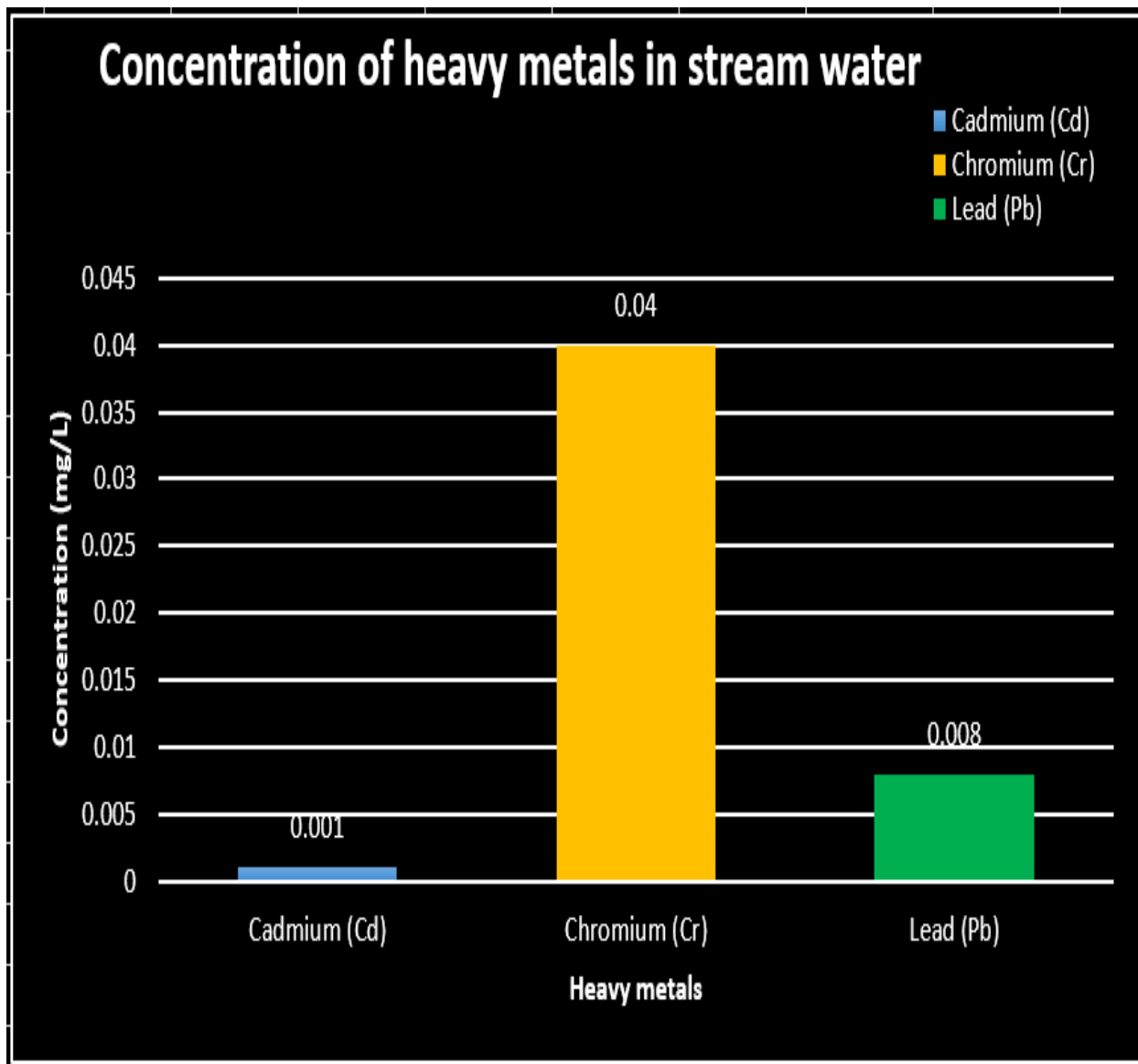


Figure 6: Concentration of heavy metals in stream water

The findings show that chromium (0.040 mg/L) is the most concentrated metal in stream water, followed by lead (0.008 mg/L) and cadmium (0.001 mg/L). Elevated chromium levels may result from industrial or agricultural runoff. Although cadmium and lead are relatively low, their presence indicates minor contamination, emphasizing the need for continuous water quality monitoring.

4.3 How do heavy metal levels in Pied crow feathers compare with those in their foraging sites?

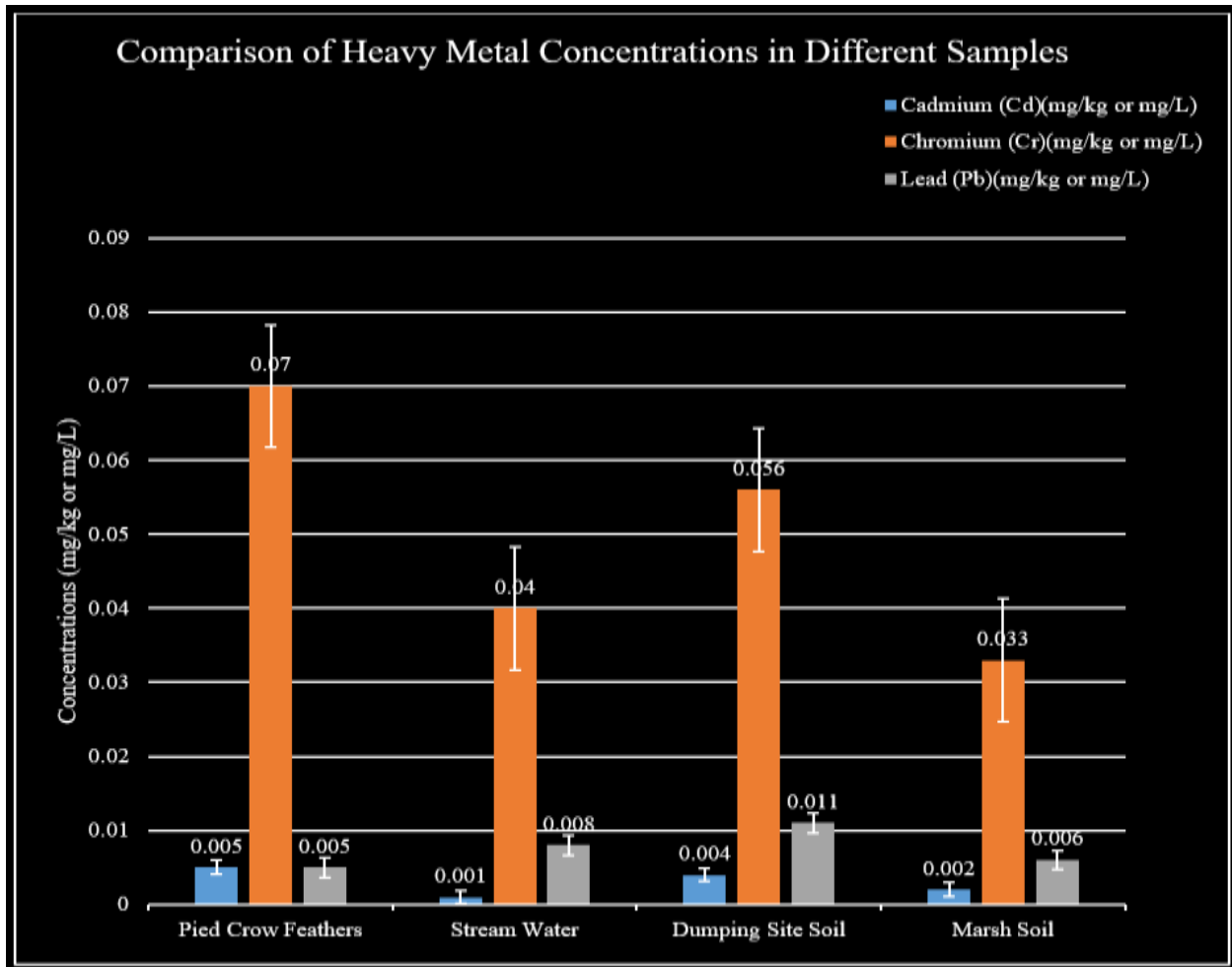


Figure 7: Comparison of heavy metal concentrations in different samples at Rubengera

Heavy metal levels in Pied crow feathers were generally higher than those in their foraging sites, indicating bioaccumulation through feeding and environmental exposure. Comparison of heavy metal concentrations shows that Pied crow feathers contained Cd (0.005), Cr (0.070), and Pb (0.005), while foraging sites exhibited lower Cd (0.001–0.004), Cr (0.033–0.056), and Pb (0.006–0.011). Chromium (Cr) showed the highest concentration in feathers (0.070 mg/kg) compared to dumping site soil (0.056 mg/kg), marsh soil (0.033 mg/kg), and stream water (0.040 mg/L), suggesting efficient uptake and retention in crow tissues. Cadmium concentrations in feathers exceeded those in foraging sites, suggesting selective uptake. Lead, however, appeared slightly lower in feathers compared to soils and water. The dumping site soil exhibited the highest

environmental metal loads, (Cd (0.004), Cr (0.056), and Pb (0.011)) among the foraging sites, suggesting strong anthropogenic input from waste materials. In contrast, stream water and marsh soil exhibited lower but notable concentrations, reflecting dispersed contamination. The elevated metal levels in crow feathers, relative to their foraging sites, suggest biomagnification through feeding and exposure pathways. Feathers reflect environmental exposure but also reveal differential accumulation, with chromium posing the greatest concern. The differences in metal accumulation trends provide strong evidence of heavy metal contamination in Pied crows and their habitat. Overall, the higher metal concentrations in feathers reflect biomagnification and confirm the Pied crow's potential as a bioindicator of localized heavy metal contamination.

In Figure 7 above, the following observations have been noted. Firstly, there is elevated chromium and cadmium in Pied crow feathers, indicative of massive bioaccumulation, as strong evidence of heavy metal contamination in Rubengera. The highest concentrations of Cr (0.070mg/kg) and Cd (0.005mg/kg) were recorded in feathers, suggesting bioaccumulation through food chains. This implies that crows are foraging in areas contaminated with these metals—likely the dumping site, streambanks, or agricultural runoff areas.

Secondly, the result confirms the sources of ecosystem pollution. Chromium, used in industrial processes such as tanning, metal plating, and dye production, suggests anthropogenic contamination likely from waste dumping or leaching. Cadmium may originate from battery waste, fertilizers, or plastic degradation, and its presence in soil and feathers implies environmental persistence. Pb is more prevalent in soil and water, less so in feathers. This may reflect less dietary exposure or selective exclusion/metabolism in crows, though accumulation still occurs.

CHAPTER 5: DISCUSSION

This chapter presents an in-depth discussion of the findings from the laboratory analysis of heavy metal concentrations in *Corvus albus* feathers, stream water, marsh soil, and dumping site soil collected in the Rubengera Sector, Karongi District. The discussion integrates field observations with regional and global literature to interpret the significance of bioaccumulated metals in Pied crows and associated implications for ecosystem health and biodiversity. The findings are also evaluated in terms of their contribution to existing knowledge and the validation of bioindicator-based environmental monitoring.

5.1 Heavy metal bioaccumulation in Pied crows (*Corvus albus*)

The results of the investigation confirmed that trace quantities of the heavy metals lead (Pb), chromium (Cr), and cadmium (Cd) were present in all environmental matrices examined. The highest concentrations of Cd and Cr were found in Pied crow feathers, with values of 0.005 mg/kg and 0.070 mg/kg, respectively. A clear pattern of bioaccumulation is seen in the metals that are deposited in bird tissues and feathers after being consumed from contaminated environmental sources, including soil, water, and prey.

According to Gochfeld (2000), feathers are reliable non-invasive biomarkers because they reflect the cumulative intake of metals during the growth period. The study's findings that the levels of Cr in the feathers (0.070mg/kg) were greater than those in the marsh soil (0.033 mg/kg), dumping site soil (0.056 mg/kg), and river water (0.040 mg/L) showed that Pied crows may absorb metal exposure from a variety of sources. The elevated feather levels also suggest that trophic transfer and bioavailability may enhance contaminant uptake, particularly in birds that feed at several trophic levels and in both terrestrial and aquatic environments.

The scavenging activities of *Corvus albus* are likely a significant contributing factor to their exposure. They live in biological niches that extend into highly contaminated places such as dumping sites and wetlands that absorb runoff, and they are omnivorous foragers that consume roadkill, small animals, and human-generated waste. Giammarino et al., (2014) reported that Hooded crows in Egypt's Helwan industrial zone exhibited comparable outcomes, with higher feather Pb and Cr levels being directly linked to scavenging close to smelters and landfills. There is a greater chance of encountering bioavailable metals with this feeding strategy.

Iqbal et al. (2021) conducted a comparative study in Pakistan and found that House crows in busy and industrial regions had significant accumulations of Pb, Cr, and Cd in their feathers. This study highlights the role that urban rubbish plays in metal exposure. The current study concludes that the presence of detectable metal levels, even in relatively remote environments, such as marsh soils, suggests that the biological reach of pollution is expanding and that bioindicators, like Pied crows, may effectively communicate this dispersion.

The results lend credence to the theory that these metals originate from human-caused sources, most likely runoff from cities, solid waste disposal sites, and unofficial burning (Nsengiyumva et al., 2021). Cadmium is known to accumulate in the food chain and affect both aquatic and terrestrial creatures (Ali et al., 2019; Sardar et al., 2013). It is commonly released from improper fertilizer, plastic, and battery disposal. Chromium, found in dyes, wood preservatives, and stainless steel, can enter ecosystems through industrial effluents and become toxic in its hexavalent form.

Worldwide, there is a wealth of documentation on these phenomena. Koivula et al. (2011), for instance, found that Great Tits that nested near a metal smelter had high levels of Cd and Zn in their feathers, which were associated with reproductive and developmental issues in the nestlings. The correlation between the feather burden and biological effects highlights the broader ecological risks associated with bioaccumulated metals.

The result provides compelling evidence in favor of using Pied crows (*Corvus albus*) as reliable bioindicators of environmental contamination. Inferences regarding the degree of pollution, possible sources, and ecological risk were made possible by the discovery that their feathers accurately reflect local contamination levels of heavy metals like cadmium (Cd) and chromium (Cr) (Burger, 1993). This methodology is in line with modern methods for monitoring biodiversity and evaluating the environment sustainably, especially in poor nations with limited financial and technological resources (Furness & Greenwood, 2013).

According to Burger and Gochfeld (2001), feather analysis is a perfect instrument for community-based environmental surveillance because it is non-invasive, economical, and suitable for recurrent monitoring. Environmental assessments can encompass both space and time thanks to the high mobility, extensive distribution, and ecological adaptability of birds like Pied crows (Giammarino et al., 2014). These characteristics enable them to function as early-warning systems for wider

ecosystem contamination and integrate exposure across trophic levels, making them exceptional sentinel species (Furness, 1993).

Crow feathers are useful in citizen science and community-led monitoring initiatives because of their practicality. Pied crows are generalist feeders and scavengers that come into contact with a variety of contaminated items, such as trash dumps and contaminated wetlands, which makes it easier to identify various contamination pathways (Burger, 2002). Further supporting their usage in participatory monitoring frameworks is their accessibility in both urban and rural settings, particularly in situations when technological bio-surveillance techniques are not available (Iqbal et al., 2021).

According to Hollamby (2003), bird bioindicators have been successfully employed worldwide to evaluate contamination from industrial pollutants, heavy metals, and pesticides. Pied crows' larger use as environmental sentinels has been confirmed by the pollution accumulation patterns of Fish Eagles in South Africa and gulls in Europe, for example (Dauwe et al. 2000; Gochfeld, 2000). The capacity of feather sampling to identify trace metals in birds with little harm and great reproducibility has been verified time and time again (Burger, 2002).

Pied crows are a cheap, reliable scientific option for assessing the health of ecosystems in areas like Rubengera, where industrial environmental monitoring infrastructure is scarce or nonexistent. Their capacity to represent the distribution of pollutants both spatially and trophically allows for the development of policies, the prioritization of mitigation or cleanup measures, and well-informed conservation planning (Furness & Greenwood, 2013). As a result, their function as bioindicators can help achieve long-term biodiversity conservation goals by guiding focused efforts to safeguard vulnerable species and ecosystems.

The study's findings support Pied crows' applicability as bioindicators. Their application is in line with worldwide trends in avian bioindication and offers a workable, scalable method for environmental health monitoring in environments with limited data. An inventive link between ecological science and conservation policy is provided by feather-based analysis, especially in situations when conventional monitoring is neither practical nor cost-effective.

5.2 Site contamination and potential impacts on ecosystem health and biodiversity

The findings of the metal concentrations point to both bird health and larger ecological degradation. Wetlands, soil, and water systems are essential to biodiversity and ecological processes. Heavy metals affect aquatic ecosystems by contaminating them, disrupting microbial communities, and reducing fertility.

Heavy metal contamination affects soil fertility and microbial activity. The highest Pb concentrations (0.011 mg/kg) were found in the soils near the disposal site, and Cd and Cr levels were similarly higher than the natural background levels. Microbial activity necessary for breakdown, nitrogen fixation, and nutrient cycling is adversely affected by such contamination (Hassan et al., 2013). Similar metal concentrations to those in this study have been linked to decreased microbial biomass in South African mining locations (Hollamby, 2003).

Additionally, signs of vegetation stress were observed in most areas where samples were collected. Rubengera observational data revealed symptoms of vegetation stress, including discolored leaves and underdeveloped roots close to disposal sites. Because chromium limits chlorophyll synthesis and hinders root elongation, these visual symptoms are common reactions to heavy metal toxicity (Nagajyoti et al., 2010). Similar to the values seen here, Zhang et al. (2018) discovered that soil Cr concentrations of only 0.05 mg/kg were adequate to lower plant biomass and productivity in experimental plots in China.

Water contamination also affects aquatic life. There is a long-term risk to fish and aquatic invertebrates due to chromium concentrations in river water (0.040 mg/L) that are close to the WHO criteria for chronic exposure. Metal buildup in the gills and tissues of fish in polluted rivers can affect their ability to breathe and reproduce. Laszlo (2006) found that Black-headed Gulls in Hungary had higher metal levels five years after a cyanide spill, suggesting that pollutants in aquatic food webs persist over time.

Crows in Rubengera that feed on water prey or along riverbanks may indirectly consume contaminants, making such chronic exposure scenarios conceivable. In higher trophic levels, such as predatory birds, animals, and maybe humans through fish ingestion, metals like Cd and Cr can gradually build up.

Furthermore, the biomagnification of heavy metal pollution is among its most alarming features. Because they are difficult to break down, metals can linger for years and build up with every trophic transfer. Fish Eagles in Southern Africa were discovered to have piscivorous diets that caused them to accumulate mercury and cadmium in their livers, which had an impact on the growth and survival of their chicks (Garcia-Heras et al., 2017). This illustrates how top predators, including mammals and birds, are susceptible to even minor environmental contamination. Pied Crow feathers had higher amounts of Cr and Cd than the surrounding ambient media, according to the current findings, which suggests that trophic accumulation is already taking place. This puts the health of the entire food chain in danger, in addition to the birds.

The result also indicates that, even at sublethal doses, flora and small species in the Rubengera Sector are probably exposed to environmental contaminants, especially heavy metals like cadmium (Cd) and chromium (Cr). Ecological processes are known to be impacted cumulatively by these contaminants. Because they aid in the spread of seeds, regulate pest populations, and act as scavengers, clearing away garbage and carrion, birds—including Pied crows—play vital roles in ecosystems (Furness & Greenwood, 1993). Ecological equilibrium is directly impacted by their well-being.

Corvus albus are especially vulnerable to bioaccumulation because they are opportunistic feeders that consume contaminated food from a variety of trophic levels, such as insects, amphibians, and waste products (Iqbal et al., 2021). As a bioamplified indicator of wider ecological danger, the higher levels of Cr and Cd discovered in their feathers in this study are a reflection of long-term environmental exposure. Burger and Gochfeld (2000) found similar trends, noting that the concentrations of feathers in urban gulls and crows were associated with pollution levels at specific sites and the general health of the ecosystem.

Primary producers and small animals are at risk due to contaminated soils and wetlands. According to Ali et al. (2019), heavy metals such as Cd and Cr have been demonstrated to alter aquatic food networks, hinder amphibian metamorphosis, and decrease insect variety and abundance. Because birds depend on these taxa for food, the disruption spreads up the trophic ladder, causing biomagnification, a process where the concentration of harmful compounds rises at higher levels of the food chain (Scheuhammer, 1987). This can eventually lead to a reduction in ecological

processes as pollination, decomposition, and seed distribution, as well as species richness (Nagajyoti et al., 2010).

In birds, long-term exposure to Cd and Cr has been associated with immunosuppression, neurological and behavioral abnormalities, reproductive failure, and feather development abnormalities (Burger & Gochfeld, 2000). More fragile taxa are probably at much higher risk if such impacts appear in Pied crows, a species that is normally hardy. Hence, alterations in Pied crow behavior or population dynamics may serve as a precursor to ecological instability. For example, Furness (1993) highlighted that behavioral changes in scavenging birds frequently occur before more general decreases in the health of the avian community.

Significant concerns are raised for more specialized and sensitive birds in the same environments when contaminants are found in a generalist species like the *Corvus albus*. Particularly vulnerable are species like the African Sacred Ibis (*Threskiornis aethiopicus*), fish-eating raptors like the African Fish Eagle (*Haliaeetus vocifer*), songbirds, and wetland specialists. Hollamby (2003) reported that fish-eating birds in South African contaminated wetlands had high levels of heavy metals, which had an impact on the behavior of the adults and the survival of the chicks. According to research conducted in contaminated wetlands in Europe, cumulative exposure to contaminants has led to a decrease in the numbers of insectivorous and piscivorous birds (Dauwe et al., 2000).

Corvus albus can survive in areas that are just slightly damaged; therefore, its contamination indicates that environmental deterioration has progressed to a considerable degree. If left uncontrolled, this could have a domino effect on reproductive success, trophic relationships, and overall species diversity (Dauwe et al., 2000). In order to avoid irreparable ecosystem loss, the results highlight the critical necessity for biodiversity monitoring and pollution mitigation in the Rubengera Sector.

Long-term pollution can also lead to the loss of ecological services, including pollination, seed distribution, and pest control, as well as the extinction of local species and reduced gene flow (Burger & Gochfeld, 2001). Wetland habitats are already under stress from agriculture and population increase, so heavy metal pollution could accelerate ecological degradation (Nsengiyumva et al. 2021).

The results of this investigation offer strong evidence in favor of including avian bioindicators—specifically, *Corvus albus*—into environmental monitoring systems at the local and national levels. The finding of high concentrations of heavy metals like cadmium (Cd) and chromium (Cr) in soils and feathers emphasizes how urgently scientifically based environmental regulations are needed. These findings can help shape or update environmental protection legislation, particularly in areas like Rubengera Sector and others that deal with pollution, sustainable waste management, and habitat preservation (Furness & Greenwood, 1993).

Bird bioindicators have been acknowledged as a useful tool for early ecosystem stress detection on a global scale, assisting policymakers in creating affordable environmental surveillance programs (Burger, 2002). Crow-based monitoring for soil and air pollution was proposed after Iqbal et al. (2021) showed how House crow feathers in Pakistan mirrored urban pollution. Hooded crows in Egypt also exposed industrial pollutants, leading to local environmental interventions, as demonstrated by Giammarino et al. (2014).

The use of these discoveries in Rubengera can help pinpoint areas of high pollution and create rehabilitation plans for wetlands and soils. Maintaining ecosystem services, including water purification, erosion management, and biodiversity support, depends on soil remediation and wetland ecosystem rehabilitation (Nagajyoti et al., 2010). Mitigating pollution also directly promotes broader conservation aims, such as the protection of aquatic animals, birds, insects, and amphibians, since environmental contamination impacts numerous trophic levels (Ali et al., 2019).

These observations are also essential for waste management policies. The establishment of sustainable waste disposal facilities, increased enforcement, and public education can all help combat unregulated dumping, which seems to be a significant source of contamination in Rubengera (Hollamby, 2003). While providing authorities and conservation organizations with ongoing data, citizen science projects using easily accessible species, such as Pied crows, may also improve environmental stewardship and community involvement (Furness et al., 2015).

In conclusion, environmental policy and conservation planning are directly impacted by this study. In Rwanda and similar contexts, it supports evidence-based decision-making aimed at reducing environmental degradation, protecting biodiversity, and promoting sustainable development by highlighting the ecological risks posed by heavy metal pollution and showcasing the value of avian bioindicators. Comparing Rubengera's findings to regional and international research, they show

that even rural and peri-urban areas are susceptible to environmental contamination, which is consistent with trends observed in more industrialized areas. These findings underscore the need for more effective waste management, targeted conservation efforts, and bioindicator-based integrated monitoring systems. In the end, maintaining ecosystem health and biodiversity in Rubengera—and similar places—will require continuous public awareness campaigns, proactive policy changes, and robust scientific monitoring systems that rely on avian bioindicators as essential tools for environmental assessment and conservation.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study has demonstrated that Pied Crows (*Corvus albus*) are effective bioindicators for monitoring environmental contamination in the Rubengera Sector, Karongi District. The presence of heavy metals, particularly Cadmium (Cd) and Chromium (Cr), in the feathers of Pied Crows, combined with elevated concentrations in soil and water samples, provides strong evidence of bioaccumulation and environmental exposure. The highest levels of Cd (0.005 mg/kg) and Cr (0.070 mg/kg) found in feathers compared to other environmental matrices indicate that Pied Crows integrate and reflect pollutants accumulated through their scavenging behavior across terrestrial and aquatic ecosystems (Burger & Gochfeld, 2000; Furness, 1993).

Notably, the dumping site soil exhibited some of the highest concentrations of Pb and Cr, highlighting it as a pollution hotspot. These findings align with global studies that recognize urban dumpsites as significant sources of heavy metals (Iqbal et al., 2021). The confirmed presence of toxic elements across multiple sites suggests ecological risks, particularly to organisms that share habitats with scavenging birds or depend on contaminated soils and waters for survival. Given the documented toxicological impacts of heavy metals on birds and other wildlife, such as reduced fertility, developmental impairments, and behavioral changes, the findings underscore the need for continuous monitoring and intervention (Burger, 1993; Dauwe et al., 2000).

6.2 Recommendations

Based on these findings, the following recommendations are proposed:

1. Routine monitoring using bioindicators: Environmental authorities and conservation institutions in Rwanda should adopt bird-based bioindicator monitoring systems. Regular sampling and analysis of feathers from Pied Crows and other species can serve as an early-warning system to detect pollution trends and inform mitigation measures (Furness & Greenwood, 1993).
2. Public Awareness Campaigns: Community education programs should be developed to raise awareness about the health risks of pollution and the role of birds as sentinels of ecosystem health. Involving local communities in citizen science projects can strengthen conservation outcomes and foster stewardship of natural resources (Ali et al., 2013).

3. Improved Waste Management and Wetland Protection: Local governments should prioritize the control of dumping sites and introduce safer waste management practices to minimize the release of toxic metals. Protecting wetlands from agricultural runoff and industrial waste is also critical to maintaining the ecological integrity of aquatic systems (Uwimana et al., 2018).
4. Further Research: Additional studies are recommended to investigate seasonal variations in metal concentrations, interspecies comparisons, and long-term trends. Expanding the research scope to include biochemical and reproductive effects on birds can help refine bioindicator models and guide biodiversity conservation strategies (Dauwe et al., 2000).

In conclusion, this research confirms the utility of Pied crows as bioindicators and provides valuable baseline data for future environmental monitoring programs in Rwanda. Integrating such cost-effective and biologically relevant tools into national conservation and pollution management plans will enhance Rwanda's capacity to safeguard ecosystem health and biodiversity.

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Appendix 1. Laboratory analysis report

	INES Testing Laboratory	Form no.: INES/TL/F-25
	TEST REPORT	Rev no: 2
		Effective Date: 25/10/2024
		Page 1 of 1


TEST REPORT

Report n° INES/CHELAB/127/2025

ORIGINAL

<p>I. Details of sample</p> <p>Name of Customer: CEPHAS Address : UR - CST Sample number : INES/TL/385/2025 Sample name: Pied Crow Feathers Sample description: Soil Date of submission: 20/06/2025</p> <p>II. Analysis of the sample</p> <p>Condition of the sample: Good Analysis completion date: 10/07/2025 Name of Laboratory : Chemistry laboratory Environmental Condition: Room temperature</p> <table border="1"> <thead> <tr> <th>Parameter tested</th> <th>Results</th> <th>Test method/SOP</th> </tr> </thead> <tbody> <tr> <td>Cadmium (ppm)</td> <td>0.005</td> <td>AAS Method</td> </tr> <tr> <td>Chromium (ppm)</td> <td>0.070</td> <td>AAS Method</td> </tr> <tr> <td>Lead (ppm)</td> <td>0.005</td> <td>AAS Method</td> </tr> </tbody> </table> <p>Responsible analyst UJENEZA Faustine </p> <p>Lab supervisor NIRERE Claudine </p> <p>Vice chancellor Father Dr. BARIBESHYA Jean Bosco </p>			Parameter tested	Results	Test method/SOP	Cadmium (ppm)	0.005	AAS Method	Chromium (ppm)	0.070	AAS Method	Lead (ppm)	0.005	AAS Method
Parameter tested	Results	Test method/SOP												
Cadmium (ppm)	0.005	AAS Method												
Chromium (ppm)	0.070	AAS Method												
Lead (ppm)	0.005	AAS Method												

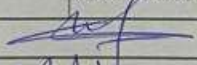
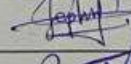



	INES Testing Laboratory	Form no.: INES/TL/F-25
	TEST REPORT	Rev no: 2
		Effective Date: 25/10/2024
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TEST REPORT

Report n° INES/CHELAB/128/2025

ORIGINAL

I. Details of sample		
Name of Customer: CEPHAS		
Address : UR - CST		
Sample number : INES/TL/384/2025		
Sample name: Marsh soil		
Sample description: Soil		
Date of submission: 20/06/2025		
II. Analysis of the sample		
Condition of the sample: Good		
Analysis completion date: 10/07/2025		
Name of Laboratory : Chemistry laboratory		
Environmental Condition: Room temperature		
Parameter tested	Results	Test method/SOP
Cadmium (ppm)	0.002	AAS Method
Chromium (ppm)	0.033	AAS Method
Lead (ppm)	0.006	AAS Method
Responsible analyst UJENEZA Faustine 		
Lab supervisor NIRERE Claudine 		
Vice chancellor Father Dr. BARIBESHYA Jean Bosco 		


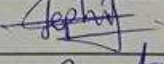
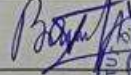


	INES Testing Laboratory	Form no.: INES/TL/F-25
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TEST REPORT

Report n° INES/CHELAB/129/2025

ORIGINAL

<p>I. Details of sample</p> <p>Name of Customer: CEPHAS</p> <p>Address : UR - CST</p> <p>Sample number : INES/TL/386/2025</p> <p>Sample name: Dumping site soil</p> <p>Sample description: Soil</p> <p>Date of submission: 20/06/2025</p>		
<p>II. Analysis of the sample</p> <p>Condition of the sample: Good</p> <p>Analysis completion date: 10/07/2025</p> <p>Name of Laboratory : Chemistry laboratory</p> <p>Environmental Condition: Room temperature</p>		
Parameter tested	Results	Test method/SOP
Cadmium (ppm)	0.004	AAS Method
Chromium (ppm)	0.056	AAS Method
Lead (ppm)	0.011	AAS Method
Responsible analyst UJENEZA Faustine 		
Lab supervisor NIRERE Claudine 		
Vice chancellor Father Dr. BARIBESHYA Jean Bosco 		



	INES Testing Laboratory	Form no.: INES/TL/F-25
	TEST REPORT	Rev no: 2 Effective Date: 25/10/2024
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INES TESTING LABORATORIES

TEST REPORT

Report n° INES/WAQLAB/046/2025


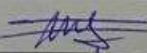
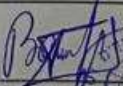
ORIGINAL

I. Details of sample

Name of Customer: CST
 Address : Rubengera
 Sample number : INES/TL/382/2025
 Sample name: H₂O River; main river
 Sample description: Water
 Date of submission: 20/06/2025

II. Analysis of the sample

Condition of the sample: Good
 Analysis completion date: 10/07/2025
 Name of Laboratory : Water quality lab
 Environmental Condition: Room temperature

Parameter tested	Results	Test method/SOP
Lead (ppm)	0.008	RS ISO 8288
Chromium (ppm total)	0.04	RS ISO 9174
Cadmium (ppm)	0.001	RS ISO 8288
Responsible analyst	UJENEZA Euphrosine	
Lab supervisor	Dr. Nyirajana Jacqueline	
Vice chancellor	Father Dr. BARIBESHYA Jean Bosco	



Appendix 2. Protocols for the preparation of samples and analysis for heavy metals

Protocol for Sample Preparation and Heavy Metal Analysis in Soil Samples Using AAS (Sharma & Tyagi, 2013)

1. Sample Collection

- Collect representative soil samples from designated sites using a clean stainless-steel auger or trowel.
- Avoid contamination from metal tools, paint, or lubricants.
- Place samples in high-density polyethylene (HDPE) containers or clean zip-lock bags.
- Label each sample clearly with site name, date, and depth.

2. Drying and Grinding

- Air-dry samples in a clean, dust-free environment at room temperature or in an oven at 40–60°C.
- Crush and grind dried samples using a non-metallic mortar and pestle or mechanical grinder.
- Sieve the samples through a 2 mm mesh, or finer if required, to remove debris and homogenize.

3. Digestion of Soil Samples

Digestion is essential to extract the metals into a solution form that can be analyzed by AAS.

Reagents Required

- Concentrated nitric acid (HNO₃)
- Concentrated hydrochloric acid (HCL)
- Deionized water
- Glass beads (optional, for preventing bumping)

Procedure

1. Weigh 1.0 gram of homogenized soil sample into a clean, acid-washed beaker.
2. Add 5 ml of concentrated HNO₃ and a few glass beads.
3. Place the beaker on a hot plate and heat gently to a slow boil.
4. Evaporate the mixture carefully until the volume reduces to 10–20 ml.
5. If undigested particles remain, add a few more ml of HNO₃ and continue heating until digestion is complete (avoid drying out).
6. Cool the digest and wash the beaker walls with deionized water (3 times).
7. Filter the solution (if necessary) into a 100 ml volumetric flask.

8. Make up to the mark with deionized water and mix thoroughly.

4. AAS Instrument Setup

Refer to the instrument-specific user manual, but generally:

- Select an appropriate lamp for the target metal (e.g., Pb, Cd, Cr).
- Use correct flame-gas combination:
 - Air-acetylene for most metals (Cr, Cd, Pb, etc.).
 - Nitrous oxide-acetylene for refractory metals (Al, Ca).
- Wavelength settings are metal-specific (consult manual).
- Ensure ventilation (exhaust 6–12 inches above burner).

5. Sample Analysis

1. Aspirate the prepared digested sample into the flame.
2. Record the absorbance or concentration displayed.
3. If the concentration exceeds the range, dilute the sample appropriately and re-run.

6. Data Calculation and Quality Control

- Calculate metal concentration using a calibration curve or direct readout.
- Apply dilution factor, if samples were diluted.
- Perform quality assurance by running:
 - Blank samples
 - Duplicates
 - Spiked recovery samples

7. Waste Disposal

- Collect all used acids and samples in a **designated waste container**.
- Follow local regulations for hazardous chemical disposal.

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- WHO (2011). *Guidelines for Drinking-Water Quality*.

Protocol for Feather Sample Preparation and Heavy Metal Analysis Using AAS

(Sharma & Tyagi, 2013)

1. Collection and Storage of Feather Samples

- Collect contour or flight feathers from target bird species (e.g., pied crows) using clean gloves and forceps.
- Avoid contamination from metal surfaces, skin oils, and tools.
- Store feathers in clean, labeled paper envelopes or acid-washed polyethylene bags.
- Record metadata (date, location, bird ID, feather type).

2. Cleaning of Feathers

To remove external contaminants (dust, soil, preen oil, etc.):

1. Rinse feathers three times in deionized water.
2. Wash feathers in non-ionic detergent solution (e.g., 0.1% Triton X-100 or mild lab detergent) for 10–15 minutes with gentle agitation.
3. Rinse thoroughly with deionized water.
4. Rinse again with acetone or ethanol to remove lipids.
5. Air-dry feathers in a clean, dust-free environment on filter paper or aluminum foil.

3. Cutting and Weighing

- Cut cleaned feathers into small pieces (1–2 cm) using ceramic scissors or acid-washed blades.
- Weigh 0.2 to 0.5 g of cut feather material using an analytical balance.
- Transfer weighed material to a clean, acid-washed glass beaker or Teflon digestion tube.

4. Acid Digestion of Feathers

Reagents Needed

- Concentrated nitric acid (HNO_3)
- Hydrogen peroxide (H_2O_2) (optional, for organic matrix)
- Deionized water

Procedure

1. Add 5 ml concentrated HNO_3 to the beaker containing the feather sample.
2. Add 1–2 ml of H_2O_2 to assist organic matrix breakdown (optional but recommended).
3. Heat the mixture on a hot plate at 60–90°C for 1–2 hours until digestion is complete and the solution is clear or pale yellow.
 - Do not allow the solution to boil dry.
 - Add a few additional ml of HNO_3 if digestion is incomplete.
4. Cool the digest to room temperature.

5. Rinse the beaker walls with deionized water (3 times).
6. Filter (if particulate remains) and transfer the solution into a 25 or 50 ml volumetric flask.
7. Make up the volume to the mark with deionized water and mix well.

5. Preparation of Standard Solutions

Follow these steps for AAS calibration:

1. Prepare three or more concentrations of standard solutions for each metal (e.g., Pb, Cd, Zn).
2. Aspirate a blank (no metal) to calibrate the instrument to zero.
3. Aspirate each standard to record absorbance.
4. Create a calibration curve (absorbance vs. concentration), unless your AAS has a direct readout feature.

6. AAS Instrumentation and Sample Analysis

- Select the correct lamp for each metal (e.g., Pb, Zn, Cd).
- Use air-acetylene flame for most heavy metals.
- Set the appropriate wavelength based on the metal.
- Aspirate the digested sample into the AAS and record absorbance or concentration.
- Dilute samples if the metal concentration exceeds the calibration range.

7. Quality Control

- Run blanks, duplicates, and spiked recovery samples.
- Ensure all reagents and glassware are metal-free or acid-washed.
- Apply dilution factors to final readings if applicable.

8. Safety and Waste Disposal

- Handle acids with gloves, goggles, and a lab coat in a fume hood.
- Collect all digestion waste in a designated hazardous waste container.
- Follow institutional and environmental guidelines for disposal.

References

- Sharma, B., & Tyagi, S. (2013). Simplification of metal ion analysis in freshwater samples using atomic absorption spectroscopy for lab students. *Journal of Laboratory Chemical Education*, 1(3), 54–58.
- APHA (2005). *Standard Methods for the Examination of Water and Wastewater*.
- Burger, J. (1995). A risk assessment for lead in birds. *Journal of Toxicology and Environmental Health*, 45(4), 369–396.

Protocol for Heavy Metal Analysis in Water Using the RS ISO Method (Kruis, 2007)

Reference Standard

- RS ISO 8288: *Water quality — Determination of lead, cadmium, chromium.... by AAS*

1. Sampling and Preservation

1.1. Sampling Containers

- Use acid-washed polyethylene (HDPE) or borosilicate glass bottles.
- For mercury analysis, glass is preferred.

1.2. Sample Collection

- Collect grab samples from surface, ground, or effluent water sources.
- Rinse bottles three times with sample water before final collection.

1.3. Preservation

- Immediately acidify each sample to $\text{pH} < 2$ using ultrapure nitric acid (HNO_3) (typically 1–2 mL per liter).
- Store samples at 4°C (in a cool box or refrigerator).
- Analyze within 28 days of collection (as per RS ISO 5667-3).

2. Reagents and Materials

- Ultrapure HNO_3 (65%) for acidification and digestion.
- Deionized water (resistivity $\geq 18 \text{ M}\Omega\cdot\text{cm}$).
- Certified multi-element standard solutions for calibration.
- Filter papers (0.45 μm pore size, if required).
- ICP-OES, ICP-MS, or AAS, depending on the method selected.

3. Sample Preparation

3.1. Filtration (for dissolved metals)

- If analyzing dissolved metals, filter samples using 0.45 μm membrane filters before digestion.

3.2. Acid Digestion (for total metals)

1. Pipette 100 mL of well-mixed, preserved water sample into a beaker or digestion tube.
2. Add 5 mL of concentrated HNO_3 .
3. Heat gently on a hot plate (not to dryness) until the volume reduces to ~ 25 mL and the solution is clear.
4. Cool, filter (if necessary), and transfer to a 50 or 100 mL volumetric flask.
5. Make up to volume with deionized water and mix.

4. Instrument Calibration

4.1. Prepare Calibration Standards

- Use certified stock solutions to prepare a series of at least 3–5 concentrations (e.g., 0.1, 0.5, 1.0, 2.0 mg/L).

4.2. Blank and Quality Control

- Run a reagent blank.
- Use quality control samples (known concentration) and spiked samples to verify accuracy and recovery.

5. Instrumental Analysis

Option A: AAS (as per RS ISO 8288) (Pb and Cd analysis)

- Use air-acetylene flame for most metals.
- Set wavelength according to metal being analyzed (e.g., Pb: 217.0 nm, Cd: 228.8 nm).
- Aspirate samples and record absorbance or concentration.

Option B: Option D: ISO 9174 (Cr Analysis in Water by AAS)

- Suitable for determining total chromium using flame atomic absorption spectrometry (FAAS).
- Detection typically down to 10 µg/L, ideal for routine environmental monitoring.
- Requires oxidation step (e.g., with nitric acid) to convert all chromium to detectable Cr(VI).
- Best for clean water samples with low matrix interference

6. Data Analysis and Reporting

- Calculate concentrations using calibration curves or instrument software.
- Apply dilution factor if samples were diluted.
- Report results in mg/L or µg/L as required.
- Compare values against Rwanda Standards, WHO, or USEPA guidelines.

7. Waste Management and Safety

- Dispose of acid and metal-containing wastes in compliance with hazardous waste regulations.
- Use PPE: lab coat, gloves, goggles.
- Work in a fume hood during digestion and acid handling.

Summary Table of Metal Wavelengths (AAS Example)

Metal	Wavelength (nm)	Flame Type
Lead (Pb)	217.0	Air-acetylene
Cadmium (Cd)	228.8	Air-acetylene
Chromium (Cr)	357.9	Air-acetylene
Copper (Cu)	324.8	Air-acetylene
Zinc (Zn)	213.9	Air-acetylene
Iron (Fe)	248.3	Air-acetylene

References

Rwanda Standards Board (RSB), *RS ISO 8288, RS ISO 17294-2, RS ISO 11885, RS ISO 5667-3*.
 WHO (2011). *Guidelines for Drinking-water Quality. 4th Edition*.
 APHA (2005). *Standard Methods for the Examination of Water and Wastewater*.

Appendix 3: Study site photos



Photo 1: Corvus albus



Photo 2: Corvus albus roosting



Photo 3: Dumping site



Photo 4: Marsh area



Photo 5: Pied Crows coming to roost



Photo 6: Pied Crows preparing to roost



Photo 7: Stream dividing the marsh area